Turk J Agric For
32 (2008) 249-258

Genetic Analysis of Grain Yield per Spike and Some Agronomic Traits in Diallel Crosses of Bread Wheat (*Triticum aestivum* L.)

Nazan DAĞÜSTÜ

Department of Field Crops, Faculty of Agriculture, Uludağ University, 16059 Bursa - TURKEY

Received: 07.05.2008

Abstract: To introduce new germplasm into breeding programs in Turkey, 3 lines [Samsun - 46 (S - 46), Samsun/Bafra - 333 (SB - 333), Population - 311 (P - 311)] and 4 cultivars [Marmara - 86 (M - 86), Gönen, Golia, and Pehlivan] of bread wheat (*Triticum aestivum* L.) were crossed in 7 × 7 diallel crosses. The trials were conducted at Uludağ University, Research and Training Center, Turkey, over 3 years (in 2000/01, in 2001/02, and in 2002/03). The 7 parents and 42 crosses were grown in a randomized complete block design with 3 replications for 2 years. The genetic analysis (variance, combining ability, correlations, and path coefficient analysis) of grain yield per spike (GYS) and some agronomic traits [plant height (PH), spike length (SL), spikelet number per spike (SNS), kernel number per spike (KNS), and 1000 kernel weight (TKW)] were evaluated. Differences among parents and hybrids were significant. General combining ability (GCA) effects were highly significant for all the components, while specific combining ability (SCA) effects were significant only for PH, GYS, and TKW. General reciprocal effects for PH and GYS and the correlations for GYS and yield components were significant in both years. Path analysis indicated that KNS had the highest effect on GYS, followed by TKW. The parents Gönen and S - 46 for KNS and P - 311 and SB - 333 for TKW and GYS showed positive GCA values in both years. They could be considered for developing desirable progenies in selection programs.

Key Words: Wheat (*Triticum aestivum* L.), combining ability, correlation and path coefficient analysis

Ekmeklik Buğday (*Triticum aestivum* L.) Diallel Melezlerinde Başakta Tane Verimi ve Bazı Agronomik Özelliklerin Genetik Analizleri

Özet: Türkiye ıslah programlarına yeni genitörler kazandırmak amacı ile 3 hat [Samsun - 46 (S - 46), Samsun/Bafra - 333 (SB - 333), Populasyon - 311 (P - 311)] ve 4 ekmeklik buğday (*Triticum aestivum* L.) ıslah çeşidi [Marmara - 86 (M - 86), Gönen, Golia ve Pehlivan] 7 × 7 diallel olarak melezlenmiştir. Denemeler Uludağ Üniversitesi, Araştırma ve Uygulama Merkezi'nde üç yıl (2000/01, 2001/02, 2002/03) yürütülmüştür. Yedi ebeveyn ve 42 melez, 3 tekerrürlü tesadüf blokları deneme desenine göre 2 yıl yetiştirilmiştir. Başakta tane verimi ve bazı agronomik özelliklerin [bitki boyu (PH), başak boyu (SL), başakta başakçık sayısı (SNS), başakta tane sayısı (KNS), başakta tane verimi (GYS), ve 1000 tane ağırlığı (TKW)] genetik analizleri (varyans, kombinasyon yeteneği, korelasyonlar ve path analizleri) belirlenmiştir. Ebeveyn ve hibridler arasındaki farklılıklar önemli olmuştur. Genel uyum kabiliyeti etkileri (GCA) bütün ele alınan öğeler için oldukça önemli bulunurken, özel uyum kabiliyeti etkileri (SCA) sadece PH, GYS ve TKW özellikleri için önemli olmuştur. PH ve GYS için resiprokal etkiler, GYS ve verim öğeleri için korelasyonlar her iki yılda da önemli olmuştur. Path analizi, KNS ve bunu takiben TKW değerlerinin GYS üzerinde önemli etkiye sahip olduğunu göstermiştir. Başakta tane sayısı bakımından Gönen, S - 46, başakta tane verimi ve 1000 tane ağırlığı bakımından P - 311, SB - 333 ebeveynleri her iki yılda pozitif genel uyum kabiliyeti göstermiştir. Bu ebeveynler arzu edilen döllerin geliştirilmesi için seleksiyon programlarında göz önüne alınabilir.

Anahtar Sözcükler: Buğday (*Triticum aestivum* L.), kombinasyon kabiliyeti, korelasyon ve path analizi

Introduction

Turkey produces 20 million tons of wheat annually, 83% being bread wheat (Turkish Statistical Institute, 2006). The high wheat production in Turkey is a historical phenomenon and is based on genetic diversity of the wheat in Turkey (Zhukovsky, 1951; Ekingen, 1987). Parent selection with desirable traits and making crosses among them is an important procedure for increased production. Plant height (PH), spike length (SL), spikelet number per spike (SNS), kernel number per spike (KNS), grain yield per spike (GYS), and 1000 kernel weight (TKW) are major components of wheat yield used

Correspondence to: ndagustu@uludag.edu.tr

as selection criteria in breeding (Topal et al., 2004). Advantages of hybrids over pure lines have been known for years and diallel crossing has long been exploited in plant breeding programs. In wheat, however, although the first hybrid was commercially released 40 years ago (Edwards, 2001), the utilization of hybrids on a large scale is at present not considered very successful (Jordaan et al., 1999; Koemel et al., 2004).

A number of research groups in Turkey are currently investigating the genetic make-up in bread wheat cultivars using molecular markers (Altıntaş et al., 2007) and crossing them in a diallel manner for grain yield per plant and other agronomic traits, in order to select the most promising genotypes to be used in various regions, including the Central Anatolia region (Kaya et al., 2006) and the Aegean region (Dere and Yıldırım, 2006).

