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GENETIC EVALUATION OF 80 IRRIGATED BREAD WHEAT GENOTYPES FOR DROUGHT TOLERANCE INDICES

R. AMIRI[1], S. BAHRAMINEJAD[2], Sh. SASANI[3] and M. GHOBADI[4]

[1] *Razi University, Department of Agronomy and Plant Breeding, Campus of Agriculture and Natural Resources, Kermanshah - 6715685438, Iran*

[2] *Razi University, Department of Agronomy and Plant Breeding, and Biotechnology for Drought Resistance, Campus of Agriculture and Natural Resources, Kermanshah - 6715685438, Iran*

[3] *Agricultural and Natural Resources Research Centre of Kermanshah, Iran*

[4] *Razi University, Department of Agronomy and Plant Breeding, and Biotechnology for Drought Resistance, Campus of Agriculture and Natural Resources, Kermanshah - 6715685438, Iran*

Abstract

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Drought stress is one of the most important problems for crop production in arid and semi-arid areas such as Iran. In order to select drought-tolerant bread wheat genotypes, an experiment was conducted on 80 genotypes in a Randomized Complete Blocks Design (RCBD) with three replicates under normal and terminal drought stress conditions in Kermanshah, Iran during 2011-2012 cropping season. Based on the potential (Yp) and stress (Ys) yields, 15 quantitative criteria of drought tolerance including: stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), harmonic mean (HAM), sensitivity drought index (SDI), drought response index (DRI), drought resistance index (DI), relative drought index (RDI), stress susceptibility percentage index (SSPI) and modified stress tolerance index (MSTI) were calculated. A positive and significant correlation was observed between Ys and Yp with MP, GMP, STI, YI, HAM, SDI, K_1STI and K_2STI indicated that these indices are the most suitable indices to screen genotypes in drought stress conditions. Principal component analysis (PCA) introduced two components. First vector showed 65.39% of variations and the second PCA explained 32.20% of the total variability. It separated the stress–tolerant from non-stress tolerant genotypes. According to all statistical procedures, Ghods, DN-11, Sepahan and Tajan were known as superior genotypes under both stressed and non-stressed conditions with high stability to drought stress.

Key words: Biplot diagram. Bread wheat. Drought tolerance indices. Principal component analysis

Abbreviations: Yp- potential yield; Ys- stress yield; SSI- stress susceptibility index; TOL- tolerance index; MP- mean productivity; GMP- geometric mean productivity; STI- stress tolerance index; YI- yield index; YSI- yield stability index; HAM- harmonic mean; SDI- sensitivity drought index; DRI- drought response index; DI- drought resistance index; RDI- relative drought index; SSPI- stress susceptibility percentage index; MSTI- modified stress tolerance index; PCA- principal component analysis

Introduction

In recent years, interest in crop response to environmental stresses has greatly received attention due to severe losses caused by these stresses (Blum, 1996). Drought as the most important abiotic stress is a major restriction to agricultural production in arid and semi-arid regions (Delmer, 2005 and Rajala et al., 2009). In arid and semi-arid regions, drought reducing more than 50% of average yields for most major crops (Wang et al., 2003).

Wheat (*Triticum aestivum* L.) is the most important cereal crop in the world. World's wheat production was about

E-mail: sohbah72@hotmail.com; rezaamiri20002007@yahoo.com; shahryarsasani@gmail.com; m.ghobadi@yahoo.com

704 million tons in 2011 (FAO, 2011). Iran is ranked as 14th in world wheat production. According to the recent reports, wheat was cultivated more than seven million ha and its total production was about 14.3 million tons in Iran, during 2010-2011 cropping season (FAO, 2011). Wheat production is restricted by drought in arid and semi-arid regions and this restriction cause different problems due to great impacts on human nutrition. Water is the major environmental factor for wheat production in Iran, where area under rainfed conditions is more than 60% of the total area under wheat cultivation (Najafian, 2003). In the west parts of Iran such as Kermanshah, more than 80% of wheat cultivating area is rainfed (Anonymous, 2011). Wheat crops usually encounter drought during grain filling period. In these areas, inadequate rainfall and high temperatures during grain filling period at the end of the growing season greatly restrict grain production (Sio-Se Marde et al., 2006 and Ghobadi et al., 2010). In Kermanshah province, large fluctuations occur at rainfall quantity and frequency year to year (Figure 1). Climatic variability and terminal water deficiency in these environments causes' large annual fluctuations in grain yield.

Genetic variation among genotypes is very important for plant breeding (Talebi et al., 2009). Understanding of plant responses to drought is worthwhile and is a fundamental part of developing stress tolerant varieties (Reddy et al., 2004 and Zhao et al., 2008). The relative performance of genotypes in drought-stress and optimum conditions seems to be a necessary and preliminary point in the identification of desirable genotypes for unpredictable rainfed conditions (Mohammadi et al., 2010). Some researchers believe in selection under favorable conditions (Betran et al., 2003), some believe to select genotypes in stress conditions (Rathjen, 1994) and some researchers prefer a mid-way and believe in selection under both stress and non-stress conditions (Byrne et al., 1995).

Some selection indices have been proposed based on a mathematical relation between stress and non-stress conditions to evaluate response of plant genotypes to drought stress (Rosielle and Hamblin 1981; Clarke et al., 1992 and Fernandez, 1992). Loss of grain yield is the main concern of plant breeders therefore, they emphasize on yield performance under drought stress conditions. However, variation in potential yield could arise from factors related to adaptation rather than drought tolerance. Thus, drought indices as measures of drought based losses of grain yield under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001).

