Evaluation of grain yield and repeatability of drought tolerance indices for screening chickpea (*Cicer aritinum* L.) genotypes under rainfed conditions

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Recieved: 10 March 2014; Accepted: 2 Dec 2014.

ABSTRACT

In order to identify drought tolerant chickpea genotypes, an experiment was conducted in the west of Iran, during 2007-2009 cropping seasons. Several selection indices were used to illustrate genotypic differences in response to drought stress. The results of combined analysis of variance showed that year, genotype, stress conditions and their interaction effects were highly significant. Correlation analysis between indices revealed that the yield index (YI), stress tolerance index (STI), geometric mean productivity (GMP) and mean productivity (MP) were correlated to grain yield and together in three years, indicating that they can be used as an alternative to each other for selecting drought tolerant genotypes in both stress and non-stress conditions. Consequently, GGE biplot showed that most ideal genotypes for rainfed conditions were genotypes G6 and G15. In conclusion, the identification of these chickpea genotypes with high yield and stability performance under unpredictable environments and high tolerance to drought stress conditions can help breeding programs in future.

Keywords: *Cicer aritinum* L., Drought stress, Drought tolerance indices, Yield stability.

INTRODUCTION

Legumes and specially chickpea (*Cicer aritinum* L.) are important for the sustainable production of food in the arid and semi-arid countries of West Asia, such as Iran. They are important sources of good quality protein in the diets of people and are valuable as animal feed. Chickpea seeds are a rich source of protein for human consumption in developing countries. Kumar and Abbo (2001) reported that about 90% of the world's chickpea is grown under rainfed conditions where terminal drought is the major stress, accompanying with high temperature stress. Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (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*., 2011) while others yet have chosen a mid-point and believe in selection under both favorable and stress conditions (Byrne *et al*., 1995; Sio-Se Mardeh *et al*., 2006; Mohammadi *et al*., 2010). However, drought indices which provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). To differentiate drought tolerant genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions. The stress susceptibility index (SSI) suggested by Fischer and Maurer (1978) for the measurement of yield stability apprehends changes in both potential and actual yields in variable environments. Clarke *et al*. (1992) used SSI to evaluate drought tolerance in wheat genotypes and found year-to-year variations in SSI for genotypes and could rank their pattern. Lan (1988) defined drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both stress and non-stress conditions. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between stress and irrigated environments and MP as the average yield of genotypes under stress and non-stress conditions. The 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 YI was recommended by Gavuzzi *et al*. (1997) in order to assess the stability of genotypes in both stress and non-stress conditions. The STI was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992).

The objectives of the study were to (i) identify ideal chickpea genotype(s) under rainfed conditions in the west of Iran (Ilam province as the semi-arid region) over three years, (ii) study repeatability and interrelationships among the tolerance/resistance indices and (iii) determine the ideal genotype(s) in terms of drought tolerance and grain yield stability.

MATERIALS AND METHODS

Experimental layout and plant material

There were three paired experiments (rainfed and supplemental irrigation), one in each year from 2006-07 to 2008-09. The experiments were conducted at Shirvan Chardavul research station of the Dry land Agricultural Research, Ilam, Iran (Latitude: 33˚ 47’ N; Longitude 46˚ 36’ E; Altitude: 975 m above sea level), during three cropping seasons (2006/07-2007/08-2008/09). The monthly and total mean rainfall and temperature during the three years in this research station are given in Figure 1. The soil at the site was silty clay loam. At each cropping season, the trials were conducted under rainfed and supplemental irrigation (two irrigations with 25 mm for each irrigation applied either at flowering to grain-filling stages to cope with terminal drought stress which is a common feature in west of Iran) conditions. The experimental layout was a randomized complete block design with four replications in both rainfed and irrigation conditions. Sowing was done by hand in 1.5 m × 5 m plots. Each plot consisted of five rows of 5 m long. Row spacing and hill-to-hill distances were 30 cm and 10 cm, respectively. The experimens tested 18 different genotypes varying in origin. Bivanij and Local check are chickpea cultivars, which are grown mostly in the rainfed areas of western Iran (Table 1). At the harvest time, the grain yield data were recorded for each genotype at each environment. Seven drought tolerance indices were calculated using the following relationships:

$$SSI = (1-(\mathrm{Ys}/\mathrm{Yp}))/(1-(\overline{Ys})/(\overline{Yp}))$$
(Fischer and Maurer, 1978)

$$STI = (Ys \times Yp)/(\overline{Yp})^2$$ (Fernandez, 1992)

$$GMP = \sqrt{Ys \times Yp}$$ (Fernandez, 1992)

$$MP = (Ys + Yp)/2$$ (Rosielle and Hamblin, 1981)

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

$$YI = (Ys)/(\overline{Ys})$$ (Gavuzzi *et al*., 1997)

$$DI = (Ys \times (Ys/Yp))/(\overline{Ys})$$ (Lan, 1988)

In the above formulas, Ys, Yp, $\overline{Ys}$ and $\overline{Yp}$ represent yield under rainfed (non-irrigated environment), yield irrigated (supplementary irrigated environment) for each cultivar, yield mean in rainfed (non-irrigated environment) and irrigated (supplementary irrigated environment) environments for all genotypes, respectively. Combined analysis of variance was carried out using SAS9.0 software. After the analysis of grain yield, ranks were assigned to genotypes for each drought tolerance index. To determine the best indices, Spearman’s rank correlation coefficients were calculated among indices and grain yield in two conditions. Finally, to identify ideal genotype (s), principle component analysis was performed by the GGE biplot (Yan *et al*., 2000).

