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Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions

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Abstract

The main objective of this research was to evaluate fourteen oat (*Avena sativa* L.) landraces and cultivars for drought tolerance using several indices. The trials were conducted both under rain-fed and irrigated conditions for three growing seasons (2001–2004) in two locations in the Central Anatolian Region of Turkey. Biplot analysis based on the Spearman's rank correlation matrix revealed that the drought indices were significantly inter-correlated with each other and can be classified into four groups. The first group, reflecting stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), linear regression coefficient (b_i), yield index (YI), rain-fed grain yield (Ys) and irrigated grain yield (Yp) appeared to be the relatively high yielding genotypes (G3, G5, G1, G2, G14, G6, G13 and G4) with high drought tolerance. The parameter of superiority index (P_i) in the second group was able to distinguish the landraces G10, G11, G12, G9 and G7 with low adaptability and low drought resistant. The third group included yield stability index (YSI) had a negative correlation with mean grain yield under irrigated conditions referred to drought resistant genotype (G8) with low yielding performance.

Key words: drought, *Avena sativa*, landraces, Turkey, biplot.

Introduction

Oat is widely grown as a rain-fed crop in semi-arid areas of Central Anatolia of Turkey, where large fluctuations occur in the amount and frequency of rainfall events from year to year and among sites within years. Yield trials are conducted in two contrasting environments: non-stress and stress. Plants are commonly considered under stress when they experience a relatively severe shortage of an essential constituent, or an excess of potentially toxic or damaging substances. The field stress environment is characterized primarily by low inputs, suboptimal levels of irrigation, nutrients, temperate, and plant protection measures (Blum, 1988). Selection of genotypes that are adapted to both stress and non-stress environments was the main objective of these yield trials. This approach is more appropriate when the genotypes are usually grown under optimal growing conditions, but periodic biotic and abiotic stress conditions may occur (Fernandez, 1992).

To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions (Clarke et al., 1984; Huang, 2000). Tolerance (TOL) (McCaig, Clarke, 1982; Clarke et al., 1992), mean productivity (MP) (McCaig, Clarke, 1982), stress susceptibility index (SSI) (Fischer, Maurer, 1978), harmonic mean (HM) (Chakherchaman et al., 2009), geometric mean productivity (GMP), and stress tolerance index (STI) (Fernandez, 1992) have all been employed under various conditions.

Fischer and Maurer (1978) explained that genotypes with an SSI of less than a unit are drought resistant, since their yield reduction in drought conditions is smaller than the mean yield reduction of all genotypes (Bruckner, Frohberg, 1987). Bansal and Sinha (1991) evaluated wheat accessions based on the stability in grain yields of various species grown across a range of soil moisture conditions, and concluded that species with a smaller linear regression coefficient (b_i) have a higher drought resistance. The superiority measure (P_i) proposed by Lin and Binns (1988) is another indicator that compares the productivity of genotypes across different environments. The superiority index (P_i) was proposed by Lin and Binns (1988). The P_i compares the productivity of genotypes across environments. This method uses the highest yielding genotype within each environment as the standard. Thence, P_i instantly relates to the agronomic target of identifying genotypes with relatively high yield potential. Cultivars with the largest yield difference than the reference would have the highest P_i value.

The objectives of this study were to (i) identify drought tolerant both oat landraces and cultivars under different conditions in the Central Anatolian Region of Turkey, (ii) determine the efficiency of tolerance indices to classify both oat landraces and cultivars into sensitive and tolerant and (iii) interpret interrelationships among the tolerance indices by biplot analysis.

Materials and methods

Plant materials, experimental layout and cultural practice. This study was carried out with nine oat (*Avena sativa* L.) landraces and five cultivars in 10 environments during 2001–2004, including five rain-fed and five irrigation (50 mm tillering and joining stage) environments, undertaken at the Bahri Dagdas International Agricultural Research Institute (BDIARI) including the locations of Konya (latitude: 37°51′43″ N; longitude: 32°33′31″ E; altitude: 1009 meter above sea level) and Çumra (latitude: 37°34′44″ N; longitude: 32°38′48″ E; altitude: 1024 meter above sea level). Nine of the oat landraces, G6 (Erzurum TR 32787), G7 (Kars TR 32856), G8 (Antalya TR 40707), G9 (Tokat TR 44419), G10 (Ordu TR 44457), G11 (Sivas TR 45320), G12 (Sivas TR 53295), G13 (Ybvd 99-00/7), G14 (Ybvd 99-00/8), were from national Gen Bank of Turkey and five cultivars, G1 (Seydişehir-2004), G2 (Faikbey-2004), G3 (Checota), G4 (Yeşilköy-330) and G5 (Yeşilköy-1779), that are widely grown by Turkish farmers were included as national checks. Experimental layout was a randomized complete blocks design with three replications in five rain-fed and five irrigation (50 mm tillering and joining stage) environments. Sowing was done by an experimental drill in 1.2 x 7 m plots, consisting of six rows with 20 cm spacings.