Drought tolerance is defined as the ability of crop to grow and produce under water deficit conditions (Khayatnezhad et al., 2010). To differentiate drought tolerant genotypes, several selection indices have been employed under various conditions. Tolerance (TOL) has been defined as the differences in grain yield in non-stress and stress conditions and mean productivity (MP) as the average yield of genotypes under non-stress and stress conditions (Rosielle and Hamblin, 1981). Stress susceptibility index (SSI) has been suggested for measurement of yield stability that calculated the changes in both potential and actual grain yields in variable environments (Fischer and Maurer, 1978 and Nouri et al., 2011). Fernandez (1992) defined stress tolerance index (STI), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. The other yield based estimates of drought resistance are geometric mean productivity

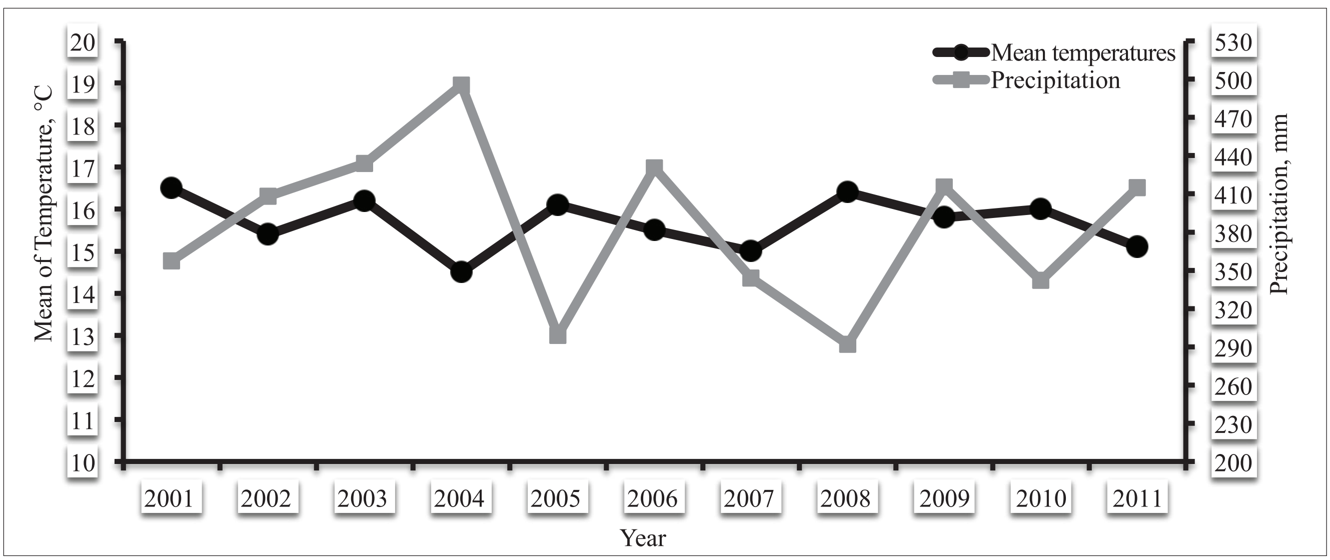

Fig. 1. Fluctuations of total precipitation (mm) and mean temperatures (°C) in Kermanshah (2001-2011)

(GMP) (Fernandez, 1992), which is frequently used by breeders interested in relative performance, since; drought stress can vary in severity in field environment over years (Ramirez and Kelly, 1998). Gavuzzi et al. (1997) defined yield index (YI), by genotype yield on average yield of stress conditions. Yield stability index (YSI) was also suggested by Bouslama and Schapaugh (1984). This parameter is calculated for a genotype using grain yield under stress relative to its grain yield under non-stress conditions. The genotypes with high YSI is expected to have high grain yield under stress and low grain yield under non-stress conditions (Mohammadi et al., 2010). The genotypes with high value of harmonic mean (HAM) and low value of sensitivity drought index (SDI) will be more desirable (Kristin et al., 1997 and Farshadfar and Javadinia, 2011). Bidinger et al. (1978) suggested drought response index (DRI) with its positive values indicating stress tolerance. Lan (1998) defined a new drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both stress and non-stress conditions. Fischer and Maurer (1978) introduced another index as relative drought index (RDI). Stress susceptibility percentage index (SSPI) is able to separate relative tolerant and non-tolerant genotypes (Moosavi et al., 2008). To improve the efficiency of STI a modified stress tolerance index (MSTI) was proposed by Farshadfar and Sutka (2002). It was calculated as kiSTI, where ki is a correction coefficient, which corrects the STI as a weight. Therefore, k_1STI and k_2STI are the optimal selection indices for stress and non-stress conditions, respectively.

Selection of genotypes under drought stress conditions is one of the main tasks of plant breeders to identify, exploit genetic variation and release the stress-tolerant cultivars (Clarke et al., 1984). The present study was undertaken to assess and identify drought tolerant genotypes among 80 bread wheat genotypes using different selection criteria so that suitable genotypes can be recommended for drought-prone areas.

Materials and Methods

Eighty bread wheat genotypes listed in Table 1 were provided from Agricultural and Natural Resources Research Centre of Kermanshah, Iran. Experiment was conducted at the Research Farm of the Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran in 2011-2012 cropping season. The characteristics of the Farm is latitude 34^{o} 21$'$north, longitude 47^{o} 9$'$ east, altitude 1319 m above sea level, clay soil texture and 450-480 mm average annual precipitation. The precipitation at the cropping season of the experiment was 308 mm. More information of soil,

Table 1
Names and codes of genotypes

Code	Genotype	Code	Genotype	Code	Genotype	Code	Genotype
1	Karaj-1	21	Alamout	41	Kaveh	61	Aflak
2	Karaj-2	22	Alvand	42	Rassoul	62	Baaz
3	Karaj-3	23	Zarin	43	Tajan	63	Shahpasand
4	Azadi	24	MV-17	44	Shiroudi	64	Omid
5	Ghods	25	Gaspard	45	Darya	65	Roshan
6	Mahdavi	26	Gascogne	46	Arta	66	Tabassi
7	Niknejad	27	Soisson	47	Morvarid	67	Sholleh
8	Marvdasht	28	Shahryar	48	N-85-5	68	Sorkhtokhm
9	Pishtaz	29	Tous	49	Arvand	69	Adl
10	Shiraz	30	Pishgam	50	Chenab	70	Sabalan
11	Sepahan	31	Mihan	51	Bayat	71	Spring B.C.of Roshan
12	Bahar	32	Oroom	52	Falat	72	Winter B.C.of Roshan
13	Parsi	33	Zaree	53	Heirmand	73	Cross of Shahi
14	Sivand	34	Inia	54	Darab-2	74	Maroon
15	M-85-7	35	Khazar-1	55	Atrak	75	Kavir
16	WS-82-9	36	Mughan-1	56	Chamran	76	Hamoon
17	Sirwan	37	Mughan-2	57	Star	77	Bam
18	DN-11	38	Mughan-3	58	Dez	78	Akbari
19	Bezostaya	39	Golestan	59	Vee/Nac	79	Sistan
20	Navid	40	Alborz	60	LineA	80	Norstar