Table 1. Details of chickpea genotypes used in three years.

Genotype cod	Genotype name	Origin	Genotype cod	Genotype name	Origin
G1	Flip 97-50c	ICARDA	G10	Flip 98-74c	ICARDA
G2	X94TH45K11	ICARDA	G11	Flip 98-126c	ICARDA
G3	X94TH15k10	ICARDA	G12	Flip 98-197c	ICARDA
G4	X94TH1k14	ICARDA	G13	Flip 98-201c	ICARDA
G5	X94TH9k1	ICARDA	G14	Flip 98-22c	ICARDA
G6	Flip 98-82c	ICARDA	G15	Flip 98-40c	ICARDA
G7	Flip 98-36c	ICARDA	G16	Flip 90-96c	ICARDA
G8	Flip 98-55c	ICARDA	G17	Bivanij	Iran
G9	Gokce	ICARDA	G18	Local check	Iran

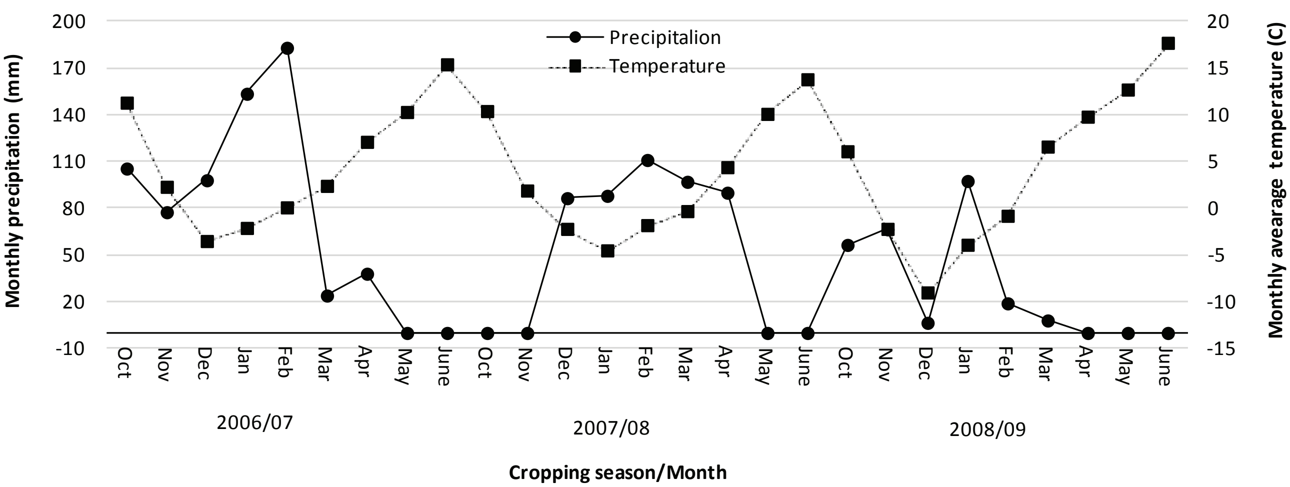

Figure 1. Distribution of monthly precipitation and monthly average temperature during three cropping seasons at Shirvan Chardavul research station, where the trials were conducted.

RESULTS AND DISCUSSION

Climatic data description during the experimental seasons

The phenomenon of temperature and precipitation during cropping seasons are given in Figure 1. In the 2006-07 cropping season, the rainfall pattern was optimal for crop growth, where the crops received 680 mm of rainfall. In the next cropping season, the crops received 472.5 mm of rainfall and the rainfall pattern was low to the last cropping season. In the third year, crops received 276.5 mm of rainfall during the cropping season. During the last two years as common phenomenon, drought spells occurred at the flowering to the grain-filling stage. In 2008-09, crops received only one third of average long-term precipitation (226.66 mm) and actually crops experienced a severe drought stress during the crop development, especially during flowering to grain filling and physiological maturity. In this year (2008-09), to escape crop failure an irrigation of 50 mm before flowering stage was applied for both rainfed and irrigated trials. In two later cropping seasons (2007-08 and 2008-09), crops had a deficient rainfall during the crop growth development as well as the grain filling stage. The pattern of temperature during the three cropping seasons was similar with few exceptions to the average temperatures in the months of December and June.

