African Journal of Biotechnology Vol. 10(15), pp. 2875-2885, 11 April, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.2197
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

Assessment of genotype x environment interaction on yield and yield components of durum wheat genotypes by multivariate analyses

Mehmet Ali Sakin[1]*, Cuma Akinci[2], Oral Duzdemir[3] and Emin Donmez[4]

[1]Gaziosmanpasa University, Department of Field Crops, Tokat, Turkey.
[2]Dicle University, Department of Field Crops, Diyarbakir, Turkey.
[3]Cankiri Karatekin University, Department of Biology, Cankiri, Turkey.
[4]Field Crops Central Research Institute, Ankara, Turkey.

Accepted 25 February, 2011

Wheat breeders have to determine the new cultivars and lines responsive to the environmental changes for grain yield and yield components. Therefore, this study was conducted to evaluate 25 durum wheat (*Triticum turgidum* spp. *durum*) genotypes including 12 registered cultivars and 13 advanced breeding lines for their stability grown in three different locations (Tokat-Kazova, Diyarbakir and Sivas-Ulas) of Turkey for two growing seasons (2005-2006 and 2006-2007), and to select genotypes having desirable traits to be used in future durum wheat breeding program. Field trials were conducted in a randomized complete block design with three replications at each location. Days to heading, plant height, number of spikes per square meter, number of kernels per spike, spike weight, 1000 kernel weight and grain yield of the genotypes were evaluated in each location. The regression coefficient (b_i) of Finlay and Wilkinson (1963) and mean square of deviation from regression (S^2_d) of Eberhart and Russell (1966) were used as the stability parameters. The results of combined analysis of variance showed a strong influence of the locations on plant height, number of spikes per square meter, number of kernels per spike, spike weight, 1000 kernel weight and grain yield. Genotypic effects were mainly observed for spike length and test weight. Year had strong impact only on the days to heading. Ecological conditions of Diyarbakir among locations offer the better opportunity for production of durum wheat. Line 5 and cultivar Gidara were both stable in yield ability and also appeared the stable group based on the cluster analysis. In the first principal component days to heading, number of spikes per square meter and spike length were the most important traits contributing to variation that obtained about 44.3%. There was a positive relationship between grain yield and number of spikes per square meter together test weight, whereas days to heading and spike length were negatively correlated to grain yield. The results of this study also imply that Line-5 and cultivar Gidara among genotypes were the most stable cultivars and can be used as breeding materials. The days to heading, number of spikes per square meter and spike length could be adequate to introduce the differences among genotypes.

Key words: Durum wheat, stability, principal component analysis, cluster analysis.

INTRODUCTION

Durum wheat (*Triticum turgidum* spp. *durum*) has a great economic value due to its importance for human diet. However, durum wheat is a crop adapted to marginal lands. Sowing area of durum wheat in the world is 13.7 million ha which constitutes 6% of the total wheat sowing area (USDA, 2009).

According to Turkish Statistical Institute (2009), durum wheat production of Turkey is 3.7 million tons/year out of 1.3 million ha of land that meets 9.5% of world durum wheat production (USDA, 2009). Ecological conditions of Turkey is appropriate for durum wheat production. Though,

*Corresponding author. E-mail: m_sakin@hotmail.com. Tel: 90-356-2521480/2123. Fax: 90-356-2521488.

Turkey imports considerable amount of durum wheat. Because, quality traits of durum wheat grown in Turkey are inadequate.

Wheat producers in Turkey are quite reluctant in appreciation of new wheat varieties due to the assumption that new varieties are vulnerable to the environmental changes. In the development of new durum wheat cultivars, effects of climate and soil properties on grain yield are of great importance. Therefore, wheat breeders should try to select lines responsive to diverse environments for better grain yield and yield components. Rharrabti et al. (2003) reported that, yield and quality of durum wheat is strongly influenced by the environmental factors in the Mediterranean countries. In general, stability parameters are employed to figure out the adaptation behavior of genotypes in diverse environmental conditions. Stability is defined as the early prediction of environmental impacts on genotypes performances (Kafa and Kirtok, 1991). Most of the models used in the stability studies are based heavily on the assumption that a positive linear correlation exists between the improved growing conditions and performances of genotypes. Many researchers thus, acknowledged that regression coefficients could be used as stability parameters for genotypes (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966).

Multivariate analysis methods are also useful tool to asses stability (Lin et al., 1986) and can be used to identify groups with desirable traits for breeding. Cluster method is an analysis (CA) that used dendrograms to display how various genotypes were differentiated. Diversity of tetraploid wheat germplasm grouped by CA and principal component analyses (PCA) explained the variation among genotypes (Anjum et al., 2002; Hailu et al., 2006; Skrbic and Onjia, 2007).

Most studies on durum wheat have focused on stability characteristics of genotypes for grain yield (Aycicek and Yurur, 1993; Korkut and Baser, 1995; Korkut and Biesantz, 1995; Yalvac et al., 1999; Budak and Yildirim, 2001; Ozberk and Ozberk, 2002; Kilic and Yagbasanlar, 2003; Kilic et al., 2005; Ozberk et al., 2004; Akcura et al., 2005; Akcura et al., 2006). However, the research on the stability characteristics as well as identification genotypes and determination desirable traits for breeding by using multivariate analysis methods are rather limited. Therefore, the objective of this study was to evaluate 25 durum wheat (*T. turgidum* spp. *durum*) genotypes including 12 registered cultivars and 13 advanced breeding lines for their stability grown in three locations (Tokat-Kazova, Diyarbakir and Sivas-Ulas) of Turkey for two growing seasons (2005 to 2006 and 2006 to 2007) and to select genotypes having desirable traits to be used in future durum wheat breeding program.