monthly temperature and total precipitation are shown in Table 2 and Figure 2, respectively. Experimental layout was in two Randomized Complete Blocks Designs (RCBD) each in three replicates under normal and drought conditions. Sowing was done by hand in plots with five rows, 1.2m length, and 0.20m row spacing and 400/m^2 plant density. Terminal (end-season) drought stress was imposed in May 17, 2012, but, non-stressed plots were irrigated three times after that, while stressed plots received no water. After physiological maturity stage, potential yield (Yp) and stress yield (Ys) were measured from two middle rows with 1.2 m length. Drought indices were calculated using the following formulas:

1. Stress susceptibility index = $SSI = \frac{1-(Ys/Yp)}{1-(\overline{Ys}/\overline{Yp})}$ (Fischer and Maurer, 1978)

2. Tolerance = TOL = Yp – Ys (Rosielle and Hamblin, 1981)

3. Mean productivity = $MP = \frac{Ys + Yp}{2}$ (Rosielle and Hamblin, 1981)

4. Geometric mean productivity = $GMP = \sqrt{(Ys \times Yp)}$ (Fernandez, 1992)

5. Stress tolerance index = $STI = \frac{Ys \times Yp}{\overline{Yp}^2}$ (Fernandez, 1992)

6. Yield index = $YI = \frac{Ys}{\overline{Ys}}$ (Gavuzzi et al., 1997)

7. Yield stability index = $YSI = \frac{Ys}{Yp}$ (Bouslama and Schapaugh, 1984)

8. Harmonic mean = $HAM = \frac{2(Ys)(Yp)}{(Ys + Yp)}$ (Kristin et al., 1997)

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

10. Drought response index = $DRI_i = \frac{Y_{act.i} - Y_{est.i}}{S.E.\,of\,Y_{est}}$ (Bidinger et al., 1978)

11. Drought resistance index = $DI = Ys \times \left[\frac{(Ys/Yp)}{\overline{Ys}}\right]$ (Lan, 1998)

12. Relative drought index = $RDI = \frac{(Ys/Yp)}{(\overline{Ys}/\overline{Yp})}$ (Fischer and Maurer, 1978)

13. Stress susceptibility percentage index = SSPI=[Yp-Ys /2($\overline{Y}_P$)]×100 (Moosavi et al., 2008)

14. Modified stress tolerance index = MSTI = KiSTI, K1= $Yp^2/\overline{Yp}^2$ and K2= $Ys^2/\overline{Ys}^2$, where ki is the correction coefficient. (Farshadfar and Sutka, 2002)

Table 2
Field soil characteristics

Soil depth, cm	Soil texture	Soil particles, %			Organic carbon, %	Organic matter, %	Available P_2O_3, ppm	Available K_2O, ppm	T.N, %	T.N.V, %	pH	EC, ds.m^{-1}
		Clay	Silt	Sand								
0-30	Clay	50.28	36	13.72	1.25	2.16	5	490	0.12	12.5	7.6	0.31

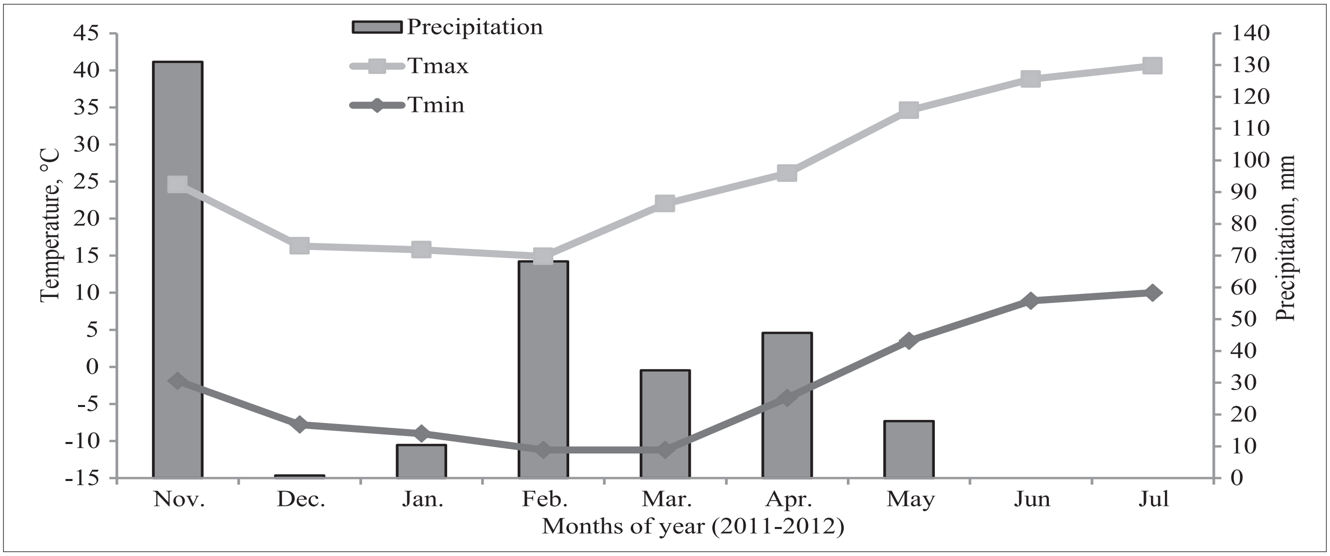

Fig. 2. Monthly total precipitation (mm) and temperature (°C) (Max. and Min.) in 2011-2012 cropping season

Where Ys is the yield of genotype under stress, Yp is the yield of genotype under irrigated conditions, $\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all genotypes under stressed and non-stressed conditions, respectively, and 1- ($\overline{Ys}$ / $\overline{Yp}$) is the stress intensity. $Y_{act.i}$, $Y_{est.i}$ and S E б Y_{est} are representative of real yield in stress conditions, estimated yield calculated by regression in stress conditions, and the standard error of estimated grain yield of all genotypes, respectively. The irrigated experiment was considered to be non-stressed conditions in order to have a better estimation of the optimum environment.