In diallel analysis, determination of the general combining abilities (GCAs) and specific combining abilities (SCAs) allows the investigation of the effects of reciprocal crosses. Additionally, the correlation and path-coefficient analysis of yield components are useful tools to determine valuable lines and hybrids (Dewey and Lue, 1959; Li et al., 2006).

The research presented in this paper utilized diallel cross analysis to provide detailed estimations of GCAs and SCAs, path-coefficient analysis and correlation of parents and hybrids on GYS and 5 other agronomic traits concerning 7 Turkish bread wheat genotypes.

Materials and Methods

Out of 681 wheat genotypes obtained from the Prof. Dr. Osman Tosun Gene Bank, Uludağ University Research and Training Center, Turkey, 3 lines were selected for their high agronomic performances (Dağüstü, 1990). Four commonly used bread wheat cultivars [Marmara - 86 (M - 86), Gönen, Golia, and Pehlivan] and 3 lines [Samsun - 46 (S - 46), Samsun/Bafra - 333 (SB - 333), Population - 311 (P - 311)], were crossed in 7 × 7 diallel crosses in 2001. The 7 parents and 42 hybrids were grown in a randomized complete block design with 3 replications for 2 years (in 2001/02 and in 2002/03) at Uludağ University. Plots of parents and hybrids consisted of 2 rows of 2 m lengths with 0.3 m between rows and 0.15 m between plants.

PH (cm), SL (cm), SNS (number), KNS (number), GYS (g), and TKW (g) were measured on 10 randomly chosen plants from each plot, as described previously (Dağüstü, 1990, 1997).

The analysis of variance for GCAs and SCAs and reciprocal effects (RE) were estimated according to Griffing (1956) by utilizing the diallel procedure (Griffing Method 1 for full diallel set, Model I) of MSTAT (statistical software developed at Michigan State University, 1983). The significant differences among the means were grouped according to least significant difference (LSD) test. Analysis of variance, coefficients of correlation, and path coefficients analysis (Dewey and Lue, 1959) of the results were calculated using the statistical program TARPOPGEN (Özcan, 1999). Path coefficient analysis was performed on the genotypic correlation coefficients: GYS as dependent variable and the other 5 as independent variables.

Results

The 6 traits measured in 2002 and 2003 varied among genotypes ($P \leq 0.05$) (Table 1). The mean values of all traits measured in the 2 years are summarized in Table 2. GYS and all its components were generally lower in the second year (2003) of the breeding experiment.

Table 1. Analysis of variance for traits examined of parents and their F1 progenies bread wheat (means square values).

Sources	df	PH		SL		SNS		KNS		GYS		TKW	
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Replications	2	491.84**	97.55ns[a]	0.41ns	1.00ns	5.60ns	16.14ns	448.14*	44.94ns	0.11ns	0.14ns	6.37ns	317.33**
Genotypes	48	600.10**	494.51**	1.29**	2.47*	3.95**	11.80*	152.68ns	127.86**	1.06**	0.46**	128.82**	185.90**
Error	96	28.05	85.54	0.47	1.43	1.96	7.71	141.33	69.41	0.30	0.22	17.54	53.93
Total	146												

P ≤ 0.05, ** P ≤ 0.01, [a]ns: not significant

PH: Plant height, SL: Spike length, SNS: Spikelet number per spike, KNS: Kernel number per spike, TKW: 1000 kernel weight, GYS: Grain yield per spike

Table 2. Mean of parents and F1 progenies for the traits examined for bread wheat lines and cultivars in 2002 and 2003.