MATERIALS AND METHODS

Twenty five durum wheat genotypes, including 12 registered cultivars and 13 advanced breeding lines, were used as plant material in this study. Nine of the registered cultivars (Aydin-93, Firat-93, Gediz-75, Harran-95, Kiziltan-91, Zenit, Altintoprak, Mirzabey and Cesit-1252) are widely grown in different regions of Turkey, whereas three cultivars (Cham 1, Waha and Gidara) are internationally established cultivars. Eight lines (Line 1, Line 4, Line 5, Line 7, Line 11, Line 19, Line 20 and Line 24) of the 13 advanced breeding lines were obtained from ICARDA (International Center of Agricultural Research in Dry Areas), three mutant lines (Line-Gdem-2-1, Line-Gdem-2 and Line-Gdem-12) from Gaziosmanpasa University and two lines (Line-286, Line-299) from Dicle University. The advanced breeding lines originated from ICARDA were previously determined to be high yielding and resistant to common wheat diseases (Sakin et al., 2004, 2005).

The trials were conducted during 2005 to 2006 and 2006 to 2007 growing seasons in three different locations: Tokat-Kazova, Diyarbakir, Sivas-Ulas. Location descriptions and agronomic details are given in Table 1. The average monthly temperatures in the first and second trial years were 10.8 and 11.1°C in Tokat, 13.7 and 12.2°C in Diyarbakir, 8.2 and 6.9°C in Sivas, respectively. At each experimental location, all genotypes were sown according to completely randomized block design with three replications (Duzgunes et al., 1987). Wheat was sown in the autumn at a sowing density of 450 plants per square meter. Each experimental plot was consisted of 6 rows, 5 m each in length. Sowings were performed by machines. All of the P fertilizer and half of the N fertilizer were applied at sowing, while the rest of the N fertilizer was applied at the Zadok's growth stage 25.

Collected data were subjected to the analysis of variance (ANOVA) using MSTATC software upon combining the growing years by respective locations (Duzgunes et al., 1987). Relative magnitude of year, location and genotype and their interactions attributed to total sum of squares were calculated as percentage (Akcura et al., 2006). Stability analysis were performed whenever the genotype x environment interactions for grain yield were determined as statistically significant ($P < 0.01$). The regression coefficient (b_i) (Finlay and Wilkinson, 1963) and mean square of deviation from regression (S^2_d) (Eberhart and Russell, 1966) values were used as the stability parameters. Wheat genotype demonstrating a higher value than the overall mean with a b_i value of 1 or close to 1 and an S^2_d value of 0 or close to 0 in grain yield was judged as a stable genotype. Additionally, graphical adaptation classifications, developed by Finlay and Wilkinson (1963) using the overall mean and b_i value, were employed for the assessment of stability parameters for grain yield of wheat genotypes. Overall mean and confidence intervals for the regression line (b = 1) were calculated by the following formula: Confidence interval = $\overline{X} \pm t.S\overline{X}$. ($\overline{X}$: overall mean, t: t-test, $S\overline{X}$: standard error). Cluster analysis procedure was carried out to establish dendrograms using the Ward's method as an amalgamation rule and squared Euclidean distance as a measure of proximity between the genotypes (Ozdemir, 2002). The computations were performed using the SPSS software (Version 11.5). Principle component analysis (PCA) was performed (Canoco for windows software) in order to figure out the grouping of genotypes according to yield and yield components.

RESULTS AND DISCUSSION

The results of variance analysis for days to heading, plant height, number of spikes per square meter, spike length, number of kernels per spike, spike weight, 1000 kernel weight, test weight and grain yield are given in Table 2. Effects of locations and years on investigated traits were statistically significant ($P < 0.01$), except for year effects

Table 1. Description of experimental locations and agronomic details.

	Tokat-Kazova		Diyarbakir		Sivas-Ulas	
Coordinate	**40°13' N 36°1' E**		**37°30' N 40°37' E**		**39°49' N 37°03' E**	
Altitude (m)	**640**		**660**		**1385**	
	2005 to 2006	**2006 to 2007**	**2005 to 2006**	**2006 to 2007**	**2005 to 2006**	**2006 to 2007**
Soil characteristics						
Available P (as P_2O_5, kg.da^{-1})	7.2	10.5	1.6	6.8	8.0	8.2
Exchangeable K (as K_2O, kg.da^{-1})	45.8	56.0	8.2	72.3	38.3	58.0
$CaCO_3$ (%)	10.8	9.7	12.0	2.6	15.4	1.0
Organic matter (%)	3.1	1.8	1.2	1.4	2.5	1.5
pH	7.8	7.8	7.6	7.8	7.6	7.9
Total salt (%)	0.04	0.04	0.09	1.1	0.02	0.02
Texture	Clay	Clay-loam	Clay-loam	Loam	Clay-loam	Clay-loam
Average temperatures from sowing to ripening (°C)	10.8	11.1	13.7	12.2	8.2	6.9
Total rainfall from sowing to ripening (mm)	375.9	312.0	538.5	530.7	327.0	263.7
Agronomic practices						
Fertilizers (kg ha^{-1})						
N (seed bed + top dressing)	60 + 60	60 + 60	60 + 60	60 + 60	60 + 60	60 + 60
P	60	60	60	60	60	60
Sowing date	28 October 2005	17 November 2006	11 November 2005	25 November 2006	27 October 2005	10 November 2006
Harvest date	11 July 2006	12 July 2007	20 June 2006	20 June 2007	02 August 2006	27 July 2007

on spike weight and test weight. Differences among the genotypes were significant for all investigated traits. Genotype x environment interactions were found to be significant for all investigated traits except for number of spikes per square meter (Table 2). The results of the combined analysis of variance (Table 2) showed a strong influence of the locations on plant height, number of spikes per square meter, number of kernels per spike, spike weight, 1000 kernel weight and grain yield**.** Genotypic effects were mainly observed for spike length and test weight. Year had strong impact only on the days to heading. Gradual changes in yield and yield components were determined by the genotype and also by the environment (Moragues et al., 2006).

Two years averaged values of yield components and grain yield of genotypes are given in Table 3. Days to heading, plant height, number of spikes per square meter, 1000 kernel weight and grain yield decreased in the second year under poor rainfall conditions of all locations (Table 1). The averaged spike length and number of kernels per spike were higher in the second year than those in the first year.

