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Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions

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Abstract

The main objective of this research was to evaluate fifteen durum wheat (*Triticum durum*) genotypes selected from joint project of Iran/ICARDA for drought tolerance using several indices. The trials were conducted under moderate levels of drought stress for three cropping seasons (2004-2006) in four locations in the highlands western of Iran. The combined ANOVA for grain yield over years and locations indicated significant differences among main effects (genotypes, years, locations) and their interactions. Principal component (PC) analysis based on the Spearman's rank correlation matrix revealed that the screening methods were significantly inter-correlated with each other and can be classified into three groups; The first group included stress susceptible index (SSI), tolerance index (TOL) and yield stability index (YSI) where had significantly negative correlation with mean grain yield under supplemental irrigation condition and were able to identify drought resistant genotypes with low yielding performance. The second group reflects the drought tolerance indices including stress tolerance index (STI), geometric mean productivity (GMP), mean productivity (MP) and superiority index (Pi) which were appear to identify the high yielding semi-dwarf genotypes (G6, G4 and G3) with high drought tolerance. The parameters of relative adaptability to drought (*b*N), regression intercept (*a*) and regression coefficient (*b*) are in third group which were able to distinguish the genotypes G6, G5 and G10 with high adaptability and relative drought resistant. The final conclusion of this study is to reveal that not only genotypes but also screening methods can be classified into distinct groups considering different concepts of drought tolerance, resistance and susceptibility under mild drought stress.

Keywords: Durum wheat; Mild drought; Principal component analysis; Rank correlation; Screening methods

Introduction

Durum wheat (*Triticum durum*) is grown on 10% of the world wheat areas. More than 11 million ha of durum wheat is grown in the Mediterranean basin under rainfall and temperatures conditions showing for their large and unpredictable fluctuations over years

(Nachit et al., 1998). 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 rain-fed conditions. There is some agreement that a high yield potential is advantageous under mild stress, while genotypes with low yielding potential and high drought tolerance may be useful when stress is severe (Voltas et al., 1999; Panthuwan et al., 2002). Several researchers have chosen the mid-way and believe in selection under both favorable and stress conditions (Fischer and Maurer, 1978; Fernandez, 1992; Clarke et al., 1992; Rajaram and Van Ginkel, 2001). Several indices have been proposed to describe the behavior of a given genotype under stress and non-stress conditions (Fisher and Maurer, 1978; Roseille and Hamblin, 1981; Bouslama and Schaupaugh, 1984; Lin and Binns, 1988; Bansal and Sinha, 1991; Fernandez, 1992; Clarke et al., 1992; Rajaram and Van Ginkle, 2001). Fischer and Maurer (1978) proposed the stress susceptibility index (SSI) (yield of a genotype under stress as a function of the yield without stress). Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the difference in yield between the stress and non-stress environments, and mean productivity (MP) as the average yield in both environments. Lin and Binns (1988) used the "superiority index" (Pi) (the mean square of the distance of the yield of a genotype from the maximum yield of all genotypes at a given location) as estimates of genotype adaptability over a range of environments. Fernandez (1992) also has been suggested a stress tolerance index (STI) and Bansal and Sinha (1991) used linear regression coefficient (*bi*) as a criteria for selection of drought resistant genotypes. Karamanos and Papatheohari (1999) used a new index of relative adaptability to drought (bN). However, the objectives of this study were to (i) identify drought resistant/tolerant durum wheat genotype under mild stress in the highlands of western Iran, (ii) determine the efficiency of screening methods to classify genotypes into resistant/sensitive and tolerant and (iii) study interrelationships among the screening methods.

