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Combining Ability and Heterosis for Yield and Fiber Quality Properties in Cotton (*G. hirsutum* L.) obtained by Half Diallel Mating Design

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Abstract

The objective of this study was to investigate the general combining ability (GCA) of parents and specific combining ability (SCA) of hybrids and also the genetic behavior for studied characteristics in the population obtained by 7x7 half diallel quantitative analysis method involving four MAR (Multi Adversity Resistance) and three commercial cotton (*Gossypium hirsutum* L.) varieties. The twenty one F_1 and seven parents were planted as a randomized complete block design with four replications in 2004. The general combining ability (GCA) variance effects of the parents and the specific combining ability (SCA) variance effects of the hybrids and the gene effects were estimated by using the half diallel analysis method 2, model 1, described by Griffing. In the populations ginning percentage, fiber length, fiber fineness and fiber elongation properties were influenced by additive; seed cotton yield, fiber strength and fiber uniformity ratio were influenced by non-additive gene effects. Significant and positive heterosis values were observed except in fiber uniformity for seed cotton yield, fiber strength, fiber fineness, fiber elongation and ginning percentage respectively. It was determined that 'Sayar 314' for seed cotton yield and fiber length, 'Tamcot CD3H' for fiber uniformity ratio, 'Tamcot Sphinx' for fiber strength, 'Tamcot Luxor' for ginning percentage and fiber elongation, 'Tamcot HQ95' for fiber fineness were the best parent cotton cultivars and also having the best (GCA) general combining abilities. It was also determined that 'Maraş 92' x 'Tamcot HQ95' for fiber fineness, 'Stoneville 453' x 'Tamcot Sphinx' for seed cotton yield, 'Tamcot HQ95' x 'Tamcot Sphinx' for ginning percentage and fiber elongation, 'Maraş 92' x 'Sayar 314' for fiber length, 'Maraş 92' x 'Tamcot HQ95' and 'Tamcot CD3H' x 'Tamcot Sphinx' for fiber strength, 'Sayar 314' x 'Stoneville 453' for fiber uniformity ratio hybrid combinations were the most promising crosses with the highest specific combining ability.

Keywords: cotton, multi adversity resistance (MAR), general combining ability, specific combining ability, heterosis

Introduction

The development of a new cotton variety with high yield and fiber quality properties is the unique target off all cotton breeders. Diallel analysis has been widely used by plant breeders in the selection of parents and crosses in the early generations (Marani, 1967; Green and Culp, 1990; Islam *et al*., 2001; Braden *et al*., 2003; Kiani *et al.,* 2007). Information pertaining to the different types of gene action, relative magnitude of genetic variance and combining ability estimates are important and vital parameters to mold the genetic makeup of the cotton crop (Subhan *et al*., 2003). This important information could prove an essential strategy to the cotton breeder in the screening of better parental combinations for further enhancement.

The combining ability describes the breeding value of parental lines to produce hybrids, general and specific combining ability as defined by (Sprague and Tatum, 1942) who stated that GCA effects were due to an additive type of gene action, but SCA effects were due to genes which exhibit non additive (dominant and epistatic) type of gene action.

Myers and Lu (1998) reported that GCA effects were more significant than SCA effects for micronaire, upper-half mean length, fiber strength and elongation suggesting that additive gene action is important for these traits. Baker and Verhalen (1975) drew similar conclusions concerning the importance of additive gene action with regards to fiber traits. Bhardwaj and Kapoor (1998) revealed that seed cotton yield and lint index were controlled by both additive and non additive genetic variances and ginning percentage were controlled by additive genetic variances. Green and Culp (1990) found that GCA effects were significant for all fiber properties except for the uniformity index. Cheatham *et al.* (2003) reported that Australian and wild cotton varieties have the genes to improve fiber quality and fertility; fineness and length primarily exhibit dominance genes effects, fiber percentage and fiber strength are controlled by additive genes effects; fiber yield and fiber elongation extension are controlled equally by additive and dominant gene effects, yield and fiber quality could be improved by using these varieties in the U.S.A breeding studies.