Genotypes	Traits											
	PH (cm)		SL (cm)		SNS (number)		KNS (number)		GYS (g)		TKW (g)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
M-86 (1)	87.8j-o	81.8d-j	11.7a-c	9.2a-e	23.3a-c	17.6a-c	71.2a-c	35.9a	2.5g-o	1.4b-e	46.0c-m	38.7a-f
Gönen (2)	74.3qr	84.1c-ı	10.6a-f	9.1a-e	22.7a-c	17.8a-c	85.1a	33.6ab	2.9c-m	1.6b-d	35.1q-s	47.6a-d
Golia (3)	55.0s	65.0ı-l	9.0g	7.0d-g	22.6a-c	17.0a-c	80.0ab	33.0ab	2.4ı-o	1.3b-e	32.6s	48.5a-c
Pehlivan (4)	84.2n-q	52.1l	10.0d-g	6.5g	21.1bc	14.3b-d	58.8bc	29.5ab	2.7d-o	1.1b-e	45.2e-o	35.6b-f
P-311(5)	109.8a-d	91.6a-f	10.7a-f	9.2a-e	21.4bc	17.9a-c	78.0a-c	39.9a	3.3b-l	1.7b-d	51.9a-f	40.8a-f
S-46 (6)	110.0a-d	102.8a-c	11.0a-f	8.4a-g	22.2bc	16.3b-d	73.2a-c	33.4ab	3.0b-l	1.8bc	45.5d-o	50.3a
SB-333 (7)	115.9a	111.2a	10.9a-f	10.3a	21.3bc	17.3a-c	69.3a-c	40.2a	3.5a-j	1.8b	46.7c-l	45.4a-f
1 × 2	85.7m-p	76.2e-k	11.4a-f	9.5a-d	22.1bc	19.4a-c	64.5a-c	38.7a	2.5g-o	1.5b-d	38.8k-r	38.1a-f
1 × 3	86.4k-p	67.4h-l	11.6a-c	9.4a-e	23.1a-c	18.9a-c	65.1a-c	38.7a	2.5h-o	1.2b-e	40.4ı-r	36.0a-f
1 × 4	92.1g-n	73.5f-k	12.0a	9.3a-e	23.3a-c	18.7a-c	67.6a-c	35.2ab	2.7e-o	1.5b-d	46.3c-l	39.8a-f
1 × 5	106.3a-f	74.8e-k	11.9ab	8.6a-g	21.7bc	17.3a-c	72.7a-c	27.4ab	3.5a-j	1.2b-e	45.1-o	44.0a-f
1 × 6	104.6a-f	71.1g-l	11.4a-f	8.9a-g	23.8a-c	16.8a-c	81.8ab	25.3ab	3.7a-f	0.8de	53.0a-e	34.7c-f
1 × 7	107.6a-f	85.5c-h	11.9ab	9.8a-c	24.0ab	18.7a-c	69.6a-c	39.5a	3.4a-k	1.6b-d	50.9a-g	40.8a-f
2 × 1	88.5ı-o	73.1f-k	11.4a-e	8.9a-g	23.4a-c	17.4a-c	71.6a-c	22.5ab	1.9m-o	0.9b-e	40.2ı-r	41.7a-f
2 × 3	71.5r	63.9j-l	10.5a-g	7.7b-g	22.1bc	16.1b-d	64.6a-c	22.2ab	1.7no	0.8c-e	37.0n-s	35.4c-f
2 × 4	85.7l-p	69.6g-l	10.0e-g	7.8a-g	22.5a-c	16.2b-d	53.2c	30.3ab	2.2l-o	1.3b-e	28.5s	48.7a-c
2 × 5	103.8b-f	89.3b-g	10.6a-f	8.8a-g	23.2a-c	17.8a-c	78.9ab	38.1a	3.1b-l	1.7b-d	45.5d-o	48.8a-c
2 × 6	97.1e-l	78.9e-j	11.1a-f	8.7a-g	22.8a-c	15.7b-d	75.8a-c	34.0ab	3.4a-k	1.7b-d	37.0m-s	46.5a-f
2 × 7	103.8b-f	77.5e-j	10.8a-f	8.3a-g	22.0bc	15.3b-d	79.6ab	31.3ab	3.9a-c	1.4b-d	48.3b-j	44.3a-f
3 × 1	75.4p-r	71.2g-l	10.6a-f	8.7a-g	23.8a-c	18.5a-c	70.8a-c	34.1ab	3.2b-l	1.6b-d	44.8e-p	44.0a-f
3 × 2	69.7r	62.4j-l	10.0e-g	8.4a-g	23.7a-c	20.0ab	82.7ab	26.3ab	2.3k-o	1.0b-e	36.1-s	39.7a-f
3 × 4	71.2r	63.2j-l	10.5b-g	8.1a-g	23.0a-c	17.5a-c	73.0a-c	31.6ab	2.8d-o	1.2b-e	37.8l-r	35.9a-f
3 × 5	84.4n-q	56.7kl	10.3c-g	7.3c-g	22.4bc	14.3b-d	79.2ab	29.3ab	4.1ab	1.2b-e	49.2-ı	38.3a-f
3 × 6	83.5n-q	65.0ı-l	9.9fg	6.9e-g	22.3bc	13.6cd	78.4a-c	26.3ab	3.7a-f	1.0b-e	46.9-k	33.8d-f
3 × 7	78.8o-r	67.4h-l	10.0e-g	7.3c-g	22.4bc	14.5b-d	79.8ab	30.0ab	3.8a-e	1.3b-e	52.0a-e	43.1a-f

Table 2. (Continued).