Correlation analysis, principal component analysis (PCA) and biplot diagram were carried out by SPSS ver.16 and Stat graphics ver.16.1.11, respectively.

Results and Discussion

Assessment of drought tolerant genotypes

Results showed that water stress reduced the grain yield of all genotypes and the mean of grain yield in non-stressed and stressed conditions were 6641.26 and 5085.05 Kg/ha, respectively. The comparison of these two data indicated that the stress intensity is mild (0.23). Considerable diversity among genotypes under stressed and non-stressed conditions can be seen from Table 3. In non-stressed conditions, Genotypes 72, 54, 8, 33, 55, 22, 69 and 23 had the highest grain yield ($\bar{x}$+1.5 δ_x) and Genotypes 80, 42, 45 and 26 showed the lowest grain yield ($\bar{x}$-1.5 δ_x). In stressed conditions, Genotypes 5, 52, 72, 6 and 8 had the highest grain yield ($\bar{x}$+1.5 δ_x) and Genotypes 80, 63, 28, 26 and 1 showed the lowest grain yield ($\bar{x}$-1.5 δ_x). Therefore, in both conditions, Genotypes 72 and 8 gave the best performance and genotypes 80 and 26 showed the worst performance. Genotypes 50, 43, 11, 5, 18, 42, 48 and 45 with 0.12, 0.20, 0.46, 0.51, 0.65, 1.42, 1.43 and 1.80 % reduction in grain yield were the most stable genotypes and 80, 70, 63, 30, 75, 77, 28, 54, 69, 79 and 37 with 54, 49, 48, 48, 46, 44, 43, 43, 41, 41 and 40% reduction in grain yield were the least stable genotypes. Genotypes 5 (Ghods) and 80 (Norstar) were the best and worst genotypes when the ranking in both conditions and the percentage of reductions was considered.

To assess drought tolerance of these genotypes Ys, Yp, SSI, TOL, MP, GMP, STI, YI, YSI, HAM, SDI, DRI, DI, RDI, SSPI and MSTI were calculated based on grain yield in stressed and non-stressed conditions (Table 3). According to SSI, genotypes 50, 43, 5, 11 and 18 were the most tolerant and genotypes 80, 70, 63 and 30 were the most susceptible genotypes. Low value of TOL index shows the tolerance of the genotype; therefore, the tolerant genotypes were selected based on low TOL. As shown in Table 3, the lowest value of this index was calculated for genotypes 50, 43, 11, 18 and 5. The highest TOL value was calculated for genotypes 54, 30, 70, 33, 69 and 75. Genotypes 43 and 5 were the most tolerant genotypes based on TOL and SSI, which their low quantity is indication of tolerant genotypes. Since genotypes, which had lower amounts of TOL index, identified as tolerant genotypes, selection genotypes according to this index lead to choosing genotypes, which had high grain yield in drought stress conditions and low yield in non-stress conditions, hence this index and SSI cannot be able to identify tolerant genotypes (Shahryari and Mollasadeghi, 2011).

Table 3
Drought tolerance indices of 80 bread wheat genotypes based on grain yield under stress and non-stress conditions