Materials and Methods

Plant Materials, experimental lay out and cultural practice

This study was carried out with 13 durum advanced genotypes along two national checks in 12 environments during 2004-2006, including six rainfed and six supplemental irrigation (50 mm after flowering) environments, undertaken at the Dryland Agricultural Research Institute (DARI) including the stations of Sararood (Kermanshah province) and Zanjireh (Ilam province). Six of the 13 advanced genotypes, G1 (Omgenil-3), G2 (Omrabi-5), G3 (Syrian-4), G6 (Mrb3/Mna-1), G5 (Waha) and G6 (Mna-1/Rfm-7), were from the international durum improvement program based on a joint project between Iran and ICARDA and seven genotypes, G7 (9A-Kor8081), G8 (12A-Mar8081), G9 (14A-Mar8081), G10 (15A-Mar8081), G11 (18A-Mar8081), G12 (19A-Mar8081), G13 (20A-Mar8081), were from the national durum improvement program. Two cultivars, G14 (Zardak as durum wheat) and G15 (Sardari as bread wheat), that are typically grown by Iranian farmers were included as national checks. Experimental layout was a randomized complete blocks design with three replications in each environment. Sowing was done by an experimental drill in 1.2 m x 6 m plots, consisting of six rows with 20 cm apart. Seeding rate was 350 seeds m^{-2} and was 10% higher than the target density for each location. Fertilizer application was 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} at planting according to the provincial soil test recommendations before sowing. Yield (kg ha^{-1}) was obtained by converting of plot yields.

Screening Methods

Stability in grain yield was estimated for each genotype using the stress susceptibility index (SSI) derived from the yield difference between stressed and non-stressed environments (Fischer and Maurer, 1978). The SSI estimates for each genotype the rate of change in yield between the stressed and non-stressed conditions relative to the mean change for all genotypes. Values of SSI lower than 1 denote low drought susceptibility (or higher yield stability) and values higher than 1 indicate high drought susceptibility (or poor yield stability). Mean productivity (MP) proposed by Rosielle and Hamblin (1981) as mean production under both stressed and non-stressed conditions was also employed to more description of the response of the genotypes. Tolerance index (TOL) as defined by Rosielle and Hamblin (1981) as the difference in yield between grain yield in the both stressed and non-stressed conditions was used to select drought tolerant genotypes, where the genotypes with low TOL value would be more stable in variable conditions (favorable and unfavorable environments). The superiority index (Pi) as suggested by Lin and Binns (1998) was used to measure stability of genotypes in different environments. The Pi was defined as the distance mean square between the cultivar’s response and the maximum response over environments (Lin and Binns, 1988). A low value of Pi indicates high relative stability.

Yield stability index (YSI) also was computed as suggested by Bouslama and Schapaugh (1984). This parameter is calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions. The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions.

The parameters of stress tolerance index (STI) and geometric mean productivity (GMP) also were calculated as proposed by Fernandez (1992) to estimate drought tolerance. The genotypes with high values of these parameters can be selected as drought tolerant genotypes.

Bansal and Sinha (1991) proposed the linear regression coefficient (*b*) of grain yield of a genotype in each environment on the environmental index (EI) (mean yield of all genotypes at each environment) as a drought resistance index. They concluded that the genotypes with a smaller linear regression coefficient (*b*) have a higher drought resistance. Relative adaptability to drought (bN) which defined by Karamanos and Papatheohari (1999) is calculated by dividing the slope (*b*) by the intercept (*a*) of regression model. Where bN could be named "relative adaptability" to drought. The bN will take its lowest values for a desirable genotype (i.e., exhibiting high *a* and low *b*) and its highest ones for the most undesirable genotypes (low *a* and high *b*).

Combined analysis of variance was used to interpreting 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. Principal component (PC) analysis method was used to classify the screening methods as well as the genotypes. All statistical analyses were carried out using SPSS software version 13.0 (SPSS, 2004).

Results

Climatological data description

The total mean rainfall during the three years in Sararood (Latitude: 34°19´ N; Longitude: 47°17´ E; Altitude: 1351 meter above sea level (MASL)) and Zanjireh (Latitude: 33°38' N; Longitude: 46°26' E; Altitude: 973 MASL) stations was 508 and 575 mm, respectively. These amounts were higher than the long-term rainfall for Sararood and Zanjireh (458 and 550 mm, respectively). For Sararood station, 573.1, 405.2 and 502 mm were received during the growing seasons 2003-04, 2004-05 and 2005-06, respectively and the respective amounts for Zanjireh station were 572, 520 and 582 mm. Rainfall was not evenly distributed over the various phases of plant development. In 2004-05, low rainfall from April until mid-June (in Sararood station) and from the second March until end May (in Zanjireh station) affected most developmental phases of the crop with more intense water stress combined with high temperatures experienced during the grain filling period. In the two other growing seasons (2003-04 and 2005-06), the climatic conditions were generally favorable with relatively high precipitation levels during flowering. In both stations and during the three growing seasons, the precipitation was concentrated in November till March. Precipitation was low in March to June and was accompanied with relatively high temperatures. In all three cropping seasons, high temperatures between 30-40 °C (Sararood station) and 35-45 °C (Zanjireh station) were frequent during grain filling and maturity periods.

