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Screening landraces of bread wheat genotypes for drought tolerance in the field and laboratory

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ABSTRACT: In order to study the response of twenty bread wheat (*Triticum aestivum* L.) landraces to drought stress two experiments were conducted in the field and laboratory using randomized complete block design and completely randomized design (CRD) with three replications. The field experiment was under rainfed and irrigated conditions during 2010-2011 cropping season. Significant positive correlation was found between grain yield in the stress (Ys) and non-stress (Yp) conditions with mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress tolerance index (STI), modified stress tolerance index (MSTI), yield index (YI) and stress non-stress production index (SNPI) indicating that these criteria discriminated drought tolerant landraces with high grain yield under stress and non-stress environments (group A). No significant correlation was observed between Ys with tolerance (TOL), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI), linear regression coefficient (b) and germination stress index (GSI), hence these indicators were not able to identify drought tolerant genotypes (group C). Absence of association between field and laboratory index (germination stress index = GSI) of drought tolerance showed that GSI can not be considered as an early selection criterion for discriminating drought tolerant genotypes. Principal component analysis (PCA) indicated that first and second PCA accounted for 87.72% of variations among the indices. Screening drought tolerant genotypes using mean rank, standard deviation of ranks and biplot analysis, discriminated genotypes Phishtaz , WC-47615 and WC-5050 as the most drought tolerant. Thus, they are recommended for improvement of drought tolerance in common wheat in hybridization programs.

***Keywords*:** Bread wheat, drought tolerance indicators, biplot, ranking method, screening criteria

INTRODUCTION

Crop Plants are exposed to various unfavorable environmental conditions during their lives, which is of a significant effect on the growth of plants (Lichtenhaler, 1996).

The main objectives of the wheat breeding programs are to increase yield potential, stability and adaptation, to improve tolerance to abiotic stresses such as drought, heat, cold, salinity and pre-harvest sprouting and durable resistance to diseases and pests, with medium to high flour quality for traditional flat bread baking (Saidi et al., 2000). Drought is one of the major environmental constraints that severely limit wheat productivity. Some estimates indicated that 50% of the approximately 230M ha sown to wheat annually in the world is frequently affected by drought. Wheat breeding has made remarkable progress in developing cultivars better able to cope with drought conditions. Increasing in grain yield of between 0.4 and 1.3% per annum have been reported for many of the drier wheat producing lands of the world (Byerlee and Traxler, 1995).

It is a difficult challenge to achieve a genetic improvement in the yield under these environments, while progress in productivity has been much higher in favorable environments (Richards, 2002).Thus, drought indicators which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used to identify drought tolerant genotypes (Mitra, 2001).

In stressful environments, yield per se is not always the most appropriate selection trait, but an approach based on the evaluation of some physiological traits involved in stress tolerance was suggested (Blum, 1988). One of the screening methods based on physiological characters is using several osmotica to induce stress in plant tissues. Seed germination in mannitol and polyethylene glycol (PEG), measurements of root length and the vigor and growth of seedlings exposed to osmotica have been proposed for drought screening (Farshadfar, 2002). The effect of PEG was evaluated on wheat (Sapra, 1991) and on wheat – agropyron disomic addition lines (Farshadfar, 2002). They concluded that PEG was very suitable for the adjustment of osmotic potential. Several selection criteria have been proposed to increase drought tolerance based on their performance in stress and non–stress environments. The stress tolerance (TOL) defined by Rosielle and Hamblin, (1981) as the differences in yield between the stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. Fischer and Maurer, (1978) proposed the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Clarke, (1992) used SSI to assess drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and could rank their pattern.It is reported that SSI more and less than 1 indicates above and below-average susceptibility to drought stress, respectively (Guttieri, 2001). The other value defined as relative drought index (RDI) was introduced by Fischer, (1998).The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Ramirez and Kelly, 1998). Also, Gavuzzi, (1997), Bouslama and Schapaugh (1984) and Choukan. (2006) introduced the yield index (YI), yield stability index (YSI), and yield reduction percentage (% reduction), respectively. Fernandez, (1992) defined a new stress tolerance index (STI) and classifiedthe manifestation of plants into the four groups of (1) – genotypes that express uniform superiority in non-irrigated and irrigated conditions (group A), (2) - genotypes which perform favorably only in non-stress conditions (group B), (3) - genotypes which yield relatively higher only in stress conditions (group C) and (4) and genotypes which perform poorly in both conditions (group D). Thus, as Fernandez demonstrated, the most suitable index for stress tolerance selection is one that is capable to distinguish the class A from other classes.