Two years averaged values of yield components and grain yield for Tokat, Diyarbakir and Sivas-Ulas locations are given in Table 3. Sivas location had the lowest averaged values for all investigated traits except for days to heading. The reason of upper grain yield at Sivas-Ulas could be also short period of dry matter production and nutrition conditions. Rharrabti et al. (2003) reported that, the drought stress negatively effects on starch accumulation in grain leading to low yield. Diyarbakir favored higher values of plant height, number of spikes per square meter, number of kernels per spike, spike weight, grain yield, but had less days to heading (Table 3). Days to

Table 2. Results of variance analysis for yield components and grain yield of 25 genotypes of durum wheat grown at three locations in 2005 to 2006 and 2006 to 2007 growing seasons.

		Mean square	F value	Variation† (%)	Mean square	F value	Variation (%)	Mean square	F value	Variation (%)
Variation Source	**df**		**Days to heading**			**Plant height**			**Number of spikes per square meter**	
Year (Y)	1	168586.9	90050.9**	43.5	12696.7	840.7**	9.7	600608.0	118.3**	6.1
Location (L)	2	63444.7	33889.0**	32.8	44397.2	2939.6**	67.5	2759410.1	543.4**	55.8
Y x L	2	43190.7	23070.3**	22.3	4487.3	297.1**	6.8	554931.5	109.3**	11.2
Replication (Lx Y)	12	3.4	1.8*	0.0	35.0	2.3**	0.3	12942.6	2.5**	1.6
Genotype (G)	24	146.6	78.3**	0.9	401.9	26.6**	7.3	12312.2	2.4**	3.0
G x Y	24	11.2	6.0**	0.1	43.0	2.8**	0.8	6684.0	1.3 ns	1.6
G x L	48	14.4	7.7**	0.2	34.4	2.3**	1.3	6560.3	1.3 ns	3.2
G x Y x L	48	7.1	3.8**	0.1	81.5	5.4**	3.0	5665.5	1.1 ns	2.7
Error	288	1.9		0.1	15.1		3.3	5077.6		14.8
Variation source			**Spike length**			**Number of kernels per spike**			**Spike weight**	
Year (Y)	1	15.8	184.9**	3.8	2824.0	127.3**	7.6	0.001	0.01 ns	2.9
Location (L)	2	31.9	373.0**	15.5	6360.0	286.8**	34.3	17.9	334.0**	43.2
Y x L	2	21.4	249.9**	10.4	931.5	42.0**	5.0	2.8	53.0**	6.9
Replication (Lx Y)	12	0.6	6.6**	1.6	94.4	4.3**	3.1	0.2	3.9**	0.10
Genotype (G)	24	9.3	3.6**	53.9	176.1	7.9**	11.4	0.3	6.0**	9.3
G x Y	24	0.3	3.6**	1.8	59.7	2.7**	3.9	0.1	1.9**	2.9
G x L	48	0.3	3.6**	3.6	47.8	2.2**	6.2	0.1	2.5**	7.9
G x Y x L	48	0.3	3.6**	3.5	88.3	4.0**	11.4	0.1	2.6**	8.2
Error	288	0.1		6.0	22.2		17.2	0.1		18.6
Variation source			**1000 kernel weight**			**Test weight**			**Grain yield**	
Year (Y)	1	660.5	126.0**	3.7	0.08	0.05 ns	0.0	404874.0	183.9**	2.4
Location (L)	2	1920.2	366.3**	21.3	490.5	310.2**	28.9	7044819.3	3199.1**	83.2
Y x L	2	3477.2	663.3**	38.5	127.0	80.4**	7.5	166429.6	75.6**	2.0
Replication (Lx Y)	12	11.3	2.2*	0.5	1.9	1.2 ns	0.7	2739.4	1.2 ns	0.2
Genotype (G)	24	99.6	19.0**	13.2	48.3	30.5**	34.1	12950.4	5.9**	1.8
G x Y	24	28.8	5.5**	3.8	3.0	1.9**	2.1	9179.5	4.2**	1.3
G x L	48	21.4	4.1**	5.7	4.3	2.7**	6.1	7804.7	3.5**	2.2
G x Y x L	48	17.9	3.4**	4.7	5.1	3.2**	7.2	11230.8	5.1**	3.2
Error	288	5.2		8.4	1.6		13.4	2202.1		3.7

*: $P < 0.05$ at significance; **: $P < 0.01$ at significance; ns: not significant; †: variation due to the total sum of squares of all treatment effects.

Table 3. Averaged values of yield components and grain yield for 25 durum wheat genotypes at three locations in two growing seasons.