Combined ANOVA analysis

The results of combined analysis of variance showed significant genotypic variation for grain yield over years and locations. The magnitude of variation attributable to the years (Y), locations (L) and genotypes (G), estimated as a percentage of variance explained (VE %) of total sum of squares (SS) was 16.9, 36.1 and 2.8%, respectively (Table 1). Highly significant interactions for Genotype×Year (GY) and Genotype×Location (GL) were also observed. The VE% for the Genotype×Year×Location (GYL) (6.4%) was higher than GL (5.1%) and GY (3.4%). The ANOVA for each station is also presented separately in Table 1, which showed that VE% for year in Sararood station was about three times more than in Zanjireh station (30.3 vs. 9.2%). The VE % for location effect (L) at Sararood and Zanjireh was 27.4 and 41.8%, respectively. YL interaction in Zanjireh station was three times more than in Sararood. The VE% for genotype main effect in Sararood and Zanjireh stations was 4.0 and 6.8%, respectively. The same relative effects for GY, GL and GYL in the both stations were observed (Table 1).

Table1. Combined analysis of variance for grain yield of 15 genotypes over years, and over year-locations during 2004-2006 growing seasons.

Source of variations	Across locations and years				Across years at Sararood location				Across years at Zanjireh location		
	df	SS	F	VE%	df	SS	F	VE%	SS	F	VE%
Year(Y)	2	56067900.18	155.78^{**}	16.87	2	43017723.76	136.89^{**}	30.26	17259699.25	42.55^{**}	9.20
Location(L)	3	119866311.3	222.03^{**}	36.07	1	38913555.57	247.67	27.37	78530169.52	387.24^{**}	41.84
YL	6	28703419.73	26.58^{**}	8.64	2	4872564.896	15.51^{**}	3.43	19621332.01	48.38^{**}	10.45
Error-1	24	8327277.644	-	2.51	12	5634797.111	-	3.96	2692480.533	-	1.43
Genotype(G)	14	9457645.193	3.75^{**}	2.85	14	5673452.111	2.58^{**}	3.99	12692929.83	4.47^{**}	6.76
GY	28	11375983.54	2.26^{**}	3.42	28	9515710.8	2.16^{**}	6.69	13442693.19	2.37^{**}	7.16
GL	42	16897345.83	2.24^{**}	5.09	14	4172134.319	1.89^{*}	2.93	3816474.763	1.34^{ns}	2.03
GYL	84	21120054.55	1.40^{*}	6.36	28	3961968.548	0.90^{ns}	2.79	5575665.548	0.98^{ns}	2.97
Error-2	336	60465209.02	-	18.20	168	26395855.56	-	18.57	34069353.47	-	18.15
Total	539	332281147	-		269	142157762.7	-	-	187700798.1	-	-

*,**significant at 5% and 1% levels, respectively; ns, non-significant; VE%: Percentage of explained variance.

Yield performance of genotypes

Significant differences in grain yield were found among the genotypes at both Sararood and Zanjireh stations. In Sararood, the highest grain yield was obtained by G15 followed by G7 and G3 under rain-fed conditions, and by G3 followed by G6 and G5 under supplemental irrigation conditions (Table 2). In Zanjireh, G6 followed by G10 and G13 gave the best yields under rainfed conditions, and under supplemental irrigation the lines of G10, G6 and G3 showed the best performance. The lowest yield was observed in 2003-04 season at Sararood station (due to the lowest yield of non-irrigated plots) and the highest yield was in 2005-06 at Sararood Station (due to highest yield in irrigated plots) (Table 2).