Combined analysis and comparison of genotypic yield

The combined analysis of variance for grain yield data of genotypes over two conditions and three years are given in Table 2. The main effects due to the water deficit stress, genotype and genotype × year interaction were found to be significant. In the three years the genotypic yields under rainfed environment revealed a greater variation than the irrigated environment. This variation can be explained, in part by the fact that traits which are appropriate for a given environment may be unsuitable in another environment (Mohammadi *et al*., 2010). In Over three years, the grain yield of genotypes under rainfed condition varied from 0.68 t h^{-1} (corresponding to G12) to 1.32 t h^{-1} (corresponding to G16 and G6), while mean yield of genotypes under irrigated conditions ranged from 1.22 t h^{-1} (corresponding to G17) to 1.85 t h^{-1} (corresponding to G15 and G6) (Table 3). In the first year (2006-07) the highest grain yield was observed in G16 under rainfed and irrigated conditions, however G3, G4 and G12 showed the lowest grain yield under both conditions. In the second year (2007-08) the highest grain yield was observed in G10 and G1 under irrigated and rainfed conditions, respectively. On the other hand, the highest grain yield was observed in G15 and G6 under irrigated condition in

Table 2. Combined analysis of variance for grain yield data of chickpea genotypes tested across three years and two environments.

Source	DF	Sum of squares	Mean squares
Year (Y)	2	22.3911	11.1955**
Rep / Y	9	0.7057	0.0784
Drought conditions (S)	1	24.7544	24.7544**
Y × S	2	0.0697	0.0348^{ns}
S × Rep / Y	9	0.3252	0.0361
Genotype (G)	17	15.4835	0.9107**
Y × G	34	17.6906	0.5203**
S × G	17	0.1641	0.5203**
Y × S × G	34	0.4045	0.0096^{ns}
Error	306	6.5615	0.0214
Total	431	88.5508	0.2054

^{ns} and **: non significant and significant at 1% level of probability.

Table 3. Grain yield (t ha^{-1}) of the genotypes in supplementary irrigated (Yp) and rainfed (Ys) environments and reduction of grain yield (R).

Genotype code	2006-07			2007-08			2008-09			Average of three years		
	Yp	Ys	R%	Yp	Ys	R%	Yp	Ys	R%	Yp	Ys	R%
1	1.45	0.91	37.06	1.69	1.30	22.92	1.79	1.40	21.72	1.64	1.20	26.64
2	1.12	0.71	36.80	1.57	1.11	29.19	2.12	1.63	22.89	1.60	1.15	28.20
3	0.97	0.47	51.15	1.17	0.69	41.02	1.69	1.27	24.53	1.27	0.81	36.32
4	0.96	0.42	56.36	1.17	0.70	39.69	1.99	1.53	23.10	1.37	0.88	35.57
5	1.62	1.07	33.64	1.23	0.79	35.68	1.66	1.13	31.78	1.50	1.00	33.51
6	1.61	1.07	33.43	1.56	1.09	29.84	2.38	1.81	23.95	1.85	1.32	28.36
7	1.20	0.65	45.20	1.33	0.80	39.24	2.29	1.70	25.47	1.61	1.06	34.19
8	1.29	0.77	40.15	1.48	1.12	23.93	1.77	1.33	24.92	1.51	1.08	28.93
9	1.23	0.64	47.87	1.28	0.85	33.40	1.46	1.01	31.47	1.32	0.83	37.18
10	1.66	1.20	27.71	1.50	1.05	30.15	1.63	1.19	26.80	1.59	1.14	28.17
11	1.06	0.61	42.48	1.26	0.84	33.53	2.08	1.62	21.98	1.47	1.02	30.24
12	0.96	0.50	48.05	1.26	0.79	37.18	1.44	0.74	48.18	1.22	0.68	44.34
13	1.27	0.73	42.15	1.24	0.81	34.91	1.93	1.42	26.28	1.48	0.99	33.24
14	1.26	0.86	31.54	1.35	0.91	32.70	2.11	1.51	28.65	1.57	1.09	30.58
15	1.63	1.25	23.43	1.46	0.95	34.65	2.47	1.76	28.42	1.85	1.32	28.59
16	2.16	1.88	12.61	1.48	1.01	31.72	1.64	1.08	33.85	1.76	1.32	24.58
17	1.05	0.62	40.47	1.15	0.65	43.19	1.34	0.88	34.04	1.18	0.72	38.91
18	1.30	0.82	36.53	1.54	1.19	22.78	1.53	1.11	27.92	1.46	1.04	28.66
Mean	1.32	0.84	36.05	1.37	0.92	32.52	1.85	1.34	27.52	1.518	1.04	31.51
Maximum	2.16	1.88	56.36	1.69	1.30	43.19	2.47	1.81	48.18	1.85	1.32	44.34
Minimum	0.96	0.42	12.61	1.15	0.65	22.78	1.34	0.74	21.71	1.18	0.68	24.58

Table 4. Resistance and tolerance indices of chickpea genotypes under stress and non-stress condition.