Bansal and Sinha, (1991) used linear regression coefficient (bi) as a criteria for selection of drought resistant genotypes. Karamanos and Papatheohari (1999) used a new index of relative adaptability to drought (bN). To improve the efficiency of STI a modified stress tolerance index (MSTI) was recommended by Farshadfar and Sutka, (2002) which corrects the STI as a weight. Moosavi (2008) offered abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI) and stress non-stress production index (SNPI) for screening drought tolerant genotypes in stress and non-stress conditions. However, the optimal selection criterion should distinguish genotypes that express uniform superiority in both stressed and non-stressed environments from the genotypes that are favorable only in one environment.

The objectives of this study were to (i) identify drought resistant/tolerant bread wheat genotypes under mild stress in the highlands of western Iran, (ii) determine the efficiency of screening methods to classify genotypes into resistant/sensitive and tolerant and (iii) study interrelationships among the screening methods.

MATERIALS AND METHODS

1-Field experiments

Twenty landraces of bread wheat (*Triticuma estivum* L.) listed in Table 1 were provided from, Seed and Plant Institute of Karaj, Iran. They were assessed using a randomized complete block design with three replications under two irrigated and rainfed conditions during 2010-2011 growing season in the Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran (47° 9′ N, 34° 21′ E and 1319 m above sea level).

One cultivar, Pishtaz, which is typically grown by Iranian farmers, was included as national check in stress and non-stress conditions. Mean precipitation in 2010–2011 was 509.50 mm. The soil of experimental field was clay loam with pH7.1. Sowing was done by hand in plots with four rows 2 m in length and 20 cm apart. The seeding rate was 400 seeds per m^2 for all plots. At the rainfed experiment, water stress was imposed after anthesis. Non-stressed plots were irrigated three times after anthesis, while stressed plots received no water. At harvest time, yield potential (Yp) and stress yield (Ys) were measured from 2 rows 1 m in length. Drought resistance indices were calculated using the following relationships:

1-Yield index = $YI = \frac{Ys}{\bar{Y}s}$(Gavuzzi, 1997).

2-Yield stability index=$YSI = Ys/Yp$ (Bouslama and Schapaugh, 1984).

3-Tolerance= $TOL = (Yp - Ys)$ (Rosielle and Hamblin, 1981).

4-Mean productivity= $MP = (Yp + Ys)/2$ (Rosielle and Hamblin, 1981).
5-Harmonic mean= $HM = 2(Yp \times Ys)/(Yp + Ys)$
6-Stress susceptibility index= $SSI = (1 - Ys/Yp)$/SI., $SI = 1 - \bar{Y}s/\bar{Y}p$ (Fischer and Maurer, 1978).
7-Geometric mean productivity= $GMP = \sqrt{(Yp)(Ys)}$, Stress tolerance index= $STI = (Yp \times Ys)/(\bar{Y}p)^2$ (Fernandez, 1992).
8-Drought resistance index = $DI = Ys \times (Ys/Yp)$ (Lan, 1998).
9-Drought susceptibility index= $DSI = (1 - \bar{Y}s/\bar{Y}p)/D$ (Fischer and Maurer, 1978).
Where D = environmental stress intensity = 1-(mean yield of all genotypes under drought/mean yield of all genotypes under well-watered conditions).
10-Coefficient of drought resistance = $CD = Ys/Yp$ (Blum, 1988)
11-Modified stress tolerance index= $MSTI = Ki\,STI$, $K1 = \frac{Yp^2}{\bar{Yp}^2}$and $K2 = \frac{Ys^2}{\bar{Ys}^2}$ (Farshadfar and Sutka, 2002) where ki is the correction coefficient.
12-Relative drought index= $RDI = \frac{\left(Ys/_{Yp}\right)}{\left(\bar{Y}s/_{\bar{Y}p}\right)}$ (Fischer and Wood, 1979).
13-Abiotic tolerance index = $ATI = [(Yp - Ys)/(\bar{Y}p - \bar{Y}s)] \times \sqrt{(Yp \times Ys)}$ (Moosavi et al., 2008).
14-Stress susceptibility percentage index = $SSPI = [(Yp - Ys)/2\bar{Y}p] \times 100$ (Moosavi et al., 2008).
15-Stress non-stress productionindex= $SNPI = \left[\sqrt[3]{(Yp + Ys)/(Yp - Ys)}\right] \times \left[\sqrt[3]{Yp \times Ys \times Ys}\right]$
(Moosavi, 2008).
16- Regression coefficient of cultivar yield on environmental index (b) **(**Bansal and Sinha, 1991).
17- Relative adaptability to drought = $bN = b/a$ where b is the slope and a is the intercept of regression model (Karamanos and Papatheohari, 1999).
In the above formulas, YS, YP, $\bar{Y}s$ and $\bar{Y}p$ represent yield under stress, yield under non-stress for each genotype, yield mean in stress and non-stress conditions for all genotypes, respectively.
For screening drought tolerant genotypes a rank sum (RS) was calculated by the following relationship:
Rank sum (RS) = Rank mean ($\bar{R}$) + Standard deviation of rank (SDR) and SDR= $(S^2i)^{0.5}$