Exploiting heterosis is one of the methods to increase cotton yield. Regarding previous studies on heterosis in cotton documented in numerous reviews, researches reported that different heterosis values obtained for yield and fiber quality properties. Lee *et al.* (1967) reported 26%

heterosis in fiber yield, also Marani (1967) reported 24.5% for lint yield, Ghulam *et al.* (1989) obtained the highest heterosis and heterobeltiosis for lint yield. For fiber quality properties no significant heterotic effects were obtained for micronaire and strength (Thomson, 1971). Meredith and Brown (1998) found that significant heterosis for lint yield, lint percentage and fiber length suggest at least one parent should have above average fiber quality.

The present study of a half diallel analysis involving four MAR cotton varieties and three regional varieties is an attempt to produce cotton hybrids with diverse genetic background for seed cotton yield and fiber quality properties.

The aim of this study was to estimate general combining ability of parents and specific combining ability of hybrids and determine the magnitude of heterosis and the pattern of gene action in the breeding program to develop high yielding and quality cotton varieties.

Materials and methods

The genetic materials were used four Multi Adversity Resistance (MAR) cotton varieties (*Gossypium hirsutum* L.) namely, 'Tamcot CD3H', 'Tamcot HQ95', 'Tamcot Sphinx', 'Tamcot Luxor' and three commercial cotton varieties (*Gossypium hirsutum* L.) namely 'Maraş 92', 'Sayar 314' and 'Stoneville 453' and their twenty one F_1 hybrids

Seven parents were crossed using a half diallel mating design in 2003. Seven parents and their twenty-one F_1 hybrids were planted in a randomized complete block design with four replications at the Southeastern Anatolia Agricultural Research Institute, Diyarbakır in 2004. Each plot contained two rows, of 12 m length at planting and 10 m length at harvest. The distance between and within the rows spacing were 0.70 m and 0.15 m, respectively. Sowing was made with combine cotton drilling machine on 15th May 2004; all plots received 120 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5. Half of the N and all P_2O_5 were applied at sowing time and the remaining N was given at the square stage as ammonium nitrate. The experiment was thinned and hoed twice by hand and three times by machine and herbicides were applied only once just before sowing. Insects were monitored throughout the experiment and decided that no insect control was necessary during the growing season. Furrow irrigation was applied seven times starting up with June 26, amounting to 750 mm water. Plots were harvested twice by hand for yield determination on October 5, 2004 and on 1st November 2004. Before harvest 25 open bolls were hand picked randomly from each genotype and were ginned on a laboratory roller-gin for lint percentage. Fiber samples were analyzed for quality characters by HVI Spectrum at the Nazilli Cotton Research Institute cotton fiber laboratory.

Seed cotton yield, ginning percentage, fiber length, fiber fineness, fiber strength, fiber elongation and fiber uniformity were analyzed with the TarPopGen computer program (Ozcan and Açıkgöz, 1999) and differences were scrutinized for significance using LSD 0.05. The general combining ability (GCA) variance effects of the parents and the specific combining ability (SCA) variance effects of the hybrids were estimated using the half diallel analysis method described by Griffing (1956) based on method 2, model 1. This method involved parents and one set of F_1. The linear model assumed is

$$X_{ij} = u + g_i + g_j + s_{ij} + 1/bc \Sigma_k \Sigma_1 e_{ijkl}$$

where, X_{ij}, value of the F_1 hybrids of ith and jth parents; u, mean of population; g_i and g_j, general combining ability (GCA) effect of ith and jth parents; S_{ij}, specific combining ability (SCA) effect of the cross involving ith and jth parent;

e_{ijkl}, error associated with ijth observation

i, j: 1, 2 ... p (number of parents)

k: 1, 2 ... b (number of replications)

l: 1, 2 ... c (number of observation per plot)

The magnitude of heterosis in terms of percentage of increase or decrease of F_1 hybrids over mid-parent (MP) for each character was computed according to Hallauer and Miranda (1981).

Results and discussion

The analysis of variance of the investigated characters in the population is presented in Tab. 1. Mean squares for genotypes were found to be highly significant for all the characters under study, indicating considerable genetic diversity, hence later analysis for combining ability was possible. The total genetic variability was partitioned to general combining ability and specific combining ability.