For irrigated plots, 50 mm of irrigation water were applied twice, at tillering and joining stage. Non-irrigated plots were grown under rain-fed conditions. Sowing was done in October in all experiments. Seed density was 550 seeds m^{-2} under rain-fed conditions and 500 seeds m^{-2} under irrigated conditions (Akçura et al., 2005). The plots were fertilized with 27 kg N ha and 69 kg P_2O_5 ha at planting and 40 kg N ha in spring at the stem elongation. 1.2 x 5 m sized-plots were harvested by a combine harvester.

Screening methods. Drought resistance indices were calculated using the following relationships:

1) yield stability index $(\mathrm{YSI}) = \frac{Ys}{Yp}$ (Bouslama, Schapaugh, 1984),

2) superiority index $(\mathrm{P_i}) = \sum_{j=1}^{n} \frac{(Xij - Mj)^2}{2n}$ (Clarke et al., 1992),

where n is the number of environments, Xij – the grain yield of ith genotype in the jth environment and Mj – the yield of the genotype with maximum yield at environment j;

3) yield index $(\mathrm{YI}) = \frac{Y_s}{\bar{Y}_s}$ (Gavuzzi et al., 1997),

4) stress tolerance index $(\mathrm{STI}) = \frac{Yp + Ys}{\bar{Y} \cdot p^2}$ (Fernandez, 1992),

5) geometric mean productivit (Fernandez, 1992), $(\mathrm{GMP}) = \sqrt{(Yp \times Ys)}$

6) stress susceptibility index $(\mathrm{SSI}) = \frac{1-(\frac{Ys}{Yp})}{1-(\frac{\bar{Ys}}{\bar{Yp}})}$ (Fischer, Maurer, 1978),

7) mean productivity $(\mathrm{MP}) = \frac{Yp + Ys}{2}$ (Hossain et al., 1990),

8) stress tolerance $(\mathrm{TOL}) = Yp - Ys$ (Hossain et al., 1990),

9) harmonic mean $(\mathrm{HM}) = \frac{2(Yp \times Ys)}{(Yp + Ys)}$ (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, Sinha, 1991).

Combined analysis of variance, correlation and biplot analyses were carried out using *SAS*, version 9.0 (SAS/STAT Software, 1999). Combined analysis of variance was used to interpret genotype environment interactions in this study. After analysis of grain yield, ranks were assigned to genotypes for each stability parameter and simple correlation coefficients using Spearman's rank correlation which were calculated on the ranks to measure the relationship between the parameters (Golabadi et al., 2006; Mardeh et al., 2006; Mohammadi et al., 2010). Biplot analysis method was used to classify the screening methods as well as the oat landraces and cultivars (Mohammadi et al., 2010).

Results

Climatological data description. For Konya location, 384.0, 296.0 and 331 mm were received during the growing seasons 2001–2002, 2002–2003 and 2003–2004, respectively and the respective amounts for Çumra station were 373 and 280 mm in 2002–2003 and 2003–2004 growing seasons. Rainfall was not evenly distributed over the various phases of plant development. In 2002–2003, low rainfall from April until mid-June (in Çumra location) and from the second week of March until end of May (in Konya location) affected most developmental phases of the crop with more intense water stress combined with high temperatures experienced during the grain filling period. In the first other growing seasons (2001–2002), the climatic conditions were generally favourable with relatively high precipitation levels during flowering. In Konya during the first growing season, the precipitation was concentrated in November till May (data not given).

Combined ANOVA analysis. The results of combined analysis of variance showed significant genotypic variation for grain yield over years and locations. The ANOVA for each location is presented separately in Table 1, which showed that VE% for year in Konya location was about twenty times more than in Çumra location (20.28 vs. 0.13%). The VE% for drought effect (Dr) at Konya and Çumra was 2.29 and 24.34%, respectively. Year drought interaction (Yr×Dr) in Konya location was five times higher than in Çumra. The VE% for genotype (Gen) main effect in Konya and Çumra locations was 28.71 and 28.15%, respectively. The same relative effects for Yr×Gen, and Gen×Yr×Dr in the both locations were observed (Table 2).