Table 1. Genotype name and codes

No	Genotype	No	Genotype
1	WC-47536	11	WC-47637
2	WC-47620	12	WC-47400
3	Phishtaz	13	WC-47473
4	Pishgam	14	WC-47371
5	WC-47374	15	WC-47615
6	WC-47632	16	WC-47388
7	WC-47358	17	WC-5050
8	WC-4987	18	WC-47359
9	WC-5045	19	WC-47619
10	WC-47617	20	WC-47379

2-Laboratory experiment

The experiment was carried out in a completely randomized design (CRD) under two different stress (-0.8 MPa) and non – stress (o bar) conditions created with the help of polyethylene glycol 6000 (PEG – 6000) by the method suggested by Michel and Kauffman (Khalilzade and Karbalai-Khiavi, 2002). Mature seeds were surface-sterilized in 70% (v/v) ethanol for 2.5 min, rinsed four times with sterile distilled water, incubated further in 2.5% sodium hypochlorite for 15 min, and rinsed several times in sterile distilled water. 25 seeds were then transferred into sterile Petri dishes of 25 mm diameter containing two Whatman filter paper moistened with 10 ml of control solution (distilled water) or the same solution added with PEG-6000. Seeds were germinated in an incubator at 20±0.5°c. Germination percentages were recorded daily up to 10 days using radicle extrusion (≥ 2 mm long) as a criterion. After 10 days the number of germinated seeds was recorded and promptness index (PI) and germination stress index (GSI) were calculated using the formula proposed by Sapra, (1991) and Bouslama and Schapaugh (1984):
PI = nd_2 (1.0) + nd_4 (0.8) + nd_6 (0.6) + nd_8 (0.4) + nd_{10} (0.2)
In which nd_2, nd_4, nd_6, nd_8 and nd_{10} represent the percentage of germinated seeds after 2, 4, 6, 8,and 10 days after sowing, respectively.
GSI (%) = [PI(in stress condition) / PI(in normal condition)] × 100

Statistical analysis

Correlation analysis and principal component analysis (PCA), based on the rank correlation matrix and biplot analysis were performed by SPSS ver. 16, and STATISTICA ver. 8.

RESULTS AND DISCUSSION

Screening drought tolerant genotypes

Water stress consistently lowered the yield of wheat genotypes in stress rather than non-stress conditions (Table 2). Based on the stress tolerance index (STI), modified stress tolerance index (MSTI) and grain yield, genotypes no. 18, 15 and 8 were found drought tolerant with high STI and grain yield under rainfed and irrigated conditions, while genotypes no. 4, 11 and 10 displayed the lowest amount of STI, MSTI and grain yield under rainfed and irrigated conditions (Table 2). For stress susceptibility index (SSI) the genotypes 15, 3 and 17 were the most and 19, 5, 12 and 7 were the least relative tolerant genotypes and for geometric mean productivity (GMP) genotypes 15, 18 and 8 were the most and genotypes 10, 11 and 4 the least relative tolerant genotypes. Although STI and GMP are able to separate group A, but they have little emphasis on stability of yield between stress and non-stress conditions.

Table 2. Ranks (R), ranks mean (R) and standard deviation of ranks (SDR) of drought tolerance indicators