Mean squares of general combining ability (GCA) were found significant for ginning percentage, fiber length, fiber fineness and fiber elongation, revealing the important role of additive gene effects, but not for seed cotton yield, fiber strength and fiber uniformity. Specific combining ability (SCA) was found significant for the seed cotton yield, fiber length, fiber fineness, fiber strength, fiber elongation and fiber uniformity, revealing that non-additive gene effects, as dominant or epistatic are important (Tab. 1)

The general combining ability (GCA) effects were higher than specific combining ability (SCA) effects for the ginning percentage, fiber length, fiber fineness and fiber elongation which indicated that additive gene action is prevailing with dominant or epistatic for the expression of these traits. Mean squares of the specific combining ability (SCA) were found to be highly significant for seed cotton yield, fiber strength and fiber uniformity, revealing important role and non-additive gene effects. The results are in agreement with the previous studies of (Baker and Verhalen, 1975; Myers and Lu, 1998; Green and Culp, 1990). Specific combining ability (SCA) was found highly significant for seed cotton yield, fiber strength and fiber uniformity, revealing an important role of non-additive

Tab. 1. Analysis of variance for genotypes and combining ability for yield and fiber quality properties in half diallel cross of cotton

Source of Variation	DF	SCY	GP	FL	FF	FS	FE	FU
Replication	3	744.159**	5.069	1.900*	1.120**	1.987	0.288	3.162*
Genotypes	27	425.742**	6.681*	3.264**	0.434**	20.234**	0.268**	3.625**
Error	81	149.100	3.427	0.527	0.131	5.154	0.108	1.125
GCA	6	71.198	3.143**	2.117**	0.256**	1.645	0.100**	0.463
SCA	21	116.503**	1.249	0.444**	0.067*	6.034**	0.058**	1.033**
Error	81	37.275	0.857	0.132	0.033	1.288	0.027	0.281
σ^2GCA/ σ^2SCA		0.611	2.516	4.768	3.820	0.272	1.724	0.448

σ^2GCA: variance of general combining ability, σ^2SCA: variance of specific combining ability * and **: significant at P ≤ 0.05 and P ≤ 0.01 respectively; DF: Degrees of freedom, SCY: Seed cotton yield (g plant), GP: Ginning percentage (%), FL: Fiber length (mm), FF: Fiber fineness (micronaire), FS: Fiber strength (g/tex), ELG: Elongation (%), UNF: Uniformity (%)

gene effects. Green and Culp (1990), Bhardwaj and Kapoor (1998) and Cheatham *et al.* (2003) presented similar results in their studies.

General combining ability effects were presented in Tab. 2. As regards the estimates for general combining ability (GCA) effects, for seed cotton yield only one parent showed significant GCA effects, negative GCA effects for seed cotton yield were predicted for 'Tamcot Luxor'. Positive GCA effects for ginning percentage were predicted for 'Tamcot Luxor'. Although 'Tamcot Luxor' was predicted to have the greatest GCA for ginning percentage, crosses with this parent showed reduced yield and fiber length. Positive GCA effects for fiber length were predicted 'Sayar 314' and 'Stoneville 453', whereas negative GCA effects were predicted for 'Tamcot Sphinx' and 'Tamcot Luxor'. Positive GCA effects for fiber fineness were predicted for 'Maraş 92' and 'Tamcot Luxor' and negative GCA effects were predicted 'Stoneville 453', 'Tamcot HQ95' and 'Tamcot Sphinx'. For fiber strength only one parent showed negative GCA effects. Positive GCA effects for fiber elongation were predicted for 'Tamcot Luxor', while negative GCA effects were predicted 'Tamcot HQ95'. For fiber uniformity only one parent showed positive GCA effects for 'Tamcot CD3H'.