Table 1. Combined analysis of variance for grain yield of 14 oat genotypes over years, and year locations during 2001–2004 growing seasons

Source	Konya				Çumra			
	DF	SS	MS	VE%	DF	SS	MS	VE%
Year (Yr)	2	85.96	42.98**	20.28	1	0.15	0.15	0.13
Rep (Yr)	6	0.80	0.13		4	0.77	0.19	
Drought (Dr)	1	9.72	9.72**	2.29	1	28.18	28.18**	24.34
Yr×Dr	2	81.78	40.89**	19.29	1	4.20	4.20**	3.63
Dr×Rep (Yr)	6	16.19			4	1.29		
Genotype (Gen)	13	121.73	9.36**	28.71	13	32.60	2.51**	28.15
Yr×Gen	26	45.41	1.75**	10.71	13	12.87	0.99**	11.11
Dr×Gen	13	6.23	0.48**	1.47	13	14.44	1.11**	12.47
Yr×Dr×Gen	26	18.28	0.70	4.31	13	6.34	0.49**	5.47
Error	156	423.94	0.25		104	0.15		
Total	251	85.96				115.81		
R^2 (%)		91				87		
CV (%)		16.33				22.57		
Mean (t ha^{-1})		3.02				1.68		

VE% – percentage of explained variance; ** – $P \leq 0.01$

Yield performance of genotypes. Significant differences in grain yield were found among the oat genotypes at Konya and Çumra locations. The main effect of moisture regimes and the interaction between genotype x drought were highly significant for grain yield (Table 1). Grain yield of cultivars varied, particularly under stress conditions, with the locations and years. This variation can be explained, in part, by the fact that grain yields suitable for a given environment with its own weather conditions may be unsuitable in another environment (Austin, 1987; Van Ginkel et al., 1998; Mardeh et al., 2006). In Konya, the highest grain yield was obtained by G3 (Checota) followed by G5 (Y-1779) and G2 (Faikbey-2004) under irrigated conditions, and by G5 (Y-1779) followed by G1 (Seydişehir-2004) and G5 (Y-1779) under rainfed conditions (Table 2). In Çumra, G5 (Y-1779) followed by G2 (Faikbey-2004) and G1 (Seydişehir-2004) gave the best yields under rain-fed conditions, and under irrigated the cultivars of G5 (Y-1779), G4 (Y-330) and G1 (Seydişehir-2004) showed the best performance. The lowest yield was observed in 2002–2003 season at Çumra location (due to the lowest yield of non-irrigated plots) and the highest yield was in 2001–2002 at Konya location (due to highest yield in irrigated plots) (Table 2).

Table 2. Mean grain yield of 14 oat genotypes under rain-fed and irrigation conditions in testing locations and years

Genotypes	2001–2002 Konya			2002–2003 Konya			2002–2003 Çumra			2003–2004 Konya			2003–2004 Çumra		
	Ys	Yp	Yr	Ys	Yp	Yr	Ys	Yp	Yr	Ys	Yp	Yr	Ys	Yp	Yr
Seydişehir-2004	4.40	5.19	0.15	2.73	3.63	0.25	1.367	2.70	0.49	2.23	4.81	0.54	1.72	2.96	0.42
Faikbey-2004	4.54	5.44	0.16	3.03	3.43	0.12	0.900	2.23	0.60	1.95	4.40	0.56	2.32	2.91	0.20
Checota	4.38	6.32	0.31	3.10	3.10	0.00	1.500	2.77	0.46	2.02	4.79	0.58	1.27	3.41	0.63
Yeşilköy-330	3.98	4.27	0.07	2.23	2.77	0.19	1.067	2.40	0.56	1.42	3.80	0.63	1.44	3.07	0.53
Yeşilköy-1779	4.63	5.52	0.16	3.63	3.10	−0.17	1.167	2.43	0.52	1.69	4.27	0.60	1.97	3.37	0.41
Erzurum TR 32787	3.18	3.79	0.16	3.70	2.70	−0.37	1.133	3.17	0.64	1.41	4.10	0.66	1.70	2.07	0.18
Kars TR 32856	2.03	2.42	0.16	2.70	1.80	−0.50	0.833	1.93	0.57	0.98	2.91	0.66	1.24	1.15	−0.07
Antalya TR 40707	3.34	3.48	0.04	2.20	2.67	0.18	0.933	1.47	0.36	1.12	1.06	−0.06	0.54	1.00	0.46
Tokat TR 44419	2.12	3.30	0.36	2.97	2.43	−0.22	0.767	1.50	0.49	1.15	2.89	0.60	1.19	0.96	−0.24
Ordu TR 44457	1.69	2.62	0.35	2.70	2.37	−0.14	0.867	1.90	0.54	0.60	1.65	0.64	1.46	1.40	−0.04
Sivas TR 45320	1.93	3.13	0.38	3.27	2.57	−0.27	1.333	2.13	0.38	1.06	2.57	0.59	0.61	1.08	0.44
Sivas TR 53295	2.28	2.93	0.22	3.53	2.37	−0.49	1.000	2.00	0.50	0.90	2.19	0.59	1.11	1.06	−0.04
Ybvd 99-00/7	3.98	5.42	0.27	3.13	3.17	0.01	1.167	2.57	0.55	1.40	3.24	0.57	0.84	1.76	0.53
Ybvd 99-00/8	4.23	5.29	0.20	3.07	3.33	0.08	1.367	2.60	0.47	2.00	3.56	0.44	1.26	2.37	0.47
Mean	3.34	4.22	0.21	3.00	2.82	−0.07	1.10	2.27	0.52	1.42	3.30	0.57	1.33	2.04	0.35
$LSD_{0.01}$	1.07	1.05		0.86	1.18		NS	0.75		1.10	1.37		1.43	2.19	