Number	Genotypes	Days to heading		Plant height		Number of spikes per square meter		Spike length		Number of kernels per spike		Spike weight		1000 kernel weight		Test weight		Grain yield	
1	Line-4	160.4	d**	76.4	cde**	367.2	b-f**	6.7	ghı**	39.5	d-g**	1.66	e-h**	37.5	jkl**	82.2	ab**	3525	a-e**
2	Line-11	159.2	e-j	73.3	ef	414.4	a-e	6.5	ıj	38.2	e-h	1.65	fgh	39.1	f-k	80.7	c-g	3638	a-d
3	Line-24	160.2	def	73.5	def	407.5	a-e	6.9	efg	40.4	c-g	1.77	b-g	40.0	e-h	80.7	c-g	3469	a-e
4	Line-1	156.6	m	80.7	a	429.4	a	6.0	m	40.6	b-g	1.74	b-g	38.9	g-l	80.9	c-f	3642	a-d
5	Line-286	158.1	jkl	73.0	fg	390.6	a-f	6.5	ıj	34.4	h	1.64	fgh	43.2	bc	80.7	c-g	3271	c-f
6	Line-7	158.3	ıjkl	69.2	hıj	410.8	a-e	6.1	lm	34.9	h	1.59	fgh	41.8	cde	80.4	efg	3599	a-d
7	Line-19	157.4	lm	69.0	hıj	420.3	abc	6.1	lm	36.9	gh	1.59	fgh	40.2	efg	81.7	a-d	3146	efg
8	Line-299	160.4	de	77.7	abc	368.9	a-f	6.7	ghı	42.0	a-e	1.86	a-d	40.8	d-g	81.7	abc	3855	a
9	Line-20	157.8	kl	77.3	bc	373.1	a-f	7.0	ef	38.0	e-h	1.71	d-h	43.9	b	81.4	b-e	3564	a-d
10	Line-5	159.9	d-g	76.9	bc	418.6	a-d	6.2	kl	41.3	a-f	1.70	d-h	38.0	h-l	82.6	a	3777	a
11	Gediz-75	158.7	ıjk	71.2	fgh	362.8	c-f	7.1	e	41.6	a-f	1.77	b-g	41.0	def	80.6	d-g	2937	fg
12	Aydin-93	158.2	ı-l	77.2	bc	415.3	a-e	5.9	m	39.9	d-g	1.63	fgh	39.7	f-ı	81.5	a-d	3767	a
13	Zenith	158.2	ı-l	65.3	k	393.9	a-f	6.8	fgh	38.0	e-h	1.57	gh	39.5	f-j	79.9	fgh	3254	def
14	Firat-93	158.7	h-k	73.0	f	415.6	a-e	6.0	m	34.7	h	1.74	c-h	46.7	a	81.0	c-f	3748	ab
15	Harran-95	159.3	d-ı	69.4	g-j	385.0	a-f	6.4	jk	39.6	d-g	1.86	a-e	42.6	bcd	79.6	gh	3661	abc
16	Altintoprak	158.9	g-k	71.7	fgh	381.7	a-f	6.6	hıj	34.8	h	1.55	h	41.7	cde	80.0	fgh	3741	ab
17	Cham 1	158.4	ı-l	70.6	f-ı	399.4	a-f	7.1	e	44.8	a	1.78	b-f	37.0	l	80.6	c-g	3735	ab
18	Waha	158.8	g-k	67.3	ıjk	425.3	ab	6.9	efg	39.7	d-g	1.71	d-h	37.6	jkl	80.4	efg	3500	a-e
19	Gidara	159.1	f-j	67.0	jk	418.6	a-d	6.0	m	39.6	d-g	1.59	fgh	37.9	ı-l	81.7	abc	3624	a-d
20	Line-Gdem-2-1	168.7	a	80.8	a	358.3	def	8.6	a	37.6	fgh	1.54	h	36.9	l	76.6	ı	2772	g
21	Line-Gdem-2	159.9	d-h	76.9	bcd	366.1	b-f	7.4	d	44.8	a	1.92	abc	39.2	f-k	79.1	h	3469	a-e
22	Line-Gdem-12	161.8	c	78.3	abc	340.6	f	7.7	c	44.0	abc	1.94	ab	39.8	e-ı	80.8	c-f	3353	b-e
23	Kiziltan-91	164.9	b	80.9	a	426.1	ab	7.3	d	39.9	d-g	1.65	fgh	37.4	kl	76.9	ı	3616	a-d
24	Mirzabey	165.2	b	80.2	ab	356.4	ef	7.9	c	44.7	ab	2.03	a	40.0	efg	76.2	ı	3640	a-d
25	Cesit-1252	164.4	b	78.3	abc	383.6	a-f	8.2	b	42.4	a-d	1.90	a-d	40.2	efg	79.1	h	3730	ab
General mean		160.1		74.2		393.2		6.8		39.7		1.72		40.0				3521	
Locations																			
Tokat-Kazova		153.7	b**	73.1	b**	351.5	b**	7.3	a**	38.8	b**	1.85	b**	43.5	a**	81.5	a**	3250	b**
Diyarbakir		143.4	c	91.9	a	544.8	a	6.6	b	46.6	a	1.99	a	40.1	b	81.1	b	5811	a
Sivas-Ulas		183.1	a	57.6	c	283.3	c	6.5	c	33.7	c	1.33	c	36.4	c	78.2	c	1503	c
Years																			
2005 to 2006		179.4	a**	79.5	a**	429.7	a**	6.6	b**	37.2	b**	1.72		41.2	a**	80.3		3821	a**
2006 to 2007		140.7	b	68.9	b	356.6	b	7.0	a	42.2	a	1.72		38.8	b	80.3		3221	b

**: P < 0.01 at significance.

Table 4. Stability parameters and mean values for grain yield of durum wheat genotypes grown at three locations in two growing seasons.

Number	Genotype	Grain yield (kg ha^{-1})		
		b_i	S^2_d	Mean
1	Line-4	1.00	363.2	3525
2	Line-11	1.20	906.3	3638
3	Line-24	1.11	5159.8	3469
4	Line-1	0.86	2203.8	3642
5	Line-286	0.95	3541.4	3271
6	Line-7	1.01	3282.5	3599
7	Line-19	0.95	5109.9	3146
8	Line-299	1.05	1018.4	3855
9	Line-20	1.06	987.1	3564
10	Line-5	1.07	100.5	3777
11	Gediz-75	0.92	2230.5	2937
12	Aydin-93	1.03	366.4	3767
13	Zenith	0.88	3339.5	3254
14	Firat-93	1.01	8714.1	3748
15	Harran-95	1.10	412.4	3661
16	Altintoprak	1.03	1876.9	3741
17	Cham 1	1.06	1384.7	3735
18	Waha	1.00	791.3	3500
19	Gidara	1.00	495.6	3624
20	Line-Gdem-2-1	0.82	8688.3	2772
21	Line-Gdem-2	1.01	1349.3	3469
22	Line-Gdem-12	0.93	1642.3	3353
23	Kiziltan-91	0.92	9324.2	3616
24	Mirzabey	0.95	12503.5	3640
25	Cesit-1252	1.06	10262.3	3730
Mean		0.99		3521
Confidence interval		0.99 ± 0.15		3521 ± 159.8

heading was the most important trait in the explaining variations in grain yield, since reflecting the stress conditions in locations (Loss and Siddique, 1994). In Tokat, genotypes had the higher values of spike length, 1000 kernel weight and test weight (Table 3). Diyarbakir location which had higher average rains and temperatures in the experimental years (Table 1) resulted to better ecological conditions for durum wheat cultivation when compared with that of Tokat and Sivas locations. Tillering and number of spikes per square meter were favored by high water supply (Garcia et al., 2003).

Grain yield of the genotypes ranged from 2772 to 3855 kg ha^{-1} with a mean value of 3521 kg ha^{-1} (Table 3). The highest grain yield was obtained from Line 299, whereas the lowest grain yield was obtained from Line-Gdem-2-1. The location was the most important factor affecting the grain yield (Table 2). The analysis indicated that, 83.2% of the total sum of squares was attributable to location. Grain yield was influenced both by genotype and by environment (Akcura et al., 2005; Fufa et al., 2005).