Grain yield of genotypes showed greater variation, particularly under non-stressed than stressed conditions (Table 2). This variation can be explained, in part, by the fact that traits which are suitable for a given environment with its own whether conditions may be unsuitable in another environment (Austin, 1987; Van Ginkel et al., 1998). The genotype of G6 had the highest mean grain yield across all environments. The genotypes of G13 and G15 produced high grain yield under stressed and low yields under non-stressed conditions. Grain yields of G8 and G12 in both rainfed and irrigated conditions were low. The lines of G3 and G5 produced high grain yields under non-stressed and low yields under stressed conditions (Table 2). Grain yield under stressed condition (YR) was positively but not significantly correlated with grain yield under irrigated conditions (YI) (r=0.39) (Table 4). Similar results were reported by Fernandez (1992) that found non-significant correlation (r=0.46) between yields under both conditions for mild stress, suggesting that a high grain yield under irrigated condition dose not necessarily result in improved yield under stressed condition. Thus, indirect selection for a drought prone environment based on the results of irrigated condition will not be efficient. However, in this study, the values of sensitivity index (SI) ranged from 0.14 to 0.52 in different environments, which indicating presence of drought stress in low and moderate levels (Fernandez, 1992).

Table 2. Mean grain yield of 15 durum wheat genotypes under rainfed and supplemental irrigation conditions in testing locations and years.

Genotypes	2004						2005						2006					
	Sararood station			Zanjireh station			Sararood station			Zanjireh station			Sararood station			Zanjireh station		
	YR[a]	YI	Y.R (%)[b]	YR	YI	Y.R (%)	YR	YI	Y.R (%)	YR	YI	Y.R (%)	YR	YI	Y.R (%)	YR	YI	Y.R (%)
G1	2231	3646	38.8	1781	3091	42.4	2665	3308	19.5	2058	2850	27.8	2951	3846	23.3	2726	3332	18.2
G2	2244	2912	22.9	1686	3693	54.3	2701	2858	5.5	2304	3758	38.7	2886	3926	26.5	2776	3627	23.4
G3	2165	3462	37.5	1525	3690	58.7	2724	3864	29.5	2642	3617	27.0	3560	4265	16.5	2296	3762	39.0
G4	1794	3311	45.8	1408	3762	62.6	3030	3187	4.9	2775	3800	27.0	3474	4048	14.2	3159	3723	15.2
G5	2186	3151	30.6	1478	3661	59.6	2599	3971	34.6	2075	3308	37.3	3247	4090	20.6	3338	4014	16.8
G6	2130	3891	45.3	1944	3772	48.4	1673	3179	47.4	3192	4036	20.9	3679	4343	15.3	3508	3709	5.4
G7	1940	3023	35.8	1469	3352	56.2	3144	3250	3.3	2950	3867	23.7	3388	3633	6.7	2267	2836	20.1
G8	1851	2618	29.3	1267	3086	59.0	2819	2982	5.5	2334	3358	30.5	2956	3398	13.0	3306	2813	-17.5
G9	1990	2810	29.2	2044	3322	38.5	2920	2977	1.9	2446	3346	26.9	3513	3786	7.2	2737	3298	17.0
G10	2029	3174	36.1	2105	3973	47.0	2744	3087	11.1	2629	4671	43.7	2840	3611	21.4	3315	3275	-1.2
G11	1885	3099	39.2	1525	3179	52.0	2871	4023	28.6	2763	3433	19.5	3420	3786	9.7	2334	2924	20.2
G12	1850	2893	36.1	1719	3158	45.6	2722	3475	21.7	2675	3446	22.4	3288	3566	7.8	2572	2870	10.4
G13	1945	3001	35.2	2117	3639	41.8	2822	3435	17.8	2258	3163	28.6	3207	3509	8.6	3632	4116	11.7
G14	1654	2769	40.3	1755	3328	47.3	3023	3464	12.7	2417	3625	33.3	3244	3491	7.1	2898	3032	4.4
G15	2013	3208	37.2	1494	3219	53.6	3236	3657	11.5	2696	2958	8.9	3401	3837	11.4	3043	3479	12.5
Mean	1994	3131	36.3	1688	3462	51.2	2779	3381	17.8	2548	3549	28.2	3270	3809	14.1	2927	3387	13.6
SI[c]	0.36			0.52			0.18			0.28			0.14			0.14		
LSD[d](5%)	458.7	681.3		605.1	639.6		564.3	991.7		708.0	666.0		405.5	531.9		657	760	
LSD(1%)	618.9	918.8		808.9	862.8		761.1	1337.7		946.0	890.0		547	717.5		878	1016	
C.V%[e]	13.8	12.9		23.47	11.1		12.2	19.86		20.1	13.5		7.41	8.35		16.30	13.95	

