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Screening Wheat Landrace Varieties for Grain Yield under Water Deficit Conditions Using Drought Tolerance Indices

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Authors' contributions

Author ZK performed the experimental works and the statistical analysis and wrote the first draft of the manuscript. Author BH designed and managed the study, wrote the protocol and revised draft of the manuscript. Author ND managed tables and graphs and contributed to manuscript revision. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

In order to evaluate the performance of wheat (*Triticum aestivum L.*) genotypes under drought stress at heading stage, 100 Iranian landraces and two commercial cultivars were grown under well- watered irrigation and a drought stress treatment as 50% field capacity (FC) irrigation that started at heading stage in 2010-2011 growing season. Results showed that spike length (SL), grain number/spike (GN), thousand kernel weight (TKW)and grain yield (GY) were reduced by 8.2%, 14.6%, 17.5% and 52.5% due to drought stress at heading stage. GN had highest heritability (88%) compared to other grain yield related traits. The range for SL varied from 4.6 to 15.0 cm and some of landraces had higher SL than commercial varieties. KC4880 had the highest GN (40.6) in drought stress condition and it was in the second rank (42.3) after KC3885 (44.6) under well-watered treatment. The mean values for grain yield per square meter in well-watered plots varied from 586.1 to 811.1 g, while under drought stress conditions the range was from 217.0 to 546.3 g. The highest TKW (44.33 g) was observed in KC4502 in well-watered treatment while the lowest (23.08 g) belonged to the genotype KC4700. There were significantly positive correlations between grain yield under well-watered conditions

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(Y_P) and the indices tolerance (TOL) (r= 0.71), mean productivity (MP) (r= 0.31) and stress susceptibility index (SSI) (r= 0.55). Principal component analysis (PCA) indicated that MP, geometric mean productivity (GMP) and stress tolerance index (STI) were more appropriate for prediction of Ys and based on biplot of two PCs genotypes were classified. Based on the positive correlation between stress tolerance index (STI) (r= 0.90) or geometric mean productivity (GMP) (r= 0.92) and grain yield, it can be concluded that the landraces such as KC4907, KC4863, KC4144, KC4779, KC4641, KC4880, KC4494, KC4502, with the highest GMP (ranged from 578.8 to 636.4) and STI (0.85-0.65) can be considered as drought tolerant in wheat breeding programs.

Keywords: Drought tolerance; grain yield; heading; wheat landraces.

1. INTRODUCTION

Bread wheat is one of the most important crops [1], which provides over 20% of calories consumed by the world's population [2]. Wheat is a source for essential calories and protein, supplying more than 75% of protein and 65% of calories in human diet [3] but its cultivation is limited due to drought in Mediterranean regions.

Water stress is a major factor in reducing the productivity of agricultural systems and food production worldwide [4,5]. Drought as a result of low precipitation and high temperature is a complex phenomenon which influences plants performance. Drought at different developmental stages can reduce crops grain yield and other economic traits [6,7]. If drought occurs after heading, wheat production in arid and semi-arid regions is greatly affected. From anthesis to maturity, if drought accompanied by high temperatures, accelerates leaf senescence and reduces the rate of grain filling and consequently kernel weight and dry matter accumulation [8,9].

The ability of crop cultivars to produce higher grain yield over stress and non-stress environments depends on the developmental stage of crop that affected by drought, the severity and stress duration [10,11]. Agronomic traits such as grain yield, grain number and grain weight have been evaluated in plants challenging with drought stress conditions [12,13,14,15,16,17]. Selection for higher grain yield under well watered conditions on the hope to achieve genotypes with acceptable performance under stress conditions has been considered as one of breeding strategies for increasing crop performance under water limited conditions [18]. Although grain yield is restricted in drought-affected cereals via low kernel number and weight, there are little agreements regarding the effect of drought on the relationship between yield and its components [19,20]. Grain yield can be analyzed through its components including number of spikes per plant, number of grains per spike and mean grain weight, which develop sequentially [21,22,23]. Early-season drought stress causes yield loss through reducing tiller viability. Prolific tillering prior to the onset of drought has been positively associated with tiller death that has variable consequences on grain yield [24,25,26]. Kernel weight is negatively correlated with the number of kernels per spike in wheat [27]. This negative relationship is often exacerbated by both drought and heat stresses, which are considered to reduce wheat kernel weight via shorter grain-filling period [28]. Drought stress during wheat maturity results in about 10% decrease in grain yield while moderate stress during the early vegetative period has been shown not to have significant effects on grain yield [29].