Genotypes	Traits											
	PH (cm)		SL (cm)		SNS (number)		KNS (number)		GYS (g)		TKW (g)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
4 × 1	88.5ı-o	62.3j-l	11.9ab	6.6fg	23.3a-c	10.8d	73.6a-c	22.2ab	3.0b-l	0.9b-e	47.4b-k	36.9a-f
4 × 2	84.9n-q	71.4g-l	11.2a-f	8.6a-g	22.7a-c	16.5b-d	57.8bc	38.5a	2.4j-o	1.7b-d	36.6-s	41.1-f
4 × 3	83.0n-q	62.4j-l	10.5a-g	8.4a-g	23.4a-c	17.4a-c	59.2bc	36.5a	2.8d-o	1.4b-e	47.1-k	39.5a-f
4 × 5	99.6d-ı	73.0f-k	10.7a-f	8.1a-g	22.3bc	15.6b-d	64.5a-c	36.6a	3.3a-l	1.7b-d	47.4b-k	47.1a-e
4 × 6	99.4d-ı	72.3f-k	10.9a-f	8.8a-g	23.1a-c	15.8b-d	70.9a-c	30.7ab	3.6a-h	1.4b-e	58.1a	46.3-f
4 × 7	105.0a-f	69.7g-l	11.7a-c	8.9a-g	23.0a-c	17.0a-c	69.7a-c	36.8a	3.2b-l	1.6b-d	49.6-h	44.3a-f
5 × 1	108.2a-e	77.4e-j	10.8a-f	7.8a-g	22.0bc	15.6b-d	63.1a-c	24.5ab	4.4a	1.6b-d	50.6-g	41.0
5 × 2	105.1a-f	93.6a-e	10.5b-g	10.2ab	22.3bc	20.2ab	73.1a-c	28.3ab	3.6a-g	1.4b-e	51.4-g	45.5-f
5 × 3	91.2h-n	79.8e-j	10.3c-g	7.3c-g	22.7a-c	16.1b-d	73.9a-c	11.3b	3.0b-l	0.4e	48.8b-l	32.6f
5 × 4	112.9a-c	68.7h-l	11.1a-f	8.4a-g	22.8a-c	18.8a-c	65.7a-c	22.4ab	3.0b-l	1.0b-e	54.8-c	37.1a-f
5 × 6	110.0a-d	91.7a-f	11.2a-f	9.1a-f	20.6b-d	17.7a-c	65.3a-c	30.1ab	1.7o	1.3b-e	50.1a-g	44.1-f
5 × 7	114.7ab	106.5ab	11.1a-f	9.7a-c	21.6bc	22.5a	64.9a-c	33.8ab	2.9c-m	2.9a	49.0b-l	37.6-f
6 × 1	108.4a-e	88.9b-g	12.1a	9.3a-e	23.7a-c	19.8ab	73.1a-c	43.8a	3.1b-l	1.6b-d	49.5a-h	41.0a-f
6 × 2	96.4f-m	86.4c-h	11.4a-f	9.4a-d	23.1a-c	19.0a-c	71.5a-c	37.9a	2.3k-o	1.3b-e	39.5j-r	34.6c-f
6 × 3	97.5e-k	72.7f-k	11.0a-f	8.5a-g	22.9a-c	18.9a-c	78.5a-c	33.6ab	2.6f-o	1.3b-e	42.9f-q	33.0ef
6 × 4	102.0c-h	84.3c-ı	11.2a-f	7.9a-g	22.3bc	16.6a-d	67.0a-c	29.2ab	2.9c-m	1.3b-e	52.7a-e	42.3a-f
6 × 5	113.0a-c	88.8b-g	11.1a-f	8.8a-g	23.5a-c	16.9a-c	76.0a-c	37.6a	3.8a-d	1.9b	53.6a-e	49.9ab
6 × 7	106.2a-f	87.2b-h	10.9a-f	8.4a-g	17.3d	15.5b-d	65.1a-c	28.1ab	2.8c-n	1.3b-e	54.4a-d	44.3a-f
7 × 1	106.7a-f	79.0e-j	11.6a-c	8.2a-g	26.2a	15.2b-d	61.9a-c	26.9ab	3.2b-l	1.2b-e	40.9h-r	43.4a-f
7 × 2	103.0c-g	91.6a-f	11.2a-f	9.9ab	23.3a-c	19.3a-c	69.5a-c	42.0a	3.1b-l	1.9b	51.8a-f	44.3-f
7 × 3	98.0e-j	74.8e-k	10.7a-f	8.1a-g	23.7a-c	16.5a-d	73.8a-c	33.1ab	3.6a-l	1.3b-e	51.2a-g	40.4-f
7 × 4	110.4a-d	85.9c-h	11.2a-f	9.2a-e	22.0bc	18.4a-c	60.9a-c	41.2a	3.2b-l	1.9b	56.0ab	44.5-f
7 × 5	106.6a-f	80.2d-j	11.7a-c	8.4a-g	20.1cd	16.4b-d	67.9a-c	29.9ab	3.3b-l	1.4b-d	45.8d-n	38.9a-f
7 × 6	106.9a-f	100.9a-d	11.5a-d	9.9a-c	21.4bc	18.9a-c	75.3a-c	43.3a	3.4a-k	1.8b-d	42.7g-q	43.4a-f
M. parents	91.01	84.09	10.56	8.54	22.09	16.9	73.65	35.05	2.9	1.51	43.3	43.8
M. F1	96.52	77.03	11.04	8.58	22.64	17.2	70.27	31.9	3.1	1.38	46.4	41.1
$LSD_{5\%}$	8.55	14.92	1.15	1.93	2.795	4.48	19.18	18.29	0.854	0.757	6.8	10.9
CV (%)	5.53	11.85	6.51	13.95	0.08	16.19	16.80	25.06	17.48	33.62	9.1	16.3

M.: Mean

The analysis of variance based on Griffing (1956) showed a predominance of GCAs for almost all traits, with the ratio GCAs/SCAs above 1.0 in all traits examined in both years, indicating the importance of additive genetic variation over non-additive gene action in this genetic material. SCAs were also significant at the 1% level for PH in both years; for GYS and TKW they were significant only in 2002. Significantly high GCAs and SCAs indicate the existence of variability due to both additive and non-additive (dominant and/or epistasis) gene(s) effects. Reciprocal effects of examined traits were significant only for PH and GYS in both years and TKW for 2002 only, probably due to the presence of cytoplasmic influences of female parents in these traits (Table 3).

The parents P - 311, S - 46, and SB - 333 for GYS, and the parents P - 311 and SB - 333 for TKW were the best general combiners, since they produced positive GCA values in both years (Table 4a). In addition, parents P - 311 and SB - 333 produced positive GCA values for TKW and GYS, which are the most important yield components in both years. These parents are especially promising for future wheat breeding programs. The parents M - 86, Golia, and Pehlivan could be omitted from crossing studies since they produced negative GCA values for GYS and TKW in both years.

The estimates of SCA effects are presented in Table 4a. Out of 42 crosses, 22 in 2002 and 17 in 2003 appeared to be good specific combiners for GYS. Three crosses showed positive SCA effects for GYS in both years. The cross 2 × 5 had the highest positive SCA effect in both years, while 2 × 6 and 3 × 4 were the other combinations.

Three crosses, 4 × 1, 5 × 2, and 7 × 5, had consistent positive REs for GYS in both years. The crosses 2 × 1, 4 × 3, 5 × 4, and 6 × 5 showed positive REs on PH in both years (Table 4b).

Correlation coefficients between traits are shown in Table 5. There were significant and positive correlations between GYS and all the traits in both years. Path analysis of direct and indirect effects of yield characters on GYS confirmed that KNS (0.4 and 28.8% in 2002; 0.6 and 56.6% in 2003) had the greatest direct effect, followed by TKW (0.4 and 28.7% in 2002; 0.2 and 51.4% in 2003) (Figure). An increase in the yield of bread wheat genotypes using KNS and TKW as selection criteria is possible, although the influence of other factors cannot be omitted.

