International Journal of Plant Breeding ©2012 Global Science Books

Screening and Repeatability of Quantitative Indicators of Drought Tolerance in Wheat-Barley Disomic Addition Lines

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ABSTRACT

To locate the genes controlling drought tolerance in barley (*Hordeum vulgare* cv. 'Betzes'), a set of complete wheat-barley disomic addition lines (DALs) along with two donor (barley) and recipient (wheat) parents were evaluated under drought stress and non-stress conditions for three cropping seasons. Several drought tolerance indices based on the grain yield of DALs in the stress and non-stress conditions were used to study the genetic variation in barley and to investigate relationship between the indices within and over the years. Differences in ranking of genotypes based on each index were observed from year to year, indicating that the drought tolerance of genotypes is influenced by year effect. The relationships among the indices and their association with mean yield based on Spearman's rank correlation were determined in each of the three cropping seasons. Principal component analysis (PCA) based on the Spearman's rank correlation matrix revealed that the screening methods were significantly inter-correlated with each other indicating that several of the statistics probably measure similar aspects of drought tolerance. The stress tolerance index (STI), geometric mean productivity (GMP), harmonic mean (HM) and mean productivity (MP) were consistently and highly correlated with each other over there cropping seasons, and, therefore, could be used to select drought tolerant genotypes with high yield performance in both stress and non-stress conditions. The stress susceptibility index (SSI), yield stability index (YSI), tolerance (TOL) and sensitivity drought index (SDI) showed consistent relationships with each other over years and can be used to screen the drought resistant and stable genotypes. According to multiple year data, most of the genes controlling drought tolerance are located on chromosome 7H in barley.

Keywords: barley, drought tolerance indices, Spearman's rank correlation, principal component analysis

INTRODUCTION

Drought stress is one of the most important threatening factors for the production of crop plants in the arid and semi-arid regions of the world (Mohammadi *et al.* 2003). Although drought can strike at any time, the crops are most susceptible to yield losses due to limited water during flowering time. The ability of a cultivar to produce high and satisfactory yield over a wide range of stress and non-stress environments is very important (Rashid *et al*. 2003). The response of plants to water stress depends on several factors such as developmental stage, severity and duration of stress, and cultivar genetics (Beltrano and Marta 2008); however, the improvement of a crop's productivity under stressed conditions requires genotypes with good stress tolerance and yield stability (Mohammadi and Amri 2011).

Targeting variety selection onto its growing environments is the prime interest of any plant breeding program. To achieve this, breeding programs usually undertake a rigorous evaluation of genotype performance across locations and years (Mohammadi and Amri 2011). Thus, developing high-yielding wheat cultivars under drought conditions in arid and semi-arid regions is an important objective of breeding programs (Leilah *et al*. 2005). Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (Reddy *et al*. 2004; Zhao *et al*. 2008). The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for unpredictable rainfed conditions (Nouri *et al*. 2011).

Some researchers believe in selection under favorable conditions (Betran *et al*. 2003), others in a target stress condition (Mohammadi *et al.* 2011b) while others yet have chosen a mid-point and believe in selection under both favorable and stress conditions (Byrne *et al*. 1995; Rajaram and van Ginkel 2001; Sio-Se Mardeh *et al*. 2006; Najafian 2009; Mohammadi *et al*. 2010; Nouri *et al*. 2011).

Attempts to measure the degree of tolerance with a single parameter have a limited value because of the multiplicity of the factors and their interactive contributing to drought tolerance under field Conditions (Guha *et al*. 2010).

Various researchers have used different methods to evaluate genetic differences in drought tolerance (Farshadfar *et al*. 2011). Drought resistance is defined by Hall in 1993 (in Nouri *et al*. 2011) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum 1996) while the values are confounded with differential yield potential of genotypes (Ramirez and Kelly 1998).

The stress tolerance (TOL) defined in 1981 by Rosielle and Hamblin (in Nouri *et al*. 2011) 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. The stress susceptibility index (SSI) suggested in 1978 by Fischer and Maurer (in Nouri *et al*. 2011) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Mohammadi *et al*. (2011a) used SSI to evaluate drought tolerance in durum wheat genotypes and found year-to-year and location to location variation in SSI for genotypes and could rank their pattern. Guttieri *et al.* (2001) suggested that SSI more and less than 1 indicates above and below-average susceptibility to drought

Received: 14 January, 2012. Accepted: 5 February, 2012.

Original Research Paper

stress, respectively.

The stress tolerance index (STI) was defined in 1992 by Fernandez (in Farshadfar *et al*. 2011) as a new advanced index, which can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions.

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). 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 yield index (YI; Gavuzzi *et al.* 1997) and yield stability index (YSI) suggested in 1984 by Bouslama and Schapaugh (in Nouri *et al*. 2011); are the other yield-based estimates which evaluate the stability of genotypes in the both stress and non-stress conditions.