Evaluation of genotypes for grain yield under drought conditions is a traditional approach to select wheat genotype. Different drought stress indices or selection criteria have been proposed to assess the level of drought tolerance in the genotypes challenged with water limited conditions [30]. Tolerance index (TOL) defined as the difference between average grain yield in stress and non-stress environments while mean productivity (MP) is the mean grain yield in stress and non stress conditions [31]. Geometric mean productivity (GMP) which is related to relative performance under drought stress is an efficient index for determination of drought tolerant genotypes [32]. The stress susceptibility index (SSI), proposed by Fischer and Maurer [33], is mostly related to drought sensitivity. Stress tolerance index (STI) as a useful criterion for determining high yielding cultivars has been defined as an efficient index for selection of drought tolerant genotypes [34]. The relative yield performance of genotypes under water limited conditions and favorable environments seems to be a common starting point in identifying desirable genotypes for unpredictable rained conditions [35]. Geravandi et al. [36] emphasized that selection based on the superiority of wheat genotypes under both drought stress and well watered conditions is more acceptable than selection strategies based on either normal or stress conditions. It has been reported that wheat cultivars producing high yields in both stress and well watered conditions can be identified via STI, GMP and MP [30,37].

Therefore, the present study was conducted to evaluate grain yield using different drought tolerance indices and to assess grain yield components in landraces under drought stress and well-watered conditions. Information of drought tolerance indices helps breeders to classify drought tolerant genotypes from the susceptible ones in breeding programs for wheat cultivation in dry lands.

2. MATERIALS AND METHODS

In order to evaluate wheat genotypes under drought stress at heading stage, an experiment with 100 Iranian landraces (collected from different climates of Iran by the Seed and Plant Improvement Institute, Karaj, Iran) and two control commercial cultivars (Bezostaya and Shiraz) was carried out in a split plot design based on randomized complete block design with three replications in the research farm station of Shiraz University in 2010- 2011 growing season. The soil texture was sandy clay with electric conductivity of 0.36 deci Siemens m^{-1} and pH 7.05. The two water regimes were well-watered or normal irrigation (100% FC) and drought stress (50% FC). Water regimes and landrace genotypes were assigned to main and sub plots, respectively. Genotypes were planted in two 3 m long rows with a seeding rate of 350 viable seeds per square meter. Drought stress regime (50% FC) started by stopping irrigation at the early heading stage. In drought stress treatment every 8 days irrigation was done to keep 50% FC. In drought stress plots, soil water content was continuously measured by sampling from soil to keep 50% FC as drought stress treatment. Number of irrigation practices and the amount of water supply were similar in pre-flowering stages in both water regime treatments. Both irrigation and drought stress trials received 75 kg N ha^{-1} and 100 kg P ha^{-1} at sowing. At early stem elongation stage, 75 Kg N ha^{-1} was also applied. To minimize other grain yield reducing factors, fungicides were used to control diseases. Weed control was implemented in all stages of crop growth. The amount of water for each trial was calculated using the following formula [38]:

$$dn = \frac{(FC - \theta_m) \times \rho b \times D}{100}$$

Where, dn (g cm^{-2}) is the height of irrigated water, FC is field capacity based on weight (%) of soil samples which was 33, 37 and 38% in 0-30 cm, 30-60 cm, and 60-90 cm soil depths respectively. ρb is soil bulk density (1.4 g cm^{-3}), D is soil depth (30 cm) and θm (%) denotes for soil moisture and calculated as follow:

$$\theta_m = \frac{\text{Wet Soil (g)} - \text{Dry Soil (g)}}{\text{Dry Soil (g)}}$$

Spike length and grain number/spike were recorded in 10 randomly selected plants in each plot. The plots were harvested manually after maturity and grain yield (g m^{-2}) was measured at 12% grain moisture content. Data on thousand kernel weight (TKW) were recorded by weighing 1000 kernels by using electric balance instrument.

