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Heterosis and Combining Ability for Yield and Fiber Properties in Cotton (*Gossypium hirsutum* L.) Under Drought Stress Conditions

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Abstract: The objective of this study was to determine the General Combining Ability (GCA) of parents and the Specific Combining Ability (SCA) of hybrids. In the breeding program to develop better yielding and high quality cotton varieties under drought stress conditions. Five cotton lines (Blightmaster, Sicala 33, Tamcot CD 3H, Cabu CS 2-1-83 and Kurak 2) and 3 testers (Maraş 92, Erşan 92 and Stoneville 453) were crossed in a line×tester mating design at Southeastern Anatolia Agricultural Research Institute in 2001. Eight genotypes and 15 F_1 hybrids were grown in a randomized complete block design with 3 replications at the same experimental area in 2002. From the trial it was found that in the population, seed cotton yield, fiber length, fiber fineness, fiber strength and fiber elongation properties were influenced by additive; lint percentage and 100 seeds weight was influenced by non-additive gene effects. Heterosis values for fineness and fiber elongation were negative, while the other characters were positive. It was observed that Blightmaster for seed cotton yield and fiber elongation, Erşan 92 for lint percentage, Sicala 33 for fiber length and fiber strength were the best parent cultivars and also having best general combining abilities. It was also obvious that Blightmaster×Stoneville 453 for seed cotton yield, Tamcot CD 3H×Erşan 92 for lint percentage, Tamcot CD 3H×Maraş 92 for fiber length, Tamcot CD 3H×Stoneville 453 for fiber fineness, Sicala 33×Stoneville 453 for fiber strength, Cabu CS 2-1-83×Maraş 92 for fiber elongation, were the most promising crosses.

Key words: Cotton, drought stress, general and specific combining ability, heterosis

INTRODUCTION

Water is the most limiting factor in cotton production and numerous efforts have been made to improve cotton drought tolerance. The improvement of a new variety with high yield and fiber properties is the unique target off all cotton breeders. The first step in a successful breeding program is to select appropriate parents. Line×tester analysis provides for the detection of appropriate parents and crosses superior in terms of the investigated traits. So, application of the analysis has been very commonly used for combining ability analysis in plant breeding.

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

Başal and Turgut (2003) stated that fertility and fiber quality characteristics can be improved together by using triple crosses, modified backcross breeding or recurrent selection methods on genotypes. Cheatham *et al*. (2003) reported that Australian varieties and wild cotton varieties have the genes to improve fiber quality and fertility; fiber percentage and fiber strength are controlled by additive genes effects; fiber yield, boll size and fiber elongation extension are controlled equal by additive and dominant genes effects, yield and fiber quality could be improved by using these varieties in the USA breeding studies. Echekwu and Alaba (1995) and Coyle and Smith (1997) reported that significant general and specific combining ability effects for lint yield. Baloch *et al*. (1995) revealed the importance of specific combining ability for yield, 100 seed weight and lint percentage and general combining ability for boll number per plant and lint percentage. Myers and Lu (1998) reported that GCA effects were more important than SCA effects suggesting that additive gene action is more important than dominant gene action or epistatic interactions. Baker and Verhalen (1975) drew similar conclusions concerning the importance of additive gene action with regards to fiber traits. Green and Culp (1990) found that GCA effects were significant for all fiber properties except uniformity index.

Heterosis is the superiority in performance of hybrid individuals compared with their parents. Regarding previous studies on heterosis in cotton, researches

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reported that different heterosis values obtained for yield components and fiber quality parameters. The value of exploitable heterosis for seed cotton yield ranged from 15.5 to 35% Al-Rawi and Kohel (1969); Thomson and Luckett (1988a and b). The value of heterosis for fiber properties were usually lower than for yield. Meredith and Brown (1998) were detected significant heterosis for total lint yield, lint percentage and fiber length.

In order to choose appropriate parents and crosses and to determine the combining abilities of parents in the early generation, line×tester analysis method has been widely used by plant breeders. The present study evaluated parents and hybrids produced from line×tester mating design.