[a]YR: yield under rain-fed condition and YI: yield under supplemental irrigation.
[b]percentage of yield reduction under non-stress condition.
[c]Sensitivity index (Fisher and Maurer, 1978).
[d]LSD: least significant difference; [e]coefficient of variation.

Analysis of 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) parameter, STI, the genotypes of G6 followed by G13, G4 and G3 with the highest values were considered to be tolerant genotypes, whereas the G8 followed by G12, G1, G14 and G2 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 followed by G9 and G15, but the highest difference was belonged to the genotypes of G3 followed by G5 and G6. These results indicate 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 suggesting these three parameters are in equal for selecting genotypes.

According to Fischer and Maurer's (1978) parameter, SSI, the genotypes G8 followed by, G9, G14, G15 were in the lowest, which were considered as genotypes with low drought susceptibility and high yield stability in the both conditions, whereas the genotypes of G3 followed by G5, G6 and G2 with SSI values higher than unit can be identify as high drought susceptibility and poor yield stability genotypes. Similar ranks for genotypes were also found by yield stability index (YSI) (Table 3). In case of comparison between the parameters to selection of the genotypes, the TOL, SSI and YSI gave same results.

Table 3. Mean grain yield and measures of different screening methods for 15 durum wheat genotypes.

Genotype code	YR	YI	Y.R%	STI	GMP	MP	TOL	SSI	*b*	*a*	*b*N (x 1000)	YSI	Pi
G1	2402	3345	28.19	0.683	2829	2874	944	1.160	0.89	442.6	2.011	0.717	29872
G2	2433	3462	29.72	0.701	2885	2948	1029	1.163	0.86	454.5	1.892	0.714	21740
G3	2485	3777	34.21	0.785	3047	3131	1292	1.472	0.73	720.0	1.014	0.653	14771
G4	2606	3638	28.37	0.787	3045	3122	1032	0.973	0.78	454.3	1.717	0.717	11349
G5	2487	3699	32.77	0.781	3014	3093	1212	1.329	0.71	803.0	0.884	0.667	17077
G6	2688	3822	29.67	0.863	3181	3255	1134	1.180	0.61	1018.8	0.599	0.696	13274
G7	2526	3327	24.08	0.703	2877	2927	800	0.844	0.8	641.4	1.247	0.757	24487
G8	2422	3042	20.38	0.613	2683	2732	620	0.497	0.92	483.0	1.905	0.800	35498
G9	2608	3257	19.93	0.708	2905	2932	648	0.730	1.07	-154.8	6.911	0.799	24222
G10	2610	3632	28.14	0.787	3057	3121	1022	0.919	0.71	780.1	0.910	0.737	14036
G11	2466	3407	27.62	0.708	2885	2937	941	1.094	0.78	689.0	1.132	0.718	24546
G12	2471	3235	23.62	0.668	2816	2853	764	0.868	1.02	78.7	12.967	0.760	26863
G13	2664	3477	23.38	0.789	3033	3070	813	0.879	0.8	527.9	1.515	0.760	19357
G14	2498	3285	23.96	0.685	2847	2892	787	0.793	0.94	276.0	3.406	0.758	23736
G15	2647	3393	21.99	0.758	2977	3020	746	0.793	0.88	349.2	2.520	0.775	20402
Mean	2534	3453	26.61	0.735	2939	2994	919	0.980	0.833	524.9	2.709	0.735	21415