2.1 Data Analysis

Screening genotypes for drought tolerance was performed using different indices. Statistical indices were consisted of SSI, TOL, MP, STI, GMP, yield index (YI), yield stability index (YSI), harmonic mean productivity (HMP), modified stress tolerance index (MSTI) and press evaluation (PEV) as follow:

$$\text{SSI} = \frac{1 - \frac{\text{Ys}}{\text{Yp}}}{1 - \frac{\overline{\text{Ys}}}{\overline{\text{Yp}}}} \qquad [33]$$

$$\text{TOL} = \text{Yp} - \text{Ys} \qquad [31]$$

$$\text{MP} = \frac{\text{Ys} + \text{Yp}}{2} \qquad [31]$$

$$\text{YI} = \frac{\text{Ys}}{\overline{\text{Ys}}} \qquad [39]$$

$$\text{YSI} = \frac{\text{Ys}}{\text{Yp}} \qquad [40]$$

$$\text{STI} = \frac{\text{Yp} \times \text{Ys}}{\overline{\text{Y}}_{\text{p}}^{2}} \qquad [34]$$

$$\text{GMP} = \sqrt{\text{Yp} \times \text{Ys}} \qquad [34]$$

$$\text{HMP} = \frac{2 \times \text{Ys} \times \text{Yp}}{\text{Yp} + \text{Ys}} \qquad [34]$$

$$\text{MSTI} = \frac{\text{Ys}^2}{\overline{\text{Ys}}^2} \qquad [34]$$

$$\text{PEV} = 1 - \frac{\text{Ys}}{\text{Yp}} \qquad [40]$$

Where, Y_p and Y_s are grain yield under normal irrigated and drought stress conditions respectively, $\bar{Y}_p$ shows mean yield over all genotypes under normal irrigated conditions and $\bar{Y}_s$ represents mean yield under drought stress conditions. Related references for each of drought indices are presented in brackets.

Analysis of variance (ANOVA) was performed using statements in SAS software and the traits means were statistically compared using Least Significant Differences (LSD) test. The correlations between drought tolerance indices and yield under normal irrigated and drought stress conditions were calculated by SAS statements. A bi-plot diagram for the genotypes and different indices was drawn based on principle component analysis (PCA) [41] using STATGRAPHICS 5.1 software. Heritability estimates were calculated as below equation:

$$h^2 = \frac{\sigma_g^2}{\sigma_e^2 + \sigma_g^2}$$

Where, σ_g^2 and σ_e^2 are respectively genotypic and error variances in ANOVA table.

3. RESULTS AND DISCUSSION

3.1 Weather Conditions in the Site of Study

Weather conditions show that the site of study has low precipitations during wheat growing seasons specifically after the end of April which coincident with the start of reproductive stages (Table 1). During the reproductive stages of wheat, there was no rainfall which shows the severe conditions for growing wheat at the site of study. Many parts of south of Iran experience such a conditions. From the end of April and the beginning of May which is usually coincident with the heading of wheat, the site of study experienced low or no rainfall accompanied with high temperatures exceeded 35°C. Hours of sunshine and transpiration was considerably increased from April. Drought and high temperature possibly reduces fertility at anthesis. High temperature at meiosis and reproductive stage of wheat growth adversely affects grain number and consequently grain yield by increasing ovule and pollen sterility or by reducing pollen tube growth [42].