The aim of this study was to determine the general combining ability of the parents and the specific combining ability and the heterosis of the hybrids in the breeding programme to develop high yielding and quality cotton varieties under drought stress conditions.

MATERIALS AND METHODS

Field site: Field experiment were conducted at the Southeastern Anatolia Agricultural Research Institute, during the 2001 and 2002 growing season. The research soils are zonal soils which are generally red-brown and included in the big soil group having a clayish nature, flat or about-to-be flat, having very small erosion and deep or medium deep. Long years climatical findings showed that there were 454 mm total rainfall and 15.8°C average temperature in every year.

Used material and design: The plant materials used in the present study were obtained by line×tester crossing. Eight upland cotton genotypes, namely Blightmaster, Sicala 33, Tamcot CD 3H, Cabu CS 2-1-83, Kurak 2, Maraş 92, Erşan 92 and Stoneville 453 were used as parents. According to this method, five lines Blightmaster, Sicala 33, Tamcot CD 3H, Cabu CS 2-1-83, Kurak 2 and three testers Maraş 92, Erşan 92 and Stoneville 453 were crossed under field conditions, in Diyarbakır, Turkey in 2001. The five varieties used as lines were selected due to resistance to drought stress conditions and three testers were selected from local varieties of *Gossypium hirsutum* L.

Parents and their 15 F_1 populations were grown at the Southeastern Anatolia Agricultural Research Institute's experimental fields in randomized complete block design with three replications in 2002. The plots contained three rows of 12 m length. Between and within the row spacings were 70 and 15-20 cm, respectively. The planting was done on 16 May 2002. 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. Insects were monitored throughout the experiment. Weeds were controlled 2 times by hand and 3 times by machine. The experiment was carried out under induced drought stress conditions by irrigating only 4 times throughout the growing season. In the first and the last irrigations the traditional timing was followed, but eventually a total of only 250 mm water was applied by increasing the time interval between irrigations.

At maturity, 25 well developed open bolls were hand harvested randomly from each genotype and were ginned on a laboratory roller-gin for lint percentage and 100 seed weight calculations. The ginned lint from each plot was weighed and divided by number of plants within each plot to determine lint yield per plant. Seed cotton weight per boll and lint percentage was obtained from each boll sample. Ten plants were selected randomly from each genotype to find the boll number per plant. Plots were harvested by hand for yield determination on 2 October 2002 and second on 8 November 2002. Fiber samples were analyzed for micronaire, length, strength, elongation and uniformity index by High Volume Instrumentation (HVI) at the Akyıl Textile Company Laboratory in Diyarbakır.

Statistical analysis: The general combining ability variance of parents and the specific combining ability variance of hybrids were estimated via line×tester variance analysis according to Singh and Chaudhry (1985). The TarPopGen computer program which developed by Özcan and Açıkgöz (1999) was used to analyze the data and differences were tested for significance using LSD.

RESULTS AND DISCUSSION

The analysis of variance (Table 1) indicated that the mean squares of genotypes for all characters investigated except 100 seed-weight and fiber uniformity were significantly different ($p<0.01$), indicating the presence of variability among hybrids and their parents.

Seed cotton yield: Table 3 it can be seen that the three parents with the largest negative general combining ability effects for seed cotton yield were Cabu CS 2-1- 83, Maraş 92 and Tamcot CD 3H, while 5 other parents Blightmaster, Sicala 33, Kurak 2, Erşan 92 and Stoneville 453 showed positive general combining ability effects. For this reason these parents were accepted better donors to increase seed cotton yield than the others.