Year	Index	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18
2007	Yp	1.45	1.13	0.97	0.96	1.62	1.62	1.20	1.30	1.24	1.66	1.07	0.96	1.28	1.26	1.63	2.16	1.05	1.30
	Ys	0.91	0.71	0.48	0.42	1.08	1.08	0.66	0.78	0.65	1.20	0.61	0.50	0.74	0.86	1.25	1.89	0.63	0.83
	SSI	1.04	1.02	1.42	1.56	0.93	0.93	1.25	1.11	1.33	0.77	1.18	1.33	1.17	0.87	0.65	0.35	1.12	1.01
	STI	0.76	0.46	0.27	0.23	1.00	1.00	0.45	0.58	0.46	1.14	0.37	0.28	0.54	0.62	1.17	2.34	0.38	0.62
	TOL	0.54	0.42	0.50	0.54	0.55	0.54	0.54	0.52	0.59	0.46	0.45	0.46	0.54	0.40	0.38	0.27	0.43	0.48
	MP	1.18	0.92	0.72	0.69	1.35	1.35	0.93	1.04	0.94	1.43	0.84	0.73	1.01	1.06	1.44	2.02	0.84	1.06
	GMP	1.15	0.90	0.68	0.64	1.32	1.32	0.89	1.00	0.89	1.41	0.81	0.69	0.97	1.04	1.43	2.02	0.81	1.04
	YI	1.07	0.84	0.56	0.49	1.26	1.26	0.77	0.91	0.76	1.41	0.72	0.59	0.87	1.01	1.47	2.22	0.74	0.97
	DI	0.68	0.53	0.27	0.22	0.84	0.84	0.42	0.55	0.40	1.02	0.41	0.31	0.50	0.69	1.13	1.94	0.44	0.62
2008	Yp	1.70	1.57	1.17	1.17	1.24	1.56	1.33	1.49	1.28	1.50	1.27	1.27	1.25	1.36	1.46	1.48	1.15	1.55
	YS	1.31	1.11	0.69	0.71	0.80	1.10	0.81	1.13	0.85	1.05	0.84	0.80	0.81	0.91	0.96	1.01	0.65	1.19
	SSI	0.70	0.90	1.26	1.22	1.10	0.92	1.20	0.73	1.02	0.93	1.03	1.14	1.07	1.00	1.06	0.97	1.33	0.70
	STI	1.16	0.92	0.42	0.43	0.52	0.90	0.57	0.88	0.57	0.83	0.56	0.53	0.53	0.65	0.74	0.79	0.39	0.97
	TOL	0.39	0.46	0.48	0.47	0.44	0.47	0.52	0.36	0.43	0.45	0.43	0.47	0.44	0.44	0.51	0.47	0.50	0.35
	MP	1.50	1.34	0.93	0.94	1.02	1.33	1.07	1.31	1.07	1.28	1.06	1.03	1.03	1.13	1.21	1.25	0.90	1.37
	GMP	1.49	1.32	0.90	0.91	0.99	1.31	1.04	1.30	1.05	1.26	1.03	1.01	1.00	1.11	1.18	1.23	0.87	1.36
	YI	1.40	1.20	0.74	0.76	0.86	1.18	0.87	1.21	0.92	1.13	0.91	0.86	0.87	0.98	1.03	1.09	0.70	1.28
	DI	1.08	0.85	0.44	0.46	0.55	0.83	0.53	0.92	0.61	0.79	0.60	0.54	0.57	0.66	0.67	0.74	0.40	0.99
2009	Yp	1.79	2.12	1.69	1.99	1.66	2.39	2.29	1.78	1.47	1.63	2.08	1.44	1.93	2.11	2.47	1.64	1.35	1.54
	Ys	1.40	1.63	1.28	1.53	1.14	1.81	1.71	1.33	1.01	1.19	1.63	0.75	1.43	1.51	1.77	1.09	0.89	1.11
	SSI	0.79	0.83	0.89	0.84	1.16	0.87	0.93	0.91	1.14	0.97	0.80	1.75	0.96	1.04	1.03	1.23	1.24	1.01
	STI	0.73	1.01	0.63	0.89	0.55	1.26	1.14	0.69	0.43	0.57	0.99	0.31	0.80	0.93	1.27	0.52	0.35	0.50
	TOL	0.39	0.49	0.42	0.46	0.53	0.57	0.58	0.44	0.46	0.44	0.46	0.69	0.51	0.61	0.70	0.56	0.46	0.43
	MP	1.60	1.88	1.48	1.76	1.40	2.10	2.00	1.56	1.24	1.41	1.86	1.09	1.68	1.81	2.12	1.37	1.12	1.32
	GMP	1.58	1.86	1.47	1.75	1.37	2.08	1.98	1.54	1.22	1.39	1.84	1.04	1.66	1.79	2.09	1.34	1.09	1.30
	YI	1.04	1.22	0.95	1.14	0.84	1.35	1.27	0.99	0.75	0.89	1.21	0.56	1.06	1.12	1.32	0.81	0.66	0.82
	DI	0.82	0.94	0.72	0.88	0.58	1.03	0.95	0.75	0.51	0.65	0.94	0.29	0.78	0.80	0.94	0.54	0.44	0.59
Over three years	Yp	1.65	1.61	1.28	1.38	1.51	1.85	1.61	1.52	1.33	1.60	1.47	1.22	1.48	1.58	1.86	1.76	1.18	1.46
	Ys	1.21	1.15	0.81	0.89	1.00	1.33	1.06	1.08	0.83	1.15	1.03	0.68	0.99	1.09	1.33	1.33	0.72	1.04
	SSI	0.85	0.89	1.15	1.13	1.06	0.90	1.08	0.92	1.18	0.89	0.96	1.41	1.05	0.97	0.91	0.78	1.23	0.91
	STI	0.86	0.80	0.45	0.53	0.66	1.07	0.74	0.71	0.48	0.79	0.66	0.36	0.64	0.75	1.07	1.02	0.37	0.66
	TOL	0.44	0.45	0.46	0.49	0.51	0.53	0.55	0.44	0.49	0.45	0.45	0.54	0.49	0.48	0.53	0.43	0.46	0.42
	MP	1.43	1.38	1.05	1.13	1.26	1.59	1.33	1.30	1.08	1.37	1.25	0.95	1.24	1.34	1.59	1.55	0.95	1.25
	GMP	1.41	1.36	1.02	1.10	1.23	1.57	1.30	1.28	1.05	1.35	1.23	0.91	1.21	1.31	1.57	1.53	0.92	1.23
	YI	1.16	1.11	0.78	0.85	0.96	1.28	1.02	1.04	0.80	1.10	0.99	0.65	0.95	1.05	1.27	1.28	0.69	1.00
	DI	0.85	0.80	0.50	0.55	0.64	0.91	0.67	0.74	0.50	0.79	0.69	0.36	0.64	0.73	0.91	0.96	0.42	0.71