Discussion

For a possible increase in productivity and profitability of bread wheat production in the South Marmara area, Turkey, high yielding tall lines, S - 46, SB - 333, and P - 311, were crossed with 4 traditional Turkish cultivars. Significant differences were recorded among the 7 wheat genotypes and their crosses. Previous studies on wheat have also demonstrated significant differences among genotypes, for grain yield and related traits of wheat (Menon and Sharma, 1997; Joshi et al., 2004).

In general, the environmental factors that influence wheat yield at a particular site are winter rainfall, weeds, diseases, and summer drought (Austin and Arnold, 1989), as well as temperature and rainfall at planting, flowering, and harvesting time (Ozkan and Akcaoz, 2003). Paradoxically, the main parameter significantly

Table 3. Analysis of variance of the combining ability for the traits examined in bread wheat cultivars and lines (means square values).

Sources	df	PH		SL		SNS		KNS		GYS		TKW	
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Genotypes	48	200.03**	164.84**	0.43**	0.82*	1.32**	3.93**	50.89ns	42.62**	0.35**	0.15**	42.94**	61.97**
GCA	6	1390.12**	904.21**	2.36**	2.66**	3.14**	3.30ns	149.79**	52.96*	0.68**	0.33**	167.94**	65.48
SCA	21	31.24**	53.22*	0.13ns	0.48ns	1.08ns	2.44ns	39.75ns	35.84ns	0.30**	0.10ns	34.22**	49.09
Reciprocal	21	28.81**	65.20**	0.18ns	0.64ns	1.03ns	5.60ns	33.78ns	46.45*	0.31**	0.16**	15.95**	73.84
Replications	2	163.95**	32.52ns	0.14ns	0.33ns	1.87ns	5.40ns	149.38*	14.98ns	1.87**	0.05ns	2.12ns	105.78**
Error	96	9.35	28.51	0.16	0.48	0.65	2.57	47.11	23.14	0.10	0.07	5.85	17.98
GCA/SCA		44.50	16.99	18.15	5.54	2.90	1.35	3.77	1.48	2.27	3.3	4.91	1.33

P ≤ 0.05, ** P ≤ 0.01, [a]ns: not significant

PH: Plant height, SL: Spike length, SNS: Spikelet number per spike, KNS: Kernel number per spike, TKW: 1000 kernel weight, GYS: Grain yield per spike

Table 4a. Estimates of general combining ability (GCA), specific combining ability (SCA), and reciprocal effects (RE) for the traits of bread wheat in 2002 and 2003.

Genotypes	PH (cm)		SL (cm)		SNS (number)		KNS (number)		GYS (g)		TKW (g)	
GCA	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
M-86 (1)	-0.45	-2.03	0.65**	0.25	0.58**	0.17	-0.91	0.84	-0.04	-0.10	-0.26	-0.23
Gönen (2)	-6.88**	0.70	-0.15	0.31	0.29	0.60	1.61	1.32	-0.3**	0.01	-5.9**	2.97**
Golia (3)	-17.12**	-11.13**	-0.70**	-0.71**	0.43*	-0.28	3.45*	-2.81*	-0.12	-0.2**	-3.2**	-0.96
Pehlivan (4)	-2.64**	-9.43**	-0.10	-0.50**	0.10	-0.88*	-6.41**	-0.58	-0.16*	-0.06	0.65	-3.8**
P-311 (5)	9.66**	5.09**	-0.06	0.07	-0.48*	0.35	0.77	-2.08	0.3**	0.09	3.67**	1.74
S-46 (6)	7.48**	7.15**	0.20*	0.10	-0.24	-0.15	2.49	0.59	0.05	0.04	1.99**	-0.42
SB-333 (7)	-6.62**	9.65**	0.15	0.47**	-0.67**	0.19	-1.00	2.71*	0.3**	0.3**	3.03**	0.72
g_i^a (0.05)	1.48	2.59	0.19	0.34	0.39	0.78	3.33	2.33	0.15	0.13	1.17	2.06
g_i^a (0.01)	1.89	3.30	0.25	0.43	0.50	0.99	4.25	3.00	0.20	0.17	1.50	2.62
SCA												
1 × 2	-1.29	-2.04	-0.03	0.06	-0.60	0.47	-3.39	5.46	-0.5**	-0.11	-0.29	-2.98
1 × 3	2.72	4.43	0.21	0.95*	-0.03	1.66	-5.38	5.65	-0.07	0.37*	0.08	1.06
1 × 4	-2.37	1.30	0.45	-0.38	0.17	-1.71	7.19	-4.31	0.02	-0.07	0.53	2.24
1 × 5	2.34	-4.98	-0.18	-0.66	-0.70	-1.18	-2.69	-5.53	0.7**	-0.02	-1.56	0.85
1 × 6	3.72*	-3.17	0.14	0.22	0.92	1.16	5.10	0.37	0.33	-0.12	3.53*	-1.65
1 × 7	1.92	-3.38	0.01	-0.31	0.57	-0.56	-3.09	-3.10	0.01	-0.20	-2.84	1.47
2 × 3	-1.13	-4.46	0.16	-0.13	-0.29	0.55	-2.16	-7.00*	-0.6**	-0.26	-0.37	-4.63
2 × 4	-0.91	1.23	-0.11	-0.21	-0.24	-0.52	-10.5*	0.92	-0.25	0.16	-8.2**	5.58*
2 × 5	5.94**	7.66*	-0.22	0.51	0.45	0.90	2.87	1.22	0.34	0.02	4.70**	2.26
2 × 6	0.42	-3.24	0.24	0.09	0.45	-0.22	-1.16	1.30	0.09	0.02	-3.8**	-2.13
2 × 7	4.63*	-3.85	0.06	-0.26	0.59	-0.62	3.17	-0.09	0.5**	-0.01	6.97**	0.42
3 × 4	1.15	5.30	0.17	0.86*	0.22	1.44	-1.69	4.70	0.02	0.19	-1.01	2.34
3 × 5	-0.49	-3.73	0.09	-0.64	0.09	-2.04*	1.57	-7.6**	0.37	-0.5**	2.51	-5.48**
3 × 6	4.39*	-5.23	-0.01	-0.30	-0.03	-0.48	1.75	-0.59	0.18	-0.08	0.10	-5.37**
3 × 7	-0.16	-5.49	-0.09	0.62	0.80	-1.56	3.60	-1.09	0.5**	-0.10	5.78**	1.84
4 × 5	3.52	-2.86	0.08	0.12	0.46	0.56	0.01	-0.54	0.02	-0.11	0.82	4.06
4 × 6	0.14	2.52	0.00	0.18	0.37	0.08	2.16	-2.78	0.35	-0.06	6.79**	-10.7**
4 × 7	4.69*	-0.46	0.14	0.50	0.59	1.24	1.93	4.12	-0.13	0.14	3.12*	-6.6**
5 × 6	-1.39	-0.06	0.03	0.20	0.28	-0.05	-3.34	2.59	-6.6**	0.07	0.24	5.53*
5 × 7	-4.70**	0.59	0.34	-0.05	-0.47	1.76	-4.10	-1.48	-0.47	0.43**	-5.3**	-4.36
6 × 7	-6.62**	-1.28	-0.07	-0.02	-2.23	0.01	-2.02	-0.36	-0.21	-0.19	-2.43	3.42
s_{ij}^b (0.05)	3.68	6.43	0.48	0.83	0.97	1.93	8.26	5.79	0.38	0.33	2.91	5.11
s_{ij}^b (0.01)	4.70	8.20	0.61	1.06	1.24	2.46	10.54	7.39	0.49	0.42	3.71	6.51