From Table 2, 4 and 5 it can be seen that 1×8, 2×7, 5×7 and 5×8 crosses had the highest seed-cotton yield; 1×8, 2×7, 3×6 and 5×7 had the highest SCA; 1×8, 5×8, 5×7 and

Table 1: Mean squares obtained from analysis of variance and combining ability for yield and fiber properties in cotton

Source of variation	df	Seed cotton yield (g plant^{-1})	Lint (%)	100 seed weight (g)	Fiber length (mm)	Fiber fineness (mic.)	Fiber strength (g tex^{-1})	Fiber elongation (%)	Fiber uniformity (%)
Replication	2	659.04*	2.16	0.74	3.06*	0.24	16.32*	0.11	6.70*
Genotypes	22	388.72**	6.06*	0.34	1.43*	0.17*	7.75*	0.28**	1.58
Parents	7	306.36	2.78	0.48	2.53**	0.32**	12.49**	0.41**	2.21
Par vs. Hyb.	1	1168.33**	24.96**	0.07	1.68	0.00	0.46	0.28	1.36
Hybrids	14	374.21*	6.35*	0.29	0.86	0.10	5.90	0.22**	1.27
GCA Lines	4	522.11*	2.26	0.23	1.42*	0.09	12.41	0.48**	1.67
GCA Testers	2	709.81*	20.85	0.26	1.79	0.07	0.47	0.45**	0.87
SCA	8	216.36	4.76	0.33	0.35	0.11	4.00	0.03	1.17
Error	44	161.41	2.92	0.23	0.67	0.09	3.60	0.07	1.31
6^2 GCA		41.115	0.339	0.004	0.097	-0.002	0.613	0.041	0.139
6^2 SCA		25.969	0.578	0.046	-0.049	0.001	0.237	-0.004	0.376
6^2 GCA/ 6^2 SCA		1.583	0.586	0.095	-1.985	-1.912	2.581	-10.250	0.369

*, ** Significant at p = 0.05 and p = 0.01, respectively

Table 2: Mean of investigated characters of parents and hybrids

Parents and hybrids	Seed cotton yield (g plant^{-1})	Lint (%)	100 seed weight (g)	Fiber length (mm)	Fiber fineness (mic.)	Fiber strength (g tex^{-1})	Fiber Elongation (%)	Fiber uniformity (%)
1. Blightmaster	57.90	40.94	9.28	26.70	4.06	28.33	6.73	82.23
2. Sicala 33	64.98	40.73	8.92	29.21	4.30	33.73	5.56	83.60
3. Tamcot CD 3H	48.50	39.23	8.91	26.73	3.73	28.23	6.16	81.96
4. Cabu CS2-1-83	54.26	39.02	8.94	27.30	3.73	31.00	6.16	81.83
5. Kurak 2	56.83	39.00	9.20	27.63	4.40	28.80	6.26	82.73
6. Maraş 92	77.09	38.66	9.67	27.72	4.56	31.03	5.73	82.53
7. Erşan 92	75.45	40.97	9.42	28.57	4.26	32.30	5.90	83.50
8. Stoneville 453	65.83	39.50	10.03	28.64	4.53	31.63	5.86	84.16
1×6	65.54	40.54	9.67	26.91	4.20	30.03	6.03	82.73
1×7	75.42	41.95	9.07	28.19	4.23	30.63	6.43	83.63
1×8	97.23	41.59	9.23	28.19	4.30	30.23	6.06	83.83
2×6	69.85	39.50	9.11	28.43	4.40	32.57	5.40	83.13
2×7	85.14	43.70	9.81	28.77	4.30	32.17	5.66	83.86
2×8	69.31	41.03	8.86	29.09	3.93	34.23	5.66	84.13
3×6	63.99	40.74	9.11	27.89	4.16	31.40	5.90	82.93
3×7	69.34	44.28	8.80	27.39	3.83	29.13	6.16	82.33
3×8	65.02	39.12	9.37	28.30	4.26	30.63	6.03	83.60
4×6	55.97	39.80	9.32	27.60	4.33	30.60	5.66	83.23
4×7	59.69	40.49	9.01	28.27	3.96	30.97	6.20	81.83
4×8	66.48	40.78	8.80	28.37	3.90	30.03	5.96	82.80
5×6	61.37	39.44	9.55	28.07	4.20	30.70	5.73	83.10
5×7	82.94	41.15	9.57	28.36	4.26	31.63	6.03	84.10
5×8	81.42	41.23	9.17	28.39	4.43	28.40	5.67	83.10