Genotype No.	Yp	R	Ys	R	TOL	R	MP	R	GMP	R	STI	R	K1STI	R	K2STI	R	GSI	R	SSI	R	YSI	R	YI	R
1	0.80	10	0.65	5	0.15	3	0.72	10	0.72	7	0.76	9	0.70	9	0.94	6	0.70	4	0.69	5	0.82	3	1.12	5
2	0.78	13	0.55	10	0.23	7	0.67	14	0.66	13	0.64	13	0.58	14	0.60	13	0.41	14	0.93	13	0.71	8	0.95	10
3	0.82	7	0.73	3	0.09	1	0.77	5	0.77	4	0.88	4	0.85	7	1.36	4	0.03	18	0.60	2	0.89	1	1.25	3
4	0.72	18	0.49	18	0.23	8	0.61	19	0.59	18	0.52	18	0.39	18	0.38	18	0.47	12	0.96	14	0.68	12	0.84	18
5	0.95	6	0.54	12	0.41	18	0.74	8	0.71	10	0.75	10	0.99	6	0.64	12	0.00	20	1.17	19	0.57	18	0.93	12
6	0.82	8	0.63	7	0.19	5	0.73	9	0.72	8	0.76	8	0.77	8	0.88	7	0.60	9	0.76	6	0.79	5	1.09	7
7	0.98	4	0.55	11	0.43	19	0.77	6	0.73	5	0.80	6	1.21	4	0.75	9	0.23	17	1.04	17	0.57	19	0.95	11
8	1.02	2	0.65	6	0.37	17	0.84	4	0.81	3	1.00	3	1.64	2	1.37	3	0.85	2	1.01	16	0.64	15	1.12	6
9	0.74	17	0.50	16	0.23	9	0.62	18	0.61	17	0.55	17	0.47	17	0.42	17	0.80	3	0.90	11	0.69	11	0.87	16
10	0.67	20	0.44	20	0.23	10	1.54	1	0.55	20	0.44	20	0.29	20	0.28	20	0.68	5	0.81	9	0.66	13	0.76	20
11	0.71	19	0.46	19	0.25	11	0.58	20	0.57	19	0.48	19	0.35	19	0.30	19	0.59	10	0.86	10	0.66	14	0.79	19
12	0.80	11	0.51	15	0.29	16	0.66	15	0.64	15	0.61	15	0.59	12	0.53	14	0.65	7	1.04	18	0.63	17	0.88	15
13	0.79	12	0.54	13	0.25	12	0.66	16	0.65	14	0.62	14	0.59	13	0.53	15	0.67	6	0.66	4	0.70	9	0.93	13
14	0.78	14	0.50	17	0.28	15	0.64	17	0.62	16	0.57	16	0.49	16	0.43	16	0.62	8	0.98	15	0.64	16	0.86	17
15	0.98	5	0.80	1	0.18	4	0.89	3	0.89	1	1.16	2	1.63	3	2.22	1	0.58	11	0.58	1	0.82	4	1.39	1
16	0.78	15	0.58	8	0.19	6	0.68	13	0.67	12	0.67	12	0.58	15	0.69	10	0.26	16	0.77	7	0.75	7	1.01	8
17	0.78	16	0.67	4	0.11	2	0.72	11	0.72	9	0.77	7	0.66	11	1.03	5	0.92	1	0.62	3	0.86	2	1.16	4
18	1.03	1	0.77	2	0.26	14	0.90	2	0.88	2	1.17	1	2.12	1	2.07	2	0.39	15	0.92	12	0.78	6	1.32	2
19	0.99	3	0.54	14	0.45	20	0.77	7	0.73	6	0.80	5	1.16	5	0.76	8	0.46	13	1.33	20	0.54	20	0.93	14
20	0.82	9	0.57	9	0.25	13	0.70	12	0.68	11	0.69	11	0.68	10	0.67	11	0.02	19	0.77	8	0.70	10	0.98	9

According to tolerance index (TOL), genotypes 3, 17 and 1 exhibited the most and genotypes 19, 7 and 5 the least relative tolerances, respectively. Abiotic tolerance index (ATI) discriminated genotypes 3, 17 and 1 as the most and genotypes 5, 8, 7, 19 and 16 as the least relative tolerant genotypes. With regard to stress non-stress production index (SNPI), which indicates relative resistance, genotypes 3, 15 and 18 were the most and 11, 10 and 14 the least relative tolerant genotypes. ATI and SSPI could separate relative tolerant and non-tolerant genotypes better than previous indices, while SNPI index is able to distinguish group A from others and has an emphasis on high and stable yield in the two conditions (Moosavi , 2008).

