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EVALUATING OF DROUGHT STRESS TOLERANCE BASED ON SELECTION INDICES IN TURKISH BREAD WHEAT LANDRACES

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ABSTRACT

The objective of this study was to evaluate the ability of several selection indices to identify drought tolerant/resistant genotypes under different conditions of Konya. Thirty six bread wheat genotypes (twenty four pure lines from Turkish bread wheat landraces and twelve modern bread wheat cultivars) were evaluated under both moisture stress (rainfed) and non stress (irrigated) conditions using a "randomized complete block design" with three replications. Nine drought tolerance indices including yield stability index (YSI), yield index (YI), superiority index (P_i), stress tolerance index (STI), geometric mean productivity (GMP), stress susceptibility index (SSI), mean productivity (MP), stress tolerance (TOL), harmonic mean (HM) and linear regression coefficient (b_i) were calculated. The indices were adjusted based on grain yield under drought condition (Ys) and normal conditions (Yp). SSI is suggested as useful indicator for wheat breeding where the stress is severe while MP, GMP, TOL HM and STI are suggested if the stress is less severe. Biplot analysis was used to explain relationship between grain yield and drought indices. Karahan-99, Bayraktar-2000, Gerek-79, PL-7, Sönmez-2000, Kıraç-66 and PL-5 were the superior genotypes for both rainfed and irrigated conditions with high PC1 and low PC2. PL-25, PL-13 and PL-23 with high PC2 were more suitable for rainfed than irrigated conditions.

Key words: biplot analysis, drought indices, Turkey, winter bread wheat landraces.

INTRODUCTION

Wheat is mainly grown on rain-fed land. About 70 % of the area of Turkey consists of semiarid environments in which available moisture constitutes a primary constraint in wheat production. Climatic variability in these marginal environments causes large annual fluctuations in grain yield.

Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes are to be evaluated efficiently (Ramirez and Kelly, 1998). Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders while progress in yield has been much higher in favorable environments (Richards *et al.*, 2002). Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). Selection of wheat genotypes with better adaptation to water stress should increase the productivity of rainfed wheat (Rajaram, 2001).

The relative yield performance of genotypes in drought stressed and more favorable environments seems to be a common starting point in the identification of traits related to drought tolerance and the selection of genotypes for use in breeding for dry environments (Clarke *et al.,* 1992). According to Fernandez (1992), genotypes can be divided into four groups based on their yield response to stress conditions: (1) genotypes producing high yield under both water stress and non-stress conditions (group A), (2) genotypes with high yield under non-stress (group B) or (3) stress (group C) conditions and (4) genotypes with poor performance under both stress and non-stress conditions (group D).

To differentiate drought resistant genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stressed conditions (Clarke *et al.,* 1984; Huang, 2000). Tolerance (TOL) (McCaig and Clarke, 1982; Clarke *et al.,* 1992), mean productivity (MP) (McCaig and Clarke, 1982), stress susceptibility index (SSI) (Fischer and Maurer, 1978), harmonic mean (HM) (Chakherchaman *et al.,* 2009), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992) All of these have been employed under various conditions. The superiority measure (P_i) proposed by Lin and Binns (1988) is another indicator that compares the productivity of genotypes across different environments.

The objectives of the study were to (i) identify drought tolerant bread wheat genotype(s) under rainfed conditions in the Central Anatolian Region of Turkey, (ii) determine the efficiency of tolerance indices to classify both modern bread wheat cultivars and pure lines into sensitive and tolerant and (iii) study interrelationships among the tolerance indices.

MATERIALS AND METHODS

The bread wheat selection and improvement program was initiated by screening landraces collected from different localities. In 2002, at least 82 populations were collected from the villages of Bozkır, Ahırlı, Hadim, Taşkent, and Seydişehir, where wheat landraces were still grown in small fields (0.005-0.05 ha) and farmers had been using their own seed for generations (Akçura, 2009). In the 2002-2005 growing seasons pure lines were selected in Konya province.

Twenty four pure lines and twelve cultivars (Gerek-79, Karahan-99, Bayraktar-2000, Dağdaş-94, Tosunbey, Demir-2000, Bezostaja-1, Konya-2002, Sönmez-2000, Katea-1, Kıraç-66 and Köse 220/39) were chosen for the study based on their reputed differences in yield performance under irrigated and non-irrigated conditions. The origins of the selected pure lines, history of selection, and standard cultivars are given in Table 1.

Experiments were conducted at Bahri Dağdaş International Agricultural Research Institute, in Konya province (Central Anatolian Region of Turkey) in 2006-2007 and 2007-2008 growing seasons. Experimental layout was a “randomized complete blocks design” with three replications in both rainfed and irrigation conditions. Sowing was done by an experimental drill in 1.2 m x 7 m plots, consisting of six rows with 20 cm apart. For irrigated plots, 50 mm of water were applied at both tillering and booting stage. Non-irrigated plots were grown under rainfed conditions. Sowing was done in October. Seed density was 550 seeds m^{-2} under rainfed conditions and 500 seeds m^{-2} under irrigated conditions (Akçura, 2011). The plots were fertilized with 27 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} at planting and 40 kg N ha^{-1} at the stem elongation. Crop plots (1.2 m x 5 m) were harvested by a combined plot harvester.

The experiments were performed in a clay- loam soil with a pH of 7.7 under rain fed and irrigated conditions in 2006-2007 and 2007-2008 growing seasons.

The total mean rainfall during the two growing seasons in Konya (Latitude: 37°51’43" N; Longitude: 32°33’31"E; Altitude: 1009 m above sea level) was 248 and 311 mm, respectively. The amounts were lower than the long-term rainfall for Konya (320 mm).