Genotypes	YP (kg/ha)	Y_S (kg/ha)	SSI	TOL (kg/ha)	MP (kg/ha)	GMP (kg/ha)	STI	YI	YSI	HAM (kg/ha)	SDI	DRI	DI	RDI	SSPI	K_1STI	K_2STI	Reduction (%)
1	5134.33	3687.47	1.20	1446.87	4410.90	4351.17	0.429	0.725	0.718	4292.25	0.282	-0.881	0.521	0.938	10.893	0.257	0.226	28.18
2	4825.33	4091.00	0.65	734.33	4458.17	4443.02	0.448	0.805	0.848	4427.93	0.152	-0.182	0.682	1.107	5.529	0.236	0.290	15.22
3	7024.07	4591.13	1.48	2432.93	5807.60	5678.77	0.731	0.903	0.654	5552.80	0.346	-0.381	0.590	0.854	18.317	0.818	0.596	34.64
4	6849.80	5880.00	0.60	969.80	6364.90	6346.40	0.913	1.156	0.858	6327.96	0.142	1.410	0.993	1.121	7.301	0.971	1.221	14.16
5	8206.47	8164.80	0.02	41.67	8185.63	8185.61	1.519	1.606	0.995	8185.58	0.005	2.823	1.597	1.299	0.314	2.320	3.917	0.51
6	7214.33	6703.00	0.30	511.33	6958.67	6953.97	1.096	1.318	0.929	6949.27	0.071	1.669	1.225	1.213	3.850	1.294	1.905	7.09
7	5707.13	5032.07	0.50	675.07	5369.60	5358.98	0.651	0.990	0.882	5348.38	0.118	0.304	0.873	1.152	5.082	0.481	0.638	11.83
8	9430.53	6643.20	1.26	2787.33	8036.87	7915.11	1.420	1.306	0.704	7795.19	0.296	0.744	0.920	0.920	20.985	2.864	2.424	29.56
9	6002.00	5822.93	0.13	179.07	5912.47	5911.79	0.792	1.145	0.970	5911.11	0.030	1.083	1.111	1.267	1.348	0.647	1.039	2.98
10	6812.53	4828.13	1.24	1984.40	5820.33	5735.14	0.746	0.949	0.709	5651.19	0.291	-0.076	0.673	0.926	14.940	0.785	0.672	29.13
11	6137.40	6108.87	0.02	28.53	6123.13	6123.12	0.850	1.201	0.995	6123.10	0.005	1.060	1.196	1.300	0.215	0.726	1.227	0.46
12	6510.07	6377.20	0.09	132.87	6443.63	6443.29	0.941	1.254	0.980	6442.95	0.020	1.482	1.229	1.279	1.000	0.904	1.480	2.04
13	6671.87	6257.33	0.27	414.53	6464.60	6461.28	0.947	1.231	0.938	6457.95	0.062	1.089	1.154	1.225	3.121	0.955	1.433	6.21
14	5891.00	4819.40	0.78	1071.60	5355.20	5328.33	0.644	0.948	0.818	5301.59	0.182	0.442	0.775	1.068	8.068	0.506	0.578	18.19
15	5318.13	4966.07	0.28	352.07	5142.10	5139.09	0.599	0.977	0.934	5136.07	0.066	0.657	0.912	1.220	2.651	0.384	0.571	6.62
16	6786.40	5901.73	0.56	884.67	6344.07	6328.63	0.908	1.161	0.870	6313.23	0.130	1.265	1.009	1.136	6.660	0.948	1.223	13.04
17	6862.33	5573.53	0.80	1288.80	6217.93	6184.45	0.867	1.096	0.812	6151.15	0.188	0.412	0.890	1.061	9.703	0.926	1.042	18.78
18	6404.27	6362.80	0.03	41.47	6383.53	6383.50	0.924	1.251	0.994	6383.47	0.006	1.464	1.243	1.298	0.312	0.859	1.447	0.65
19	5906.33	5476.00	0.31	430.33	5691.17	5687.10	0.733	1.077	0.927	5683.03	0.073	1.041	0.998	1.211	3.240	0.580	0.850	7.29
20	7040.53	6254.47	0.48	786.07	6647.50	6635.87	0.998	1.230	0.888	6624.26	0.112	1.617	1.093	1.160	5.918	1.122	1.510	11.16
21	5916.53	4345.00	1.13	1571.53	5130.77	5070.24	0.583	0.854	0.734	5010.43	0.266	-0.336	0.628	0.959	11.832	0.463	0.426	26.56
22	8784.20	5815.67	1.44	2968.53	7299.93	7147.45	1.158	1.144	0.662	6998.14	0.338	0.159	0.757	0.865	22.349	2.026	1.515	33.79
23	8643.60	5198.20	1.70	3445.40	6920.90	6703.07	1.019	1.022	0.601	6492.10	0.399	-0.386	0.615	0.785	25.939	1.726	1.065	39.86
24	7478.20	4583.53	1.65	2894.67	6030.87	5854.62	0.777	0.901	0.613	5683.52	0.387	-1.028	0.552	0.800	21.793	0.985	0.631	38.71
25	5710.60	4281.13	1.07	1429.47	4995.87	4944.40	0.554	0.842	0.750	4893.61	0.250	-0.040	0.631	0.979	10.762	0.410	0.393	25.03
26	4641.20	3663.20	0.90	978.00	4152.20	4123.30	0.385	0.720	0.789	4094.61	0.211	-0.555	0.569	1.031	7.363	0.188	0.200	21.07
27	5577.60	4410.40	0.89	1167.20	4994.00	4959.78	0.558	0.867	0.791	4925.80	0.209	0.025	0.686	1.033	8.787	0.393	0.420	20.93
28	6237.40	3519.07	1.86	2718.33	4878.23	4685.07	0.498	0.692	0.564	4499.54	0.436	-1.443	0.390	0.737	20.465	0.439	0.238	43.58
29	6893.33	5498.87	0.86	1394.47	6196.10	6156.75	0.859	1.081	0.798	6117.64	0.202	0.810	0.863	1.042	10.499	0.926	1.005	20.23
30	8208.60	4264.27	2.05	3944.33	6236.43	5916.39	0.794	0.839	0.519	5612.77	0.481	-1.772	0.436	0.678	29.696	1.212	0.558	48.05
31	7163.47	4645.87	1.50	2517.60	5904.67	5768.93	0.755	0.914	0.649	5636.31	0.351	-0.532	0.593	0.847	18.954	0.878	0.630	35.14
32	4738.47	3753.40	0.89	985.07	4245.93	4217.27	0.403	0.738	0.792	4188.80	0.208	-0.669	0.585	1.035	7.416	0.205	0.220	20.79
33	9424.93	5664.47	1.70	3760.47	7544.70	7306.66	1.210	1.114	0.601	7076.12	0.399	-0.544	0.669	0.785	28.311	2.438	1.502	39.90
34	6934.40	5055.00	1.16	1879.40	5994.70	5920.59	0.795	0.994	0.729	5847.40	0.271	-0.590	0.725	0.952	14.149	0.866	0.785	27.10
35	5238.07	4936.47	0.25	301.60	5087.27	5085.03	0.586	0.971	0.942	5082.80	0.058	-0.044	0.915	1.231	2.271	0.365	0.552	5.76
36	7193.87	4372.00	1.67	2821.87	5782.93	5608.17	0.713	0.860	0.608	5438.69	0.392	-1.047	0.523	0.794	21.245	0.837	0.527	39.23
37	7357.60	4414.73	1.71	2942.87	5886.17	5699.28	0.736	0.868	0.600	5518.34	0.400	-1.198	0.521	0.784	22.156	0.904	0.555	40.00
38	5213.07	4925.00	0.24	288.07	5069.03	5066.99	0.582	0.969	0.945	5064.94	0.055	0.230	0.915	1.234	2.169	0.359	0.546	5.53
39	6926.53	4493.13	1.50	2433.40	5709.83	5578.69	0.706	0.884	0.649	5450.57	0.351	-0.955	0.573	0.847	18.320	0.768	0.551	35.13
40	5673.33	5205.53	0.35	467.80	5439.43	5434.40	0.670	1.024	0.918	5429.38	0.082	0.702	0.939	1.198	3.522	0.489	0.702	8.25