the third year (2008-09). In addition to G17, G12 and G9 had good yield performances over the testing environments. Also, in order to demonstrate the effects of stress, the reduction percentage of grain yield was calculated for genotypes in each year and over three years. The highest and lowest reduction percentages of grain yield under rainfed were observed in the 2006-07 and 2008-09 growing seasons, respectively (Table 3). In general, the mean grain yield of genotypes over three years was reduced to 36.05% under rainfed conditions. These findings are similar to those of several other researches investigating water deficit stress effects on grain yield during several years. Reduction of grain yield during different cropping seasons was also reported by Mohammadi *et al*. (2010), Akcura *et al*. (2011) and Nouri *et al*. (2011).

Comparing genotypes based on resistance/tolerance indices

The drought tolerance indices and the genotypic ranks based on the indices over three years are presented in Table 4. Differences were found in ranking genotypes from one drought resistance index to another, indicating that the indices differed in discriminating drought tolerant genotypes. In the case of the indices STI, MP and GMP, G6 followed by G15 and G16 were found to be drought tolerant, while G12, G17 and G3 with the lowest values of these indices were found to be intolerant. Based on the SSI indices, G16 followed by G10 and G1 were found drought tolerant with the lowest SSI, while G17, G12 and G9 displayed the highest values for SSI index. Other genotypes were identified as semi-tolerant or semi-sensitive to drought stress. As shown in Table 4, a greater TOL value was related to G7 followed by G12 and G15, indicating that these genotypes had a larger grain yield reduction under rainfed condition and showed a higher drought sensitivity. The lowest TOL was found in G18 (local check genotype), followed by G16 and G1. Therefore, these genotypes had a lower grain yield reduction under the rainfed condition. YI parameter, proposed by Gavuzzi *et al*. (1997), ranks genotypes only on the basis of their yield under the stress condition. According to the YI parameter, G16, G6 and G15 genotypes were found to have a high performance under stress condition. Drought resistance index (DI) discriminated G15, G6 and G15 as the most relative resistant genotypes. As described by Hohls (2001) selection for MP should increase yield in both stress and non-stress conditions unless the correlation between yields in contrasting environments is highly negative. The genotypes showing a high yielding performance in both stress and non-stress conditions were those genotypes with high values of MP and GMP. In the studies conducted by Khalili *et al*. (2012) and Naghavi *et al*. (2013) it was shown that grain yield was positively correlated with MP, GMP and STI indices in both conditions, and they used the GMP and STI to identify high yielding genotypes in both stress and non-stress conditions.