Note. Ys – grain yield under rain-fed conditions, Yp – grain yield under irrigated conditions, Yr – grain yield reduction.

The cultivar of G3 (Checota) had the highest mean grain yield across all environments. Grain yields of most of landraces in both rain-fed and irrigated conditions were low. Among landraces G6 (Erzurum TR 32787) and G14 (Ybvd 99-00/8) produced high grain yields both under irrigated and rain-fed conditions (Table 2). Grain yield under irrigated conditions was positively correlated with rain-fed conditions (Fig. 1). Same oat genotypes produced higher grain yield in both, rain-fed and irrigated, conditions, suggesting that a high potential yield under optimum conditions does not necessarily result in improved yield under stress conditions. Thus, indirect selection for a drought-prone environment based on the results of optimum condition will be efficient.

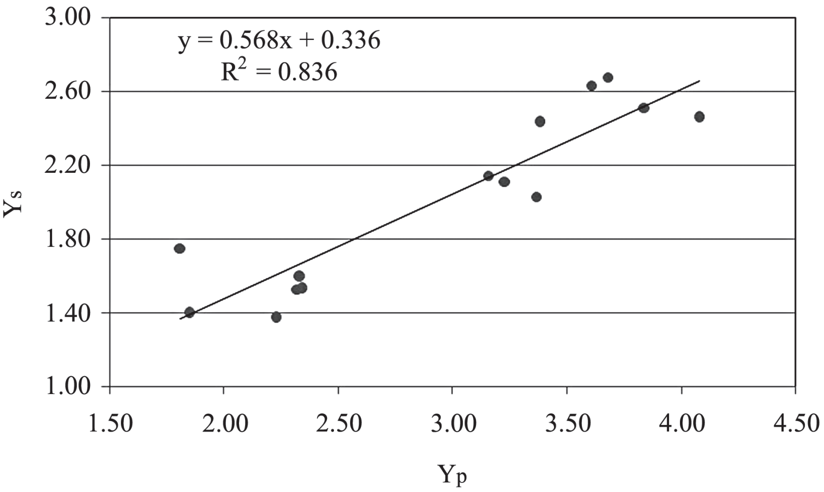


Figure 1. Relationship between rain-fed grain yield (Ys) and irrigated grain yield (Yp) in oat genotypes across environments

Screening procedures. The mean values of screening methods for characterizing drought tolerance and adaptation of genotypes to different environments are presented in Table 3. Using Fernandez's (1992) parameters, STI, the cultivars of G3 (Checota) followed by G1 (Seydişehir-2004), G4 (Yeşilköy-2004) and G2 (Faikbey-2004) with the highest values were considered to be tolerant genotypes, whereas the G10 (Ordu TR 44457) followed by G8 (Antalya TR 40707) and G7 (Kars TR 32856) with the lowest STI were intolerant (Table 3). In case of the parameter TOL, the lowest difference between yields in both conditions (TOL) was observed for the G8 (Antalya TR 40707) followed by G10 (Tokat TR 44419) and G11 (Sivas TR 45320), but the highest difference belonged to the genotypes of G3 (Checota) followed by G6 (Erzurum TR 32787) and G5 (Y-1779). These results indicate that the genotypes with high STI usually have high difference in yield in two different conditions. In general, similar ranks for the genotypes were observed by GMP and MP parameters as well STI, which suggests that these three parameters are equal for selecting genotypes.