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

	YR	YI	STI	GMP	MP	TOL	SSI	*b*	*a*	bN	YSI
YI	0.39										
STI	0.78**	0.84**									
GMP	0.70**	0.88**	0.96**								
MP	0.60*	0.95**	0.93**	0.98**							
TOL	-0.04	-0.91**	-0.58*	-0.66**	-0.76**						
SSI	0.11	-0.83**	-0.45	-0.52*	-0.64**	0.94**					
b	0.34	0.91**	0.77**	0.78**	0.84**	-0.82**	-0.73**				
a	0.20	0.74**	0.59*	0.60*	0.64*	-0.68**	-0.62*	0.91**			
bN	0.26	0.82**	0.68**	0.68**	0.73**	-0.75**	-0.68**	0.96**	0.99**		
YSI	0.11	-0.82**	-0.42	-0.51*	-0.64*	0.97**	0.95**	-0.74**	-0.62*	-0.69**	
Pi	0.65**	0.87**	0.89**	0.94**	0.94**	-0.70**	-0.51*	0.74**	0.49	0.59*	-0.56*

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

The regression coefficients for the fifteen genotypes ranged from 0.61 (G6) to 1.07 (G9). Corresponding to Bansal and Sinha's (1991) method, the genotypes of G6 followed by G5, G3 and G4 with the lowest regression coefficient had the highest drought resistance and the genotypes of G9 followed by G12, G14, and G8 with the highest value were considered as drought non-resistant genotypes.

The intercept values varied from 78.7 (G12) to 1018.8 (G6) and the coefficient of determination (R^2) values (data not shown) of the linear regression of yield vs. environmental index (EI) for each genotype varied from 0.68 (G10) to 0.96 (G4). The higher values of the intercepts (*a*) in the five semi-dwarf durum wheat genotypes i.e., G6, G5, G10, G4, G3 with intercept values 1018.8, 803.0, 780.1, 542.3, 720.0 kg/ha, respectively showed higher yield potential in comparison with the taller genotypes G12 and G9 with intercept values of 78.7 and 154.8 kg/ha, respectively.

Based on Karamanos and Papatheohari's (1999) parameter, bN, a desirable genotype should be showing the lowest bN and an undesirable genotype vice versa. The genotypes of G6, G5, G10 and G3 were found as desirable genotypes, whereas the undesirable genotypes were G12, G9, G14 and G15 (Table 3).

In keeping with Lin and Binns's (1988) parameter (Pi), the genotypes of G4 followed by G6, G10, G3 and G5 with low PI values indicated high relative stability and these genotypes also had high grain yield performance. In relation to this method, the genotypes G8, G1, G13, G11 and G7 with high Pi values showed low relative stability (Table 3).

Interrelationships among screening methods

Spearman's rank correlation coefficients between YR and some screening methods were significant whereas the YI showed high rank correlation with the all methods ($P<0.01$; Table 4). The means of genotype yield in both conditions were correlated to the Pi ($r=0.65^{**}$ for YR and 0.89^{**} for YI), STI ($P<0.01$), GMP ($P<0.01$) and MP ($P<0.05, 0.01$). The methods of STI, GMP, MP, Pi, bN and bi 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 genotypes. The parameters of TOL, SSI and YSI had significantly positive correlation with each other ($P<0.01$), but had significantly negative correlation with the YI, *b* and bN ($P<0.01$) and *a* parameters ($P<0.05$). Bansal and Sinha's (1966) parameter had significantly positive correlation with regression intercept (*a*) and relative adaptability (bN) (P<0.01).

Each of the mentioned methods produced a genotype order. The Spearman's rank correlation matrix was calculated and a PC analysis based on this rank correlation matrix was performed. The first two PCs of ranks the methods, which these accounted for 90.6% of the variance of the original variables. The PC1 vs. PC2 are illustrated in Figure 1. When both axes were considered simultaneously, three groups can be identified: where group I is including the methods of SSI, TOL and YSI whereas the methods of *b*N, *a* and *b* classified in the group II and remain methods, STI, GMP, MP and Pi, which are intermediated between groups I and II. The PC1 separated two contrasting groups of methods (Groups I and II), which in group II, the parameters are strongly correlated with yield under irrigation, whereas the parameters in group I have significantly negative correlation with YI. Therefore, suitable genotypes according to the methods in group II recommended for regions where growing conditions are favorable and for the parameters in first group vice versa. Mean grain yield under supplemental irrigation (YI) was included the group II, suggesting the genotypes comprised those methods where YI had the main influence on the ranking across environments, whereas the parameters in group III were strongly related to the yields in the both conditions.