Table 3: General combining ability effects of parents for yield and fiber properties in cotton

Parents	Seed cotton yield (g plant^{-1})	Lint (%)	100 seed weight (g)	Fiber length (mm)	Fiber fineness (mic.)	Fiber strength (g tex^{-1})	Fiber elongation (%)	Fiber uniformity (%)
1. Blightmaster	8.15	0.33	0.09	-0.38	0.06	-0.59	0.27**	0.17
2. Sicala 33	3.57	0.38	0.03	0.61*	0.02	2.09**	-0.34**	0.48
3. Tamcot CD 3H	-5.13	0.35	-0.14	-0.28	-0.09	-0.47	0.12	-0.26
4. Cabu CS2-1-83	-10.53*	-0.66	-0.19	-0.06	-0.11	-0.36	0.03	-0.60
5. Kurak 2	3.99	-0.41	0.20	0.12	0.11	-0.65	-0.09	0.20
6. Maraş 92	-7.90 *	-1.01*	0.12	-0.36	0.07	0.16	-0.16*	-0.19
7. Erşan 92	3.25	1.29**	0.02	0.04	-0.06	0.02	0.18*	-0.07
8. Stoneville 453	4.64	-0.27	-0.14	0.32	-0.01	-0.19	-0.02	0.26

*, ** Significant at p = 0.05 and p = 0.01, respectively

2×7 had the highest heterosis values. Therefore, 1×8, 2×7, 5×8 and 5×7 crosses were selected as the promising lines to increase seed cotton yield in the breeding programme. The variance due to GCA was higher and more significant than SCA in case of seed cotton yield reflecting the role of additive type of gene action (Table 1). The results are in compromise with the findings of Green and Culp (1990), Kapoor (2000) and Leidi (2003)

Lint percentage: As shown in Table 3, a significant and positive general combining ability effect for lint percentage was exhibited by only one parental tester (Erşan 92), whereas a significant and negative general combining ability effect for lint percentage was shown by one parental tester (Maraş 92)

As can be seen from Table 4 most of the specific combining ability effects of the F_1 hybrids were not

Table 4: Specific combining ability effects of hybrids for yield and fiber properties in cotton

Hybrids	Seed cotton yield (g plant^{-1})	Lint (%)	100 seed weight (g)	Fiber length (mm)	Fiber fineness (mic.)	Fiber strength (g tex^{-1})	Fiber elongation (%)	Fiber uniformity (%)
1×6	-5.95	0.20	0.22	-0.48	-0.12	-0.42	0.01	-0.46
1×7	-7.23	-0.70	-0.28	0.37	0.05	0.30	0.06	0.30
1×8	13.19	0.50	0.05	0.10	0.07	0.12	-0.08	0.16
2×6	2.98	-0.89	-0.27	0.03	0.11	-0.58	-0.00	-0.38
2×7	7.11	1.00	0.53	-0.04	0.15	-0.85	-0.12	0.22
2×8	-10.10	-0.10	-0.26	0.00	-0.26	1.43	0.12	0.15
3×6	5.77	0.37	-0.10	0.39	0.00	0.81	0.02	0.17
3×7	-0.03	1.60	-0.31	-0.51	-0.19	-1.21	-0.05	-0.55
3×8	-5.74	-1.98	0.42	0.12	0.19	0.40	0.02	0.37
4×6	3.16	0.46	0.15	-0.11	0.18	-0.09	-0.11	0.80
4×7	-4.28	-1.16	-0.05	0.14	-0.03	0.40	0.06	-0.71
4×8	1.12	0.69	-0.10	-0.03	-0.15	-0.30	0.04	-0.09
5×6	-5.96	-0.15	0.00	0.16	-0.17	0.29	0.08	-0.13
5×7	4.43	-0.74	0.12	0.03	0.02	1.36	0.03	0.73
5×8	1.53	0.89	-0.12	-0.20	0.14	-1.65	-0.11	-0.60