Table 3. Mean grain yield and measures of different screening methods for 14 oat genotypes

Genotypes	Code	Yp	Ys	Yr	SSI	MP	TOL	STI	GMP	YI	P_i	YSI	b_i	HM
Seydişehir-2004	G1	3.68	2.67	0.27	0.86	3.18	1.01	0.73	3.14	1.33	0.15	0.73	1.18	3.1
Faikbey-2004	G2	3.61	2.63	0.27	0.85	3.12	0.98	0.72	3.08	1.31	0.15	0.73	1.26	3.04
Checota	G3	4.08	2.46	0.4	1.25	3.27	1.62	0.75	3.16	1.22	0.1	0.6	1.42	3.07
Yeşilköy-330	G4	3.16	2.14	0.32	1.02	2.65	1.02	0.61	2.6	1.06	0.54	0.68	0.99	2.55
Yeşilköy-1779	G5	3.84	2.51	0.35	1.09	3.18	1.33	0.73	3.1	1.25	0.12	0.65	1.29	3.04
Erzurum TR 32787	G6	3.37	2.03	0.4	1.25	2.7	1.34	0.62	2.61	1.01	0.64	0.6	0.94	2.53
Kars TR 32856	G7	2.23	1.37	0.38	1.21	1.8	0.86	0.41	1.75	0.68	1.98	0.62	0.62	1.7
Antalya TR 40707	G8	1.81	1.75	0.03	0.1	1.78	0.06	0.41	1.78	0.87	2.07	0.97	0.82	1.78
Tokat TR 44419	G9	2.32	1.53	0.34	1.08	1.93	0.8	0.44	1.88	0.76	1.64	0.66	0.84	1.84
Ordu TR 44457	G10	1.85	1.4	0.25	0.77	1.62	0.45	0.37	1.61	0.69	2.47	0.75	0.59	1.59
Sivas TR 45320	G11	2.33	1.59	0.32	1.00	1.96	0.74	0.45	1.93	0.79	1.79	0.68	0.73	1.89
Sivas TR 53295	G12	2.34	1.53	0.35	1.09	1.94	0.81	0.45	1.89	0.76	1.79	0.65	0.74	1.85
Ybvd 99-00/7	G13	3.23	2.11	0.35	1.09	2.67	1.12	0.62	2.61	1.05	0.51	0.65	1.35	2.55
Ybvd 99-00/8	G14	3.38	2.43	0.28	0.89	2.91	0.95	0.67	2.87	1.21	0.29	0.72	1.21	2.83
Mean		2.95	2.01	0.31	0.97	2.48	0.94	0.57	2.43	1.00	1.02	0.69	1.00	2.38

Note. SSI – stress susceptibility index, MP – mean productivity, TOL – stress tolerance, STI – stress tolerance index, GMP – geometric mean productivity, YI – yield index, P_i – superiority index, YSI – yield stability index, b_i – linear regression coefficient, HM – harmonic mean.

According to Fischer and Maurer's (1978) parameter, SSI, the genotypes G8 (Antalya TR 40707) followed by, G10 (Ordu TR 44457, G2 (Faikbey-2004), G1 (Seydişehir-2004) had the lowest values, which were considered as genotypes with low drought susceptibility and high yield stability in the both conditions, whereas the genotypes of G3 (Checota) followed by G6 (Erzurum TR 32787), G13 (Ybvd 99-00/7) and G5 (Y-1779) with SSI values higher than unit can be identified as high drought susceptibility and poor yield stability genotypes (Table 3). In the case of comparison between the parameters for selection of the genotypes, the TOL and SSI gave similar results.

The regression coefficients for the fourteen genotypes ranged from 0.59 (G10) to 1.42 (G3). Corresponding to Bansal and Sinha's (1991) method, the genotypes of G10 followed by G7, G11 and G12 with the lowest regression coefficient had the highest drought resistance and the genotypes of G3 followed by G13, G5, and G2 with the highest value were considered as drought non-tolerant genotypes (Fig. 2).

In keeping with Lin and Binns's (1988) parameter (P_i), the genotypes of G3 followed by G5, G2 and G1 with low P_i values indicated high relative stability and these genotypes also had high grain yield performance. In relation to this method, the genotypes G10, G8, G7, G11 and G12 with high P_i values showed low relative stability (Table 3).

Interrelationships among screening methods. Spearman's rank correlation coefficients between grain yield (Yp and Ys) and most of screening methods were significant whereas the both HM and TOL showed high rank correlation with the all methods ($P < 0.01$; Table 4). The means of genotype yield in both conditions were correlated to all screening methods except YSI ($P < 0.01$). The methods of STI, GMP, MP, HM, YI, and b_i were highly correlated ($P < 0.01$), which indicated that one of these methods could be used as an alternative for the others in evaluation of oat genotypes. The parameters of TOL and SSI had significantly positive correlation with each other ($P < 0.01$), but had significantly negative correlation with the YSI, SSI and TOL ($P < 0.01$). In line of P_i, the genotypes with the highest yield under both stress and non stress conditions exhibited the lowest P_i value. This is shown by the significantly negative correlation between P_i and yield under rain-fed and irrigated conditions ($P < 0.01$).