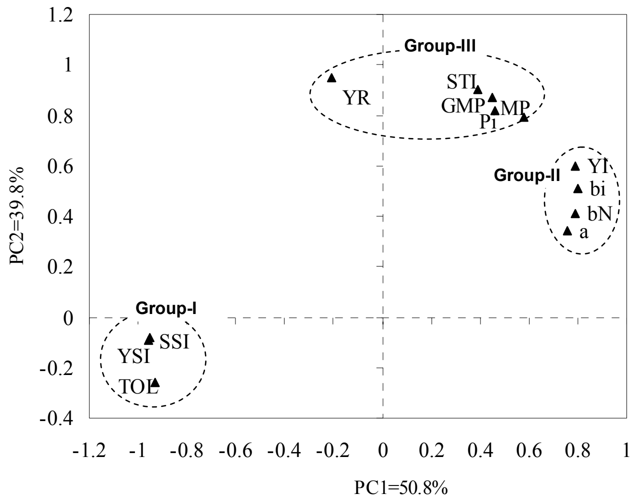

Figure 1. Biplot based on first two principal component axes (PC1 and 2) for testing screening methods derived from 15 durum wheat genotypes.

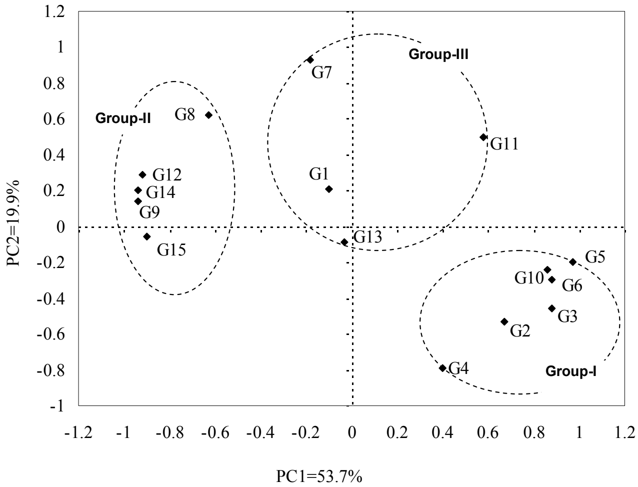

Figure 2. Biplot based on first two principal component axes (PC1 and 2) for fifteen durum wheat genotypes across testing screening methods.

The PC analysis was also performed for the ranks of genotypes obtained from different screening methods. The results showed that the first two PCs explained 73.6% of variance in data set. The first two PCs were employed to generate biplot. In biplot, the PCs axes divided the genotypes into three groups; where group I included the genotypes of G6, G3, G4, G5, G10 and G2 with good performance and high drought tolerance. The genotypes of G8, G12, G9, G14 and G15 in group II with low performance were stable and low sensitive to drought. Group III was consisted of the G13, G1, G11 and G7 with low-to moderate-yielding performance and had low relatively sensitivity/resistance to drought stress.

Discussion

The parameters of STI, GMP, MP and Pi were able to identify high yielding genotypes in both rainfed and irrigated conditions when the stress was mild. The STI, GMP and MP were used 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). For this reason, MP also like the GMP and STI as were reported by Fernandez (1992) was able to differentiate genotypes belong 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 can not select high yielding genotypes in both stressed and non-stressed environments, if the correlation yield in contrasting environments is highly negative. 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. At the present study, G6 followed by G10 and G4 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.