Because the GE interaction was significant for grain yield, stability analyses were performed by using linear regression techniques. The stability parameters, determined by the regression coefficient (b_i) of Finlay and Wilkinson (1963) and mean square of deviation from regression (S^2_d) of Eberhart and Russell (1966) were presented in Table 4 and the adaptation classifications, determined by Finlay and Wilkinson (1963), were depicted in Figure 1. Regression coefficients ranged from 0.82 to 1.20 for grain yield. This variation indicates differences in responses to environmental changes. Line 4 and cultivar Gidara can be considered as judged by their b_i values (Table 4) and adaptation classifications (Figure 1), whereas line 5 can only be considered stable by the S^2_d value (Table 4). Other genotypes were not stable indicated by the employed stability parameters (b_i and S^2_d) for grain yield. Stability parameters of Line 286, Line 19, Line-Gdem-2-1, Line-Gdem-12, cultivar Gediz-75 and Zenith were less than unit (b_i = 1.0) and had low grain yield. Therefore, these genotypes were considered to be adapted to poor environments. Regression coefficients of Line 1, Kiziltan 91 and Mirzabey were less than unit (b_i =

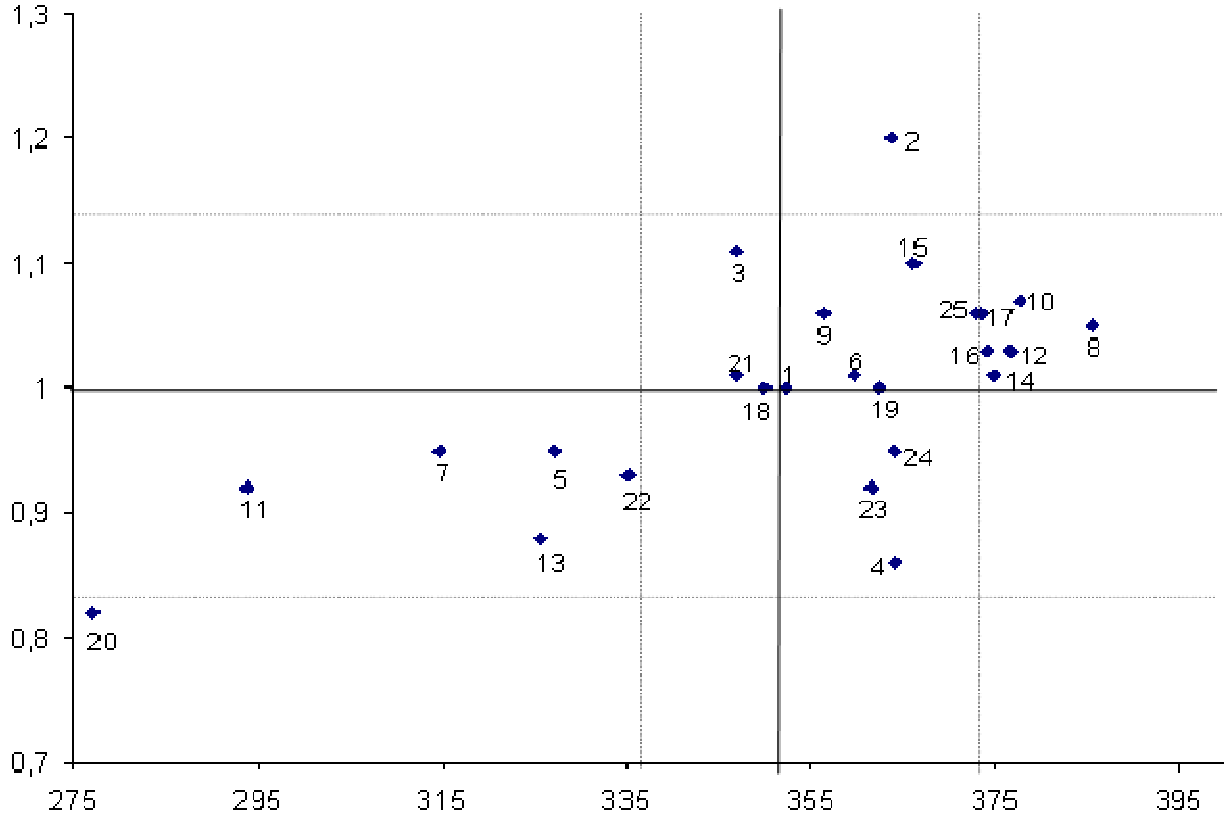

Figure 1. Adaptation classifications of durum wheat genotypes in regard to grain yield.

Table 5. Cluster analysis classification in regard to yield components and grain yield of durum wheat genotypes grown at three locations in two growing seasons.

Group 1	Group 2	Group 3	Group 4
(10) Line-5	(1) Line-4	(6) Line-7	(21) Line-Gdem-2
(12) Aydin-93	(8) Line-299	(16) Altintoprak	(22) Line-Gdem-12
(4) Line-1	(9) Line-20	(5) Line-286	(24) Mirzabey
(2) Line-11	(15) Harran-95	(14) Firat-93	(25) Cesit-1252
(3) Line-24		(7) Line-19	(20) Line-Gdem-2-1
(18) Waha		(13) Zenith	
(19) Gidara		(11) Gediz-75	
(17) Cham-1			
(23) Kiziltan-91			

1.0), however, they had higher grain yield. Thus, these genotypes could be considered as progenitors in breeding programs for high grain yield. Since the grain yield of Line 11, Line 7, Line 299, Line 20, Aydin 93, Firat 93, Harran 95, Altintoprak, Cham 1, Cesit 1252 had higher grain yields over the mean yield and had high b_i values (b_i >1.0). Hence, they are expected to have high yield under favorable conditions.