*, ** Significant at p = 0.05 and p = 0.01, respectively

Table 5: The heterosis values of yield and fiber properties in cotton

Hybrids	Seed cotton yield (g plant^{-1})	Lint (%)	100 seed weight (g)	Fiber length (mm)	Fiber fineness (mic.)	Fiber strength (g tex^{-1})	Fiber elongation (%)	Fiber uniformity (%)
1×6	-2.90	1.84	2.03	-1.10	-2.71	1.19	-3.21	0.42
1×7	13.12	2.41	-3.01	2.00	1.58	1.05	1.84	0.92
1×8	57.16	3.39	-4.37	1.88	0.00	0.84	-3.70	0.76
2×6	-1.67	-0.50	-2.01	-0.11	-0.75	0.58	-4.42	0.07
2×7	21.25	6.96	6.98	-0.43	0.38	-2.57	-1.75	0.37
2×8	5.97	2.27	-6.47	0.57	-10.94	4.75	-0.87	0.29
3×6	1.89	4.60	-1.95	2.43	0.40	5.97	-0.84	0.83
3×7	11.88	10.42	-3.98	-0.94	-4.17	-3.74	2.21	-0.48
3×8	13.74	-0.62	-1.10	2.22	3.24	2.35	0.27	0.65
4×6	-14.79	2.46	0.10	0.33	4.40	-1.34	-4.76	1.27
4×7	-7.97	1.23	-1.87	1.19	-0.82	-2.16	2.76	-1.01
4×8	10.70	3.87	-7.25	1.42	-5.63	-4.09	-0.83	-0.23
5×6	-8.35	1.56	1.20	1.43	-6.32	2.62	-4.45	0.56
5×7	25.40	2.90	2.82	0.91	-1.53	3.55	-0.83	1.18
5×8	32.75	5.04	-4.61	0.91	-0.75	-6.01	-0.83	-0.41

*, ** Significant at p = 0.05 and p = 0.01, respectively

significant for the lint percentage. From Table 2, 4 and 5 it can be seen that 3×7, 2×7, 5×8 and 4×8 hybrids showed high specific combining ability effects and high heterosis value for lint percentage. Therefore these crosses most promising lines to increase for lint percentage. As shown in Table 1, SCA was higher than GCA for lint percentage expressed non-additive gene action, which is in accordance with the previous results of Marani (1968), Verhalen *et al*. (1971), Khan *et al* (1981), Tariq *et al*. (1992) and Kapoor (2000).

100 seed weight: As seen in Table 1 there were non significant differences among genotypes for 100 seed weight. General combining ability and specific combining ability effects were also not significant for these properties. Among the parents highest 100 seed weight were obtained Stoneville 453 (10.03). Heterosis value for 100 seed weight were determined negative most of hybrids. Just as 2×7 (Sicala 33 × Erşan 92) hybrid combinations had highest heterosis value (6.98%) and another 4 hybrids combinations were positive heterosis value.

Fiber length: Sicala 33 line showed the best GCA effects for fiber length (Table 3), but SCA effects were non-significant for all crossed genotypes. Six crosses showed lower and negative specific combining ability effects, indicating unfavorable combinations for fiber length (Table 4). Heterosis ranged between -1.10 and 2.43% in the population. Tamcot CD 3H × Maraş 92 (3×6) and Tamcot CD 3H × Stoneville 453 (3×8) hybrids had the highest heterosis value (Table 5). As seen in Table 1, The variance of GCA was higher than SCA's variance suggested additive gene action, which corresponds to findings Kanoktıp (1987), Green and Culp (1990) and Tariq *et al*. (1992).

Fiber fineness: Four lines showed positive and 4 lines showed negative GCA for fiber fineness, but these were non significant. Heterosis value ranged between -10.94 and 4.40%. The 4×6 (Cabu CS 2-1-83 × Maraş 92) had the highest positive heterosis value (4.40%) and 2×8 (Sicala 33×Stoneville 453) had the highest negative heterosis value (-10.94%). Nine hybrids combinations were negative while the others were positive, in this respect, in the population. Because of the lower micronaire value (Table 2) and higher negative SCA effects (Table 4) and higher negative heterosis (Table 5), the 2×8 combination was selected as the promising hybrid to improve fiber fineness in the breeding programme. From Table 1, proportion of GCA variance to SCA variance is bigger than ±1 reflecting the role of additive gene action. These results conform the findings of Kanoktıp (1987) and Al-Enani and Atta (1990).

