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HETEROSIS AND COMBINING ABILITY ESTIMATES IN 6 X 6 HALF-DIALLEL CROSSES OF DURUM WHEAT (*TRITICUM DURUM* DESF.)

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Abstract

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In the study, the heterosis percentages and combining ability effects were determined for heading time (HT), thousand kernels weight (TKW) and plant yield (PY) of 6 durum wheat parents and their 15 half-diallel crosses. Two local populations (Beyaziye and Bagacak) and four cultivars (Kunduru 1149, Cakmak-79, Diyarbakir-81 and Duraking) of durum wheats were used as parents in the study. Heterosis percentages for high-parent and mid-parent were - 2.16 % and - 0.74 % for heading date; - 1.64 % and 3.78 % for 1000 kernel weight; - 2.24 % and 5.24 % for plant yield, respectively. The highest heterosis percentage for mid-parent was determined at the hybrids of 'Kunduru 1149 x Diyarbakir81' (1.10 %) for heading date; 'Kunduru 1149 x Cakmak 79' (12.86 %) for 1000 kernel weight; 'Beyaziye x Duraking' (37.67 %) combination for plant yield. The general combining ability (GCA) and specific combining ability (SCA) components of variance were significant for three traits studied. The levels of heterosis and general and specific combining abilities of parental lines were sufficient to sustainable production of hybrid breeding and early selection of breeding lines.

Key words: breeding, general combining ability, diallel analysis, specific combining ability, yield

Introduction

After the success of hybrid maize during the 1930s, the phenomenon of heterosis or hybrid vigour has been investigated in all major self- and cross-pollinated species (Uddin et al., 1992). Heterosis and combining ability are the two most important aspects of any hybrid crop.The heterotic effect is in general more pronounced in cross-pollinated than in self-pollinated crops (Gallais, 1988), however, significant levels of heterosis have been reported in a number of self-pollinated crops (Fonseca and Petterson, 1968; Gyawali et al., 1968; Walton, 1969; Ozgen, 1989; Bitzer et al., 1982; Topal et al., 2004).

Observations of heterosis in wheat date back to 1919, when Freeman (1919) studied heading time, height, and leaf width in crosses involving durum wheat and 3 common wheats. Recent discoveries have stimulated interest in and speculation as to the possibility of commercial production of hybrid wheat (Briggle, 1963). Many reports have been published establishing the fact that heterosis does occur with proper combinations of parents (Altinbas and Tosun, 1994; Larik et al., 1995; Yagdi and Karan, 2000).

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Although the concept of hybrid wheat is not new, during the first 20 years, resources were invested in research related to fertility restoration, sterilizing agents, and crossability. Knowledge of heterotic groups from which to draw parental germplasm for hybrid combinations is limited. Improvement of complex characters such as grain yield may be accomplished through the component approach of breeding. This method in general assumes strong associations of yield with a number of characters making up yield and simpler inheritance for these component characters (Edwards et al., 1976). Amaya et al. (1972) found that dominance effects predominated in grain yield; whereas, additive affects primarily controlled plant height and heading date of durum wheat. Generally researches are focusing on the general and specific combining abilities of parental lines and on identifying heterotic groups for yield.

Wheat is an important cool season cereal in Turkey with 9.3 million hectares cultivated and 21 million tonnes annual production (Anonymous, 2005). Durum wheat production makes up 30% of the total production of Turkey (Anonymous, 2002). In view of the importance of the durum wheat and the low average yields in Turkey, an improvement programme was initiated at Department of Field Crops, Faculty of Agriculture, Dicle University in 1998 to develop high yielding varieties. However, the breeding of new lines could only be undertaken after the effects of individual components had been determined.

This study was conducted to evaluate the outstanding durum wheat parents grown in the south-eastern part of Turkey and to determine the possible hybrid combinations.