The grain yield (GY) was determined and expressed as ton per hectare (t ha^{-1}). Data on other yield related traits were also recorded viz., number of spike m^{-2} (NS), number of grains m^{-2} (NG), weight of grains $spike^{-1}$ (g) (WGS), number of grains $spike^{-1}$ (NGS), plant height (cm) (PH).

Drought resistance indices were calculated using the following relationships:

1. Yield stability index (YSI) = $\frac{Ys}{Yp}$ (Bouslama and Schapaugh, 1984).
2. Superiority index (P_i)= $\sum_{j=1}^{n} \frac{(Xij-Mj)^2}{2n}$ (Clarke *et al.,* 1992).
where n is the number of environments, Xij the grain yield of ith genotype in the jth environment and Mj is the yield of the genotype with maximum yield at environment j.
3. Yield index (YI)= $\frac{Ys}{\bar{Ys}}$ (Gavuzzi *et al.,* 1997).
4. Stress tolerance index (STI)=$\frac{Yp+Ys}{\bar{Y}p^2}$ (Fernandez, 1992).
5. Geometric mean productivity (GMP)= $\sqrt{(Yp \; x \; Ys)}$ (Fernandez, 1992).
6. Stress susceptibility index (SSI)= $\frac{1-(\frac{Ys}{Yp})}{1-(\frac{\bar{Ys}}{\bar{Yp}})}$ (Fischer and Maurer, 1978)
7. Mean productivity (MP)= $\frac{Yp+Ys}{2}$ (Hossain *et al.,* 1990).
8. Stress tolerance (TOL)= $Yp - Ys$ (Hossain *et al.,* 1990).

Harmonic mean (HM) =$\frac{2(Yp \; x \; Ys)}{(Yp+Ys)}$ (Chakherchaman *et al.,* 2009).

10. Linear regression coefficient (b_i): The coefficient of linear regression of grain yield of a cultivar in each environment on the environmental index (mean yield of all cultivars at any environment) (Bansal and Sinha, 1991).

Combined analysis of variance, correlation and biplot analyses were carried out using SAS, version 9.0 (SAS Institute, 1999).

RESULTS

The results of analysis of variance for GY, PH, NG, NS, WGS and NGS are presented in Table 2. Among the genotypes, significant differences were observed for all investigated characters (Table 2).

The main effect of moisture regimes and the interaction between genotpes x moisture regimes were highly significant for the measured traits. Grain yield and studied traits of genotypes varied, particularly under stress conditions, year by year (Table 3 and 4). Drought stress significantly decreased GY, PH, NG, NS, WGS and NGS (Table 3 and 4).

Grain yields of rainfed conditions ranged between 1.06 and 2.12 t ha^{-1} and of irrigated conditions between 2.73 and 5.73 t ha^{-1} (Table 3). Mean grain yield in rainfed conditions was 58% smaller than in irrigated

Table 1. Details of landraces pure lines from landraces and Cultivars

		Pure Lines			
No	**Pure Line Code**	**Site (Province-Town-Village)**	**Altitute (m)**	**Local Name**	**Selection History**
13	PL-1	Konya-Ahırlı-Kuruçay	1150	Akbaşak	02-03 BDKEYÇ 94-13
14	PL-2	Konya-Bozkır-Aslantaş	1300	Akbaş	02-03 BDKEYÇ 8-4
15	PL-3	Konya-Bozkır-Akçapınar	1100	Yatmaz	02-03 BDKEYÇ 97-07
16	PL-4	Konya-Bozkır-Bayboğan	1150	Akbaş	02-03 BDKEYÇ 17-08
17	PL-5	Konya-Bozkır-Yelbeyi	1150	Yatmaz	02-03 BDKEYÇ85-07
18	PL-6	Konya-Bozkır-Kovanlık	1300	Akbaş	02-03 BDKEYÇ 25-5
19	PL-7	Konya-Bozkır-Soğucak	1300	Yatmaz	02-03 BDKEYÇ 30-24
20	PL-8	Konya-Bozkır-Akçapınar	1100	Yatmaz	02-03 BDKEYÇ 97-20
21	PL-9	Konya-Bozkır-Dedemli	1350	Akbuğday	02-03 BDKEYÇ 62-09
22	PL-10	Konya-Bozkır-Dedemli	1350	Akbuğday	02-03 BDKEYÇ 62-19
23	PL-11	Konya-Bozkır-Dedemli	1350	Akbuğday	02-03 BDKEYÇ 66-23
24	PL-12	Konya-Bozkır-Dedemli	1050	Akbuğday	02-03 BDKEYÇ 71-19
25	PL-13	Konya-Bozkır-Hamzalar	1200	Akbuğday	02-03 BDKEYÇ 77-13
26	PL-14	Konya-Bozkır-Hamzalar	1200	Akbuğday	02-03 BDKEYÇ 77-19
27	PL-15	Konya-Bozkır-Hamzalar	1200	Akbuğday	02-03 BDKEYÇ 77-21
28	PL-16	Konya-Bozkır-Hisarlık	1100	Sarı buğday	02-03 BDKEYÇ 87-02
29	PL-17	Konya-Bozkır-Taşbaşı	1200	Kılçıksız	02-03 BDKEYÇ80-07
30	PL-18	Konya-Bozkır-Yazıdamı	1100	Akbuğday	02-03 BDKEYÇ 90-07
31	PL-19	Konya-Bozkır-Taşağıl	1200	Akbuğday	02-03 BDKEYÇ 83-04
32	PL-20	Konya-Bozkır-Taşbaşı	1200	Kılçıksız	02-03 BDKEYÇ 83-13
33	PL-21	Konya-Bozkır-Bayboğan	1150	Akbuğday	02-03 BDKEYÇ 16-1
34	PL-22	Konya-Bozkır-Karacaardıç	1200	Akbuğday	02-03 BDKEYÇ 19-12
35	PL-23	Konya-Bozkır-Soğucak	1300	Mor buğday	02-03 BDKEYÇ 29-24
36	PL-24	Konya-Bozkır-Dedemli	1350	Akbuğday	02-03 BDKEYÇ 67-18
		Modern Bread Wheat Cultivars			
1		Gerek-79			
2		Karahan-99			
3		Bayraktar-2000			
4		Dağdaş-94			
5		Tosunbey			
6		Demir-2000			
7		Bezostaya-1			
8		Konya-2002			
9		Sönmez-2000			
10		Kate-a1			
11		Kıraç-66			
12		Köse 220/39			

Table 2. Mean squares for agronomic traits of 36 bread wheat genotypes.