3.2 Analysis of Variance, Traits Means and Heritability

The results of ANOVA showed that the effects of irrigation, genotype and their interactions were significant for SL, GN, TKW and GY (Table 2). Heritability estimates were computed based on expected mean squares in ANOVA table. Among grain yield components, GN had the highest heritability (88%). Heritability of GY, TKW and SL were mediums (Table 2). High heritability is related to higher response to selection for breeding traits of interest. Mean spike length under drought stress (9.2 cm) was lower than the mean under normal irrigated (10.1 cm) plots (Table 3). KC4621 had the largest (15 cm) spike under well-watered conditions while under drought stress it was in the fourth rank (12.3 cm) after KC4554 (13.3 cm), KC4502 (13 cm) and KC4528 (12.7 cm) respectively. There was no difference between spike length of KC4502 (13 cm) under well-watered and drought stress conditions. Grain number varied from 21.3 to 44.6 under well-watered conditions although the range was 18.3 to 40.6 under drought stress regime. KC3885 (44.6) and KC4880 (42.3) had the highest GN under well-watered conditions. These genotypes had also high GN under drought stress regime. The means for GN in 10 top landraces were higher than the means obtained for the commercial cultivars, Bezostaya and Shiraz under both stress and well irrigation regimes

(Table 3). The highest TKW (44.3 g) was recorded in KC4502 under normal irrigated conditions, while the lowest one (23.0 g) obtained in the genotype KC4700 in 50% FC level (Table 2). Under drought stress conditions, the genotypes KC4863, KC4528, KC4779, KC4880, KC4890, KC4498, KC4494, KC4529, KC4907, KC4502 and KC4554 had the highest TKW (ranged 36.02-38.71 g), while in normal irrigated conditions KC4502, KC4779, KC4907, KC4863 and Bezostaya had higher TKW than other genotypes (Table 3).

Mean grain yield of wheat genotypes under normal irrigated and 50% FC conditions are presented in Table 3. The results showed that the mean grain yield under normal irrigated conditions was about twice the grain yield under drought stress.

The means for grain yield (g m^{-2}) in normal irrigated plots varied from 586.1 to 811.1, while under drought stress conditions the range was from 217.0 to 546.3 (Suppl. Table 1). The average reduction in grain yield due to drought conditions was about 52.5% compared to normal irrigated conditions. The differences between grain yield under drought and normal irrigated conditions were significant in most genotypes but no significant differences between two water regimes were observed for the genotypes KC4144, KC4528, KC4529, KC 3885, KC4907, KC4840, KC4880, KC4641 and Bezostaya (Suppl. Table 1). The genotypes KC4494, KC4907, KC4498, KC4890, KC4880, KC4641 and Bezostaya showed higher grain yield (513.3-546.3 gm^{-2}) under 50% FC water regime (Suppl. Tables 1 and 3).

Table 1. Weather conditions and soil properties of the site of study during growing season of wheat cultivation (2010-11)

Month	Temperature (°C)			RH (%)	Rain (mm)	Sunshine (H/day)	E -PAN (mm)
	Min	Max	AVR				
November-2010	-3.6	19.8	8.1	35.0	0.0	9.1	-
December-2010	-7.5	16.5	4.4	33.1	0.0	7.6	-
January-2011	-3.1	11.4	4.1	47.9	102.0	6.0	-
February-2011	-0.5	11.7	5.6	50.7	74.5	6.5	-
March-2011	1.5	17.7	9.6	46.8	56.3	7.8	-
April-2011	4.5	22.3	13.4	51.4	30.5	8.5	4.2
May-2011	9.3	29.7	19.5	43.5	0.0	10.6	8.5
June-2011	13.4	35.4	24.3	20.3	0.0	11.1	9.4
July-2011	15.8	35.7	25.7	20.0	0.0	10.3	10.0
Soil properties							
Sand (%)	18	pH	7.5	K (mg kg^{-1})	450		
Silt (%)	40	TKN (%)	12	P (mg kg^{-1})	22		
Clay (%)	33	OC (%)	1.26				
EC (dS m^{-1})	1	CaCO3 (%)	20				

dS: decisiemens, OC: organic carbon, RH: relative humidity, E-PAN: PAN evapotranspiration, TKN: total Kjeldahl N, EC: electrical conductivity of saturated paste, K: NH_4OAc-extractable potassium

3.3 Drought Related Indices

Analysis of variance showed that the mean squares of genotypes for drought tolerance indices were significant (Table 4). This shows that significant variations were existed among landrace varieties for statistical indices that can be used for drought tolerance screening.