The classifications by cluster analysis are listed in Table 5 and Figure 2. The cluster analysis on the basis of means for nine traits indicated that, genotypes formed two main clusters with four groups. The groups 1, 2 and 3 are located in the first cluster, whereas the group 4 in the second cluster. The majority of the genotypes are placed in the first cluster. Ozcan et al. (2005) reported that, mean square of deviation from regression (S^2_d) is the major factor directing the formation of clusters. The genotypes (Line 5 (10), Aydin 93 (12), Line 1 (4), Line 11 (2), Line 24 (3), Waha (18), Gidara (19), Cham 1 (17), Kiziltan 91 (23)) located in group 1 were stable genotypes

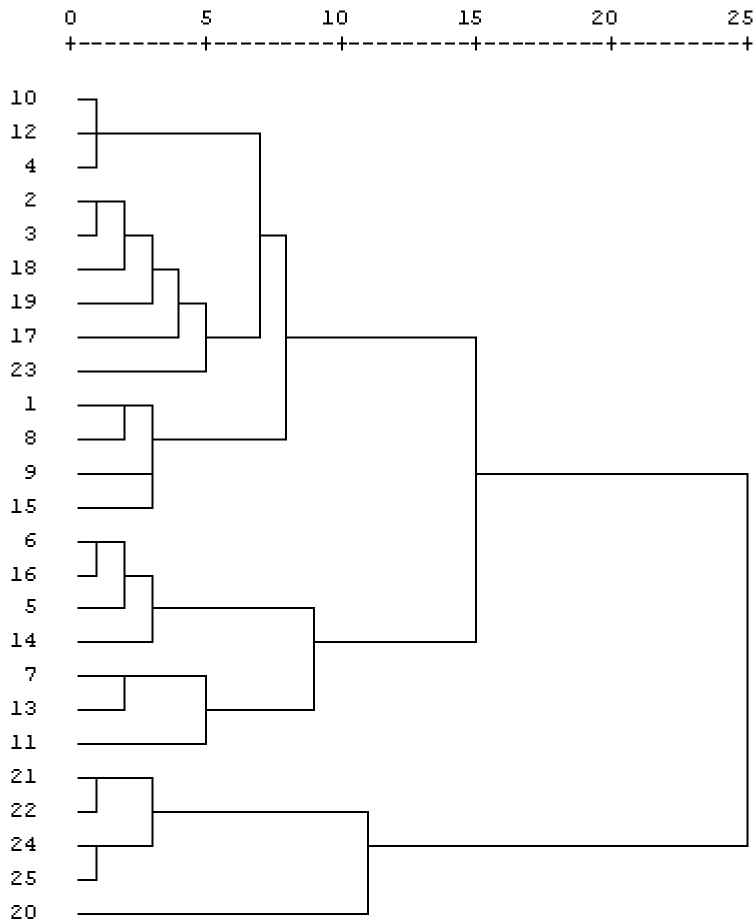

Figure 2. Cluster analysis classifications of durum wheat genotypes in regard to yield components and grain yield.

and shown medium level of performances for the grain yield. The genotypes (Line-Gdem-2 (21), Line-Gdem-12 (22), Mirzabey (24), Cesit-1252 (25) and Line-Gdem-2-1 (20)) located in the second cluster generally exhibited more days to heading, higher plant height, longer spike, more number of kernels per spike, higher spike weight, but lower test weight values. The genotypes in the second cluster displayed larger S^2_d values. Line 5 (10) and cultivar Gidara (19) were both stable in yield ability (Table 4, Figure 1) and also appeared in the stable group based on the cluster analysis (Table 5, Figure 2).

In addition, Line 5 (10), Line 1 (4), Line 11 (2) and Line 24 (3) were grouped together with standard cultivars Cham 1 (17), Waha (18) and Gidara (19) located in the inferior class (Table 5, Figure 2). Mutant lines namely Gdem -2-1 (20), Gdem-12 (21) and Gdem-2 (22) were in different group from their mother cultivar (Gediz-75). The reason that the variation was obtained by mutation.

Principal component analysis (PCA) was performed to obtain more reliable information on how to identify groups of genotypes that have desirable yield traits for breeding. In the first principal components days to heading, number of spikes per square meter and spike length were the most important traits contributing to variation that obtained about 44.3%. The PC1 axis explained most of the variation observed in genotypes (Table 6), and thus, PC1 sco-res could effectively represent the genotype effect (Yan et al., 2001; Egesi et al., 2007). The days to heading, number of spikes per square meter and spike length could be adequate to introduce the differences among genotypes. In the second principal component, obtained variation of about 24.4% of was caused mainly by grain yield (Table 6). Grain yield is a complex plant trait and a function of several other traits (Fufa et al., 2005). Thousand kernel weight (TKW) constituted a large part of the total variation (12.4%) explained by the third principal component (Table 6). In addition, Figure 3 show that there was a positive relationship between yield and number of spikes per square meter together test weight, whereas days to heading and spike length were nega-tively correlated to grain yield. Moragues et al. (2006) used PCA to explain the variation and reported that grain yield was positively correlated to TKW, fertile tillering, the number of spikes per square meter and the duration of grain filling period of durum wheat genotypes. In another study, the first three PCs explained 72% of the all variations

Table 6. Results of principal component analysis in regard to yield components and grain yield of durum wheat genotypes.

Parameter	PC1	PC2	PC3
Days to heading	**0.7219**	0.1295	-0.0139
Plant height	0.5504	-0.2746	0.2452
Number of spikes per square meter	**-0.7577**	-0.1891	-0.4466
Spike length	**0.9253**	0.1873	0.0328
Number of kernels per spike	0.6941	-0.5884	-0.2892
Spike weight	0.5218	-0.6093	0.2308
Thousand kernel weight	-0.3584	0.1106	**0.8611**
Test weight	-0.5711	-0.1991	-0.0110
Grain yield	-0.3394	**-0.8637**	0.2006
Proportion of total variance %	44.3	24.4	12.4
% Cumulative variance	44.3	68.7	81.1