Source	DF	GY	PH	NS	NG	NGS	WGS
Year (Yr)	1	0.6**	110560**	278973**	299515196**	7958**	7.94**
Rep(Yr)	4	1.5	257	25822	16175230	198	1.46
Drought (Dr)	1	540.6**	253316**	4589270**	1102303761**	755**	1.95**
Yr*Dr	1	56.7**	34830**	500617**	84516630**	536**	0.14**
Dr*Rep(Yr)	4	1.5	27	7279	4218125	7	0.01
Genotype (Gen)	35	1.9**	325**	70800**	6775343**	212**	0.21**
Yr*Gen	35	2.1**	151**	12766**	4340863**	25**	0.04**
Dr*Gen	35	1.6**	55**	22097**	2990120**	5**	0.02**
Yr*Dr*Gen	35	0.7**	45**	9112**	1909862**	3**	0.01**
Error	280	0.4	46	3718	1151694	8	0.03
R^2(%)		0.89	0.97	0.90	0.86	0.89	0.78
CV (%)		20.85	8.12	11.12	15.97	10.95	15.94
Mean		2.86	83.58	538.33	6718.83	25.75	0.92

**: $P \leq 0.01$ GY: grain yield, :NS number of spike m^{-2}, NG: number of grain m^{-2}, WGS: weight of grains $spike^{-1}$, NGS: number of grain $spike^{-1}$, PH: plant height.

Table 3. Grain yield (t ha^{-1}) of the genotypes in irrigated (IR) non-irrigated (NIR) environments and reduction of grain yield

	Genotypes	Growing Seasons						Average of Two Years		
		2006-2007			2007-2008					
	Cultivars	IRR	NIR	%YR	IRR	NIR	%YR	IRR	NIR	%YR
1	Gerek-79	5.03	1.4	0.73	5.49	2.07	0.62	5.26	1.71	0.67
2	Karahan-99	5.61	1.20	0.79	5.84	2.79	0.52	5.73	1.99	0.65
3	Bayraktar-2000	5.20	1.15	0.78	5.86	2.58	0.56	5.53	1.87	0.66
4	Dağdaş-94	4.80	0.97	0.80	4.98	2.03	0.59	4.89	1.50	0.69
5	Tosunbey	4.19	1.02	0.76	6.20	2.23	0.64	5.20	1.62	0.69
6	Demir-2000	3.89	0.83	0.79	5.61	2.44	0.56	4.75	1.64	0.66
7	Bezostaya-1	3.53	0.84	0.76	4.55	2.06	0.55	4.04	1.45	0.64
8	Konya-2002	2.79	0.82	0.71	5.56	2.49	0.55	4.18	1.66	0.60
9	Sönmez-2000	4.65	0.99	0.79	4.24	2.30	0.46	4.45	1.64	0.63
10	Kate-a1	4.23	0.91	0.79	5.79	2.85	0.51	5.01	1.88	0.62
11	Kıraç-66	4.03	0.99	0.75	4.10	2.26	0.45	4.06	1.63	0.60
12	Köse 220/39	3.34	0.76	0.77	2.12	1.36	0.36	2.73	1.06	0.61
	Means	4.27	0.99	0.77	5.03	2.29	0.53	4.65	1.64	0.64
	Pure Lines									
13	PL-1	4.84	1.48	0.69	3.06	2.24	0.27	3.95	1.86	0.53
14	PL-2	4.34	1.52	0.65	3.47	1.99	0.43	3.90	1.76	0.55
15	PL-3	4.51	1.51	0.67	2.82	2.09	0.26	3.66	1.80	0.51
16	PL-4	4.67	1.41	0.70	3.26	2.22	0.32	3.97	1.82	0.54
17	PL-5	4.64	1.40	0.70	3.47	2.02	0.42	4.05	1.71	0.58
18	PL-6	4.52	1.44	0.68	2.36	2.05	0.13	3.44	1.75	0.49
19	PL-7	4.84	1.29	0.73	4.58	2.08	0.55	4.71	1.69	0.64
20	PL-8	4.88	1.33	0.73	2.70	2.08	0.23	3.79	1.70	0.55
21	PL-9	3.80	1.36	0.64	2.02	1.97	0.03	2.91	1.67	0.43
22	PL-10	3.58	1.28	0.64	2.24	1.96	0.12	2.91	1.62	0.44
23	PL-11	4.73	1.43	0.70	2.75	2.18	0.21	3.74	1.80	0.52
24	PL-12	4.43	1.65	0.63	2.65	1.92	0.28	3.54	1.78	0.50
25	PL-13	4.83	1.92	0.60	2.25	2.20	0.02	3.54	2.06	0.42
26	PL-14	4.61	1.72	0.63	2.93	2.06	0.30	3.77	1.89	0.50
27	PL-15	4.33	1.63	0.62	3.05	2.01	0.34	3.69	1.82	0.51
28	PL-16	4.55	1.72	0.62	3.09	2.05	0.34	3.82	1.89	0.51
29	PL-17	3.42	1.43	0.58	2.90	1.88	0.35	3.16	1.65	0.48
30	PL-18	4.64	1.99	0.57	3.31	2.26	0.32	3.97	2.12	0.47
31	PL-19	4.05	1.38	0.66	3.36	2.02	0.40	3.70	1.70	0.54
32	PL-20	4.09	1.46	0.64	2.77	2.18	0.21	3.43	1.82	0.47
33	PL-21	4.14	1.35	0.67	3.04	2.01	0.34	3.59	1.68	0.53
34	PL-22	4.23	1.63	0.61	3.24	2.19	0.33	3.74	1.91	0.49
35	PL-23	4.23	1.68	0.60	2.81	2.15	0.23	3.52	1.92	0.46
36	PL-24	2.75	1.47	0.47	3.12	1.86	0.40	2.94	1.67	0.43
	LSD (0.01)	1.72	0.58		1.74	0.59		1.62	0.86	
	Means	4.16	1.61	0.61	2.99	2.07	0.30	3.57	1.84	0.48
	Grand Mean	4.22			4.01			4.11	1.74	