This study was conducted to (i) evaluate the efficiency of added chromosomes of barley to genetic background of bread wheat (*Triticum aestivum* var. 'Chinese spring') for drought tolerance (ii) repeatability and relationship among different drought resistance indices and (iii) identify the chromosomes which are carrying the genes controlling drought tolerance in barley.

MATERIALS AND METHODS

Plant materials

The plant material consisted of 9 genotypes including 7 disomic addition lines (DALs) of barley (*Hordeum vulgare* L., 2n = 2x = 14, HH, cv. 'Betzes') (H = donor) in the genetic background of bread wheat (*Triticum aestivum* L., 2n = 6x = 42, AABBDD, cv. 'Chinese spring' = CS) along with two donor (barley, cv. 'Betzes') and recipient (bread wheat, cv. CS) parents.

Bread wheat addition lines have been produced with numerous species related to wheat, including barley (cv. 'Betzes'), rye (*Secale cereale*) and agropyron (*Agropyron elongatum*). Among these, the CS/'Betzes'-barley DAL has been widely used all over the world to study the effect of individual barley chromosomes on quality parameters and resistance to biotic and abiotic stresses in the wheat genetic background, and to locate various genetic markers in barley.

Wheat is an important crop, but its ability to adapt in poor environment conditions, is inferior to some of wild grass species. Barley (cv. 'Betzes') one of its wild grass species, possess some good traits, which help its adaptation to unsuitable conditions. The CS/'Betzes'-barley DAL are valuable cytogenetically not only for gene mapping but also for experimental transfer of barley genes into wheat (Taketa and Taketa 2001).

The DALs were named as 1H to 7H indicating the addition of chromosomes 1H to 7H into the genome of CS, respectively. The genotypes were cultivated in a randomized complete block design with three replications under two stress and non-stress conditions in Kermanshah location for three cropping seasons (2009-2011). Each plot consisted of 3 rows with 1 m in length and 20-cm row spacing.

At each cropping season, the trials were conducted under stress (rainfed) and non-stress (two irrigations) conditions during flowering and grain-filling stages.

The seeds were kindly provided by Dr. M. Tahir, ICARDA, Syria. The experiment was conducted at the experimental farm of college of agriculture, Razi University, Kermanshah, Iran (47° 20′ N latitude, 34° 20′ E longitude and 1351 m altitude). Climate in this region is classified as semi-arid with mean annual rainfall of 478 mm and mean annual temperature of 13.8°C.

Statistical analysis

The grain yield data were recorded for each genotype at each environment and were subjected to calculate the drought selection criteria. The drought resistance indices were calculated using the following formula:

(1) $SSI = \frac{1 - Ys/Yp}{1 - \overline{Y}s/\overline{Y}p}$

suggested in 1978 by Fischer and Maurer 1978 (in Nouri *et al*. 2011)

where Ys and Yp are the mean yield of genotypes under stress and non-stress conditions, respectively. $\overline{Y}s$ and $\overline{Y}p$ are the mean yield of all genotypes under stress and non-stress conditions, respectively.

$1 - \overline{Y}s/\overline{Y}p$ is the stress intensity. The genotypes with SSI < 1 are more resistant to drought stress conditions.

(2) $STI = \frac{(Ys)(Yp)}{(\overline{Y}p)^2}$

defined in 1992 by Fernandez (in Farshadfar *et al*. 2011). Genotypes with high STI values are tolerant to drought stress.

(3) $TOL = Yp - Ys$

suggested in 1981 by Rosielle and Hamblin (in Nouri *et al*. 2011). Genotypes with low values of this index are more stable in two different conditions.

(4) $MP = \frac{Ys + Yp}{2}$

suggested in 1981 by Rosielle and Hamblin 1981 (in Nouri *et al*. 2011): Genotypes with a high value of this index are more desirable.

(5) $GMP = \sqrt{(Ys)(Yp)}$

suggested in 1992 by Fernandez (in Nouri *et al*. 2011). The genotypes with a high GMP value are more desirable.

(6) Harmonic mean or $HM = \frac{2(Ys)(Yp)}{(Ys + Yp)}$.

The genotypes with a high value of this index are more desirable.

(7) Yield stability index or $YSI = \frac{Ys}{Yp}$

suggested in 1984 by Bouslama and Schapaugh (in Nouri *et al*. 2011). Genotypes with high YSI values are regarded as stable genotypes under stress and non-stress conditions.

(8) Yield index or $YI = \frac{Ys}{\overline{Y}s}$ (Gavuzzi *et al.* 1997).

Genotypes with a high value of this index are suitable for drought stress conditions.

(9) Sensitivity drought index or $SDI = \frac{Yp - Ys}{Yp}$ (Farshadfar and Javadinia 2011).

Genotypes with a low value of this index are more desirable.