Specific combining ability effects of the hybrids for seed cotton yield and fiber quality properties are presented in Tab. 3. Based on the results of SCA effects for hybrids 'Sayar 314' x 'Tamcot Luxor', 'Stoneville 453' x 'Tamcot CD3H' and 'Stoneville 453' x 'Tamcot Sphinx' for seed cotton yield, 'Sayar 314' x 'Tamcot HQ95' and 'Tamcot HQ95' x 'Tamcot Sphinx' for ginning percentage were found to be the best specific combinations. Significant and positive specific combining ability effects for fiber length were observed in five crosses of the twenty-one cross combinations, 'Maraş 92' x 'Sayar 314', 'Maraş 92' x 'Stoneville 453', 'Maraş 92' x 'Tamcot HQ95', 'Sayar 314' x 'Stoneville 453', 'Tamcot HQ95' x 'Tamcot Luxor'. In contrast, significant and negative specific combining ability were observed in 'Maraş 92' x 'Tamcot HQ95' and 'Stoneville 453' x 'Tamcot CD3H' cross combinations for fiber fineness as these hybrid combinations seem to be desirable for this propose. Significant and positive SCA effects for fiber strength were observed in five of the twenty-one cross combinations. 'Maraş 92' x 'Tamcot HQ95', 'Sayar 314' x 'Stoneville 453', 'Sayar 314' x 'Tamcot Sphinx', 'Stoneville 453' x 'Tamcot CD3H', 'Tamcot CD3H' x 'Tamcot Sphinx'. Significant and positive SCA effects for fiber elongation were observed in three crosses 'Maraş 92' x 'Tamcot HQ95', 'Sayar 314' x 'Stoneville 453' and 'Tamcot HQ95' x 'Tamcot Sphinx'. Significant and positive SCA effects for fiber uniformity were observed in only one cross 'Sayar 314' x 'Stoneville 453' as these hybrid combination were found to be the best combinations for fiber uniformity.

Tab. 2. Predicted general combining ability effects (GCA) for yield and fiber properties of seven parents

Parents	SCY	GP	FL	FF	FS	FE	FU
'Maraş 92'	0.185	-0.142	0.221	0.245**	-0.015	-0.018	0.083
'Sayar 314'	3.330	-0.200	0.538**	0.109	0.188	-0.043	-0.213
'Stoneville 453'	0.343	-0.370	0.259*	-0.159**	-0.866*	-0.058	-0.076
'Tamcot CD3H'	-0.907	-0.507	0.061	-0.023	0.267	0.094	0.335**
'Tamcot HQ95'	2.182	-0.213	0.213	-0.191**	-0.141	-0.155**	-0.291
'Tamcot Sphinx'	0.388	0.182	-0.400**	-0.124*	0.456	0.013	-0.061
'Tamcot Luxor'	-5.521**	1.250**	-0.893**	0.144*	0.111	0.168**	0.224
SE	1.884	0.286	0.112	0.056	0.350	0.051	0.164

SE: Standard error, * and ** :significant at P ≤0.05 and P ≤0.01 respectively, SCY: Seed cotton yield (g plant), GP: Ginning percentage (%), FL: Fiber length (mm), FF: Fiber fineness (micronaire), FS: Fiber strength (g/tex), ELG: Elongation (%), UNF: Uniformity (%)

Tab. 3. Predicted specific combining ability effects (SCA) for yield and fiber properties of hybrids