Changes in ranking of genotypes in response to drought stress

Differences were found from year to year in ranking of genotypes based on grain yield and each drought resistance/tolerance index (Tables 5), indicating that the drought tolerance of genotypes is influenced by the year effect (Mohammadi *et al*., 2011; Mohammadi and Amri, 2011) (Table 2). Under this situation, it would be useful to identify genotypes with consistent tolerance to drought from year to year. Under the drought stress (rainfed environment) condition, the grain yield in G16, G1 and G6 was the highest in the first, second and third years, respectively. Under the non-stress condition, G16 in the first year, G1 in the second year and G15 in the third year were the high yielding genotypes. Mohammadi *et al*. (2011) reported that the tolerance of genotypes to stress is variable from year to year. For MP, GMP and YI indices G16, G15 and G10 in the first year; G1, G18 and G2 in the second year and G15, G6 and G7 in the third year were the first three ranking genotypes. According to TOL index, the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. In the first year, G15, G15 and G14; in the second year G18, G8 and G1 and in the third year G1, G3 and G18 had the least reduction in yield, therefore, they can be characterized as resistant genotypes. According to the SSI parameter, the resistant genotypes were not consistent from year to year. In another word, similar to other indices, the SSI gave different ranks to genotypes in different years. The genotypes with the least values in the first year includ G16, G15 and G10; whereas those in the second year were G18, G1 and G8. In the third year genotypes G1, G11 and G2 showed the highest resistance to drought stress. According to the SSI parameter, 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). Akcura *et al*. (2011) showed that, under a severe drought stress, SSI can be a more useful index discriminating resistant genotypes. Also, this index (SSI) was used for the identification of resistant durum genotypes under cold, moderate and warm conditions by Mohammadi *et al*. (2011). Based on the STI parameter, G16, G15 and G10 in the first year; G1, G18 and G2 in the second year; and G15, G6 and G7 in the third year, appeared the most tolerant genotypes. The first three top genotypes based on the DI were G4, G3 and G12 in the first year; G17, G3 and G4 in the second year; and G12, G17 and G9 in the third year. Since different indices introduced different genotypes as drought tolerant, to determine the most desirable drought tolerant genotypes according to all indices, mean ranks and standard deviations of ranks for all drought tolerance criteria were calculated. In this regard, genotypes G16, G15 and G10 in the first year; G1, G18 (local check genotype) and G2 in the second year; and G6, G2 and G15 in the third year exhibited the best mean ranks and almost low standard devia-

Table 5. Ranks of indices for tested genotypes based on grain yield under stress and non-stress in the tree years (2007-09).