Material and Methods

Two local populations (Beyaziye and Bagacak) and four cultivars (Kunduru 1149, Cakmak-79, Diyarbakir-81 and Duraking) of durum wheats (Table 1) were used as parents in the study. They were crossed in 6 x 6 half-diallel crosses to produce the 15 possible F_1 hybrids in 1998. Parents and their F_1 hybrids were grown at the experimental field of the Faculty of Agriculture, University of Dicle, Diyarbakir, Turkey during 1998-1999 growing season. The soil characteristic of experimental field was clay loam, with pH 7.6, and organic matter and $CaCO_3$ contents of 1.44 and 2.64%, respectively. Average temperature, rainfall and relative humidity of the growing seasons are shown in Table 2. Total annual precipitation was 302.4 mm, which was less then average (491.4 mm) of the site. The experimental plots were arranged in a randomized complete block design with 4 replications (Cakmakci and Acikgoz, 1994; Sarawgi et al., 1997; Czapar et al., 2002).

Sowings were made 10 November 1998. Each block consisted of 15 F_1 and 6 parent plants on single 2 m rows which were 30 cm apart. Plant spacing was

Table 1

Some characters of durum wheat parents used in the experiment

Name of genotype/pedigree	Features
Kunduru 1149/released in Turkey (1967)	Winter type, normal yielding, tall plant height, late maturity, normal kernels,
Cakmak 79/released in Turkey (1988)	Winter type, normal yielding, normal plant height, late maturity, normal kernels,
Beyaziye/local population	Spring type, normal yielding, tall plant height, late maturity, big kernels,
Bagacak/local population	Spring type, normal yielding, tall plant height, late maturity, big kernels,
Diyarbakir 81/released in Turkey (1987)	Spring type, normal yielding, normal plant height, normal maturity, big kernels,
Duraking/ not released in Turkey	Spring type, normal yielding, normal plant height, late maturity, normal kernels

Table 2
Meteorological data for 1998-1999 growing season in Diyarbakir (monthly average)*

Months	Average temperature, °C			Rainfall, mm			Relative humudity, %		
	Years			Years			Years		
	1998	1999	LTA[1]	1998	1999	LTA[1]	1998	1999	LTA[1]
January	-	4.5	1.6	-	15.6	74.6	-	71	77
February	-	5.3	3.6	-	45.5	68.4	-	67	73
March	-	8.1	8.3	-	52	66.2	-	65	66
April	-	13.6	13.9	-	76.1	73.5	-	64	63
May	-	21	19.3	-	22.4	40.8	-	43	56
June	-	27.3	25.9	-	1.1	7.2	-	31	36
July	-	-	31	-	-	0.7	-	-	27
August	-	-	30.3	-	-	0.6	-	-	27
September	-	-	24.9	-	-	2.6	-	-	31
October	12.5	-	17.1	0.2	-	30.8	33	-	48
November	5.6	-	9.8	27.2	-	54.6	59	-	68
December	16.2	-	4.1	62.3	-	71.4	79	-	77

[1] Long term averages.
[*] Turkish State Meteorological Service, Diyarbakir Meteorology Station, Turkey.

10 cm. By sowing 60 kg ha^{-1} nitrogen and phosphate in the form of diammonium phosphate (20.20.0.) and in tillering stage 40 kg ha^{-1} ammonium nitrate (26%), was applied as fertilizer.

During the study, heading time (HT), thousand kernel weight (TKW) and plant yield (PGY) were measured. All measurements for the following characters were made on plot basis:

Heading time*:* number of days from emergence of seedling to the date when the first spike had completely emerged from the flag-leaf sheath.

Thousand kernel weight*:* weight of 1000 randomly selected kernels

Plant yield: plant number / total grain yield of each plot.

The plant material was evaluated by analysis of the data on heterosis and combining ability for heading time (HT), thousand kernels weight (TKW) and plant yield (PY) at the F_1 generation. The analyses of variance for general (GCA) and specific (SCA) combining abilities were carried out according to Griffing's (1956) Method 2 (half-diallel set), Model 1. Heterosis (MP: mid-parent) and heterobeltiosis (BP: best parent) values were, respectively, calculated by using this formula (Fonseca and Patterson, 1968):

MP= (value of F_1- mean of parents/mean of parents) x 100

BP= (value of F_1- value of best parent/value of best parent) x 100

Analysis of variance was done using a computerised statistical program called MSTAT-C (MSTAT-C, 1990).