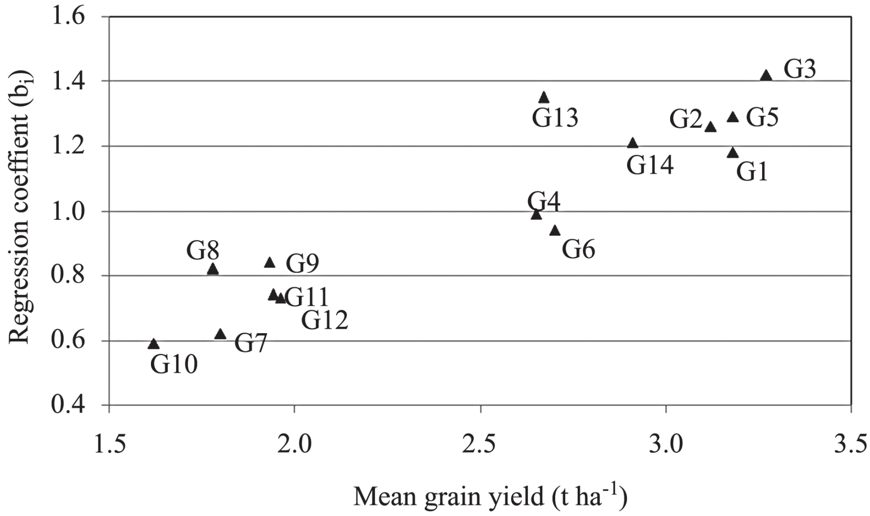


Figure 2. Plot of the variance between the regression coefficients against mean grain yield for 14 oat genotypes over environments

Table 4. Spearman's rank correlation between screening methods and grain yield

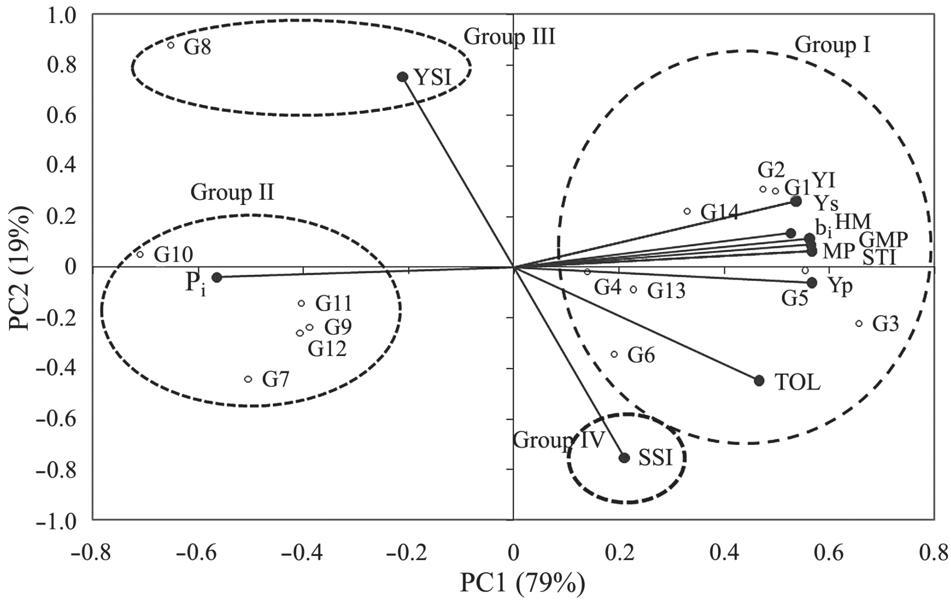
	Yp	Ys	SSI	MP	TOL	STI	GMP	YI	P_i	YSI	b_i
Ys	0.86**										
SSI	0.34	−0.10									
MP	0.99**	0.89**	0.30								
TOL	0.83**	0.62*	0.66**	0.81**							
STI	0.99**	0.91**	0.28	1.00**	0.81**						
GMP	0.98**	0.92**	0.23	0.99**	0.78**	1.00**					
YI	0.86**	1.00**	−0.10	0.89**	0.62*	0.91**	0.92**				
P_i	−0.97**	−0.89**	−0.28	−0.97**	−0.80**	−0.97**	−0.97**	−0.89**			
YSI	−0.33	0.11	−1.00**	−0.30	−0.64**	−0.27	−0.23	0.11	0.27		
b_i	0.85**	0.83**	0.26	0.85**	0.78**	0.88**	0.87**	0.83**	−0.92**	−0.25	
HM	0.95**	0.95**	0.13	0.97**	0.73**	0.98**	0.98**	0.95**	−0.96**	−0.12	0.86**

Note. SSI – stress susceptibility index, MP – mean productivity, TOL – stress tolerance, STI – stress tolerance index, GMP – geometric mean productivity, YI – yield index, P_i – superiority index, YSI – yield stability index, b_i – linear regression coefficient, HM – harmonic mean; ** – $P \leq 0.01$.