Year	Index	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18
2007	Yp	6	13	16	17	4	5	12	8	11	2	14	17	9	10	3	1	15	7
	Ys	6	11	17	18	4	4	12	9	13	3	15	16	10	7	2	1	14	8
	SSI	9	8	17	18	6	5	14	10	15	3	13	16	12	4	2	1	11	7
	STI	6	11	17	18	4	5	13	9	12	3	15	16	10	7	2	1	14	8
	TOL	13	4	10	15	17	14	15	11	18	7	6	8	12	3	2	1	5	9
	MP	6	13	17	18	4	5	12	9	11	3	14	16	10	8	2	1	15	7
	GMP	6	11	17	18	4	5	13	9	12	3	15	16	10	7	2	1	14	8
	YI	6	11	17	18	4	4	12	9	13	3	15	16	10	7	2	1	14	8
	DI	12	9	2	1	14	15	6	10	4	16	5	3	8	13	17	18	7	11
	Mean	7.78	10.11	14.44	15.67	6.78	6.89	12.11	9.33	12.11	4.78	12.44	13.78	10.11	7.33	3.78	2.89	12.11	8.11
	SDR	10.53	12.77	19.41	20.99	11.61	11.03	14.49	10.16	15.66	9.00	16.30	18.42	11.31	10.12	8.50	8.26	15.64	9.31
2008	Yp	1	2	17	16	15	3	10	6	11	5	12	12	14	9	8	7	18	4
	YS	1	4	17	16	14	5	13	3	10	6	11	14	12	9	8	7	18	2
	SSI	2	4	17	16	13	5	15	3	9	6	10	14	12	8	11	7	18	1
	STI	1	3	17	16	15	4	11	5	10	6	12	13	14	9	8	7	18	2
	TOL	3	10	15	11	7	12	18	2	5	9	4	14	6	8	17	13	16	1
	MP	1	3	17	16	15	4	10	5	11	6	12	13	14	9	8	7	18	2
	GMP	1	3	17	16	15	4	11	5	10	6	12	13	14	9	8	7	18	2
	YI	1	4	17	16	14	5	13	3	10	6	11	14	12	9	8	7	18	2
	DI	18	15	2	3	6	14	4	16	9	13	8	5	7	10	11	12	1	17
	Mean	3.57	5.33	14.50	13.83	12.92	6.08	11.00	6.08	9.83	7.17	10.67	12.17	12.00	9.00	9.00	7.83	15.17	4.33
	SDR	9.31	9.03	19.57	17.85	15.90	9.30	15.32	10.74	11.73	9.37	13.15	15.32	14.54	9.78	12.21	9.89	20.95	10.04
2009	Yp	9	4	11	7	12	2	3	10	16	14	6	17	8	5	1	13	18	15
	Ys	9	4	11	6	13	1	3	10	16	12	5	18	8	7	2	15	17	14
	SSI	1	3	6	4	15	5	8	7	14	10	2	18	9	13	12	16	17	11
	STI	9	4	11	7	13	2	3	10	16	12	5	18	8	6	1	14	17	15
	TOL	1	10	2	8	12	14	15	5	9	4	6	17	11	16	18	13	7	3
	MP	9	4	11	7	13	2	3	10	16	12	5	18	8	6	1	14	17	15
	GMP	9	4	11	7	13	2	3	10	16	12	5	18	8	6	1	14	17	15
	YI	9	4	11	6	13	1	3	10	16	12	5	18	8	7	2	15	17	14
	DI	12	14	8	13	5	18	17	9	3	7	16	1	10	11	15	4	2	6
	Mean	8.14	5.36	9.86	7.21	12.07	4.43	5.64	9.43	13.86	11.21	6.07	15.43	8.50	7.93	5.00	13.00	15.00	12.86
	SDR	12.71	8.61	13.34	9.57	14.83	9.60	10.39	11.49	17.76	14.02	9.88	21.35	9.44	11.68	11.24	16.53	19.77	16.74
Over three years	Yp	4	6	16	14	10	2	5	9	15	7	12	17	11	8	1	3	18	13
	Ys	4	5	16	14	12	2	9	8	15	6	11	18	13	7	3	1	17	10
	SSI	2	4	15	14	12	5	13	8	16	3	9	18	11	10	6	1	17	7
	STI	4	5	16	14	12	1	8	9	15	6	11	18	13	7	2	3	17	10
	TOL	3	7	9	11	14	15	18	4	13	6	5	17	12	10	16	2	8	1
	MP	4	5	16	14	10	1	8	9	15	6	12	17	13	7	2	3	18	11
	GMP	4	5	16	14	12	1	8	9	15	6	11	18	13	7	2	3	17	10
	YI	4	5	16	14	12	2	9	8	15	6	11	18	13	7	3	1	17	10
	DI	4	5	16	14	12	2	11	7	15	6	10	18	13	8	3	1	17	9
	Mean	3.67	5.22	15.11	13.67	11.78	3.44	9.89	7.89	14.89	5.78	10.22	17.67	12.44	7.89	4.22	2.00	16.22	9.00
	SDR	4.37	6.06	17.43	14.67	12.98	7.95	13.65	9.50	15.67	6.87	12.39	18.17	13.33	9.16	8.85	3.00	19.34	12.39

tions. Finally, genotypes G10, G6, G15 and G16 exhibited the best mean ranks and low standard deviations of ranks over three years, hence they were identified as the most drought tolerant genotypes (Table 5). The results showed a great deal of inconsistency in ranking of genotypes as tolerant/resistant based on each one of the indices over years.

Relationships and repeatability of drought tolerance indices

Correlation analysis between grain yield and drought tolerance indices can be a good criterion for screening the best cultivars and indices used. Spearman's rank correlation coefficients among the drought tolerance/resistance and mean yield under stress and non-stress

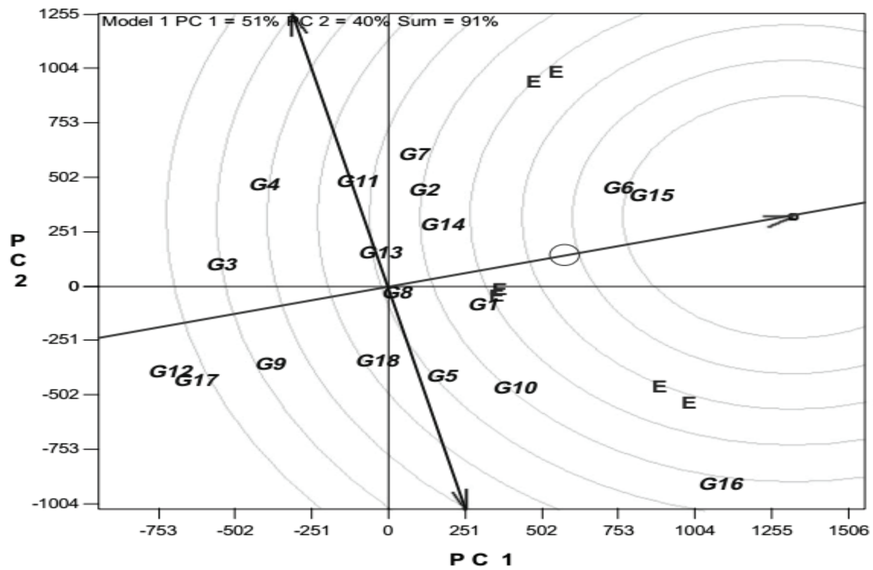

Figure 2. GGE Biplot methodology, with the first two principal axes of the interaction (PC1 and PC2) for the average grain yield (tonh^{-1}) of 18 genotypes in three years under two different environmental conditions at Shirvan Chardavul research station, west of Iran (Numbers inside the figure are genotypes no. (see Table 1)).