Efficiency of the added chromosome (EAC; Farshadfar *et al.* 2003) into the genetic background of bread wheat cv. CS, for each DAL was calculated for grain yields under both stress and non-stress conditions and for each of the drought resistance indices as follows:

$$EAC\% = [\frac{(Y_{DAL} - Y_{CS})}{Y_{CS}}] \times 100$$

where Y_{DAL} and Y_{CS} are the value for each trait/index for a given DAL and recipient parent (CS), respectively.

After analysis of grain yield, ranks were assigned to genotypes for each drought resistance index. A genotype with the highest value for each of the criteria Ys, Yp, STI, GMP, MP, HM, YSI and YI received a rank of 1, while for genotypes with the lowest value for each of the indices SSI, SDI and TOL received a rank of 1. Spearman's rank correlation coefficients were calculated on the ranks to measure the relationship between the indices for each cropping season. A biplot analysis based on rank matrix data for each of the three years was also used to study the repeatability of relationships between the screening methods within and over the years.

Table 1 Mean values and related ranks for tested genotypes based on grain yield under stress and non-stress conditions and some estimated drought resistance indices.

Genotypes	Ys	Yp	STI	YSI	YI	SDI	HM	SSI	MP	GMP	TOL
CS (recipient)	41.5	57.4	0.426	1.060	0.819	-0.060	45.0	-1.240	49.5	47.2	15.9
Betzes (donor)	45.8	58.5	0.498	1.056	0.945	0.011	47.6	-0.920	52.2	49.8	12.6
1H	49.9	82.3	1.127	0.643	1.021	0.357	61.6	1.137	66.1	63.8	32.4
2H	60.9	69.1	0.771	0.940	1.155	0.061	62.8	0.309	65.0	63.9	8.2
3H	48.4	73.3	0.627	0.719	0.912	0.214	55.1	1.274	60.9	57.9	24.9
4H	53.4	61.7	0.605	0.878	0.984	0.122	55.0	0.660	57.6	56.3	8.3
5H	33.5	77.9	0.603	0.420	0.705	0.579	46.1	1.437	55.7	50.6	44.4
6H	39.9	76.5	0.596	0.522	0.788	0.477	52.3	1.407	58.2	55.2	36.6
7H	91.8	93.6	1.947	1.297	1.669	-0.298	89.1	-1.855	92.7	90.8	1.9
Ranks											
CS (recipient)	7	9	9	2	9	2	9	2	9	9	5
Betzes (donor)	6	8	8	3	6	3	7	3	8	8	4
1H	4	2	2	7	3	7	3	6	2	3	7
2H	2	6	3	4	5	4	2	4	3	2	2
3H	5	5	4	6	4	6	4	7	4	4	6
4H	3	7	5	5	2	5	5	5	6	5	3
5H	9	3	6	9	1	9	8	9	7	7	9
6H	8	4	7	8	8	8	6	8	5	6	8
7H	1	1	1	1	7	1	1	1	1	1	1

Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

RESULTS AND DISCUSSION

Yield performance of genotypes

The mean yield of genotypes under stress condition varied from 33.5 g (addition line 5H) to 91.8 g (addition line 7H), while the mean yield of genotypes under non-stress conditions ranged from 57.4 g (CS) to 93.6 g (addition line 7H). Thus the grain yield of genotypes under drought stress conditions showed greater variation than non-stress conditions (**Table 1**). This variation can be explained, in part, by the fact that traits which are suitable for a given environment may be unsuitable in another environment (Van Ginkel *et al.* 1998; Mohammadi *et al.* 2010).

It is also concluded that chromosome 7H carries the genes controlling grain yield in both stress and non-stress conditions over three cropping seasons (**Table 1**).

Grain yield under stress condition was positively correlated (r = 0.534), but not significant, with non-stress condition (**Fig. 1**) suggesting that a high yield under non-stress condition is a moderate result in improving yield under stress. Thus, indirect selection for a drought-prone environment based on the results of non-stress condition will be moderately efficient. This is in agreement with findings in durum wheat (Mohammadi *et al.* 2010) and bread wheat (Dadbakhsh *et al.* 2011) where a positive, but non-significant, association was found between genotypic yields under both stressed and non-stressed conditions. According to **Fig. 1**, the 7H DAL performed well in both stressed and non-stressed conditions.

The mean values of drought resistance indices and the genotypic ranks based on the indices over three cropping seasons are also given in **Table 1**. Differences in ranking genotypes were found from one drought resistance index to another, indicating that the indices differ in their ability to discriminate drought-tolerant genotypes (**Table 1**).

According to STI and YSI (**Table 1**) genotype 7H was identified as the most stable and drought-tolerant DAL in both stressed and non-stressed conditions over three cropping seasons.

The yield stability index (YSI) which evaluates the yield of genotypes under stress relative to their non-stressed condition, should be an indicator of drought resistant in genetic materials. Thus genotypes with a high YSI value are expected to have high yield under both stressed and non-stressed conditions.