Table 3
Continued

Genotypes	YP (kg/ha)	Y_S (kg/ha)	SSI	TOL (kg/ha)	MP (kg/ha)	GMP (kg/ha)	STI	YI	YSI	HAM (kg/ha)	SDI	DRI	DI	RDI	SSPI	K_1STI	K_2STI	Reduction (%)
41	7548.87	5374.80	1.23	2174.07	6461.83	6369.75	0.920	1.057	0.712	6278.97	0.288	-0.144	0.753	0.930	16.368	1.189	1.028	28.80
42	4589.67	4524.27	0.06	65.40	4556.97	4556.85	0.471	0.890	0.986	4556.73	0.014	-0.008	0.877	1.287	0.492	0.225	0.373	1.42
43	6107.87	6095.67	0.01	12.20	6101.77	6101.77	0.844	1.199	0.998	6101.76	0.002	1.133	1.196	1.303	0.092	0.714	1.213	0.20
44	6539.73	6304.20	0.15	235.53	6421.97	6420.89	0.935	1.240	0.964	6419.81	0.036	1.608	1.195	1.259	1.773	0.906	1.437	3.60
45	4621.60	4538.60	0.08	83.00	4580.10	4579.91	0.476	0.893	0.982	4579.72	0.018	-0.006	0.877	1.283	0.625	0.230	0.379	1.80
46	6646.73	6182.13	0.30	464.60	6414.43	6410.22	0.932	1.216	0.930	6406.02	0.070	0.911	1.131	1.215	3.498	0.933	1.377	6.99
47	5152.60	4298.73	0.71	853.87	4725.67	4706.34	0.502	0.845	0.834	4687.10	0.166	-0.739	0.705	1.090	6.429	0.302	0.359	16.57
48	6334.80	6244.00	0.06	90.80	6289.40	6289.24	0.897	1.228	0.986	6289.07	0.014	1.330	1.210	1.287	0.684	0.816	1.352	1.43
49	8286.67	5783.47	1.29	2503.20	7035.07	6922.84	1.087	1.137	0.698	6812.40	0.302	-0.025	0.794	0.912	18.846	1.692	1.406	30.21
50	5465.80	5459.07	0.01	6.73	5462.43	5462.43	0.677	1.074	0.999	5462.43	0.001	1.501	1.072	1.304	0.051	0.458	0.780	0.12
51	7895.07	5125.27	1.50	2769.80	6510.17	6361.16	0.917	1.008	0.649	6215.56	0.351	-0.451	0.654	0.848	20.853	1.297	0.932	35.08
52	7587.60	6889.87	0.39	697.73	7238.73	7230.32	1.185	1.355	0.908	7221.92	0.092	1.668	1.230	1.186	5.253	1.547	2.176	9.20
53	6893.27	5126.80	1.09	1766.47	6010.03	5944.78	0.801	1.008	0.744	5880.23	0.256	-0.285	0.750	0.971	13.299	0.863	0.814	25.63
54	9493.67	5407.73	1.84	4085.93	7450.70	7165.14	1.164	1.063	0.570	6890.52	0.430	-1.208	0.606	0.744	30.762	2.379	1.316	43.04
55	8888.00	6385.60	1.20	2502.40	7636.80	7533.61	1.287	1.256	0.718	7431.81	0.282	0.087	0.902	0.938	18.840	2.305	2.029	28.15
56	6893.33	5672.87	0.76	1220.47	6283.10	6253.40	0.887	1.116	0.823	6223.83	0.177	0.416	0.918	1.075	9.189	0.955	1.103	17.71
57	5661.53	3977.53	1.27	1684.00	4819.53	4745.41	0.511	0.782	0.703	4672.43	0.297	-1.182	0.550	0.918	12.678	0.371	0.312	29.74
58	6866.87	5110.40	1.09	1756.47	5988.63	5923.89	0.796	1.005	0.744	5859.84	0.256	-0.192	0.748	0.972	13.224	0.851	0.804	25.58
59	6149.40	5616.53	0.37	532.87	5882.97	5876.93	0.783	1.105	0.913	5870.90	0.087	0.569	1.009	1.193	4.012	0.671	0.955	8.67
60	5022.53	4154.80	0.74	867.73	4588.67	4568.11	0.473	0.817	0.827	4547.64	0.173	-0.548	0.676	1.080	6.533	0.271	0.316	17.28
61	7367.80	5942.93	0.83	1424.87	6655.37	6617.12	0.993	1.169	0.807	6579.10	0.193	0.391	0.943	1.053	10.727	1.222	1.356	19.34
62	5348.33	4311.00	0.83	1037.33	4829.67	4801.73	0.523	0.848	0.806	4773.97	0.194	-0.689	0.683	1.053	7.810	0.339	0.376	19.40
63	5306.07	2722.80	2.08	2583.27	4014.43	3800.97	0.328	0.535	0.513	3598.85	0.487	-1.507	0.275	0.670	19.449	0.209	0.094	48.69
64	5606.27	4850.73	0.58	755.53	5228.50	5214.83	0.617	0.954	0.865	5201.21	0.135	0.661	0.825	1.130	5.688	0.439	0.561	13.48
65	8016.00	5905.67	1.12	2110.33	6960.83	6880.40	1.073	1.161	0.737	6800.88	0.263	0.222	0.856	0.962	15.888	1.564	1.448	26.33
66	6296.20	5527.93	0.52	768.27	5912.07	5899.57	0.789	1.087	0.878	5887.11	0.122	0.570	0.954	1.147	5.784	0.709	0.933	12.20
67	4839.20	4208.53	0.56	630.67	4523.87	4512.86	0.462	0.828	0.870	4501.89	0.130	-0.450	0.720	1.136	4.748	0.245	0.316	13.03
68	5502.53	4423.47	0.84	1079.07	4963.00	4933.59	0.552	0.870	0.804	4904.35	0.196	-0.627	0.699	1.050	8.124	0.379	0.418	19.61
69	8670.47	5034.00	1.79	3636.47	6852.23	6606.60	0.990	0.990	0.581	6369.77	0.419	-1.271	0.575	0.758	27.378	1.687	0.970	41.94
70	7927.53	4013.73	2.11	3913.80	5970.63	5640.83	0.721	0.789	0.506	5329.25	0.494	-1.664	0.400	0.661	29.466	1.028	0.449	49.37
71	7448.80	4870.67	1.48	2578.13	6159.73	6023.34	0.823	0.958	0.654	5889.97	0.346	-0.597	0.626	0.854	19.410	1.035	0.755	34.61
72	9535.20	6703.33	1.27	2831.87	8119.27	7994.85	1.449	1.318	0.703	7872.34	0.297	0.290	0.927	0.918	21.320	2.987	2.518	29.70
73	6044.80	4800.00	0.88	1244.80	5422.40	5386.56	0.658	0.944	0.794	5350.96	0.206	-0.355	0.750	1.037	9.372	0.545	0.586	20.59
74	5588.87	3796.53	1.37	1792.33	4692.70	4606.33	0.481	0.747	0.679	4521.56	0.321	-0.987	0.507	0.887	13.494	0.341	0.268	32.07
75	7859.40	4237.67	1.97	3621.73	6048.53	5771.10	0.755	0.833	0.539	5506.38	0.461	-1.893	0.449	0.704	27.267	1.058	0.524	46.08
76	7154.60	5143.07	1.20	2011.53	6148.83	6066.02	0.834	1.011	0.719	5984.32	0.281	-0.061	0.727	0.939	15.144	0.968	0.853	28.12
77	7543.00	4221.33	1.88	3321.67	5882.17	5642.83	0.722	0.830	0.560	5413.23	0.440	-1.364	0.465	0.731	25.008	0.931	0.498	44.04
78	6511.47	4709.33	1.18	1802.13	5610.40	5537.57	0.695	0.926	0.723	5465.68	0.277	-0.203	0.670	0.945	13.568	0.668	0.596	27.68
79	8226.80	4806.33	1.77	3420.47	6516.57	6288.14	0.896	0.945	0.584	6067.73	0.416	-1.110	0.552	0.763	25.752	1.376	0.801	41.58
80	3171.87	1449.93	2.32	1721.93	2310.90	2144.53	0.104	0.285	0.457	1990.13	0.543	-1.681	0.130	0.597	12.964	0.024	0.008	54.29