Although MP, YI, YSI, GMP, HMP and STI showed positive correlations with Ys, only MP, STI and GMP had positive relation with both Ys and Yp (Table 5). The negative correlation (r= -0.87) of TOL with Ys indicated that selection of genotypes based on higher TOL values may results in lower grain yield under drought stress conditions. Therefore, it can be concluded that the landraces of KC4689, KC2178, KC3879, KC4700, KC1948, KC809, KC4791, KC3107, KC2167, KC4692, KC4637, KC4830 and Shiraz with higher TOL (ranged 453.5-558.9) were sensitive to water limited conditions (Suppl. Table 1). The SSI values showed highly negative correlation (r= -0.95) with grain yield under stress (Ys) condition (Table 4).

Table 2. Analysis of variance and heritability estimates for grain yield and its components in 102 bread wheat genotypes

Source	Mean Squares				
	DF	SL (cm)	TKW (g)	GN	GY (gm^{-2})
Block	2	0.53	7.04	26.16	306.72
Irrigation	1	141.2**	5423**	3257.7**	18019166**
Error (a)	2	1.593	7.318	1.109	2595
Genotype	101	23.52**	72.48**	72.26**	11481**
Genotype × Irrigation	101	4.301**	9.183*	29.12**	19630**
Error (b)	404	1.045	7.075	5.05	941.5
Heritability (%)		69.0	61.0	88.0	0.65
CV (%)		10.5	8.0	7.4	5.6

** and ** show that mean squares are significant at 0.05 and 0.01 respectively. GN: grain number per spike, GY: grain yield per square meter, SL: spike length, TKW: thousand kernel weight*

Positive correlations between grain yield under drought stress conditions and both STI (r=0.90) and GMP (r=0.92) indices were observed (Table 5). Correlation coefficients show that STI, GMP, HMP, MSTI and MP are more efficient than other indices for selecting high yielding genotypes under drought stress conditions. Therefore, it can be concluded that genotypes such as KC4907, KC4863, KC4144, KC4779, KC4641, KC4880, KC4494 and Bezostaya with the highest values for STI (0.85-0.65) and GMP (ranged 578.8 to 636.4), can be considered as drought tolerant (Suppl. Table 1). There were significant and positive correlations between grain yield (Y_P) under non-stress condition and TOL (r=0.71), MP (r=0.31) and SSI (r=0.55) (Table 5). The genotypes KC4907, KC4863, KC4779, KC4641, and KC3892 had higher MP than other genotypes. PEV had significantly positive correlation with Yp (r= 0.55) while MSTI was strongly correlated with Yp (r= 0.99). Talebi et al. [43] indicated that MP, GMP and STI were the most effective indices in identifying high yielding cultivars under moisture stress environments. Such results were also confirmed by Farshadfar et al. [44] and Nouraein et al. [45]. Ackura et al. [46] showed that SSI is suggested as useful indicator for wheat breeding where the stress is severe while MP, GMP, TOL and STI are suggested if the stress is less severs.

3.4 Correlations and Path Coefficients

Correlation coefficients of traits are presented in Table 6. After GN (r=0.57), SL had the highest (r=0.50) positive correlation with GY. SL had negative correlation with TKW that shows increasing in the size of spike decreases grain weight. Therefore, path analysis was performed to interpret the better understanding of the interrelationships of traits and the cause and effects of correlations among traits.