Hybrid Combinations	SCY	GP	FL	FF	FS	FE	FU
'Maraş 92' x 'Sayar 314'	2.894	-0.643	1.076**	-0.025	-1.274	-0.147	0.679
'Maraş 92' x 'Stoneville 453'	3.579	-0.763	0.587*	-0.139	1.348	-0.197	0.174
'Maraş 92' x 'Tamcot CD3H'	7.092	0.687	0.465	-0.100	-1.618	0.116	0.730
'Maraş 92' x 'Tamcot HQ95'	-2.903	-1.060	0.784**	-0.364**	4.190**	0.265*	0.756
'Maraş 92' x 'Tamcot Sphinx'	-0.088	0.405	-0.931	-0.111	-2.607**	0.032	-0.341
'Maraş 92' x 'Tamcot Luxor'	7.213	0.872	-0.053	0.193	-0.429	-0.123	0.707
'Sayar 314' x 'Stoneville 453'	-2.038	-0.072	1.033**	-0.143	2.877**	0.361**	2.103**
'Sayar 314' x 'Tamcot CD3H'	-2.893	0.137	-0.114	0.106	-0.056	-0.058	0.692
'Sayar 314' x 'Tamcot HQ95'	6.552	1.638*	-0.251	0.134	-2.748**	-0.075	-1.147**
'Sayar 314' x 'Tamcot Sphinx'	-5.000	-1.224	0.329	-0.203	3.355**	0.290*	-0.544
'Sayar 314' x 'Tamcot Luxor'	15.711**	-1.130	-0.415	-0.176	-2.200*	-0.398**	-0.997*
'Stoneville 453' x 'Tamcot CD3H'	13.422**	-0.542	0.287	-0.276*	3.634**	-0.043	-0.678
'Stoneville 453' x 'Tamcot HQ95'	7.102	-0.719	-0.947**	-0.113	-0.059	-0.295*	-1.352**
'Stoneville 453' x 'Tamcot Sphinx'	19.579**	0.156	-0.075	0.065	-3.855**	-0.227	0.286
'Stoneville 453' x 'Tamcot Luxor'	2.258	1.378	0.318	0.315*	1.122	0.050	-0.799
'Tamcot CD3H' x 'Tamcot HQ95'	-12.778**	-0.545	0.006	0.214	-1.559	-0.212	-0.763
'Tamcot CD3H' x 'Tamcot Sphinx'	5.200	0.895	0.396	0.284*	3.612**	-0.279*	-0.393
'Tamcot CD3H' x 'Tamcot Luxor'	8.899	-1.915**	-0.474	0.516**	0.922	-0.002	0.590
'Tamcot HQ95' x 'Tamcot Sphinx'	7.250	1.926**	-0.139	0.305*	1.684	0.434**	0.066
'Tamcot HQ95' x'Tamcot Luxor'	-1.424	-1.427*	0.800**	-0.126	0.729	-0.121	-0.285
'Tamcot Sphinx' x 'Tamcot Luxor'	-5.319	-0.627	-0.508**	-0.170	-0.900	0.147	-1.282**
SE	4.663	0.707	0.277	0.138	0.867	0.125	0.405

SE: Standard error, * and **:significant at P ≤ 0.05 and P ≤ 0.01 respectively; SCY: Seed cotton yield (g plant), GP: Ginning percentage (%), FL: Fiber length (mm), FF: Fiber fineness (micronaire), FS: Fiber strength (g/tex), ELG: Elongation (%); UNF: Uniformity (%)