For stress susceptibility percentage index (SSPI) and bi index, the genotypes 3, 17 and 1 were the most and 19, 7 and 5 were the least relative tolerant genotypes. Based on mean productivity index (MP) genotypes 10, 18 and 15 were found drought tolerant while genotypes 11, 4 and 9 indicated the lowest amount of MP. Using harmonic mean (HM), genotypes 15, 18 and 8 were the most drought toleranr while genotypes 10, 11 and 4 showed the least amount of HM. According to drought susceptibility index (DSI), genotypes 3, 17 and 15 exhibited the most and genotypes 19, 5 and 7 the least relative tolerances, respectively. For relative drought index (RDI) and coefficient of drought resistance (CD), the genotypes 3, 17, 15 and 1 were the most and 19, 5 and 7 were the least relative tolerant genotypes. Based on drought resistance index (DI) genotypes 15, 3 and 18 were found drought tolerant, while genotypes 10, 11 and 19 indicated the lowest amount of DI. For bN index, the genotypes 3, 17, 15 were the most and 20, 13 and 4 were the least relative tolerant genotypes. These indices have been used in different studies (Salim and Saxena, 1993; Garrity and O’Toole, 1994; Abebe, 1998; Pantuwan, 2002b; Yue, 2005; Sio-Se Mardeh, 2006; Farshadfar , 2013).

Using GSI as the selection criteria the most desirable genotypes were 17, 8 and 9 while, genotypes 5, 20 and 4 displayed the lowest amount of GSI (Table 2).The absence of significant correlation between GSI and field indices, displaying that it cannot be screened as a drought tolerance criterion in identifying drought tolerance cultivars. This result was contradicted by Farshadfar, (2002) and Farshadfar and Vaisi (2011).

Screening drought tolerance criteria

Yield in stress (Ys) and non-stress (Yp) conditions were significantly and positively correlated with SNPI, K1STI, K2STI, STI, GMP, MP, HM, YI indicating that these criteria are able to discriminate group A (genotypes that express uniform superiority in both environmental conditions) (Fernandez 1992) from the others (Table 3). Significant correlations were not observed between SSPI, b, TOL and GSI with yield in stress (Ys) and non-stress (Yp) conditions. Majidi, (2011) reported positive and significant correlations between Yp with TOL, MP, GMP, STI, SSI and HM selection indices. They reported that correlations between Y_S with GMP, STI, and HM showed that selection based on these indices may increase yield in stress and non-stress conditions. Khalilzade and Karbalayi Khiavi (2002) and Farshadfar , (2001) illustrated that the most appropriate indicators for selection of drought tolerant cultivars, are indices showing a relatively high correlation with grain yield in both environmental conditions. The observed relations were consistent with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2002) in maize and Golabadi, (2006) in durum wheat.

Table 3. Association between drought tolerance indices with Ys and Yp

	Ys	Yp	TOL	MP	GMP	STI	YI	YSI	SSI	GSI	CD	DSI	DI	HM	K1STI	K2STI	RDI	ATI	SSPI	b	bN	SNPI
Ys	1.000																					
Yp	.617**	1.000																				
TOL	.418	-.376	1.000																			
MP	.544*	.638**	-.051	1.000																		
GMP	.868**	.889**	.024	.701**	1.000																	
STI	.865**	.878**	.011	.698**	.991**	1.000																
YI	1.000**	.617**	.418	.544*	.868**	.865**	1.000															
YSI	.684**	-.074	.904**	.138	.298	.296	.684**	1.000														
SSI	.495*	-.215	.851**	.087	.146	.131	.495*	.887**	1.000													
GSI	-.135	-.359	.197	-.155	-.236	-.227	-.135	.114	.183	1.000												
CD	.684**	-.074	.904**	.138	.298	.296	.684**	1.000**	.887**	.114	1.000											
DSI	.692**	-.063	.901**	.152	.314	.313	.692**	.997**	.896**	.108	-.066	1.000										
DI	.898**	.310	.674**	.271	.620**	.615**	.898**	.872**	.681**	.036	-.015	.880**	1.000									
HM	.940**	.792**	.185	.663**	.971**	.971**	.940**	.457*	.284	-.119	.068	.468*	.741**	1.000								
K1STI	.740**	.968**	-.230	.689**	.953**	.949**	.740**	.069	-.078	-.274	.104	.081	.438	.901**	1.000							
K2STI	.943**	.773**	.205	.650**	.964**	.967**	.943**	.469*	.289	-.110	.125	.481*	.758**	.989**	.875**	1.000						
RDI	.669**	-.093	.914**	.126	.284	.283	.669**	.995**	.872**	.143	-.113	.992**	.868**	.447*	.053	.457*	1.000					
ATI	.134	-.614**	.917**	-.143	-.262	-.268	.134	.744**	.713**	.242	-.341	.729**	.405	-.108	-.496*	-.084	.756**	1.000				
SSPI	.409	-.383	.995**	.002	.017	.003	.409	.899**	.862**	.205	-.257	.896**	.651**	.176	-.238	.197	.907**	.929**	1.000			
B	.412	-.380	.998**	-.026	.020	.006	.412	.901**	.854**	.194	-.266	.898**	.662**	.179	-.235	.200	.908**	.925**	.998**	1.000		
bN	.686**	.411	.423	.475*	.668**	.665**	.686**	.454*	.265	-.092	.454*	.457*	.534*	.704**	.529*	.713**	.462*	.266	.427	.424	1.000	
SNPI	.947**	.505*	.535*	.459*	.770**	.776**	.947**	.771**	.576**	-.024	.051	.782**	.938**	.856**	.617**	.878**	.758**	.265	.525*	.529*	.648**	1.000