Biplot analysis was used to explain the relationship between grain yield and drought indices. The first two PCs of ranks the methods accounted for 98% of the variance of the original variables. The PC1 vs. PC2 are illustrated in Figure 3. When both axes were considered simultaneously, four groups were identified: where group I includes the methods of STI, MP, GMP, HM, b_i, YI and TOL, SSI classified in the group II, YSI classified in group III, P_i classified group IV.

The PC1 separated two contrasting groups of methods (groups I, II and III, IV), which in group I, the parameters are strongly correlated with yield under irrigated and rain-fed conditions, whereas the parameters in group I have significantly negative correlation with P_i and YSI. Therefore, suitable genotypes according to the methods in group I are recommended for regions where growing conditions are favourable and for the parameters in first group vice versa.

The biplot analysis was also performed for the ranks of genotypes obtained from different screening methods (Fig. 3). In biplot, the PCs axes divided the genotypes into three groups; where group I included the genotypes of G6, G4, G13, G5, G3, G1, G2 and G14 with good performance and high drought tolerance. The genotypes of G10, G11, G9, G12, G7 and G10 in group II with low performance were stable and low sensitive to drought. Group III consisted of the G8 with low-to moderate-yielding performance and had relatively low sensitivity/resistance to drought stress.



Note. Details of oat genotypes and screening methods are given in Table 3.

Figure 3. Biplot based on first two principal component axes (PC1 and PC2) for 14 oat genotypes across testing screening methods

Discussion

There is general agreement that modern high yielding oat cultivars (often with short stature) are more adapted to favourable growing conditions, while old cultivars and landraces have more stable yield under drought stress conditions. This view is supported by our experiment, as the average yield of cultivars grown under irrigated conditions was almost double that of landraces under the same conditions (Table 3). The poor yielding cultivars/landraces in the present study were tall, sensitive to lodging, the desirable traits for rain-fed condition but undesirable for irrigated condition. The reason for lower grain yield under rain fed conditions was mainly due to a reduction in some grain yield components.

The parameters of STI, GMP, MP, YI, HM b_i and P_i were able to identify high yielding oat genotypes in both rain-fed and irrigated conditions. Similarly, The STI, GMP and MP were used in different plants for screening drought tolerant high yielding genotypes in the both conditions (Fernandez, 1992; Mohammadi et al., 2003). These three parameters under level of moderate stress were correlated with yield under both conditions (Table 4). 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). For this reason, MP also like the GMP and STI as were reported by Fernandez (1992) was able to differentiate genotypes belonging to A-group (Fernandez, 1992), including genotypes with high yield performance in both conditions, from the others (B, C or D groups). As described by Hohls (2001), MP cannot select high yielding genotypes in both stressed and non-stressed environments, if it correlates highly negatively with grain yield in contrasting environments. MP is related to yield under drought stress if it is not too severe and the difference between Ys and Yp is not too large. In these cases, genotypes with a high MP would belong to A-group. At the present study, G3 (Checota) followed by G5 (Y-1179) and G1 (Seydişehir-2004) with high yields under both conditions, exhibited also the highest MP values. This result is in agreement with Hossain et al. (1990) that used MP as a criterion for selecting wheat genotypes adapted to moderate stress conditions. The results showed that the smaller TOL value, the lower is the grain yield reduction under rain-fed conditions and consequently lower drought sensitivity. A significantly positive correlation was found between TOL and grain yield both conditions (Yp and Ys) ($P < 0.01$).

The linear regression of genotype yield in each environment on the mean genotype yield over ten environments was shown in Figure 2. When this is associated with high mean yield, genotypes have general adaptability and when associated with low mean yield, genotypes are poorly adapted to all environments. Regression values above 1.0 describe genotypes with higher sensitivity to environmental change (below average stability), and greater specificity of adaptability to high yielding environments. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change (above average stability), and therefore increasing specificity of adaptability to low yielding environments. Thus, oat genotypes, e.g. G3 (Checota), G13 (Ybvd 99-00/7) and G2 (Faikbey-2004) had larger b_i values indicating greater sensitivity to environmental change. They were relatively better in favourable (irrigated) environments, but less well adapted to low yielding environments than landraces G6 (Erzurum TR 32787) and cultivar G4 (Y-330). The inability of these cultivars (Checota and Faikbey-2004) to maintain yield under poor growing conditions may presumably be because of their lesser ability to tolerate stresses relative to others (Fig. 2).