conditions. The mean yield of 12 bread wheat cultivars under rain fed and irrigated conditions were 1.64 and 4.65 t ha^{-1}, respectively (Table 3). For pure lines, mean grain yield under rainfed and irrigated conditions were 1.84 and 3.57 t ha^{-1}, respectively (Table 3). The mean grain yield of cultivars and pure lines was reduced (64% and 48%, respectively) under rainfed conditions (Table 3).

Karahan-99, Bayraktar-2000 and Gerek-79 were the most productive cultivars in irrigated and the least productive one in rainfed conditions. For the pure lines, PL-7 and PL-5 had the highest grain yield in irrigated environment. In rainfed conditions, PL-18 and PL-13 pure lines produced the highest and second highest grain yields of 2.12 t ha^{-1} and 2.06 t ha^{-1}, respectively (Table 3).

As shown in Table 5, the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. A positive correlation between irrigated yield (GY_{IR}) and SSI, TOL and a negative correlation between grain yield of rainfed (GY_{NIR}) and SSI, TOL (Table 6) suggest that selection based on SSI and TOL will result in reduced yield under irrigated conditions. Especially, negative correlation between SSI and GY_{NIR} was expected because

Table 4. Studied Traits of bread wheat genotypes (averaged over 2 years)

Genotypes	PH			NS			NG			NGS			WGS		
	IRR	NIR	%R	IRR	NIR	%R	IRR	NIR	%R	IRR	NIR	%R	IRR	NIR	%R
Cultivars															
Gerek-79	97.8	52.9	0.46	718	569	0.21	9520	6373	0.33	26.80	23.60	0.12	0.84	0.70	0.17
Karahan-99	104.5	56.2	0.46	616	374	0.39	8263	4573	0.45	25.73	23.52	0.09	0.88	0.72	0.17
Bayraktar-2000	95.9	52.8	0.45	720	415	0.42	9412	5075	0.46	27.40	24.94	0.09	0.93	0.81	0.13
Dağdaş-94	121.1	63.5	0.48	576	391	0.32	8007	4554	0.43	27.33	23.91	0.13	0.99	0.77	0.22
Tosunbey	101.3	54.7	0.46	460	341	0.26	8800	5620	0.36	36.87	32.36	0.12	1.21	1.00	0.17
Demir-2000	117.2	59.7	0.49	433	385	0.11	7116	5383	0.24	33.20	28.78	0.13	1.25	0.99	0.21
Bezostaya-1	109.3	57.8	0.47	532	339	0.36	8082	4589	0.43	30.10	27.56	0.08	1.21	1.02	0.16
Konya-2002	92.9	52.8	0.43	376	334	0.11	6429	4867	0.24	35.13	30.48	0.13	1.45	1.12	0.23
Sönmez-2000	103.8	53.9	0.48	439	399	0.09	8181	6535	0.20	35.33	32.44	0.08	1.29	1.05	0.19
Kate-a1	101.3	52.8	0.48	390	355	0.09	7708	6151	0.20	38.57	34.87	0.10	1.17	0.93	0.20
Kıraç-66	112.8	60.4	0.46	669	398	0.41	9049	4992	0.45	27.87	25.51	0.08	0.84	0.73	0.14
Köse 220/39	106.0	54.6	0.49	831	442	0.47	8186	4016	0.51	20.73	18.93	0.09	0.74	0.62	0.17
Mean	105.3	56.0	0.47	563	395	0.27	8229	5227	0.36	30.42	27.24	0.10	1.07	0.87	0.18
Pure Lines															
PL-1	114.4	63.0	0.45	637	372	0.42	8585	4658	0.46	27.40	25.60	0.07	1.06	0.93	0.12
PL-2	107.5	58.4	0.46	673	456	0.32	8308	5094	0.39	25.07	22.63	0.10	0.98	0.83	0.15
PL-3	108.7	58.8	0.46	667	427	0.36	8833	5652	0.36	27.83	26.71	0.04	1.03	0.99	0.04
PL-4	118.6	63.4	0.47	572	429	0.25	7751	4709	0.39	27.63	23.02	0.17	1.08	0.88	0.18
PL-5	108.1	58.9	0.45	627	426	0.32	8382	4647	0.45	27.20	22.74	0.16	0.98	0.79	0.20
PL-6	105.8	59.8	0.43	681	403	0.41	7971	4137	0.48	23.33	20.64	0.12	0.81	0.74	0.09
PL-7	98.2	54.3	0.45	751	501	0.33	9956	6278	0.37	27.07	25.65	0.05	0.84	0.73	0.13
PL-8	110.3	58.6	0.47	631	490	0.22	8867	5738	0.35	28.83	24.60	0.15	1.07	0.85	0.21
PL-9	109.3	61.4	0.44	771	497	0.35	8008	4995	0.38	22.20	21.63	0.03	0.82	0.84	-0.02
PL-10	102.9	58.2	0.43	753	448	0.41	6978	4114	0.41	19.63	19.07	0.03	0.78	0.73	0.06
PL-11	111.4	62.8	0.44	696	532	0.24	7542	5209	0.31	22.93	20.72	0.10	0.87	0.77	0.11
PL-12	106.2	57.2	0.46	767	407	0.47	12308	5548	0.55	32.87	28.31	0.14	1.13	0.96	0.15
PL-13	108.2	60.3	0.44	688	463	0.33	8974	5509	0.39	26.57	24.31	0.09	1.04	0.90	0.13
PL-14	104.5	59.4	0.43	660	455	0.31	6863	4390	0.36	21.60	20.15	0.07	0.89	0.81	0.09
PL-15	107.4	59.6	0.45	688	424	0.38	8400	4753	0.43	24.93	22.65	0.09	0.99	0.85	0.14
PL-16	116.3	65.3	0.44	627	483	0.23	8519	5680	0.33	27.77	24.61	0.11	0.99	0.90	0.09
PL-17	105.2	61.2	0.42	741	489	0.34	9143	5657	0.38	26.43	24.24	0.08	0.84	0.79	0.06
PL-18	115.7	66.8	0.42	672	488	0.27	8641	5737	0.34	26.37	24.27	0.08	0.94	0.88	0.06
PL-19	113.7	64.5	0.43	757	528	0.30	7538	5388	0.29	20.80	20.91	-0.01	0.80	0.81	-0.01
PL-20	112.7	63.8	0.43	631	498	0.21	8373	5656	0.32	27.43	23.88	0.13	1.01	0.87	0.14
PL-21	119.7	66.0	0.45	601	393	0.35	7858	4396	0.44	25.73	22.42	0.13	0.98	0.85	0.13
PL-22	111.8	62.8	0.44	643	435	0.32	8608	5075	0.41	27.60	24.19	0.12	1.00	0.86	0.14
PL-23	103.1	61.2	0.41	746	429	0.42	8250	4108	0.50	22.50	19.48	0.13	0.91	0.75	0.18
PL-24	97.8	59.9	0.39	652	456	0.30	5977	4518	0.24	19.67	20.00	-0.02	0.77	0.81	-0.05
Mean	**109.6**	**62.5**	**0.43**	**676**	**462**	**0.31**	**8095**	**5072**	**0.37**	**24.78**	**22.59**	**0.08**	**0.93**	**0.84**	**0.09**
Grand Mean	**107.5**	**59.3**	**0.45**	**619.4**	**428.5**	**0.29**	**8162**	**5150**	**0.36**	**27.60**	**24.92**	**0.09**	**1.00**	**0.86**	**0.14**