*. Correlation is significant at the 0.05 level; **. Correlation is significant at the 0.01 level

Ramirez and Kelly (1998) reported that selection based on a combination of both SSI and GMP indices may provide a more desirable criterion for improving drought resistance in common beans. Selection through SSI chooses genotypes with relatively low Y_P but high Y_S. This index ranges between 0 and 1 and the greater this index, the greater susceptibility of the genotype to stress; however, it can not separate group A from group C (Fernandez, 1992). It is reported that yield-based SSI index did not differentiate between potentially drought resistant genotypes and those that possessed low overall yield potential (White and Singh, 1991; Clarke , 1992).

Selection through TOL chooses genotype with low Y_P and high Y_S (group C), hence, TOL was limited to distinguish between group C and group A (Fernandez, 1992). Rosielle and Hamblin proposed MP as the mean yield for a genotype in both stress and non-stress conditions. It can select genotypes with high Y_P but with relatively low Y_S (group B), however, the main disadvantage of this index is the lack of separation of group A from group B. By decreasing TOL and increasing MP, the relative tolerance increases (Fernandez, 1992; Rosielle an Hamblin, 1981**).** A high STI demonstrates a high tolerance, and the best advantage of STI is its ability to distinguish group A from others. MP, GMP and STI indices are useful to select higher yielding genotypes in both environmental conditions. However, drought tolerance can be defined as an ability of plant to be stable in stressed environment compared to non-stress conditions. Therefore, a genotype with higher yielding capacity can not be always perceived as tolerant. GMP is more powerful than MP in separating group A and has a lower susceptibility to different amounts of Y_S and Y_P, so MP, which is based on arithmetic mean, will be biased when the difference between Y_S and Y_P is high. The higher GMP value, the greater the degree of relative tolerance. It seems that STI, GMP and MP indices can identify cultivars producing high yield in both stress and non- stress conditions (Talebi, 2009). Pireivatlou. (2010) also reported that STI can be a reliable index for selecting high yielding genotypes.

ATI or SSPI select genotypes especially on the basis of yield stability, while, selection by SNPI is based on two characteristics simultaneously, namely yield stability as well as high Y_P and Y_S (with more emphasis on high Y_S than high Y_P) so, this index has a very strong and significant positive correlation with Ys in both data sets (Table 3). Although SNPI and STI are very similar and highly correlated, but in addition to high yield in stress and non-stress conditions and stable yield more emphasized is on SNPI than on STI and these characteristics, make SNPI a better index than STI for identifying genotypes with stable and high yield in both environmental conditions (Moosavi, 2008).

Principal component analysis

The relationships among different indices are graphically displayed in a biplot of PCA1 and PCA2 (Figure 1). The first and second components justified 87.72% of the variations between criteria. The PCA1 and PCA2 mainly distinguish the indices in different groups.