YI, proposed by Gavuzzi *et al.* (1997), ranks genotypes only on the basis of their yield under stressed conditions, therefore does not discriminate genotypes of group "A"

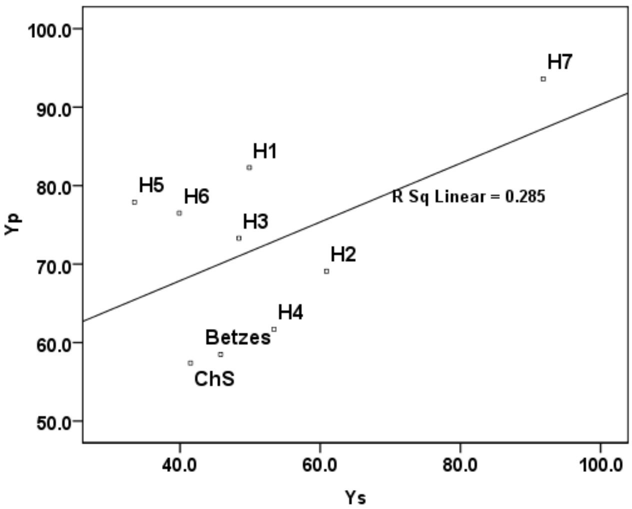

Fig. 1 Correlation between grain yields under stress (Ys) and non-stress (Yp) of genotypes over three cropping seasons.

(genotypes that perform well under both stress and non-stress conditions) defined by Fernandez (1992). According to YI, the DAL 7H followed by 2H and 1H were found to be high performers under stress (**Table 1**). The same results were obtained for HM.

SDI, which evaluates the genotypes for their sensitivity to drought, was able to identify DAL 5H followed by 6H as genotypes with high sensitivity to drought stress, while 7H was detected as the most drought tolerant.

According to SSI, the genotypes 7H followed by CS and 'Betzes' parents had the lowest values and were considered as genotypes with low drought-susceptible and -resistant genotypes in both conditions unlike genotypes 5H followed by 6H with the highest SSI values and which could be identified as high drought-susceptible genotypes. These genotypes also received similar ranks when YSI and SDI were evaluated (**Table 1**).

Yield under irrigated condition showed an increase in value by about 40% than yield under stress conditions over the three cropping seasons. Since MP is the mean under stressed and non-stressed conditions it will be correlated with yield under both stressed and non-stressed conditions (**Table 2**). For this reason, MP was able to differentiate genotypes belonging to group A from other genotypes. As described by Hohls (2001), selection for MP should increase yield in both stressed and non-stressed conditions

Table 2 Spearman rank correlations among yields and drought resistance indices over three cropping seasons.

	Ys	Yp	STI	YSI	YI	SDI	HM	SSI	MP	GMP
Yp	0.20									
STI	0.77*	0.73*								
YSI	0.57	-0.33	0.05							
YI	0.03	0.27	0.33	-0.57						
SDI	0.57	-0.33	0.05	1.00	-0.57					
HMP	0.87**	0.57	0.93**	0.22	0.10	0.22				
SSI	0.58	-0.28	0.08	0.98**	-0.55	0.98**	0.23			
MP	0.70*	0.77*	0.95**	0.02	0.12	0.02	0.95**	0.05		
GMP	0.82**	0.65	0.97**	0.12	0.18	0.12	0.98**	0.13	0.97**	
TOL	0.85**	-0.18	0.37	0.85**	-0.25	0.85**	0.55	0.83**	0.30	0.47

*, ** Significant at 5% and 1% level of probability, respectively.

Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

unless the correlation between yield in contrasting environments is highly negative. In our case, 7H with the highest yield in both stressed and non-stressed conditions, was the genotype with the highest MP value. Ilker *et al*. (2011) used MP as a resistance criterion for wheat genotypes in moderate stress conditions. Mohammadi *et al*. (2010) used MP to identify high-yielding genotypes in both rainfed and irrigated conditions when the stress was mild.

These results indicate the genotypes with high STI usually have a large difference in yield in two different conditions. In general, similar ranks for the genotypes were observed by GMP and MP as well as STI, suggesting that these three parameters are equally useful for selecting genotypes (**Table 1**). Spearman's rank correlation coefficients showed that they are strongly correlated in ranking genotypes (**Table 2**).

For TOL, the least difference between yield in both stressed and non-stressed conditions was observed for DAL 7H followed by 2H. Comparison of parameters revealed that TOL, SSI and YSI gave the same results (**Table 1**), supported by the correlation between these parameters (**Table 2**).