Results

Analysis of variance showed significant differences among genotypes for heading time (HT), thousand kernels weight (TKW), and plant grain yield (PGY) (Table 3). Mean squares for general combining ability (GCA) and specific combining ability (SCA) effects for HT, TKW and PGY were significant. The fact that GCA and SCA were significant indicates that both additive and non-additive gene action are involved in traits in the genotypes studied. GCA, which measured the additive effects of genes, was superior in magnitute to SCA for HT and TKW. GCA/SCA values were

Table 3
Analysis of variance for heading time (HT), thousand kernel weight (TKW) and plant yield (PY) of 6 durum wheat parents and F_1 progeny of durum wheat

Sources	d.f.	Mean Square		
		HT	TKW	PY
Replications	3	9.847*	6.937*	1.955*
Genotypes	20	32.454**	34.732**	1.498**
GCA+	5	109.267**	87.8706**	1.9158**
SCA++	15	6.851**	17.2001**	1.3538**
Error	60	0.692	2.146	0.352
Total	83	42.993	43.815	3.805
CV (%)		0.66	3.75	11.18

*, **= Significant at p <0.05 and p <0.01 level, respectively,
+ = General combining ability, ++ = Specific combining ability

calculated as 5.3 for HT, 1.7 for TKW and 0.5 for PGY. Effects of SCA were of minor importance for HT and TKW. SCA expression was detected only for GPY. Except GPY, there was a marked superiority of GCA over the SCA mean squares, suggesting that these traits were mediated mainly by additive gene action. Interestingly most of genetic variation was due to SCA for PGY. This trait was mediated mostly by dominance gene action (Table 4).

The parent of 'Duraking' was the earliest over all genotypes and among F_1 hybrids '1 x 6' and '5 x 6' were earliest. The range of HT among genotypes was 7.8 day. The average TKW and PGY over cultivars were 39.0 g and 5.31 g plant^{-1}, respectively. 'Cakmak 79' had the highest PGY among all parents and the F_1 of '3 x 6' had highest PGY. The F_1 hybrids '1 x 4' and '3 x 4' had highest TKW. The TKW for landrace parents 'Beyaziye' and 'Bapacak' were higher than other parent, 41.0 and 42.1 g, respectively. Hybrids had earlier flowering, significantly higher TKW and higher PGY than parents.

Negative values for the GCA and SCA effects for HT indicate a contribution to earlines, or longer grain filling duration, while positive for the GCA and SCA effects indicate a tendency low growing rate. Cultivar 'Diyarbakir 81' and 'Duraking' was characterized by increasing GCA effect for early heading. On the contrary, 'Kunduru 1149' and 'Bagacak' had positive GCA showing long HT (Table 5). The landraces of 'Beyaziye' and Bagacak' were generally found to be best combiners for TKW. Generally 'Cakmak 79' and 'Diyarbakir 81' had high positive GCA effects and contrary 'Kunduru 1149' and 'Duraking' had negative GCA effects. F_1 hybrids had earlier HT and higher TKW and PGY than the parent means.

In cross combinations, positive and negative SCA effects were identified for all traits. However, the signs of SCA effects were generally positive for TKW and negative for PGY. Five cross combination had positive SCA effects both TKW and PGY. '1 x 4' was the most efficient hybrid for all TKW and PGY. Hybrids had positive or negative SCA effects for HT.

The average difference between parents and hybrids was generally due to heterosis for all traits. Six hybrids for TKW, five hybrids for GYP had best parent heterosis, as expected with a predominance of additive effects.