In line of Pi, the genotypes with the highest yield under both stress and non stress conditions exhibited the highest 'Pi' value. This is shown by the significantly positive correlation between 'Pi' and yield under rainfed and irrigated conditions ($P<0.01$). Lin et al. (1986) used 'Pi' to differentiate stress resistant genotypes, similar to GMP, STI and MP, because it was significantly correlated with yields in both conditions as well as the other parameters in group III.

TOL, SSI and YSI were found to be more useful indices in discriminating drought resistant/susceptible genotypes. SSI has been widely used by other researchers for this purpose (Clarke, et al., 1984, 1992; Fischer and Maurer, 1978; Winter et al., 1988). To decrease the influence of yield reduction from stressed to non-stressed conditions, Yadav and Bhatnagar (2001) suggested the use of SSI in combination with yield under stress. These two parameters were employed previously by Gavuzzi et al. (1993) to identify genotypes with superior drought adaptation in trials conducted in several locations of western Iran. In the case of this combination, G9, G15 and G13 were the best genotypes whereas the G8 with the lowest yield in both conditions showed the lowest SSI.

The results showed that the smaller TOL value, the lower is the grain yield reduction under rainfed conditions and consequently lower drought sensitivity. A significantly positive correlation was found between TOL and grain yield under irrigated conditions (YI) ($P<0.01$), but this correlation is not confirmed under rainfed conditions (YR) (Table 4), suggesting that selection based on TOL will result in yield reduction under rainfed condition. Similar results were reported by Clarke et al. (1992) and Rosielle and Hamblin (1981) showed that a selection based on TOL, failed to identify the best genotypes. The linear regression of grain yield of genotypes on environmental index (EI) showed that two genotypes were representative of contrasting responses. i.e., G6 showed the highest intercept value (1018.8 kg/ha) and lowest slope value (0.61), and this value was lower with respect to the mean slopes (0.83) and this genotype ranked among the genotypes as the best with high adaptability, whereas G12 had contrasting behavior. Bansal and Sinha (1991) used this method to evaluate wheat genotypes over variable environments. Hohls (2001) reported that the genotypes with high stress tolerance had low *b* value even when a range of stressed and non-stressed environments were used. Keim and Kronstad (1979) pointed out that the *b* value alone is not a sufficient indicator of adaptability of genotypes evaluated by the regression method. A consideration of the yield performance either under stressed or non-stressed conditions would also be important. This study has allowed classifying genotypes in two groups based on their adaptability (high potential yield) and stability (low linear regression slope). The First group includes genotypes with high potential yield and low slope (G6, G3, G5, G4, G10 and G11) and the second group includes genotypes with low potential yield and high slope (Table 3).

To better understanding of the relationships among screening methods and to separate drought resistant genotypes from others, principal component (PC) analysis based on the rank correlation matrix was performed in two subjects of screening methods and genotypes. These analyses were able to classify resistant/tolerant genotypes as well as classify the screening methods. Using STI, GMP, MP and Pi, the genotypes G6 followed by G4 and G3 were found to be the most drought tolerant genotypes. Also, using SSI, TOL and YSI, the genotypes G8, G9, G14, G15 and G12 were found to be the lowest susceptible to drought and difference in yields in both conditions. According to regression model the genotypes of G6 followed by G5, G3 and G9 were resistant and adapted to different environments.

In this study the national checks 'Zardak' and 'Sardari', which, although selected for mild drought stress environments, were out yielded by advanced durum wheat lines of G6, G5, G4, G3 and G10, having high adaptability (Table 3). Significant breeding progress and yield gains are evident when comparing the promising durum wheat lines with the checks 'Zardak' and 'Sardari'. 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 concluded 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. In conclusion, the parameters Pi, MP, GMP, STI and linear regression model (*a* and *b*) can be suggested to select drought tolerant genotypes with high yield performance under mild stress conditions, particularly for western parts of Iran, where the drought condition is predominant over the years and favorable years are infrequent. The methods of SSI, TOL and YSI can be also used as useful indicators to distinct sensitive/resistant genotypes, where the stress is mild. The regression analysis of grain yield on environmental index provided enough information on the drought resistance and adaptability of genotypes. Therefore, it can be used as useful method to study the response of genotypes to variable environments under mild stress conditions.

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