GY: grain yield, :NS number of spike m^{-2}, NG: number of grain m^{-2}, WGS: weight of grains $spike^{-1}$, NGS: number of grain $spike^{-1}$, PH: plant height.

genotypes that suffer less yield loss from irrigated to rainfed conditions also tend to have high yield in stress environments. SSI identified some genotypes such as Köse 220/39, Katea-1 and PL-7 as stress resistant though they did not have outstanding yield performance in stress primarily because of their low potential yield (Table 3). Thus, genotypes with the lowest yield under irrigated conditions exhibited the highest P_i value. This is confirmed by a negative and significant correlation between P_i and yield under non-stress conditions (Table 6). On the other hand, the association between P_i and yield under stress was non significant. Selection based on YSI and P_i value will result in increased yield under irrigated conditions. SSI showed a negative correlation with yield under rain fed conditions, while showed a positive correlation with yield under irrigated conditions (Table 6). YI, YSI, STI, GMP, MP and HM were significantly and positively correlated with stress yield. These indices showed that cultivars may be ranked only on the basis of their yield under stress (Tables 3) and so does not discriminate genotypes of group A. conditions. The mean yield of 12 bread wheat cultivars under rain fed and irrigated conditions were 1.64 and 4.65 t ha^{-1}, respectively (Table 3). For pure lines, mean

Table 5. Resistance indices of 36 bread wheat genotypes (averaged over 2 years)