Heterosis values estimated for investigated traits in F_1 hybrids were given at Table 6. HT, TKW and PGY showed positive and negative MP and BP heterosis in all the hybrids. Heterosis values among all the crosses for HT varied from 1.1 % to -2.2 % and

Table 4
Mean of heading time (HT), thousand kernel weight (TKW) and plant yield (PY) of parents and their F_1 progeny from a half-diallel cross in durum wheat

Parents and crosses	HT, days	TKW, g	PY, g
(1) Kunduru 1149	129.2 a	36.17 gh	4.350 de
(2) Cakmak 79	129.1 a	34.54 hı	5.992 ab
(3) Beyaziye	128.6 ab	41.04 bc	5.455 bc
(4) Bagacak	129.7 a	42.06 abc	5.210 bcd
(5) Diyarbakir 81	123.6 def	40.30 cde	5.398 bc
(6) Duraking	122.0 g	33.99 ı	4.365 de
1 x 2	129.8 a	39.91 cde	5.392 bc
1 x 3	128.8 ab	41.40 bc	4.780 cde
1 x 4	129.8 a	44.07 a	5.543 bc
1 x 5	127.8 bc	40.33 cde	5.793 bc
1 x 6	122.8 fg	32.71 ı	3.955 e
2 x 3	126.8 c	38.54 def	5.588 bc
2 x 4	129.0 ab	36.94 fg	5.000 bcd
2 x 5	123.8 def	38.01 efg	5.615 bc
2 x 6	124.3 de	37.23 fg	5.225 bcd
3 x 4	129.3 a	42.78 ab	5.342 bc
3 x 5	124.5 d	40.46 bcd	5.222 bcd
3 x 6	123.3 defg	39.99 cde	6.760 a
4 x 5	124.0 def	40.31 cde	5.628 bc
4 x 6	124.5 d	40.81 bcd	5.088 bcd
5 x 6	123.0 efg	38.04 efg	5.785 bc
Mean	126.4	39.03	5.31
Parent	127	38.02	5.13
F_1	126.1	39.44	5.38
LSD (0.05)	1.18	2.07	0.839

0.5 % to -5.0 % for mid-parent (MP) and best-parent (BP) heterosis, respectively. MP and BP heterosis values reached to 12.9 % and 10.3 % for TKW, 37.7 % and 23.9 % for PGY, respectively. Especially for PGY, there were very high heterosis values in '1 x 4', '1 x 5', '3 x 6' and '5 x 6' hybrids which had highest PGY among the hybrids. Of 15 crosses, MP heterosis were found to be increasing effects in 10 crosses for early HT, in 11 crosses for high TKW, in 9 crosses for high PGY. One, six and five F_1 hybrids were in the range of best-parental values, indicating over dominance for HT, TKW and PGY, respectively.

When the correlations were calculated using the hybrids or the parents separately, the relationship between PGY, HT and TKW remained non significant (data not shown).

Discussion

The best performed hybrid, '3 x 6', outyielded the best yielding parents at 23.9 %. The average yield advantage for '1 x 5', '3 x 6' and '5 x 6' hybrids over

Table 5
Value of general combining ability (GCA) and specific combining ability (SCA) in heading time (HT), thousand kernel weight (TKW) and plant yield (PY) of parents and their F_1 progeny in durum wheat

Parents and crosses	HT, days	TKW, g	PY, g
GCA			
(1) Kunduru 1149	1.598	-0.302	-0.375
(2) Cakmak 79	0.917	-1.684	0.205
(3) Beyaziye	0.654	1.508	0.18
(4) Bagacak	1.442	1.979	-0.018
(5) Diyarbakir 81	-1.783	0.57	0.209
(6) Duraking	-2.827	-2.071	-0.2
gi^{+} (0.05)	0.018	0.056	0.009
SCA			
1 x 2	0.897	2.862	0.254
1 x 3	0.159	1.168	-0.334
1 x 4	0.372	3.366	0.627
1 x 5	1.597	1.046	0.65
1 x 6	-2.36	-3.944	-0.779
2 x 3	-1.159	-0.301	-0.106
2 x 4	0.303	-2.383	-0.496
2 x 5	-1.722	0.098	-0.108
2 x 6	-0.178	1.958	-0.089
3 x 4	0.816	0.266	-0.128
3 x 5	-0.71	-0.644	-0.475
3 x 6	-0.916	1.526	1.471
4 x 5	-1.997	-1.265	0.128
4 x 6	-0.453	1.875	-0.003
5 x 6	1.272	0.515	0.467
sij^{++} (0.05)	0.136	0.421	0.069