Two genotypes with low/high yield may have equal SSI rate in both conditions, so selection process based on this index cause to breeders to make a mistake (Naeimi et al., 2008). The results revealed that genotypes 5, 72 and 8 were the tolerant genotypes based on MP, GMP, STI, HAM and YI, which their high quantity is indicating tolerant genotypes (Table 3). Based on these current indices, Genotypes 80 and 63 were the most susceptible genotypes. Genotypes 50, 43, 11, 5 and 18 had the highest and genotypes 80, 70, 63 and 30 had the lowest yield stability index (YSI). Based on SDI and SSPI, Genotypes 50, 43, 11, 5 and 18 were the most and Genotypes 70 and 30 were the least tolerant genotypes. Genotypes 5, 52 and 18, displayed high DRI, DI and RDI, while Genotypes 80, 30, 63, 75 and 70 showed the lowest amount. The highest amount of modified stress tolerance index (K_1STI and K_2STI) was attributed to Genotypes 72, 8 and 5 while Genotypes 80, 63 and 26 had the lowest MSTI.

Based on all calculated drought indices, Genotypes 5 (Ghods), 18 (DN-11), 72 (Winter B.C.of Roshan), 8 (Marvdasht), 43 (Tajan), 11 (Sepahan) and 50 (Chenab) were tolerant and genotypes 80 (Norstar), 63 (Shahpasand), 70 (Sabalan), 30 (Pishgam) and 75 (Kavir) were susceptible to drought stress.

Correlation analysis

To determine the most desirable drought tolerance criteria, correlation between grain yield under stress and non-stress conditions and drought tolerance indices were calculated (Table 4). The results indicated that except DRI and DI, all the studied drought tolerance indices were significantly correlated with grain yield in both conditions. These indices are suitable to screen drought tolerant and high yielding genotypes (winter B.C.of Roshan and Marvdasht) in stress and non-stress conditions. The STI, GMP and MP were used in different plants to screen drought tolerant high yielding genotypes in both conditions (Fernandez, 1992; Sanjari-Pireivatlou and Yazdansepas, 2008; Mohammadi et al., 2010 and Karimizadeh and Mohammadi, 2011). Grain yield under stressed conditions (Ys) had significantly positive correlation (r=0.534**) with grain yield under non-stressed conditions (Yp) showing that stress intensity was mild. Therefore, indirect selection in mild drought stress will be efficient based on the results of non-stressed conditions for wheat genotypes (Akcura and Ceri, 2011). However, this finding did not confirm the results of the other reported studies (Fernandez, 1992 and Mohammadi et al., 2010). It could be due to high stress intensity in their experiments.

The results showed that SSI, TOL, MP, GMP, STI, YI, HAM, SDI, SSPI, K_1STI and K_2STI had significant ($P \leq 0.01$) and positive correlations with grain yield under non-stressed

Table 4
Correlation between different drought tolerance indices (n=80)

	Yp	Ys	SSI	TOL	MP	GMP	STI	YI	YSI	HAM	SDI	DRI	DI	RDI	SSPI	K_1STI	K_2STI
Yp	1.000																
Ys	0.534**	1.000															
SSI	0.405**	-0.539**	1.000														
TOL	0.666**	-0.276*	0.936**	1.000													
MP	0.907**	0.840**	-0.009	0.290**	1.000												
GMP	0.870**	0.881**	-0.088	0.211	0.996**	1.000											
STI	0.867**	0.864**	-0.056	0.222*	0.986**	0.988**	1.000										
YI	0.533**	1.000**	-0.540**	-0.276*	0.840**	0.881**	0.864**	1.000									
YSI	-0.406**	0.539**	-1.000**	-0.936**	0.008	0.087	0.055	0.539**	1.000								
HAM	0.827**	0.915**	-0.165	0.132	0.986**	0.997**	0.983**	0.915**	0.164	1.000							
SDI	0.406**	-0.539**	1.000**	0.936**	-0.008	-0.087	-0.055	-0.539**	-1.000**	-0.164	1.000						
DRI	0.000	0.809**	-0.832**	-0.714**	0.403**	0.472**	0.465**	0.809**	0.831**	0.536**	-0.831**	1.000					
DI	0.067	0.876**	-0.862**	-0.696**	0.479**	0.546**	0.529**	0.876**	0.861**	0.607**	-0.861**	0.950**	1.000				
RDI	-0.406**	0.538**	-1.000**	-0.936**	0.008	0.085	0.055	0.539**	1.000**	0.163	-1.000**	0.831**	0.861**	1.000			
SSPI	0.666**	-0.276*	0.936**	1.000**	0.290**	0.211	0.222*	-0.276*	-0.936**	0.132	0.936**	-0.714**	-0.696**	-0.936**	1.000		
K_1STI	0.927**	0.629**	0.248*	0.499**	0.908**	0.885**	0.926**	0.629**	-0.249*	0.857**	0.249*	0.162	0.219	-0.249*	0.498**	1.000	
K_2STI	0.634**	0.898**	-0.284*	-0.072	0.854**	0.876**	0.919**	0.898**	0.283*	0.891**	-0.283*	0.660**	0.706**	0.283*	-0.072	0.797**	1.000