Tab. 4. Heterosis of F_1 hybrid combinations for yield and fiber properties

Hybrid Combination	SCY	GP	FL	FF	FS	FE	FU
'Maraş 92' x 'Sayar 314'	14.86	-2.63	6.76	-5.02	-4.45	-2.98	1.87
'Maraş 92' x 'Stoneville 453'	29.31	-2.49	4.71	-7.81	8.74	-5.12	0.94
'Maraş 92' x 'Tamcot CD3H'	23.30	0.58	3.75	-1.17	-1.60	-0.34	1.73
'Maraş 92' x 'Tamcot HQ95'	3.25	-2.99	4.55	-11.29	15.41	4.48	0.90
'Maraş 92' x 'Tamcot Sphinx'	13.85	1.62	-2.37	-4.73	-7.67	2.12	-0.26
'Maraş 92' x 'Tamcot Luxor'	29.31	0.07	1.24	4.33	-2.29	-4.07	1.02
'Sayar 314' x 'Stoneville 453'	18.57	-1.30	5.92	-6.87	14.29	4.62	2.66
'Sayar 314' x 'Tamcot CD3H'	7.67	-1.23	1.51	5.25	3.87	-3.21	1.10
'Sayar 314' x 'Tamcot HQ95'	14.05	3.07	0.76	1.71	-7.25	-1.44	-1.93
'Sayar 314' x 'Tamcot Sphinx'	5.67	-2.82	1.74	-5.80	11.76	6.76	-1.07
'Sayar 314' x 'Tamcot Luxor'	39.39	-4.99	-0.30	-2.55	-7.66	-8.60	-1.56
'Stoneville 453' x 'Tamcot CD3H'	45.91	-2.45	2.50	-4.31	22.12	-4.26	-0.83
'Stoneville 453' x 'Tamcot HQ95'	27.05	-2.21	-1.97	-4.44	6.32	-6.86	-2.48
'Stoneville 453' x 'Tamcot Sphinx'	56.11	0.98	-0.02	0.78	-7.86	-3.78	-0.39
'Stoneville 453' x 'Tamcot Luxor'	35.37	1.22	1.89	9.41	7.59	-2.48	-1.62
'Tamcot CD3H' x 'Tamcot HQ95'	-9.42	-2.22	0.71	11.20	0.81	-5.69	-1.65
'Tamcot CD3H' x 'Tamcot Sphinx'	22.20	2.33	1.05	13.75	17.23	-5.11	-1.06
'Tamcot CD3H' x 'Tamcot Luxor'	33.16	-6.84	-1.44	21.58	6.51	-3.77	0.14
'Tamcot HQ95' x 'Tamcot Sphinx'	17.91	5.52	-1.04	9.60	8.48	9.64	-1.37
'Tamcot HQ95' x'Tamcot Sphinx'	9.27	-5.07	2.72	0.77	3.61	-4.01	-1.73
'Tamcot Sphinx' x 'Tamcot Luxor'	11.10	-2.21	-2.76	0.25	-2.45	2.27	-2.75

SCY: Seed cotton yield (kg ha -1), GP: Ginning percentage (%), FL: Fiber length (mm), FF: Fiber fineness (micronaire), FS: Fiber strength (g/tex), ELG: Elongation (%), UNF: Uniformity (%)

Heterosis estimates of hybrid combinations are presented in Tab. 4. It is indicated that maximum and positive heterosis values for seed cotton yield were observed in 'Stoneville 453' x 'Tamcot Sphinx' (56.11%), 'Stoneville 453' x 'Tamcot CD3H' (45.91%) and 'Sayar 314' x 'Tamcot Luxor' (39.39%). These results confirm the findings of Kumar *et al*. (1974), Gençer (1980), Ashwathama *et al.* (2003) and Rauf *et al*. (2005) who reported significant heterosis for seed cotton yield. Regarding the ginning percentage, only one of the crosses 'Tamcot HQ95' x 'Tamcot Sphinx' (5.52%) had significant heterosis, hybrid vigour being also observed by Meredith and Brown (1998), Ganapathy *et al*. (2005) and Rauf *et al*. (2005). For fiber length, 'Maraş 92' x 'Sayar 314' (6.76%) and 'Sayar 314' x 'Stoneville 453' (5.92%) showed the highest heterosis value. For fiber fineness, 'Maraş 92' x 'Tamcot HQ95' (-11.29%) and 'Maraş 92' x 'Stoneville 453' (-7.81%) showed negative heterosis values, which indicate that the greater the micronaire value, the lower the fineness. The results are in the agreement with earlier research findings of El-Debaby *et al*. (1997) and Rauf *et al*. (2005). For fiber strength 'Stoneville 453' x 'Tamcot CD3H' (22.12%), 'Tamcot CD3H'x 'Tamcot Sphinx' (17.23%) and 'Maraş 92' x 'Tamcot HQ95' (15.41%) showed the highest heterosis values. 'Tamcot HQ95'x 'Tamcot Sphinx' (9.64%) exhibited maximum heterosis for fiber elongation and 'Sayar 314' x 'Stoneville 453' (2.66%) for fiber uniformity.

Conclusions

In conclusion, in this study significant additive genetic effects were observed for ginning percentage, fiber length, fiber fineness and fiber elongation, on the other hand, non-additive genetic effects were observed for seed cotton yield, fiber strength and fiber uniformity. Therefore, selection in advanced generations may be more appropriate for characters under non-additive genetic effects, but early generations selection may be more appropriate for characters under additive genetic effects, because effective selection in early generations of segregating material can be achieved when additive genetic effects are substantial and environmental effects are low.

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