$^{+}$ = Critical differences between GCA effects of parents
$^{++}$ = Critical differences between SCA effects of the F_1 hybrid

MP heterosis were 18.9, 37.7 and 18.5 %, respectively (Table 6). These levels of heterosis are greater than the 15% claimed by Boland and Walcott (1985) to be minimum level of heterosis required for the viable commercial production of hybrid wheat using the cytoplasmic male sterility fertility restoration system. The results obtained in this study indicate that the levels of yield performance and heterosis comparable with those reported by others (Topal et al., 2004; Budak, 2001; Bitzer and Fu, 1972).

The highest yielding hybrids in these experiment, ‘1 x 5’, ‘3 x 6’ and ‘5 x 6’ exhibited the highest level of heterosis. This observation emphasizes that it is absolute yield similar magnitude of heterosis which is

Table 6
Heterosis values (%) over mid-parent (MP) and better parent (BP) for heading time (HT), thousand kernel weight (TKW) and plant yield (PY) in durum wheat crosses

Crosses	HT		TKW		PY	
	MP, %	BP, %	MP, %	BP, %	MP, %	BP, %
1 x 2	0.5	0.54	12.86	10.34	4.29	-9.93
1 x 3	-0.07	0.16	7.22	0.87	-2.5	-12.37
1 x 4	0.27	0.46	12.65	4.77	15.96	6.39
1 x 5	1.1	3.4	5.49	0.09	18.85	7.31
1 x 6	-2.22	0.66	-6.75	-9.56	-9.24	-9.39
2 x 3	-1.59	-1.4	2.01	-6.06	-2.39	-6.75
2 x 4	-0.3	4.37	-3.55	-12.17	-10.73	-16.55
2 x 5	-2.01	0.16	1.57	-5.68	-1.4	-6.29
2 x 6	-0.99	1.89	8.63	7.78	0.88	-12.8
3 x 4	0.11	0.54	2.96	1.71	0.16	-1.89
3 x 5	-1.26	0.73	-0.51	-1.41	-3.77	-4.27
3 x 6	-1.59	1.07	6.58	-2.55	37.67	23.92
4 x 5	-2.09	0.32	-2.11	-4.16	6.08	4.24
4 x 6	-1.07	2.05	7.31	-2.97	6.26	-2.34
5 x 6	0.16	0.82	2.39	-5.6	18.49	7.16
Mean	-0.74	1.05	3.78	-1.64	5.24	-2.24

important, as heterosis is a real measure dependent on both hybrid and parental performance. This is not correlated the finding of Uddin et al. (1992), emphasized grain yield more imported than heterosis.

Conclusion

The observed level of heterosis of '1 x 2', '1 x 4', '1 x 5', '3 x 6', '4 x 5', '4 x 6' and '5 x 6' was above the value estimated by Brown et al. (1966) (13%), Bitzer and Fu (1972) (9.6%), Rajaram (2001) (11%) as being required to sustain the hybrid wheat production. The coefficient of variation values were low all characters in this study (Table 3). These values indicate that reliable information can be obtained from small plot experiments. This is consisted with the study of Uddin et al. (1992). High heterosis of hybrids for the traits suggested the possible exploration of durum hybrids to raise grain yield potential within the existing genetic variation. Also some hybrids can be successfully designed to capitalize on contrasting heterotic groups present in less adapted parents carrying alien substitutions and translocations, for example, or in genotypes with a more extreme expression of yield components.

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