Table 4b. Estimates of general combining ability (GCA), specific combining ability (SCA), and reciprocal effects (RE) for the traits of bread wheat in 2002 and 2003.

Genotypes	PH (cm)		SL (cm)		SNS (number)		KNS (number)		GYS (g)		TKW (g)	
RE	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
2 × 1	1.42	1.53	0.00	0.33	0.63	0.98	3.57	-1.68	-0.33	0.33	-0.68	-1.83
3 × 1	-5.48**	-1.88	-0.52	0.33	0.35	0.23	2.85	2.28	0.35	-0.21	-2.20	-3.98
3 × 2	-0.87	0.78	-0.27	-0.38	0.77	-1.95	9.02	-2.05	0.29	-0.10	0.47	-2.17
4 × 1	-1.80	5.62	-0.07	1.38**	-0.02	3.93**	2.99	6.52	0.20	0.30	-0.55	1.43
4 × 2	-0.43	-0.90	0.60*	-0.38	0.08	-0.12	2.28	-4.10	0.09	-0.17	-4.03*	3.82
4 × 3	5.88**	0.42	0.20	-0.13	0.18	0.07	-6.87	-2.42	-0.01	-0.08	-4.62*	-1.78
5 × 1	0.95	-1.28	-0.57*	0.40	0.17	0.85	-4.78	1.47	0.46*	-0.20	-2.75	1.53
5 × 2	0.65	-2.15	-0.07	-0.70	-0.47	-1.23	-2.90	4.87	0.27	0.14	-2.93	1.65
5 × 3	3.42	-11.57**	0.02	0.00	0.15	-0.88	-2.67	9.00**	-0.6**	0.38*	0.18	2.85
5 × 4	6.67**	2.17	0.22	-0.17	0.25	1.62	0.62	7.10*	-0.15	0.38*	-3.67*	5.00
6 × 1	1.92	-8.87*	0.12	-0.20	-0.07	-1.52	-4.33	-9.20**	-0.31	-0.42*	1.77	-3.18
6 × 2	-0.32	-3.78	0.15	-0.37	0.17	-1.63	-2.15	-1.95	-0.54*	0.19	-1.23	5.97**
6 × 3	7.02**	-3.87	0.55*	-0.80	0.30	-2.63*	0.07	-3.63	-0.53*	-0.13	1.97	0.40
6 × 4	1.27	-6.02	0.13	0.48	-0.37	-0.43	-1.95	0.73	-0.30	0.03	2.70	21.02**
6 × 5	1.52	1.45	-0.07	0.17	1.43**	0.37	5.33	-3.77	1.07**	-0.27	-1.77	-2.93
7 × 1	-0.48	3.25	-0.13	0.82	-1.05	1.75	-3.85	6.28	-0.12	0.19	5.0**	-1.30
7 × 2	-0.40	-7.07	0.22	-0.80	0.67	-1.98	-5.07	-5.35	-0.43	-0.22	-1.77	-0.02
7 × 3	9.63**	-3.70	0.35	-0.42	0.67	-1.03	-2.97	-1.58	-0.10	-0.02	0.42	1.38
7 × 4	2.72	-8.13*	0.08	-0.12	-0.48	-0.70	-4.40	-2.18	-0.20	-0.12	-3.20	13.89**
7 × 5	-4.07	13.2**	0.32	0.67	-0.75	3.0**	1.52	1.95	0.15	0.8**	1.60	-0.68
7 × 6	0.37	-6.40	0.30	-0.75	2.07**	-1.73	5.08	-7.58*	0.32	-0.25	5.8**	0.47
r_{ij}^{c} (0.05)	4.24	7.40	0.55	0.95	1.12	2.22	9.51	6.67	0.44	0.38	3.35	5.88
r_{ij}^{b} (0.01)	5.41	9.44	0.70	1.22	1.43	2.84	12.13	8.50	0.56	0.48	4.27	7.50