Genotypes	Yp	Ys	SSI	MP	TOL	STI	GMP	YI	Pi	YSI	b	HM
Cutivars												
Gerek-79	5.26	1.71	1.20	3.48	3.55	0.44	3.00	0.98	0.23	0.33	1.46	2.58
Karahan-99	5.73	1.99	1.16	3.86	3.73	0.49	3.38	1.14	0.09	0.35	1.61	2.96
Bayraktar-2000	5.53	1.87	1.18	3.70	3.67	0.47	3.21	1.07	0.13	0.34	1.55	2.79
Dağdaş-94	4.89	1.50	1.23	3.19	3.39	0.40	2.71	0.86	0.48	0.31	1.44	2.29
Tosunbey	5.20	1.62	1.22	3.41	3.57	0.43	2.90	0.93	0.42	0.31	1.41	2.47
Demir-2000	4.75	1.64	1.17	3.19	3.11	0.40	2.79	0.94	0.60	0.34	1.27	2.43
Bezostaya-1	4.04	1.45	1.14	2.75	2.59	0.35	2.42	0.83	1.12	0.36	1.08	2.13
Konya-2002	4.18	1.66	1.07	2.92	2.52	0.37	2.63	0.95	1.23	0.40	0.98	2.37
Sönmez-2000	4.45	1.64	1.12	3.04	2.81	0.38	2.70	0.94	0.76	0.37	1.25	2.40
Kate-a1	5.01	1.88	1.11	3.45	3.13	0.44	3.07	1.08	0.40	0.38	1.31	2.73
Kıraç-66	4.06	1.63	1.07	2.84	2.44	0.36	2.57	0.93	1.03	0.40	1.07	2.32
Köse 220/39	2.73	1.06	1.09	1.90	1.68	0.24	1.70	0.61	3.19	0.39	0.79	1.52
Pure Lines												
PL-1*	3.95	1.86	0.94	2.91	2.09	0.37	2.71	1.07	1.38	0.47	1.00	2.53
PL-2	3.90	1.76	0.98	2.83	2.15	0.36	2.62	1.01	1.25	0.45	0.95	2.42
PL-3	3.66	1.80	0.90	2.73	1.86	0.35	2.57	1.03	1.68	0.49	0.89	2.42
PL-4	3.97	1.82	0.96	2.89	2.15	0.37	2.69	1.04	1.28	0.46	1.01	2.49
PL-5	4.05	1.71	1.03	2.88	2.35	0.36	2.63	0.98	1.18	0.42	1.06	2.40
PL-6	3.44	1.75	0.87	2.59	1.69	0.33	2.45	1.00	2.10	0.51	0.85	2.32
PL-7	4.71	1.69	1.14	3.20	3.03	0.40	2.82	0.97	0.53	0.36	1.30	2.48
PL-8	3.79	1.70	0.98	2.75	2.09	0.35	2.54	0.98	1.72	0.45	1.02	2.35
PL-9	2.91	1.67	0.76	2.29	1.25	0.29	2.20	0.96	2.74	0.57	0.65	2.12
PL-10	2.91	1.62	0.79	2.26	1.29	0.29	2.17	0.93	2.64	0.56	0.65	2.08
PL-11	3.74	1.80	0.92	2.77	1.94	0.35	2.60	1.04	1.68	0.48	0.95	2.43
PL-12	3.54	1.78	0.88	2.66	1.76	0.34	2.51	1.02	1.87	0.50	0.83	2.37
PL-13	3.54	2.06	0.74	2.80	1.48	0.35	2.70	1.18	2.08	0.58	0.77	2.60
PL-14	3.77	1.89	0.89	2.83	1.88	0.36	2.67	1.08	1.54	0.50	0.88	2.52
PL-15	3.69	1.82	0.90	2.76	1.87	0.35	2.59	1.05	1.55	0.49	0.86	2.44
PL-16	3.82	1.89	0.90	2.85	1.93	0.36	2.68	1.08	1.43	0.49	0.89	2.53
PL-17	3.16	1.65	0.85	2.41	1.51	0.30	2.29	0.95	2.11	0.52	0.67	2.17
PL-18	3.97	2.12	0.83	3.05	1.85	0.38	2.90	1.22	1.20	0.53	0.85	2.77
PL-19	3.70	1.70	0.96	2.70	2.01	0.34	2.51	0.97	1.45	0.46	0.90	2.33
PL-20	3.43	1.82	0.83	2.63	1.61	0.33	2.50	1.04	1.85	0.53	0.78	2.38
PL-21	3.59	1.68	0.95	2.63	1.91	0.33	2.45	0.96	1.66	0.47	0.88	2.29
PL-22	3.74	1.91	0.87	2.82	1.83	0.36	2.67	1.10	1.40	0.51	0.84	2.53
PL-23	3.52	1.92	0.81	2.72	1.60	0.34	2.60	1.10	1.75	0.54	0.77	2.48
PL-24	2.94	1.67	0.77	2.30	1.27	0.29	2.21	0.96	2.36	0.57	0.52	2.13

*: Pure Lines from Turkish bread wheat landraces, YSI: Yield stability index, P_i: Superiority index, YI: Yield index, STI: Stress tolerance index, GMP: Geometric mean productivity, SSI: Stress susceptibility index, MP: Mean productivity, TOL: Stress tolerance, HM: Harmonic mean, b_i: Linear regression coefficient

Table 6. Simple correlation coefficients between resistance indices and traits in irrigated (IR) and non-irrigated (NIR) conditions

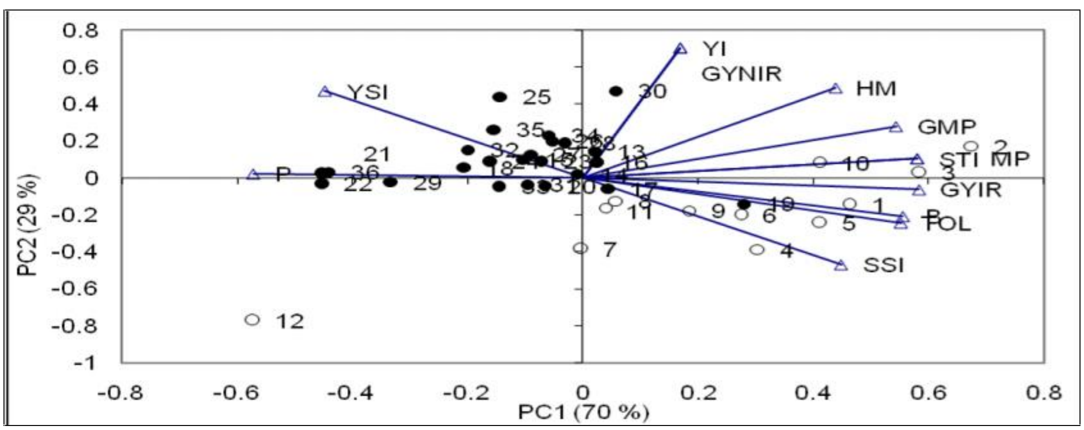
Traits	b_i	YSI	YI	P_i	STI	GMP	SSI	MP	TOL	HM
GY_{IR}	0.95**	-0.81**	0.2	-0.96**	0.97**	0.89**	0.81**	0.97**	0.97**	0.68**
GY_{NIR}	0.03	0.38*	1.00**	-0.25	0.41**	0.63**	-0.39*	0.42**	-0.05	0.85**
PH_{IRR}	-0.1	0.14	0.05	0.1	-0.17	-0.12	-0.15	-0.16	-0.21	-0.05
PH_{NIR}	-0.46**	0.55**	0.29	0.33*	-0.36**	-0.22	-0.56**	-0.35**	-0.53**	-0.02
NS_{IRR}	-0.37**	0.46**	-0.03	0.52**	-0.45**	-0.40*	-0.46**	-0.45**	-0.48**	-0.28
NS_{NIR}	-0.27	0.39*	0.14	0.29	-0.26	-0.18	-0.39*	-0.25	-0.35*	-0.06
NG_{IRR}	0.25	-0.11	0.13	-0.17	0.2	0.2	0.1	0.2	0.15	0.2
NG_{NIR}	0.32	-0.23	0.23	-0.42**	0.40*	0.41**	0.22	0.40*	0.32	0.37*
NGS_{IRR}	0.48**	-0.53**	0.05	-0.58**	0.53**	0.47**	0.53**	0.53**	0.56**	0.34*
NGS_{NIR}	0.46**	-0.51**	0.05	-0.57**	0.52**	0.46**	0.50**	0.52**	0.54**	0.33*
WG_{IRR}	0.25	-0.33*	0.06	-0.38*	0.32*	0.3	0.33*	0.33*	0.33*	0.24
WGS_{NIR}	0	-0.05	0.18	-0.19	0.15	0.18	0.05	0.15	0.07	0.21