Table 3. Descriptive parameters of traits in wheat landraces under well-watered and drought conditions

	Spike length		Grain /spike		Thousand kernel weight		Grain yield	
	WW	**DS**	**WW**	**DS**	**WW**	**DS**	**WW**	**DS**
Minimum	4.6	3.3	21.3	18.3	26.7	23.0	586.1	217.0
Maximum	15.0	12.6	44.6	40.6	44.3	40.3	811.1	564.3
Mean	10.1	9.2	32.7	28.1	34.9	31.4	722.1	379.0
Cultivar/ landrace								
Shiraz	12.3	7.6	37.6	26.3	35.0	27.7	811.1	326.5
Bezostaya	12.0	11.3	36.3	37.6	42.7	34.7	666.7	513.3
10 Top Landraces	KC4641 (15.0)	KC4554 (13.3)	KC3885 (44.6)	KC4880 (40.6)	KC4502 (44.3)	KC4863 (38.7)	KC4703 (806.5)	KC4494 (564.3)
	KC4528 (14.7)	KC4502 (13.0)	KC4880 (42.3)	KC4502 (40.0)	KC4779 (42.6)	KC4528 (38.3)	KC3892 (806.2)	KC4907 (563.9)
	KC4840 (14.0)	KC4528 (12.7)	KC4144 (42.3)	KC4144 (39.3)	KC4863 (41.8)	KC4779 (38.1)	KC3879 (805.5)	KC4498 (561.0)
	KC4514 (13.7)	KC4641 (12.3)	KC3894 (42.0)	KC3885 (38.3)	KC4554 (41.2)	KC4880 (38.0)	KC2178 (803.4)	KC4890 (555.0)
	KC4144 (13.6)	KC4494 (12.3)	KC4527 (41.7)	KC4870 (38.7)	KC4907 (41.1)	KC4890 (37.1)	KC4523 (802.0)	KC4529 (551.0))
	KC4863 (13.4)	KC4840 (12.0)	KC4527 (41.6)	KC4641 (37.7)	KC4510 (41.1)	KC4498 (37.0)	KC4518 (801.7)	KC4880 (547.7)
	KC4494 (13.3)	KC4144 (12.0)	KC4571 (41.3)	KC4554 (37.3)	KC4890 (41.0)	KC4494 (36.9)	KC4527 (799.3)	KC4641 (545.6)
	KC809 (13.3)	KC4863 (11.0)	KC4641 (39.7)	KC4494 (35.0)	KC4529 (40.7)	KC4529 (36.8)	KC3107 (799.2)	KC4840 (544.3)
	KC4779 (13.0)	KC4700 (11.0)	KC4514 (39.7)	KC4840 (33.7)	KC4880 (40.5)	KC4907 (36.7)	KC1948 (798.7)	KC4779 (538.0)
	KC4502 (13.0)	KC4826 (11.0)	KC4907 (39.0)	KC4517 (44.7)	KC4511 (40.5)	KC4502 (36.1)	KC4632 (798.3)	KC3885 (532.3)
LSD (0.05)	1.6		3.6		4.1		51.2	

Using stepwise regression analysis GN, SL and TKW entered to the model of grain yield and these traits were selected for analysis of path coefficients. Path analysis results indicated that the highest direct (0.47) effect on grain yield was explained by SL although it had negative indirect (-0.084) effect via GN (Table 7). Positive indirect effect of SL via TKW on grain yield was suppressed by its negative effect via GN indicating that increase in GN may reduce TKW. Relatively low correlation of GN (r=0.28) with GY can be explained by its low direct (0.335) effect compared to the effects of TKW and SL.

3.5 PCA and Bi- plot

The first pair PC was selected to construct bi-plot of drought indices and genotype distribution. The PC analysis indicated that MP, GMP and STI were better predictors of Ys because of their positive correlations and also narrow angels that were found among their vectors in bi-plot diagram (Fig. 1). Genotypes such as KC1948 (30), KC4830 (32), KC4700 (24), KC4523 (23) and Shiraz (101) were in the vicinity of TOL and SSI.