a: Critical differences between GCA effects of parents

b: Critical differences between SCA effects of the *ij*th F1 hybrid

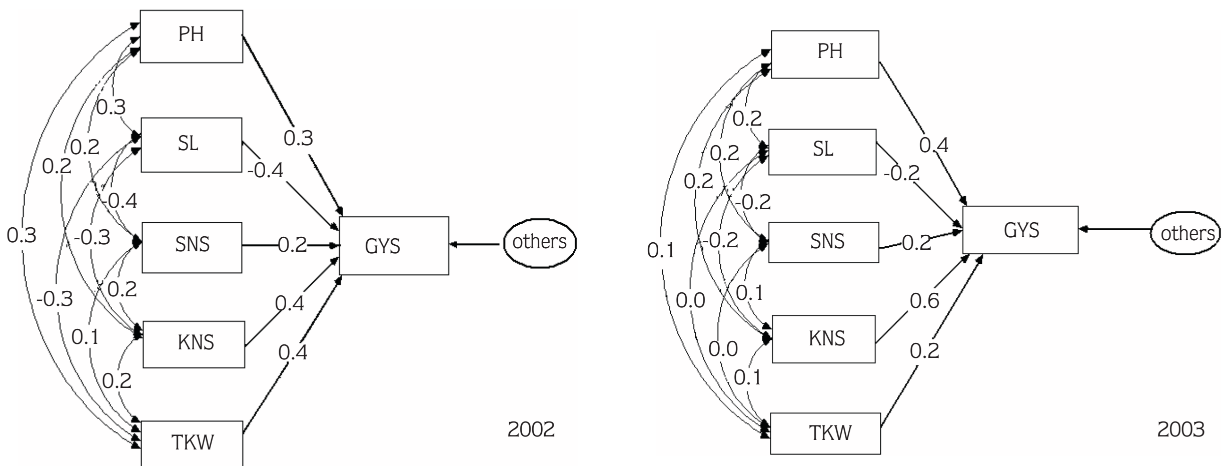
c: Critical differences between reciprocal effects of the *ji*th F1 hybrid

Table 5. Correlation coefficients between grain yield per spike and other traits in bread wheat lines and cultivars.

Traits	PH		SL		SNS		KNS		TKW	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
GYS	0.680**	0.554**	0.632**	0.484**	0.665**	0.430**	0.669**	0.665**	0.737**	0.267**
PH			0.837**	0.599**	0.729**	0.411**	0.583**	0.400**	0.847**	1.147ns
SL					0.896**	0.792**	0.747**	0.633**	0.793**	0.038ns
SNS							0.815**	0.527**	0.753**	-0.040ns
KNS									0.653**	0.133ns

** Correlation coefficient is significant at P ≤ 0.05, ns: Not significant

PH: Plant height, SL: Spike length, SNS: Spikelet number per spike, KNS: Kernel number per spike, TKW: 1000 kernel weight, GYS: Grain yield per spike



PH: Plant height, SL: Spike length, SNS: Spikelet number per spike, KNS: Kernel number per spike, TKW: 1000 kernel weight, GYS: Grain yield per spike

Figure. Path analysis showing direct and indirect effects of 5 traits on grain yield per spike in bread wheat lines and cultivars in 2002 and 2003.

different in our 2-year study was annual precipitation, which was double in the second year, when a much lower yield performance was recorded in all the genotypes. Physiologically, higher rainfall around flowering may cause stress conditions during plant development and reduce grain yield (Araus et al., 2003). Interestingly, wheat yield is negatively correlated with maximum rainfall during flowering (Ozkan and Akcaoz, 2003). On the other hand, a simple general explanation for why in the second year the yield was much lower in all genotypes might be that the much higher winter rainfalls might cause considerable leaching of soil nitrogen (Austin and Arnold, 1989). Therefore, in the second year (2003), the plants were possibly grown under multiple stress factors, and crosses that had similar values might be more promising.

GCA effects were significant for almost all the traits tested. Our results are similar to the findings reported by Barnard et al. (2002) and Joshi et al. (2004), which showed that additive genetic variance was the main component of genetic variance of various economic traits in bread wheat. GCA variances for almost all traits were higher than SCA variances. These results suggest that genetic variation among crosses was primarily of the additive gene effects. Highly significant SCA effects for PH in both years and for GYS and TKW in 2002 indicate possible heterotic effects in these traits. The non-additive gene action or over-dominance was also important for the above characters. It can be concluded that both additive and non-additive gene actions are responsible for the existence of variability in the present study. Both additive and non-additive effects were also illustrated for grain yield and its components by Sheikh et al. (2000) in wheat. P - 311 and SB - 333 were the best parents due to their high GCA effect for TKW, while P - 311, S - 46, and SB - 333 were the best parents due to their high GCA effects for GYS. Although they were the best general combiners, they did not produce the best hybrid combinations in all tested hybrids. This might be due to the large number of genes and it would be difficult to accumulate all of them in homozygous pure lines due to linkage limitations (Singh et al., 1969).