Changes in the genotypic ranks of drought resistance indices over the years

Differences in ranking of genotypes based on each index were found from year to year, indicating that the drought tolerance of genotypes is influenced by a year effect (**Table 3**). In the case of yield under stress condition (Ys), 2H, 7H and 1H DALs were the top-yielding genotypes in first, second and third cropping seasons, respectively while for yield under non-stress condition (Yp), 3H, 7H and 1H DALs were high-yielding genotypes in first, second and third cropping seasons, respectively. The genotypes with high drought tolerance (high STI) were 2H followed by 3H and 6H in first year, 7H followed by 2H and 4H in the second year, and 1H followed by 5H and 6H in the third year, indicating that the tolerance of genotypes to stress varied from year to year. Similar results were already noted in durum wheat by Mohammadi *et al*. (2011).

For YSI, 7H followed by 2H and 4H in the first year; 7H, 4H and 2H in the second year; and 7H followed by recipient and donor parents in the third year, were found to be high stable genotypes under different growing conditions

Table 3 Ranks of genotypes for grain yield in the both stress and non-stress conditions and drought resistance indices for each cropping season.

Year / genotype	Ys	Yp	STI	YSI	YI	SDI	HM	SSI	MP	GMP	TOL
First year											
CS (recipient)	9	9	9	7	9	7	9	7	9	9	3
Betzes (donor)	7	8	8	4	7	4	8	4	8	8	2
1H	6	7	7	5	6	5	6	5	7	7	4
2H	1	2	1	2	1	2	1	3	2	1	6
3H	2	1	2	6	2	6	2	6	1	2	9
4H	5	6	4	3	5	3	5	2	5	5	5
5H	8	4	5	9	8	9	7	9	6	6	8
6H	4	3	3	8	4	8	3	8	3	3	7
7H	3	5	6	1	3	1	4	1	4	4	1
Second year											
CS (recipient)	5	2	4	8	5	7	5	7	4	4	8
Betzes (donor)	8	5	7	6	8	8	8	8	7	7	7
1H	6	9	8	5	6	5	7	5	8	8	5
2H	3	6	2	2	3	2	2	2	2	2	2
3H	4	8	5	3	4	3	4	3	5	5	3
4H	2	7	3	1	2	1	3	1	3	3	1
5H	9	3	9	9	9	9	9	9	9	9	9
6H	7	4	6	7	7	6	6	6	6	6	6
7H	1	1	1	4	1	4	1	4	1	1	4
Third year											
CS	6	9	9	2	6	2	9	2	9	9	3
Betz	3	7	4	3	3	3	5	3	4	4	2
1H	1	1	1	6	1	7	1	6	1	1	9
2H	5	5	5	4	5	4	4	4	7	5	4
3H	9	4	7	9	9	6	7	9	5	7	8
4H	8	6	8	5	8	5	8	5	8	8	5
5H	4	2	2	7	4	8	2	7	2	2	6
6H	7	3	3	8	7	9	3	8	3	3	7
7H	2	8	6	1	2	1	6	1	6	6	1

Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

Table 4 Spearman rank correlation between drought resistance indices based on each cropping season.

Year	Parameters	Ys	Yp	STI	YSI	YI	SDI	HMP	SSI	MP	GMP
First year	Yp	0.78*									
	STI	0.82**	0.93**								
	YSI	0.53	-0.03	0.10							
	YI	1.00**	0.78*	0.82**	0.53						
	SDI	0.53	-0.03	0.10	1.00**	0.53					
	HM	0.97**	0.88**	0.92**	0.33	0.97**	0.33				
	SSI	0.47	-0.10	0.05	0.98**	0.47	0.98**	0.27			
	MP	0.92**	0.95**	0.93**	0.20	0.92**	0.20	0.97**	0.15		
	GMP	0.93**	0.93**	0.95**	0.27	0.93**	0.27	0.98**	0.20	0.98**	
	TOL	-0.27	-0.75*	-0.72*	0.57	-0.27	0.57	-0.47	0.58	-0.58	-0.53
Second year	Yp	-0.02									
	STI	0.92**	0.25								
	YSI	0.78*	-0.53	0.63							
	YI	1.00**	-0.02	0.92**	0.78*						
	SDI	0.85**	-0.47	0.70*	0.95**	0.85**					
	HM	0.97**	0.08	0.97**	0.73*	0.97**	0.82**				
	SSI	0.85**	-0.47	0.70*	0.95**	0.85**	1.00**	0.82**			
	MP	0.92**	0.25	1.00**	0.63	0.92**	0.70*	0.97**	0.70*		
	GMP	0.92**	0.25	1.00**	0.63	0.92**	0.70*	0.97**	0.70*	1.00**	
	TOL	0.80**	-0.52	0.65	0.98**	0.80**	0.98**	0.77*	0.98**	0.65	0.65
Third year	Yp	0.08									
	STI	0.58	0.78*								
	YSI	0.48	-0.80**	-0.37							
	YI	1.00**	0.08	0.58	0.48						
	SDI	0.23	-0.90**	-0.62	0.90**	0.23					
	HM	0.55	0.82**	0.98**	-0.38	0.55	-0.63				
	SSI	0.48	-0.80**	-0.37	1.00**	0.48	0.90**	-0.38			
	MP	0.45	0.82**	0.93**	-0.53	0.45	-0.68	0.88**	-0.53		
	GMP	0.58	0.78*	1.00**	-0.37	0.58	-0.62	0.98**	-0.37	0.93**	
	TOL	0.25	-0.87**	-0.43	0.88**	0.25	0.85**	-0.47	0.88**	-0.57	-0.43

*, ** Significant at 5% and 1% level of probability, respectively.

Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

(**Table 3**).

Based on YI disomic addition lines 2H, 3H and 7H in the first year, 7H, 4H and 2H in the second year and 1H, 7H and donor parent in the third year, appeared as the top genotypes.

SDI gave dissimilar ranks to genotypes in different years. For instance, DALs 2H, followed by 3H and 7H in the first year, 4H followed by 2H and 3H in the second year and 1H followed by 7H and donor parent in the third year had the least sensitivity to drought stress. The genotypes with the highest HM value were: 2H followed by 3H and 6H in the first cropping season, 7H followed by 2H and 4H in the next cropping season and 1H followed by 5H and 6H in the third growing season.

According to SSI, the resistant genotypes from year to year were not consistent. In other word, similar to other indices, SSI gave different ranks to genotypes in different years. The genotypes with the least SSI value in the first year were 7H, 4H and 2H, whereas those in the second year were 4H, 2H and 3H and in the last year the genotypes 7H, followed by recipient and donor parents had the highest resistance to drought stress. According to SSI, the genotypes with SSI less than unit are drought resistant, since their yield reduction in drought condition is smaller than the mean yield reduction of all genotypes (Sio-Se Mardeh *et al*. 2006). This index (SSI) was used for identification of durum resistant genotypes under cold, moderate and warm conditions by Mohammadi *et al*. (2011a).

The three first top genotypes based on the MP were 3H, 2H and 6H in the first year, 7H, 2H and 4H in the second year and 1H, 5H and 6H in the third year. According to GMP, the three first top genotypes were 2H followed by 3H and 6H; 7H, 2H and 4H; and 1H, 5H and 6H in the first, second and third cropping seasons, respectively.

According to the TOL index (Shiranirad and Abbasian 2011), the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. In the first and third years, 7H followed by donor and recipient parents had the least reduction in yield and can be characterized as resistant genotypes. Similarly, in the second year, 4H, 2H and 3H showed least differences in yield production under both stress and non-stress conditions, thus can be identified as resistant genotypes.

The results, however, suggest a remarkable inconsistency in ranking of genotypes as tolerant/resistant based on each of the indices over years.

Efficiency of added chromosomes (EAC%)

The efficiency values of the added chromosomes (EAC%) into the genetic background of Chinese spring (CS, recipient parent) are given in **Table 4**. This criterion showed that the yield of addition line 7H, which carry chromosome No. 7 of barley, relative to recipient parent (CS) increased under stress condition by 121.2% followed by 2H and 4H with a 46.7 and 28.7% increase, respectively. Under non-stress condition, the highest EAC% was belonged to 7H (EAC = 63.1%) followed by 1H (EAC = 43.4%) and 5H (EAC = 35.7%). Thus 7H, which carrying the chromosome no. 7 of barley, was responsible for carrying most of the genes controlling drought stress. For example, by adding this chromosome into the genetic background of CS, 375% efficiency was added to the CS on the bases of STI; while based on STI, the chromosomes no. 1H and 2H of barley increased efficiency of CS by 164.6 and 81.0%, respectively. In the case of YSI, chromosome no. 7 was the only chromosome which positively increased (22.4%) stability performance of CS. Chromosome no. 7 also increased the efficiency of CS on the bases of each of the indices YI, HM, MP, GMP, SDI and SSI. The highest efficiency based on the TOL index was found for chromosomes no. 5 followed by 6, and 3 with EAC% = 179.2, 130.2 and 103.8%, respectively.

Table 5 Estimation of efficiency of the added chromosome (EAC) to background of recipient parent (Chinese spring, CS) for each line based on grain yield under stress and non-stress conditions and some measured drought resistance indices over three cropping seasons.

Genotypes	Ys	Yp	STI	YSI	YI	SDI	HMP	SSI	MP	GMP	TOL
CS (recipient)	0	0	0	0	0	0	0	0	0	0	0
Betzes (donor)	10.4	1.9	16.9	-0.4	15.4	-118.3	5.8	-25.8	5.5	5.5	-20.8
1H	20.2	43.4	164.6	-39.3	24.7	-695.0	36.9	-191.7	33.5	35.2	103.8
2H	46.7	20.4	81.0	-11.3	41.0	-201.7	39.6	-124.9	31.3	35.4	-48.4
3H	16.6	27.7	47.2	-32.2	11.4	-456.7	22.4	-202.7	23.0	22.7	56.6
4H	28.7	7.5	42.0	-17.2	20.1	-303.3	22.2	-153.2	16.4	19.3	-47.8
5H	-19.3	35.7	41.5	-60.4	-13.9	-1065.0	2.4	-215.9	12.5	7.2	179.2
6H	-3.9	33.3	39.9	-50.8	-3.8	-895.0	16.2	-213.5	17.6	16.9	130.2
7H	121.2	63.1	357.0	22.4	103.8	396.7	98.0	49.6	87.3	92.4	-88.1

Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

Similarity/dissimilarity among indices over the years

The Spearman's rank correlation coefficients among the nine drought resistance indices and mean yields under both stress (Ys) and non-stress (Yp) conditions for each set of yearly data are given in **Table 5**. The relationship between yields under both stress and non-stress conditions was found to be significant in one out of three years, indicating that the relationship between genotypic yields is influenced by year effect. Significant relationships ($P < 0.01$) were also observed between Ys with STI, GMP, MP, HM and YI in two out of three years, indicating that selection of genotypes for these indices will improve yield under stress condition. The yield under non-stress condition positively associated with STI, GMP, MP and HM in two out of three years, showing that they are ranking the genotypes in similar fashions. The observed relations were in agreement with those reported by Farshadfar and Sutka (2002) in maize, Mohammadi *et al*. (2010) and Nouri *et al*. (2011) in durum wheat and Shiranirad and Abbasian (2011) in rapeseed.

The indices STI, GMP, MP, HM were positively ($P < 0.01$) associated with yield under both stress and non-stress conditions in one out of three years. Repeatable correlations were found between STI, GMP, MP and HM over three cropping seasons, displaying that they can be used as alternative of each other for evaluation of drought-tolerant genotypes.

The criteria YSI, SSI and SDI were consistently correlated ($P < 0.01$) with each other over three cropping seasons, indicating that they give similar results in identifying drought resistant genotypes. Significant relationship ($P < 0.01$) between YSI and SSI has already been reported by Mohammadi *et al*. (2010) and Nouri *et al*. (2011).

Biplot analysis of rank correlations matrix

Each of the mentioned screening indicators produced a genotype order. To better understanding the relationships among screening criteria and to separate drought resistant genotypes, principal component analysis (PCA) based on the rank correlation matrix was performed for each cropping season. Thus, selection based on a combination of indices may provide useful criteria for improving drought resistance of genetic materials.

In the biplot, a vector is drawn from the biplot origin to the respective indices markers to facilitate visualization of the relationships among the indices. The correlation coefficient between any two indices is approximated by the cosine of the angle between their vectors. Acute angles indicate positive correlations, obtuse angles negative correlations and right angles no correlation (Yan and Rajcan 2002).

The first two PCs accounted for 95.4-97.6% of total variation based on yearly data. In the first year, the first two PCs accounted for 97% of total variation (**Fig. 2**). According to **Fig. 2**, a close correlation was found between SSI, SDI and YSI, indicating that they are the same in ranking of genotypes. The angle between these three indices with TOL index was below 90 degrees showing that they rank the genotypes in a similar manner. Maximum angle between the rest indices was less than 90 degrees, indicating that they give similar results in genotypes ranking. Most of the indices in this group revealed negative correlation with TOL index, exhibiting that they rank the genotypes in opposite direction (**Fig. 2**).

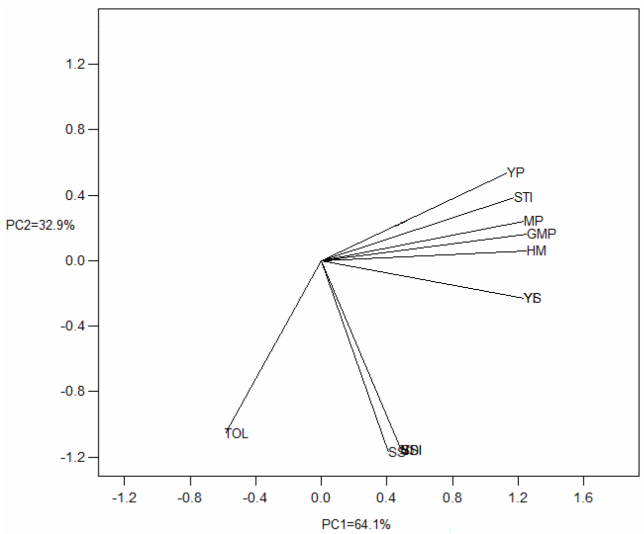

Fig. 2 Biplot view of relations among drought resistance indices in 2009 cropping season. Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

Fig. 3 is a biplot based on rank correlation matrix of data in the second year, which accounted for 97.6% of total variation. According to **Fig. 3**, strong positive correlations were found between SSI, SDI, TOL and YSI, displaying that they are closely associated in ranking of the genotypes. This group of indices negatively associated with yield under non-stress (Yp) condition. No relation was found between yield under stress and non-stress conditions, as indicated by the right angle between their vectors. The indices of STI, GMP, MP, YI and Ys were highly correlated as revealed by the acute angle between their vectors.