To better understand the relationships among screening methods and to separate drought resistant genotypes from others, biplot analysis based on the rank correlation matrix was performed in two subjects of screening methods and genotypes. Biplot analysis revealed that the first PCA explained 79% of the variation with Yp, Ys, MP, GMP, STI, HM, b_i and YI (Fig. 3). 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 19% of the total variability and had positive correlation with YSI. Therefore the second component can be named as a drought-tolerant dimension and it separates the stress-tolerant genotypes from non-drought tolerant ones. Thus, selection of genotypes that have high PCA1 and low PCA2 is suitable for both rain-fed and irrigated conditions (Kaya et al., 2006). Using STI, GMP, MP, STI, b_i and HM, the genotypes G3 (Checota) followed by G5 (Y-1779), and G14 (Ybvd 99-00/8) were found for rain-fed and irrigated conditions with high PC1 and low PC2. The genotypes G8 (Antalya TR 40707), G1 (Seydişehir-2004) and G2 (Faikbey-2004) with high PC2 are more suitable for rain-fed than irrigated conditions. Also, using SSI and TOL, the genotypes G6 (Erzurum TR 32787) with low PC2 were found to be the least susceptible to drought and difference in yields in both conditions.

The use of oat landraces has been neglected in oat 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; they outyield local landraces under good management practices and well watered conditions, while landraces have usually outyielded the exotic material under low input conditions (Blum, 1988; Ceccarelli, Grando, 1991; Dencic et al., 2000; El Madidi et al., 2005; 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 from 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) have suggested. In the present study, two landraces of G14 (Ybvd 99-00/8) and G6 (Erzurum TR 32787) had high grain yield under both rain-fed and irrigation conditions compared with other oat landraces. Significant breeding progress and yield gains are evident when comparing the promising oat landraces with the checks Checota, Seydişehir-2004 and Y-1779. If the strategy of breeding program is to improve yield in a stressed and non-stressed environments, it may be possible to focus on local adaptation to increase gains from selection conducted directly in that environment (Atlin et al., 2000; Hohls, 2001). However, selection should be based on the resistance indices calculated from the yield under both conditions, when the breeder is looking for the genotypes adapted for a wide range of environments or location with unpredictable conditions.

Conclusions

1. The parameters stress tolerance index (STI), geometric mean productivity (GMP), mean productivity (MP), superiority index (P_i), linear regression coefficient (b_i), yield index (YI) and harmonic mean (HM) can be suggested to select drought tolerant genotypes with high yield performance under dry and irrigated conditions.

2. The methods of yield stability index (YSI) can be also used as useful indicators to distinguish sensitive/resistant genotypes, where the stress is severe.

3. The results showed that the smaller stress tolerance (TOL) value, the lower is the grain yield reduction under rain-fed conditions and consequently lower drought sensitivity.

4. Among cultivars G3 (Checota) had the highest mean grain yield across all environments.

5. Among landraces G6 (Erzurum TR 32787) and G14 (Ybvd 99-00/8) produced high grain yields under both irrigated and rain-fed conditions.

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Sėjamosios avižos (*Avena sativa* L.) turkiškų vietinių veislių atsparumo sausrai rodiklių įvertinimas atrankai įvairiomis aplinkos sąlygomis

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Santrauka

Tyrimų tikslas – įvertinti sėjamosios avižos (*Avena sativa* L.) keturiolikos vietinių veislių atsparumą sausrai pagal keletą rodiklių. Bandymai vykdyti natūralaus lietaus ir lietinimo sąlygomis tris vegetacijos sezonus (2001–2004 m.) dviejose vietovėse Turkijos centriniame Anatolijos regione. *Biplot* analizė, paremta Spearmano rangų koreliacijos matrica, atskleidė, kad sausros rodikliai esmingai koreliuoja ir gali būti suskirstyti į keturias grupes. Pirmai grupei būdinga tolerancijos stresui indeksas (STI), vidutinis produktyvumas (MP), geometrinis vidutinis produktyvumas (GMP), harmoninis vidurkis (HM), tiesinės regresijos koeficientas (b_i), derliaus indeksas (YI), grūdų derlius lietaus sąlygomis (Ys) ir grūdų derlius lietinimo sąlygomis (Yp). Tai leido nustatyti gana didelio derlingumo genotipus (G3, G5, G1, G2, G14, G6, G13 bei G4), pasižyminčius dideliu atsparumu sausrai. Į antrą grupę pagal pranašumo indekso (P_i) rodiklį išskirtos vietinės veislės G10, G11, G12, G9 bei G7, pasižyminčios mažu prisitaikymu ir mažu atsparumu sausrai. Trečia grupė, kurioje nustatyta neigiama koreliacija su vidutiniu grūdų derliumi drėkinimo sąlygomis, apėmė derliaus stabilumo indeksą (YSI), kuris leido nustatyti sausrai atsparų genotipą (G8), pasižymintį mažu grūdų derliumi.

Reikšminiai žodžiai: sausra, *Avena sativa*, vietinės veislės, Turkija, *biplot* analizė.