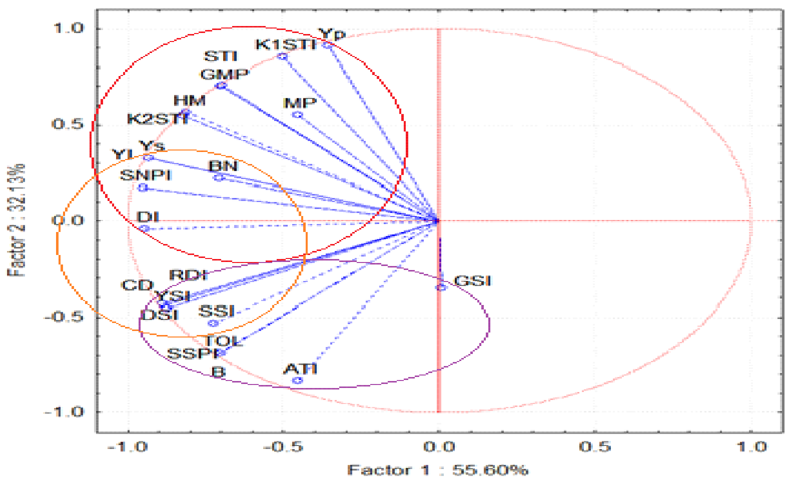

Figure 1. Screening drought tolerance indicators using biplot analysis

The PCs axes separated K1STI, K2STI, STI, HM, YI, BN, SNPI, DI, GMP, MP, Ys and Yp in group 1 (G1). Ys, YI, BN, SNPI, DI, RDI, CD, YSI, DSI and SSI were separated as groups 2 (G2). The PCs axes separated RDI, CD, YSI, DSI, SSI, TOL, SSPI, B, ATI and GSI in group (G3). The cosine of the angle between the vectors of two indices approximates the correlation between them. For instance, G1 indices were positively correlated (an acute angle), the same conclusion was obtained for the G2 indices. The cosine of the angles does not precisely translate into correlation coefficients, since the biplot does not explain all of the variation in a dataset. Nevertheless, the angles are informative enough to allow a whole picture about the interrelationships among the stability estimates (Yan and Kang, 2003).

Ranking method

The estimates of drought tolerance criteria (Table 2) indicated that the identification of drought-tolerant genotypes based on a single criterion was contradictory. For example, according to MP genotypes no. 10, 18 and 15 were found drought tolerant, while according to STI genotypes 18, 15 and 8 exhibited the most relative tolerances. To determine the most desirable drought tolerant genotypes according to the all indices mean rank and standard deviation of ranks of all criteria were calculated and based on these two criteria the most desirable drought tolerant genotypes were identified. In consideration to all indices, genotypes (17), (15) and (3) showed the best mean rank and low standard deviation of ranks in stress condition, hence they were identified as the most drought tolerant genotypes, while genotypes (11), (14) and (4) as the most sensitive, so they are recommended for crossing and genetic analysis of drought tolerance using diallel mating design or generation mean analysis and also for the QTLs (quantitative trait loci) mapping and marker assisted selection. The same procedures have been used for screening quantitative indicators of drought tolerance in durum wheat (Mohammadi, 2011), in maize (*Zea mays* L.) (Farshadfar and Sutka, 2002), and in rye (*Secale cereal* L.) (Farshadfar, 2003, 2012).

REFERENCES

Abebe A, Brick MA and Kirkby RA. 1998. Comparison of selection indices to identify productive dry bean lines under diverse environmental conditions. Field Crops Res 58: 15–23.

Bansal KC and Sinha SK. 1991. Assessment of drought resistance in 20 accessions of *Triticum aestivum* and related species. Part 1: total dry matter and grain yield stability. Euphytica 56: 7-14.

Blum A. 1988. Breeding crop varieties for stress environments. Critical Rev Plant Sci 2: 199–238.

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

Byerlee D and Traxler G. 1995. National and international wheat improvement research in the post green revolution period: Evolution and impacts. Am J Agr Econ 77:268–278.

Choukan R, Taherkhani T, Ghannadha MR and Khodarahmi M. 2006. Evaluation of drought tolerance in corn (*Zea mays* L.) lines with drought tolerance indices. Iran J Agric Sci 8:79-89.

Clarke JM, DePauw RM and TownleySmith TF. 1992. Evaluation of methods for quantification of drought tolerance in wheat. Crop Sci 32: 723–728.

Farshadfar E, Elyasi P and Aghaee M. 2012. In Vitro selection for drought tolerance in common wheat (*Triticumae stivum* L) genotypes by mature embryo culture. Am J of Sci Res 48: 102-115.

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

Farshadfar E, Mohammadi R, Aghaee M and Sutka J. 2003. Identification of QTLs involved in physiological and agronomic indicators of drought tolerance in rye using a multiple selection index. Acta Agron Hung 51(4):419–428.

Farshadfar E, Mohammadi R and Sutka J. 2002. Association between field and laboratory predictors of drought tolerance in wheat disomic lines. Acta Agron Hung 50(3): 377–381.

Farshadfar E, Poursiahbidi MM and 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(2):143-158.

Farshadfar E and Sutka J. 2002. Screening drought tolerance criteria in maize. Acta Agron Hung 50(4):411–416.

Farshadfar E and Vaisi Z. 2011. Correlation between field and laboratory indicators of drought tolerance in wheat-barley disomic addition lines. Ann Biol Res 2(6):546-553.