*: $P \leq 0.05$, **: $P \leq 0.01$, GY: grain yield, :NS number of spike m^{-2}, NG: number of grain m^{-2}, WGS: weight of grains $spike^{-1}$, NGS: number of grain $spike^{-1}$, PH: plant height.

grain yield under rainfed and irrigated conditions were 1.84 and 3.57 t ha^{-1}, respectively (Table 3). The mean grain yield of cultivars and pure lines was reduced (64% and 48%, respectively) under rainfed conditions (Table 3).

Karahan-99, Bayraktar-2000 and Gerek-79 were the most productive cultivars in irrigated and the least productive one in rainfed conditions. For the pure lines, PL-7 and PL-5 had the highest grain yield in irrigated environment. In rainfed conditions, PL-18 and PL-13 pure lines produced the highest and second highest grain yields of 2.12 t ha^{-1} and 2.06 t ha^{-1}, respectively (Table 3).

As shown in Table 5, the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. A positive correlation between irrigated yield (GY_{IR}) and SSI, TOL and a negative correlation between grain yield of rainfed (GY_{NIR}) and SSI, TOL (Table 6) suggest that selection based on SSI and TOL will result in reduced yield under irrigated conditions. Especially, negative correlation between SSI and GY_{NIR} was expected because genotypes that suffer less yield loss from irrigated to rainfed conditions also tend to have high yield in stress environments. SSI identified some genotypes such as Köse 220/39, Katea-1 and PL-7 as stress resistant though they did not have outstanding yield performance in stress primarily because of their low potential yield (Table 3). Thus, genotypes with the lowest yield under irrigated conditions exhibited the highest P_i value. This is confirmed by a negative and significant correlation between P_i and yield under non-stress conditions (Table 6). On the other hand, the association between P_i and yield under stress was non significant. Selection based on YSI and P_i value will result in increased yield under irrigated conditions. SSI showed a negative correlation with yield under rain fed conditions, while showed a positive correlation with yield under irrigated conditions (Table 6). YI, YSI, STI, GMP, MP and HM were significantly and positively correlated with stress yield. These indices showed that cultivars may be ranked only on the basis of their yield under stress (Tables 3) and so does not discriminate genotypes of group A.



[●: pure lines from landraces (see Table 1 for details), ○: modern bread wheat cultivars (1: Gerek-79, 2: Karahan-99, 3: Bayraktar-2000, 4: Dağdaş-94, 5: Tosunbey, 6: Demir-2000, 7: Bezostaja-1,8: Konya-2002, 9: Sönmez-2000, 10: Katea-1, 11: Kıraç-66, 12: Köse 220/39), ▲: drought tolerance indices]

Figure 1. Biplot based on first two principal component axes (PC1 and 2) both drought indices and bread wheat genotypes.

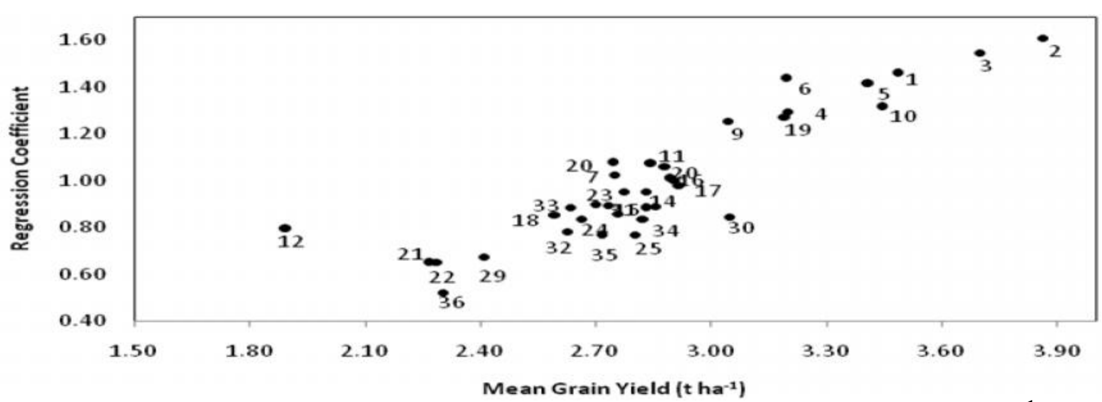


Figure 2. Plot of the variaagnce between the regression coefficients against mean grain yield (t ha^{-1}) for 36 bread wheat genotypes over environments.