Table 4. Analysis of variance of drought related indices in 102 wheat genotypes

		Mean of square									
Source	DF	MSTI	SSI	PEV	HMP	GMP	STI	YSI	YI	MP	TOL
Block	2	0.34	0.022	0.005	423.85	139.15	0.001	0.005	0.008	87.27	5177.75
Genotype	101	0.74**	0.258**	0.058**	12522**	8601.6**	0.035**	0.058**	0.149**	5815**	38709**
Error	202	0.031	0.01	0.002	750.05	583.79	0.03	0.002	0.007	482.58	1653.44
CV		16.74	9.92	9.93	5.59	4.65	9.37	6.32	8.09	4.01	11.83

** and ** represent probability level of significance at the 0.05 and 0.01 respectively*

Table 5. Correlation coefficients between drought tolerance indices and grain yield under stress (Ys) and well-watered (Yp) conditions for 102 bread wheat genotypes

Index	TOL	MP	YI	YSI	STI	GMP	HMP	PEV	SSI	MSTI	Y_P	Y_S
Y_P	0.71	0.31	-0.31	-0.59	0.11	0.04	-0.11	0.55	0.55	-0.34	1	
Y_S	-0.87	0.78	0.99	0.91	0.90	0.92	0.97	-0.96	-0.95	0.99	-0.32	1

Coefficients higher that 0.10 and 0.20 are significant at 0.05 and 0.01 respectively

Table 6. Correlation coefficients of grain yield and its components in wheat

	SL	GN	(TKW)	(GY)
Spike length (SL)	1.0	0.34**	-0.25**	0.50**
Grain number /spike (GN)		1.0	0.17^{ns}	0.57**
Thousand kernel weight (TKW)			1.0	0.28**
Grain yield (GY)				1.0

***: significant at 0.01 probability level, ns: non-significant*

Table 7. Path coefficients for the direct and indirect effects of yield components on grain yield of wheat landraces genotypes

Trait		Indirect effect			
	Direct effect	GN	TKW	SL	Correlation with grain yield
GN	0.335	-	0.061	-0.118	0.28
TKW	0.362	0.057	-	0.16	0.57
SL	0.47	-0.084	0.123	-	0.50

GN: grain number/spike, TKW: thousand kernel weight, SL: spike length

The genotypes KC4499 (3), KC4907 (4), KC4863 (8), KC4528 (27), KC4641 (50), KC4494 (63) and Bezostaya (102) were placed in close to the MP, STI, MSTI and GMP indices (Fig. 1). Nouraein et al. [45] used bi-plot analysis for better understanding of statistical drought indices and found that GMP, MP and STI were the most appropriate indices to identify wheat genotypes under stress condition. Using PCA analysis for screening wheat drought tolerance, Talebi et al. [43] found that the first PCs explained 0.81 of total variations with higher contribution of Ys, Yp, MP, STI and GMP. In their study [43] the second PCs which was named stress-tolerance dimension were highly affected by TOL, SSI and YSI. Results of bi-plot analysis conducted by Ackura et al. [46] revealed the first PCs explained 70.0% of the variation with Yp, MP, GMP and STI and this PC named as yield potential and drought tolerance.