Fig. 4 represents the biplot analysis of matrix data in the third year which accounted for 95.4% of total variation. Based on **Fig. 4**, strong positive correlations were found between SSI, YSI, TOL and SDI as indicated by the acute angles between their vectors. Ys and YI were identical in ranking of genotypes, as shown by the zero angle between their vectors. This case was also observed in the two previous cropping seasons (**Figs. 2, 3**). Positive correlations were also found between STI, GMP, HM, MP and Yp.

Comparison of relationships between the indices resulted from three years shows some repeatable correlations among indices (**Figs. 1-3**). Repeatable correlations were found between SSI, YSI, TOL and SDI over three years. These indices were also negatively correlated with STI,

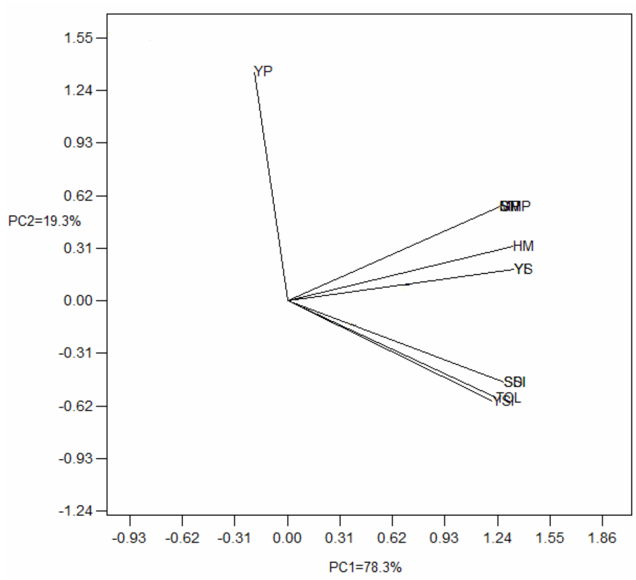

Fig. 3 Biplot view of relations among drought resistance indices in 2010 cropping season. Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensitivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

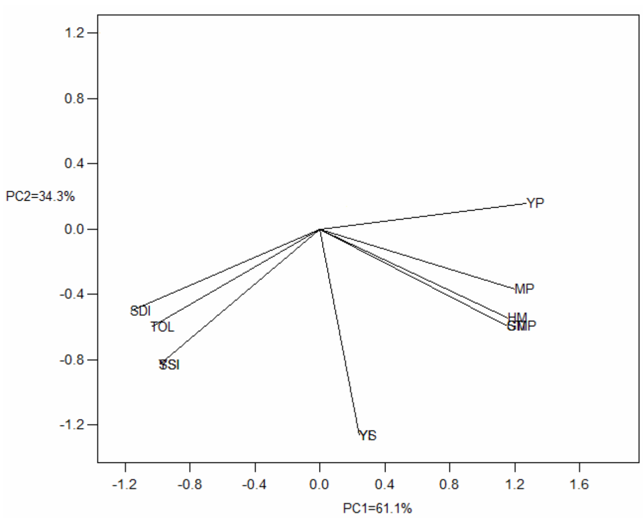

Fig. 4 Biplot view of relations among drought resistance indices in 2011 cropping season. Ys: yield under stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; YI: yield index; SDI: sensivity drought index; HM: harmonic mean; SSI: susceptible stress index; MP: mean productivity; GMP: geometric mean productivity.

GMP, HM and MP over three years, exhibiting that these two groups of indices rank the genotypes in opposite directions. The relationships between indices can be supported by the correlation coefficient analysis (**Table 5**). However, exact match is not expected, because the biplot describes the interrelationships among all traits on the basis of overall pattern of the data, whereas correlation coefficients only describe the relationship between two indices (Yan and Rajcan 2002).

CONCLUSION

The findings from this study showed that the relationship between yield under both stress and non-stress conditions is influenced by year effect. Differences in ranking of genotypes based on each index from year to year, indicating that the drought tolerance of genotypes are also influenced by year effect. Highly significant correlations were found between several of the drought tolerance criteria indicating that several of the indices probably measure similar aspects of drought tolerance. The STI, GMP, HM, MP were consistently and highly correlated with each other over the three cropping seasons, and, therefore, could be used to select drought tolerant genotypes with high yield performance in both stress and non-stress conditions. The SSI, YSI, TOL and SDI showed consistent relationships with each other over the years and can be used to screen the drought resistant and stable genotypes. According to multiple year data, most of the genes controlling drought tolerance in barley are located on chromosome 7H.

ACKNOWLEDGEMENTS

The authors thank Dr. Jaime A. Teixeira da Silva for significant improvements to grammar in the former half of the manuscript.

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