Fiber strength: As shown in Table 3, a significant and positive GCA effects for fiber strength was exhibited by only one parental line Sicala 33. Maraş 92 and Erşan 92 had positive general combining ability effects while other parents effects were negative. In the experiment, most of the specific combining ability effects of F_1 hybrids were not significant (Table 4).

Highest specific combining ability effects were observed in the 2×8 (Sicala 33 × Stoneville 453), 3×6 (Tamcot CD 3H × Maraş 92) and 5×7 (Kurak 2 × Erşan 92) combinations also having highest heterosis values 5.97, 4.75 and 3.55%, respectively. As seen in Table 1, the variance due to GCA was higher than SCA's variance. The results indicated additive gene action for fiber strength. Kanoktıp (1987), Green and Culp (1990), Cheatham *et al*. (2003) and Leidi (2003) also reported similar results for this character.

Fiber elongation: For fiber elongation it was determined that the variations in genotypes, parents, hybrids, GCA Lines, GCA testers were significant (Table 1). In terms of significant general combining ability, while the parents Blightmaster and Erşan 92 showed positive effects, those of Sicala 33 and Maraş 92 parents were negative (Table 3). Because of the high and positive general combining abilities effects, Bligtmaster and Erşan 92 were selected as the most promising parents to improve this property.

Positive but non-significant specific combining ability effects were observed in 9 hyrids combinations, while this effect was negative in other combinations. Fiber elongation heterosis ranged between 4.76 and 2.76% 4×7 (Cabu CS 2-1-83 × Erşan 92) having the highest heterosis value and also high specific combining ability effects. From Table 1, it is obvious that effect of the additive gene action on mentioned character. These results are in agreement with the previous studies of Myers and Lu (1998), who also found additive gene action for fiber elongation.

Fiber uniformity: There were non significant differences among genotypes in fiber uniformity (Table 1). In the whole experiment, general combining ability and specific combining ability effects were not significant for fiber uniformity, too. Sicala 33 had the highest general combining ability effects. Specific combining ability effects for fiber uniformity were determined to be negative in most of the hybrids. Among the hybrids 4×6 (Cabu CS 2-1-83 × Maraş 92) and 5×7 (Kurak 2 × Erşan 92) combinations showed highest specific combining ability effects and heterosis.

CONCLUSIONS

In order to improve yield and fiber quality properties of cotton under drought stress conditions, some suitable parents and promising hybrids were determined in this study. Namely Blightmaster for seed cotton yield and fiber elongation; Erşan 92 for lint percentage; Sicala 33 for fiber length and fiber strength were selected as the good parents.

It was observed that heterosis value for fiber properties are usually lower than those of seed cotton yield in the population created in this study.

The results of this study suggests that 1×8 (Blightmaster × Stoneville 453), 5×8 (Kurak 2 × Stoneville 453) and 5×7 (Kurak 2 × Erşan 92) for seed cotton yield; 3×7 (Tamcot CD 3H × Erşan 92) for lint percentage; 3×8 (Tamcot CD 3H × Stoneville 453) for fiber fineness; 3×6 (Tamcot CD 3H × Maraş 92) for fiber length; 4×7 (CS 2-1-83 × Maraş 92) for fiber elongation; 2×8 (Sicala 33 × Stoneville 453) for fiber strength can be proposed as the most promising crosses. On the other hand, considerably additive genetic effects observed in this investigation for seed cotton yield, fiber length, fiber fineness, fiber strength and fiber uniformity characters, for mentioned characters selection in early generations may be more appropriate, while non-additive genetic effects obtained from lint percentage and 100 seed weight selection in advanced generation may be more appropriate for these characters because effective selection in early generations of segregating material can be achieved when additive gene effects are substantial and environmental effects are small.

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