Table 6. Spearman's rank correlation coefficients among yields under stress and non-stress conditions with drought tolerance and resistance indices based on each year and over years.

Year	Index	Yp	Ys	SSI	STI	TOL	MP	GMP	HM	YI	DI
2007	Yp	1	0.971**	0.866**	0.974**	0.14	0.988**	0.974**	0.972**	0.971**	-0.932**
	Ys	-	1	0.942**	0.997**	0.273	0.987**	0.997**	0.999**	1.00**	-0.985**
2008	Yp	1	0.956**	0.914**	0.989**	0.336	0.991**	0.989**	0.981**	0.956**	-0.938**
	Ys	-	1	0.979**	0.982**	0.543*	0.976**	0.982**	0.991**	1.00**	-0.993**
2009	Yp	1	0.979**	-0.587*	0.990**	0.37	0.990**	0.990**	0.990**	0.979**	.944**
	Ys	-	1	-0.678**	0.994**	0.249	0.994**	0.994**	0.994**	1.00**	.981**
2007-09	Yp	1	0.950**	0.810**	0.965**	0.001	0.977**	0.965**	0.965**	0.950**	0.917**
	Ys	-	1	0.922**	0.99^{2**}	0.261	0.983**	0.992**	0.992**	1.000**	0.992**

* and **: significant at 5% and 1% levels of probability, respectively.

conditions for each set of yearly data are given in Table 6. The relationship between yields under both stress and non-stress conditions was found to be significantly positive in all three years, indicating that relationship between genotypic yields are influenced by the year effect (Table 2). A suitable index must have a significant correlation with grain yield under both conditions (Mitra, 2001). Significant positive relationships were observed between the Ys with the SSI, STI, GMP, MP and YI in two out of three years, indicating that selecting genotypes for these indices will not always improve yield under stress condition. Significant positive correlations were also found between Yp with the indices SSI, STI, YI, GMP, MP and DI in two out of three years. These results can be supported by other works (Farshadfar and Sutka, 2002; Mohammadi *et al*., 2010; Nouri *et al*., 2011). The indices STI, YI, GMP and MP had a significantly positive correlation with grain yield under both stress and non-stress conditions in the three years, indicating that these indices are able to discriminate group A genotypes (genotypes with high yield in both stress and non-stress conditions) in these years. Sio-Se Mardeh *et al*. (2006) showed that correlation was positive between MP, GMP, Ys and Yp. Naghavi *et al*. (2013) reported that GMP, MP and STI were positively correlated with grain yield under both conditions. Repeatable relationships were observed between grain yield with STI, YI, GMP and MP over three years, suggesting that one of them can be used as alternative to others for the evaluation of drought tolerant genotypes. These results are in agreement with the previous studies (Mohammadi *et al*., 2010; Akcura *et al*., 2011, Nouri *et al*., 2011; Shirani-Rad *et al*., 2011 Farshadfar *et al*., 2012; Khalili *et al*., 2012).

Identifying ideal genotype(s) over years based on principle component analysis

The principle component analysis (PCA) was used to identify ideal genotypes. This analysis revealed that the first two PCA explained 91% of the total variation. An ideal genotype should have an invariably high average yield in all environments. This ideal genotype is graphically defined by the longest vector in PC1 and without projections in PC2, represented by the arrow in the center of the concentric circles (Costa de Mattos *et al*., 2013). G6 and G15 genotypes were located in the first and second concentric circles (Figure 2); these genotypes are closest to the ideal and can be considered desirable in terms of yield and stability of the grain yield. Also, G1, G2, G7, G10, G14 and G16 genotypes located in the fifth circle were identified as moderately tolerant genotypes.

CONCLUSION

In conclusion, the findings from this study showed that yields were influenced by the year effect under both environments. Differences in ranking of genotypes based on each index from year to year, indicating that the drought tolerance of genotypes are also influenced by the year effect. Highly significant correlations were found between several stability measures indicating that these indices measure similar aspects of drought tolerance/resistance. YI, GMP, MP and STI indices highly correlated with grain yield in both environments are introduced as the best indices in the three years. Consequently, based on the results of this study screening drought tolerant genotypes using drought tolerance indices discriminated genotype G6 and G15 as the most drought tolerant. Therefore, they are recommended to be used as parents for the improvement of drought tolerance in other genotypes.

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