Fernandez GCJ. 1992. Effective selection criteria for assessing plant stress tolerance. In: Kuo, C.G. (ed) Adaptation of food crops to temperature and water stress. In Proc. Int. Symp., Taipei, Taiwan.

Fischer RA and Maurer R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust J Agric Res 29: 897-912.

Fischer RA and Rees D, Sayre KD, Lu ZM, Condon AG, Saavedra AL. 1998. Wheat yield progress associated with higher stomatal conductance and photosynthetic rate, and cooler canopies. Crop Sci 38:1467-11475.

Fischer RA and Wood T. 1979. Drought resistance in spring wheat cultivars III. Yield association with morphological traits. Aust J Agric Res 30: 1001-1020.

Garrity DP and O'Toole JC. 1994. Screening rice for drought resistance at the reproductive phase. Field Crops Res 39: 99–110.

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

Golabadi M, Arzani A and Mirmohammadi Maibody SAM. 2006. Assessment of drought tolerance in segregating populations in durum wheat. Afr J Agric Res 1: 162-171.

Guttieri MJ, Stark JC, Brien K and Souza E. 2001. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Crop Sci 41: 327-335.

Karamanos AJ and Papatheohari AY. 1999. Assessment of drought resistance of crop genotypes by means of the water potential index. Crop Sci 39: 1792-1797.

Khalilzade GH and Karbalai-Khiavi H. 2002. Investigation of drought and heat stress on advanced lines of durum wheat. Paper presented at the 7th Irainan congress of crop sciences. University of Guilan, Iran, 25-27 August 2002

Lan J. 1998. Comparison of evaluating methods for agronomic drought resistance in crops. Acta Agric Boreali-occidentalis Sinica 7: 85–87.

Lichtenhaler HK. 1996. Vegetation stress: an introduction to the stress concept in plants. J Plant Physiol 148: 4-14.

Majidi M, Tavakoli V, Mirlohi A and Sabzalian MR. 2011. Wild safflower species (*Carthamus oxyacanthus* Bieb.): A possible source of drought tolerance for arid environments. Aust J Crop Sci 5(8):1055-1063.

Mitra J. 2001. Genetics and genetic improvement of drought resistance in crop plants. Curr Sci 80:758-762.

Mohammadi M, Karimizadeh R and Abdipour M. 2011. Association of canopy temperature depression with yield of durum wheat genotypes under supplementary irrigation and rain-fed conditions. Aust J Crop Sci 5(4):487– 493.

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

Pantuwan G, Fukai S, Cooper M, Rajatasereekul S and O'Toole JC. 2002. Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands. II. Selection of drought resistant genotypes. Field Crops Res 73: 169–180.

Pireivatlou AS, Masjedlou BD and Aliyev RT. 2010. Evaluation of yield potential and stress adaptive trait in wheat genotypes under post anthesis drought stress conditions, Afric J of Agric Res 5: 2829-2836.

Ramirez P and Kelly JD. 1998. Traits related to drought resistance in common bean. Euphytica 99: 127-136.

Richards RA, RebetzkeGJ, Condon AG and Herwaarden AF. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci 42: 111-121.

Rosielle AA and Hamblin J. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci 21: 943-946.

Saidi A, Akbari A, Mozzaffari J, Heidari A, SerjaAzari M, Pirayeshfar B, Yazdansepas A, Salim SN and Saxena MC. 1993. Adaptation of spring-sown chickpea to the Mediterranean basin. 2. Factors influencing yield under drought. Field Crops Res 34: 137–146.

Sapra VT**,** Savage E**,** AnaleAO and Bell CA. 1991. Varietal differences of wheat and triticale to water stress. J Agron Crop Sci 167: 23-28.

Sio-Se Mardeh A, Ahmadi A, Poustini K and Mohammadi V. 2006. Evaluation of drought resistance indices under various environmental conditions. Field Crop Res 98: 222- 229.

Talebi R, Fayaz F and Naji AM. 2009. Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). Gen Appl Plant Physiol 35: 64-74.

White JW and Singh SP. 1991. Breeding for adaptation to drought. In: Van Schoonhoven A,Voysest O (eds.), Common Beans. Research for crop improvement. CAB Int CIAT, Colombia

Yan W and Kang MS. 2003. GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL, USA

Yue B, Xiong L, Xue W, Xing Y, Lijun L and Xu C. 2005. Genetic analysis for drought resistance of rice at reproductive stage in field with different types of soil. Theor Appl Genet 111: 1127–1136.