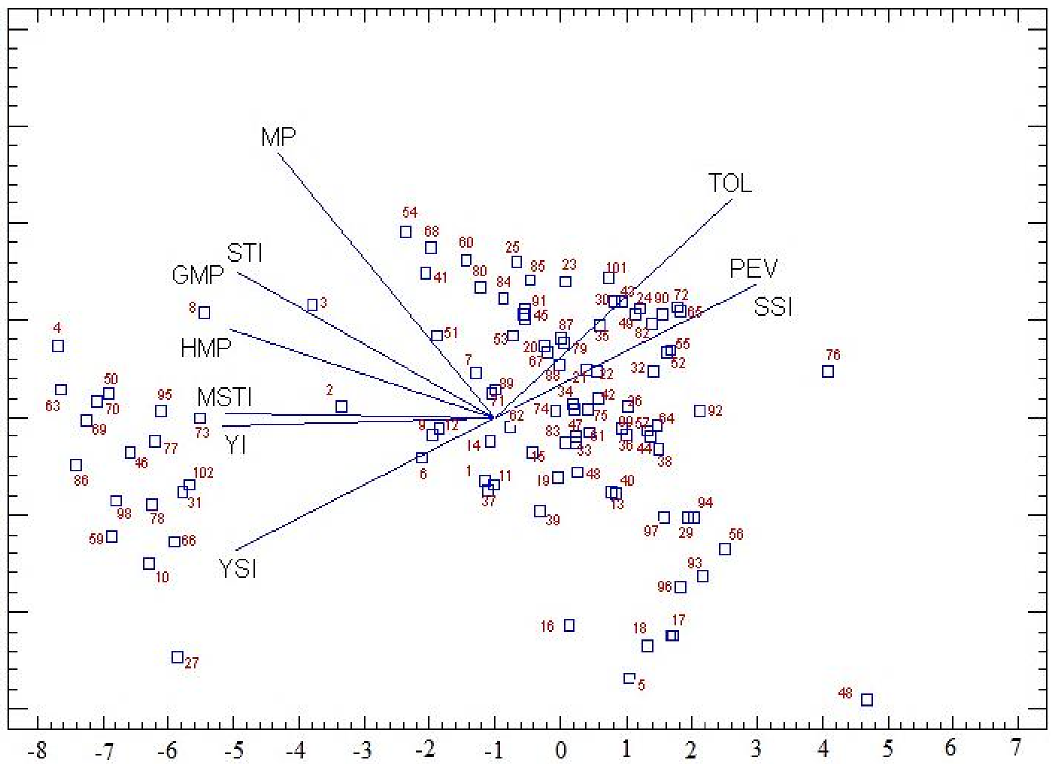

Fig. 1. Bi-plot for 102 wheat genotypes and different drought tolerance indices. Numbers refer to the name of genotypes in Suppl. Table 1

4. CONCLUSION

Climatic data of the site of study show that our region faces low precipitation and also water deficit conditions during reproductive stages of wheat growth. As a consequence, breeding programs for selecting high yielding genotypes adapted to drought stress after heading is of necessary. In general, the results of present study showed the existence of genetic variation and significantly different responses of wheat landraces to drought occurred at heading stage. Also, drought stress reduced grain yield and its components in wheat genotypes. Similar results [5] indicated that drought occurred during grain filling stage significantly reduced the TKW and grain yield of wheat genotypes. Drought stress can reduce grain yield via slow or reduced nutrients transfer from leaves to seeds [47]. Our results showed that grain number per spike had the highest heritability and highest correlation with grain yield under drought stress and could be useful in breeding for wheat drought tolerance.

Our findings indicated that the TOL and the SSI indices were correlated with low grain yield and its components under drought stress, whereas STI, GMP and MP were indices parameters for identifying high yielding genotypes under both drought and irrigated conditions. Similar results indicated that wheat genotypes with higher TOL had lower grain yield under drought stress [48,49]. The SSI index has been widely used to identify drought sensitive crop plants challenged with water limited conditions [48,49,50].

The indices MP, GMP and STI had positive correlation with Yp and Ys under both water regime conditions. The positive correlation between Ys under pre and post-anthesis drought stress conditions and different indices such as MP, GMP and STI has been reported in other studies [34,37,51,52,53,54,55]. According to the results of Fernandez [34] and Richards [56], indices that have a high and positive correlation with grain yield in both stress and non-stress environments, are the best indicators for screening drought tolerant crops in breeding programs. Analysis of bi-plot and principal components indicated that MP, GMP and STI were better predictors of Ys and can be used for selection of high yielding genotypes under drought conditions.

In conclusion, it can be concluded that the genotypes KC4499, KC4907, KC4863, KC4528, KC4641, KC4494, KC4890, KC4529, KC4870, KC4510, KC4144, KC4498, KC4554, K3885, KC4779, KC4511 and KC4840 are relatively tolerant to drought stress and can be used in breeding programs for drought tolerant cultivars.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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