GYS had a positive and significant correlation with all other traits. These results were in agreement with the previous reports by Topal et al. (2004) and Li et al. (2006). Path analysis of the yield components in this study showed that the components having highest correlations to yield also had the largest direct effects on yield. Similar results were reported by Akanda and Mundt (1996). The KNS and TKW had the highest positive direct effect on GYS in both years. The parents Gönen and S - 46 for KNS and P - 311 and SB - 333 for TKW produced positive GCA values in both years. They were the best combiners for TKW and KNS. Therefore, they could be considered in the development of desirable progenies in selection programs.

Acknowledgments

The author is grateful to Dr. G.A. Fragkiadakis, Technological Education Institute (T.E.I.) of Crete, Greece, for his critical reading of the manuscript and valuable suggestions.

References

Altıntaş, S., F. Toklu, S. Kafkas, B. Kilian, A. Brandolini and H. Ozkan. 2008. Estimating genetic diversity in durum and bread wheat cultivars from Turkey using AFLP and SAMPL markers. Plant Breeding. 127: 9-14.

Akanda, S.I. and C.C. Mundt. 1996. Path coefficient analysis of the effects of stripe rust and cultivar mixtures on yield and yield components of winter wheat. Theor. Appl. Genet. 92: 666-672.

Araus, J.L., D. Villegas, N. Aparicio, L.F. Garcia del Moral, S. El Hani, Y. Rharrabti, J.P. Ferrio and C. Royo. 2003. Environmental factors determining carbon isotope discrimination and yield in durum wheat under Mediterranean conditions. Crop Sci. 43: 170-180.

Austin, R.B. and M.H. Arnold. 1989. Variability in wheat yields in England: Analysis and future prospects. In: Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries. (Eds., J.R. Anderson and P.B.R. Hazell), The Johns Hopkins Univ. Press, London, pp. 100-106.

Barnard, A.D., M.T. Labuschagne and H.A. van Niekerk. 2002. Heritability estimates of bread wheat quality traits in the Western Cape province of South Africa. Euphytica. 127: 115-122.

Dağüstü, N. 1990. Anadolu ve Trakya Kökenli Buğday Genetik Materyalinde Kimi Agronomik Özellikler Üzerinde İncelemeler. Yüksek Lisans Tezi. Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, p. 146.

Dağüstü, N. 1997. Research on agronomic characteristics of wheat genetic materials originated from Anatolia and Thrace. J. Agric. Fac., Uludağ Univ. 13: 1-10.

Dere, Ş. and M.B. Yıldırım. 2006. Inheritance of grain yield per plant, flag leaf width, and length in an 8 x 8 diallel cross population of bread wheat (*T. aestivum* L.). Turk. J. Agric. For. 30: 339-345.

Dewey, D.R. and K.H. Lu. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agron. J. 51: 515-518.

Edwards, I.B. 2001. Hybrid wheat. In: The World Wheat Book: A History of Wheat Breeding, (Eds.: A.P. Bonjean and W.J. Angus), Lavoiser Publishers, Paris, pp. 1019-1045.

Ekingen, H.R. 1987. The micro gene centers in Turkey and importance of them. In: National Cereal Symp., Bursa, Turkey, Published for TMO, Ankara, pp. 353-358.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9: 463-493.

Jordaan, J.P., S.A. Engelbrecht, J.H. Malan and H.A. Knobel. 1999. Wheat and heterosis. In: The Genetics and Exploitation of Heterosis in Crops (Eds., J.G. Coors and S. Pandey), ASA-CSSA-SSSA Publication, Madison, USA, pp. 411-421.

Joshi, S.K., S.N. Sharma, D.L. Singhania and R.S. Sain. 2004. Combining ability in the F1 and F2 generations of diallel cross in hexaploid wheat (*Triticum aestivum* L. em. Thell). Hereditas. 141: 115-121.

Kaya, Y., M. Akçura and S. Taner. 2006. GGE-biplot analysis of multi-environment yield trials in bread wheat. Turk. J. Agric. For. 30: 325-337.

Koemel, J.E., A.C. Guenzi, B.F. Carver, M.E. Payton, G.H. Morgan and E.L. Smith. 2004. Hybrid and pureline winter wheat yield and stability. Crop Sci. 44:107-113.

Li, W., Z.-H. Yan, Y.-M. Wei, X.-J. Lan and Y.-L. Zheng. 2006. Evaluation of genotype environment interactions in Chinese spring wheat by the AMMI model, correlation and path analysis. J. Agron. Crop Sci. 192: 221-227.

Menon, U. and S.N. Sharma. 1997. Genetics of yield determining factors in spring wheat over environments. Indian J. Genet. 57: 301-306.

Ozkan, B. and H. Akcaoz. 2003. Impacts of climate factors on yields for selected crops in southern Turkey. Mitig. Adapt. Strat. Gl. Change. 7: 367-380.

Özcan, K. 1999. Development of statistical programme for population genetics studies. PhD Thesis. Ege Univ. Sci Inst., İzmir, Turkey.

Sheikh, S., I. Singh and J. Singh. 2000. Inheritance of some quantitative traits in bread wheat (*T. aestivum* L. em Thell.). Ann. Agric. Res. 21: 51-54.

Singh, K.B., D. Sharma and P.D. Mehndiratta. 1969. Study of combining ability and genetic parameters for yield and its components in wheat. Japan. J. Genetics. 44: 367-377.

Topal, A., C. Aydın, N. Akgün and M. Babaoglu. 2004. Diallel cross analysis in durum wheat (*Triticum durum* Desf.): identification of best parents for some kernel physical features. Field Crops Res. 87: 1-12.

Turkish Statistical Institute. 2006. http://www.tuik.gov.tr/, http://www.turkstat.gov.tr

Zhukovsky, P.M. 1951. The climatical zones of Anatolia. The agricultural structure in Turkey. Sugar Factory Company Publications, Ankara, Turkey, 20: 25-81, 887.