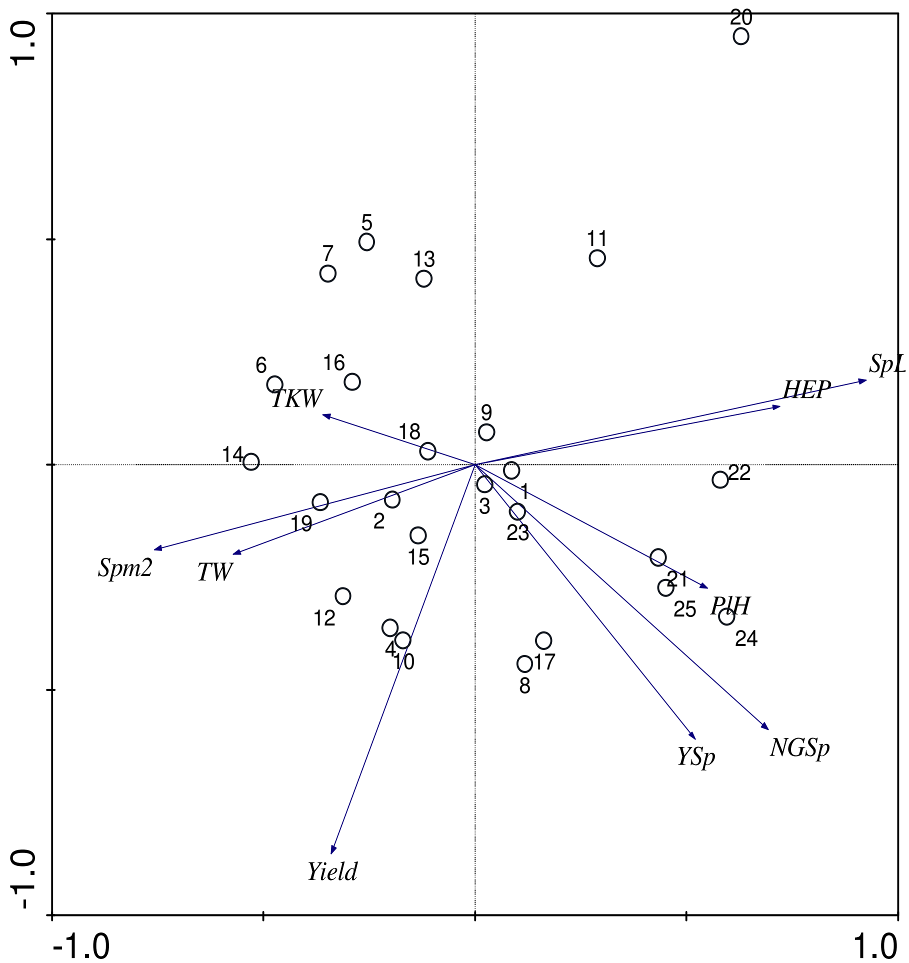

Figure 3. Varimax rotated principal component loadings in regard to yield components and grain yield of 25 durum wheat genotypes (1(Line-4), 2 (Line-11), 3 (Line-24), 4 (Line-1), 5 (Line-286), 6 (Line-7), 7 (Line-19), 8 (Line-299), 9 (Line-20), 10 (Line-5), 11 (Gediz-75), 12 (Aydin-93), 13 (Zenit), 14 (Firat-93), 15 (Harran-95), 16 (Altintoprak), 17 (Cham 1), 18 (Waha), 19 (Gidara), 20 (Line-Gdem-2-1), 21 (Line-Gdem-2), 22 (Line-Gdem-12), 23 (Kiziltan-91), 24 (Mirzabey), 25 (Cesit-1252)) (HEP: days to heading; PlH: plant height; Spm2: number of spikes per square meter; SpL: spike length; NGSp: number of kernels per spike; YSp: spike weight; TKW: thousand kernel weight; TW: test weight; Yield: grain yield).

from the durum wheat cultivars and selected lines and it was reported that, the first PC was related to the difference between grain yield and plant height (Akar et al., 2009). When analyzed (Figure 3), genotypes of Line 1 (4), Line 5 (10) and Aydin 93 (12) had high or low values (Table 3) with respect to number of spikes square meter, days to heading, spike length and grain yield traits that contributed to variation in first and the second components. PCA allowed comparative evaluation of genotypes for yield components and grain yield and helped identify genotypes that were desirable relative to several traits.

Conclusions

The results of this study indicated that, strong influence of environmental conditions on days to heading, plant height, number of spikes per square meter, number of kernels per spike, spike weight, 1000 kernel weight and grain yield. Genotypic effects were mainly observed for spike length and test weight. Diyarbakir location which had higher average rains and temperatures in the experimental years resulted better ecological conditions for durum wheat cultivation when compared with that of Tokat and Sivas locations. The highest grain yield was obtained from Line 299, whereas the lowest grain yield was obtained from Line-Gdem-2-1. Line-4 and cultivar Gidara can be considered as judged by their b_i values and adaptation classifications, whereas genotype line 5 can only be considered stable by the S^2_d value. Line 5 and cultivar Gidara were both stable in yield ability and also appeared in the stable group based on the cluster analysis. In the first principal component days to heading, number of spikes per square meter and spike length were the most important traits contributing to variation that obtained about 44.3%. There was a positive relationship between grain yield and number of spikes per square meter together test weight, whereas days to heading and spike length were negatively correlated to grain yield. The re-sults of this study also imply that Line 5 and cultivar Gidara among genotypes were the most stable cultivars and can be used as breeding materials. The days to heading, number of spikes per square meter and spike length could be adequate to introduce the differences among genotypes.

Abbreviations

TKW, Thousand kernel weight; **PCA,** principal component analysis.

REFERENCES

Akar T, Mert Z, Yazar S, Sanal T, Avci M (2009). Sustainable use of winter durum wheat landraces under Mediterranean conditions. Afr. J. Biotechnol. 8(17): 4108-4116.

Akcura M, Kaya Y, Taner S (2005). Genotype-environment interaction and phenotypic stability analysis for grain yield of durum wheat in the Central Anatolian Region. Turk. J. Agric. For. 29: 369-375.

Akcura M, Kaya Y, Taner S, Ayranci R (2006). Parametric stability analyses for grain yield of durum wheat. Plant Soil Environ. 52: 254-261.

Aycicek M, Yurur N (1993). A research on determining adaptation and stability performances of some durum wheat cultivars (*Triticum turgidum var. durum* L.) grown in Bursa conditions. J. Agr. Fac. Uludag Univ., 10: 173-180 (Turkish).