DISCUSSION

There is general agreement that modern high yielding wheat cultivars are more adapted to favorable growing conditions, while old cultivars and landraces have more stable yield under drought stress conditions (Ceccarelli and Grando, 1991; Blum, 1996, Mardeh *et al.,* 2006). Ceccarelli (1989) reported a 25– 61% superiority of landraces over modern genotypes under stress conditions and 6–18% superiority of modern genotypes over landraces under non-stress conditions. In the study, it was observed a higher superiority of landraces over modern genotypes under stress conditions with a maximum of 11% and lower superiority of modern genotypes to landraces under non-stress conditions with a maximum of 23% (Table 3).

The poor yielding cultivars/pure lines in the present study were tall, sensitive to lodging, and with low NGS and NG, the desirable traits for rainfed condition but undesirable for irrigated condition (Mardeh *et al*., 2006). The reason for lower grain yield under rainfed condition was mainly due to a reduction in NS and NG. The NG in rainfed condition was lower about 36% than in irrigated condition. The average NS in rainfed and irrigated conditions was 428.5 and 619.4, respectively (Table 4). Several studies indicated that semi dwarf stature is preferred in late season drought condition (Fischer and Maurer, 1978; Richards, 1996; Van Ginkel *et al.,* 1998). Van Ginkel *et al.,* (1998) also found that many NGS was critical to high yield only in irrigated condition and it was negatively correlated with yield under late season drought condition. Also, water deficit occurred from anthesis to maturity, and this usually results in poor assimilation, reduced translocation of photosynthates to the grain and higher respiratory losses (Al-Khatib and Paulsen, 1984; Acevedo, 1990; Shpiler and Blum, 1991). Consequently, the effect of drought stress was manifested in lower number and weight of kernels per spike as in grain yield (Table 4).

Biplot analysis revealed that the first PCA explained 70.0% of the variation with Yp, MP, GMP and STI (Figure 1). Thus, the first dimension can be named as the yield potential and drought tolerance. Considering the high and positive value of this PCA on biplot, selected genotypes will be high yielding under rain-fed and irrigated environments. The second PCA explained 29% of the total variability and had positive correlation with Ys, YI and YSI. Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from non-stress tolerant ones. Thus, selection of genotypes that have high PCA1 and low PCA2 are suitable for both rain-fed and irrigated conditions. Therefore, Karahan-99, Bayraktar-2000, Gerek-79, PL-7, Sönmez-2000, Kıraç-66 and PL-5 are the superior genotypes for both rainfed and irrigated conditions with high PC1 and low PC2. PL-25, PL-13 and PL-23 with high PC2 were more suitable for rain-fed than irrigated conditions.

It was interesting to note positive correlation between SSI and Yp indicating that stress susceptibility was positively correlated with non-stressed yield (Fischer and Wood 1979; Ceccarelli and Grando, 1991). This suggested that some characteristics that contribute to yield potential may act to increase susceptibility to stress and that selection for both SSI and Yp may counteract each other. However, Ehdaie and Shakiba, (1996) in wheat found that there was no correlation between stress susceptibility and yield under optimum environments.

The STI, GMP and MP were used for screening drought tolerant high yielding genotypes in the both conditions (Fernandez, 1992; Mohammadi *et al.,* 2003; Mohammadi *et al.,* 2010). These parameters under level of high to moderate stress were correlated (indicate -ve or +ve) with yield under both conditions (Table 6). For this reason, MP also were reported by Fernandez (1992) who was able to differentiate genotypes belong to A-group (including genotypes with high yield performance in both conditions, from the others (B, C or D groups). MP is related to yield under drought stress if it is not too severe and the difference between YR and YI is not too large. In these cases, genotypes with a high MP would belong to A-group (Mohammadi *et al.,* 2010). When the stress was severe, SSI were found to be more useful indices discriminating resistant genotypes, although none of the indicators could clearly identify cultivars with high yield under both rain-fed and irrigated conditions.

Modern bread wheat cultivars e.g. Karahan-99, Bayraktar-2000, Gerek-79 and Dağdaş-94 had larger b_i values indicating greater sensitivity to environmental change. They were relatively better in favorable environments, but less adapted to low yielding environments than pure lines PL-23 and PL-18. The inability of these cultivars (Karahan-99 and Bayraktar-2000) to maintain yield under poor growing conditions may presumably be because of their lesser ability to tolerate stresses relative to others (Figure 2).

The use of bread wheat landraces has been neglected in bread wheat breeding programmes in Turkey on the basis that they have low-yield potential under irrigated conditions. There is general agreement that modern high-yielding cultivars are more adapted to favourable growing conditions while landraces have usually out yielded the exotic material under low input conditions (Blum, 1988; Ceccarelli and Grando, 1991; Dencic *et al.,* 2000; Akçura, 2011). Ceccarelli *et al*., (1998) claimed that the most effective way to improve the productivity of crops grown in less-favourable areas is to use locally adapted germplasm and select form target environments. The drought conditions are predominant over the years and wet years are infrequent in the Central Anatolian Region of Turkey. Thus, selection should be based on the yield in the target environments as Ceccarelli (1987), Ceccarelli and Grando (1991) and Rathjen (1994) have suggested.

If the strategy of breeding program is to improve yield in a small stress or non-stress environment, it may be possible to explain local adaptation to increase gains from selection conducted directly in that environment (Atlin *et al.,* 2000; Hohls, 2001; Mardeh *et al.,* 2006). The findings of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment. SSI is suggested as useful indicator for wheat breeding, where the stress is severe while MP, GMP, TOL HM and STI are suggested if the stress is less severe.

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