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

conditions, while YSI and RDI showed significant ($P \leq 0.01$) and negative correlations. The MP, GMP, STI, YI, YSI, HAM, DRI, DI, RDI, K_1STI and K_2STI revealed a significant ($P \leq 0.01$) and positive correlations with yield under stressed condition, while SSI, TOL, SDI and SSPI exhibited significant ($P \leq 0.05$) and negative correlations. The highest correlation (r^2 = 1.00**) was observed between Ys and YI which confirmed results of other reported studies (Ghobadi et al., 2012 and Farshadfar and Elyasi, 2012).

Principal Component Analysis

A biplot as a better approach than a simple correlation analysis is necessary to identify superior genotypes for both stress and non-stress conditions, because genotypes in biplot analysis are compared simultaneously for all attributes. The first two principal component analysis (PCAs) accounted for about 97.59% of total variation of data set (Table 5). Therefore, the first two PCs were employed to draw a biplot. The relationships among different indices are graphically displayed in a biplot of PCA1 and PCA2 (Figure 3). The analysis indicated that the first PCA explained 65.39% of the variation with Yp, Ys, MP, GMP, STI, HAM, K_1STI and K_2STI. First dimension can be named as the yield in both environments and drought tolerance. Second component explained 32.20% of the total obtained variation and can be named drought susceptible dimension with high yield in non-stressed and low yield in stressed conditions. Hence, selection of genotypes with high PCA1 and low PCA2 are suitable for both stress and non-stress environments (Golabadi et al., 2006 and Shahryari and Mollasadeghi, 2011).

Fernandez (1992) classified genotypes according to their production under non-stress and stress conditions to four groups: genotypes with high production under both conditions (Group A), genotypes with high production only under non-stress conditions (Group B), genotypes with high production only under stress conditions (Group C) and at last genotypes with low production under both conditions (Group D). Thus, Genotypes 5, 52, 6, 20, 18, 12, 13, 11, 44, 46, 43 and 48 with rather higher PCA1 and lower PCA2 are superior genotypes under both stressed and non-stressed conditions. These genotypes had stable performance in the circumstances of low sensitivity to drought stress. So, they are belong to

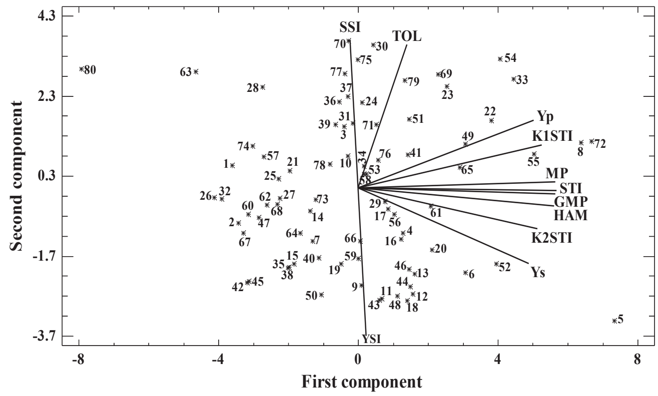

Fig. 3. Biplot based on first two principal component axes for 80 bread wheat genotypes

Group A. These genotypes also had high Yp, Ys, GMP, MP, STI, HAM, YI, YSI, K_1STI and K_2STI. These indices are able to select and identify genotypes with high grain yield in both conditions (Fernandez, 1992). Genotypes 72, 54, 8, 33, 55, 22, 69, 23, 49, and 65 could be known as Group B. These genotypes are suitable for non-stressed conditions. Genotypes 80, 63, 28, 74, 57, 1 and 21 are drought susceptible and had low yield in both conditions (Group D). Genotypes 42, 50, 45, 38, 35, 15, 40, 7, 64 and 67 with high amount of yield stability index (YSI) had a relatively low yield in both conditions, but they were more stable genotypes than the others (Group C). Moosavi et al. (2008) introduced Ghods (5) as a relative resistant cultivar based on abiotic-stress tolerance index (ATI) and stress non-stress production index (SNPI). Moreover, based on MP, GMP and STI, Ghods was introduced as resistant cultivar to drought stress among 6 tested cultivars (Ahmadi et al., 2005). The resistance to drought was reported in a genotype (Ghods*3/Kavvko//Ghods*3/Kaz/Kavko) with a genetic background of Ghods in its pedigree (Aghaei-Sarbarzeh et al., 2008).

Conclusions

What can be concluded from these results are: 1) identifying the genotypes with high and stable yield in both conditions which are Ghods (5), DN-11 (18), Sepahan (11) and

Table 5
Principal components analysis for drought tolerance indices

Component	Eigen value	Cumulative Percentage	Yp	Ys	SSI	TOL	MP	GMP	STI	YSI	HAM	K_1STI	K_2STI
1	7.192	65.385	0.33	0.32	-0.02	0.09	0.37	0.37	0.37	0.01	0.37	0.35	0.34
2	3.542	97.585	0.24	-0.27	0.53	0.51	0.02	-0.02	-0.01	-0.53	-0.06	0.15	-0.15

Tajan (43); 2) identifying genotypes with low yield in both conditions and susceptible to drought which are Norstar (80) and Shahpasand (63) and 3) suggesting genotypes, winter B.C.of Roshan (72), Darab-2 (54), Marvdasht (8), Zaree (33), Atrak (55), Alvand (22), Adl (69) and Zarin (23) for the environments with low chance of drought stress.

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