Anjum FM, Butt MS, Van Zuilichem DJ, Ahmad I (2002). Classification of quality of spring wheats by cluster analysis. Int. J. Food Sci. Technol. 37: 101-106.

Budak N, Yildirim MB (2001). Interpreting genotype x environment interaction by using AMMI Statistics Model in mutant durum wheat populations. 4th Field Crop Cong. Turkey, 17-21 September, Tekirdag, pp. 57-62 (Turkish).

Duzgunes O, Kesici T, Kavuncu O, Gurbuz F (1987). Methods of Research and Experiment (Statistics Methods II), Ankara Univ. Agr. Fac. No: 1021, p. 381, Ankara (Turkish).

Eberhart SA, Russell WA (1966). Stability parameters for comparing varieties. Crop Sci. 6: 36-40.

Egesi CN, Ilona P, Ogbe FO, Akoroda M, Dixon A (2007). Genetic variation and genotype x environment interaction for yield and other agronomic traits in Cassava in Nigeria. Agron. J. 99: 1137-1142.

Finlay KW, Wilkinson GN (1963). The analysis of adaptation in a plant breeding program. Aust. J. Agric. Res. 14: 742-754.

Fufa H, Baenziger BS, Beecher BS, Graybosch RA, Eskridge KM, Nelson LA (2005). Genetic improvement trends in agronomic performances and end-use quality characteristics among hard red winter wheat cultivars in Nebraska. Euphytica, 144(1-2): 187-198.

Garcia del Moral LF, Rharrabti Y, Villegas D, Royo C (2003). Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: An ontogenic approach. Agron. J. 95: 266-274.

Hailu F, Merker A, Harjit-Singh, Belay G, Johansson E (2006). Multivariate analysis of diversity of tetraploid wheat germplasm from Ethiopia. Genet. Resour. Crop Eviron. 53: 1089-1098.

Kafa I, Kirtok Y (1991). Researches on genotype x environment interactions and adaptation performances of ten spring wheat cultivars in Cukurova conditions. J. Fac. Agric. Cukurova Univ. 5(2). (Turkish).

Kilic H, Yagbasanlar T (2003). Studies on determination the genotype x environment interaction of durum wheat (Triticum turgidum ssp. durum) for some quality traits in the southeastern Anatolian conditions. 5th Field Crop Cong. Turkey, 13-17 October, Diyarbakir, pp. 180-185 (Turkish).

Kilic H, Erdemci I, Karahan T, Aktas H, Karahan H, Kendal E (2005). Determination of adaptation capability of some durum wheat cultivars in the southeastern Anatolian conditions. GAP IV. Agr. Cong. 21-23 September, Sanliurfa, pp. 768-773 (Turkish).

Korkut KZ, Baser I (1995). Researches on genotype x environment interactions and stability parameters of grain yield in bread wheat (*Triticum aestivum* L.). J. Tekirdag Univ. Agric. Fac. 2(2): 63-68. (Turkish).

Korkut KZ, Biesantz A (1995). Stability Analysis in Durum Wheats Grown in the Mediterranean Region. Symposium Über Wissenschaftliche Ergebnisse Deutsch-Türkischer Üniversitatspartnerschaftern im Agrarbereich. September 12-17, Ankara.

Lin CS, Binns MR, Lefkovitch LP (1986). Stability analysis: Where do we stand?, Crop Sci. 26: 894-900.

Loss SP, Siddique KHM (1994). Morphological and physiological yield increases in Mediterranean environments traits associated with wheat. Adv. Agron. 52: 229-276.

Moragues M, Garcia del Moral LF, Moralejo M, Royo C (2006). Yield formation strategies of durum wheat landraces with distinct pattern of dispersal within the Mediterranean basin I: Yield components. Field Crop. Res. 95: 194-205.

Ozberk I, Ozberk F (2002). An assessment of genotype x environment interactions in durum wheat by rank method. Anadolu J. AARI., 12 (2): 21-34. (Turkish).

Ozberk I, Ozberk F, Coskun Y, Demir E, Dogru C (2004). An assessment of genotype x environment interactions in durum wheat variety registration trials by rank stability method. Harran Univ. J. Fac. Agric. 8(1): 71-75. (Turkish).

Ozcan H, Aydin N, Bayramoglu HO (2005). Yield stability and correlation among the stability parameters in wheat. J. Agric. Sci. 11(1): 21-25. (Turkish).

Ozdemir K (2002). The data statistically analyzing by pocket programs. Kaan Press (4. edition), Eskisehir, Turkey. (Turkish).

Rharrabti Y, Garcia del Moral LF, Villegas D, Royo C (2003). Durum wheat quality in Mediterranean environments III. Stability and comparative methods in analyzing G x E interaction. Field Crop. Res. 80: 141-146.

Sakin MA, Yildirim A, Gokmen S (2004). Determining the yield, some yield and quality components of some durum wheat cultivars and lines in Tokat-Kazova conditions. J. Agric. Sci. 10 (4): 481-489 (Turkish).

Sakin MA, Yildirim A, Gokmen S (2005). Determining some yield and quality characteristics of mutants induced from a durum wheat (*Triticum durum* Desf.) cultivar. Turk. J. Agric. For. 29(1): 61-67.

Skrbic B, Onjia A (2007). Multivariate analyses of microelement contents in wheat cultivated in Serbia (2002). Food Cont. 18: 338-345.

TUIK 2009. Turkish Statistical Institute. www.tuik.gov.tr

USDA (2009). Global Durum Wheat production, www.fas.usda.gov, http://www.ers.usda.gov/data/wheat/WheatYearbook.aspx

Yalvac K, Atli A, Cetin L, Dusunceli F, Tuncer T, Ozan AN, Albustan S, Yazar S, Zencirci N, Eser V, Baran I (1999). Situation of yield, quality and disease resistance of bread and durum wheat cultivars improved by Field Crops Central Research Institute in Central Anatolia**.** Cereal Symp. 8-11 June, Konya, pp. 95-99. (Turkish).

Yan W, Hunt LA (2001). Interpretation of genotype x environmental interaction for winter wheat yield in Ontario. Crop Sci. 41(1): 19-25.