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ESTIMATION OF COMBINING ABILITY IN F_2 POPULATION OF UPLAND COTTON UNDER DROUGHT AND NON-DROUGHT REGIMES

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Abstract

A six-by-six complete *Gossypium hirsutum* L., diallel cross was evaluated for general and specific combining abilities in F_2 generation during 2006 under drought and non drought conditions at Shah Abdul Latif University Farm, Khairpur. The characters considered were plant height, leaf area, leaf fresh weight, leaf dry weight, number of leaves per plant, number of sympodial branches per plant, number of bolls per plant, boll weight and seed cotton yield per plant. Irrigation treatments were three; normal seven irrigations schedule upto 150 days of crop maturity, four irrigations (medium stress) upto 150 days of crop maturity and two irrigations upto 150 days of maturity (stress conditions). General and specific combining ability analysis revealed that the mean squares for GCA and SCA were significant for all the characters under all the irrigation treatments. The general combining ability estimates of parents for all the characters under study and under all the irrigation treatments were highest for CRIS-134 except for boll weight under four irrigations where CRIS-52 excelled all the parents. Similarly, CRIS-9 followed CRIS-134 in GCA estimates scoring, and ranked second in all irrigation treatments and for all the characters except for boll weight under seven irrigations (where MARVI was second highest), under four irrigations here CRIS-110 was second highest) and under two irrigations where CRIS-52 was second highest. Thus GCA estimates of parents for boll weight are affected by drought conditions and therefore in the selection of desirable parents to give desirable combinations for boll weight, only those combinations be selected with highly significant difference for boll weight towards bigger boll size. Testing of such combinations is recommended to continue upto F_5 and F_6 generations to get homogeneity of high performing lines/advance strains. As regards to specific combining ability estimates, hybrid CRIS-9 x CRIS-134 gave highest SCA value of 11.54 for seed cotton yield under seven irrigations treatment, while CRIS-9 x CRIS-191 gave highest SCA value of 9.91 under four irrigations treatment for seed cotton yield. Under stress conditions (two irrigations), CRIS-9 x CRIS-134 gave highest SCA value of 12.35 for seed cotton yield. As the seed cotton yield is the main and important attribute for almost all the stakeholders, therefore it is suggested that the particular hybrid CRIS-9 x CRIS-134 may be produced which in present study, has been isolated to give highest SCA values under normal as well as under drought conditions (only two irrigations).

Introduction

In Pakistan, cotton accounts for 60% of total foreign exchange earnings through the export of raw cotton and cotton products. It also provides raw material to local domestic cotton industry. It has 85% share in total vegetable oil produced in the country. Cottonseed cake, an important by-product, is a valuable source of protein for ruminant cattle. About 40% labour force of the country is employed in cotton fields and cotton processing mills. It accounts for 8.2% of value added in agriculture and about 2% in GDP. Pakistan ranks fourth in area and production of cotton in the world. Pakistan has 9.36% of total world cotton area, 10.18% of production, 8.06% of consumption and 4.55% of total world export of raw cotton. Globally, Pakistan is one of the largest cotton producing and consuming countries of the world (Cotistics, 2008).

World crop production is largely limited by abiotic stresses such as drought, temperature, salinity, water logging and flooding etc., (Boyer, 1982 & Ahmad *et al*., 2009). Among these, drought is the major abiotic stress causing not only significant yield reduction (Baloch *et al*., 2011, Soomro *et al*., 2010 & Mirbahar *et al*., 2009) but also erratic variation from year to year in various cultivation zones. Economically, quite a number of species experience variable soil-water contents depending on irrigation, rainfall, leaf area, transpiration, and evaporation index. Thus, during their life cycle, all crops experience drought of various intensities at one time or the other, causing yield reduction.

Varietal selection plays an important role in water use efficiency for higher cotton production. Improved recommended production package technologies and scheduling methodology have promoted productivity and water use efficiency. The genetic yield potential of today's cotton plant in our country is at least 5 to 10 times the average yields that we attain each year. The primary cause of potential yield reductions is unfavorable physical environment, haphazard and irregular application of package production technology, ill-management of available irrigation resources and dictated choice to use conventionally fatigued mixture of varieties. Thus, the very objective of drought tolerance in cotton is defeated then and there.

General combining ability (GCA) is used to explore the average performance/contribution of a parental line in hybrid combinations (Sprague & Tatum, 1942). Falconer & Mackay (1996) defined it as the mean performance of the line in all crosses when expressed as deviation from the mean of all crosses. GCA consists of additive and additive epistatic variances (Matzinger, 1963).

Specific combining ability (SCA) is used to isolate those cases in which certain combinations behave relatively better or worse than would be expected on the basis of their average performance of lines involved (Sprague & Tatum, 1942). It is roughly the deviation, to a greater or lesser extent, from the sum of the GCAs of its two parents. SCA consists of dominance and all types of epistatic variances which are also regarded as estimates of the effects of non-additive gene actions (Falconer & Mackay, 1996). Relative contribution of general and specific combining ability variances to the total phenotypic variance of population is very important in interpreting genetic structure of a breeding population and consequently in deciding the breeding methodology. High estimates of general combining ability variances indicate predominance of additive gene action, while high estimates of specific combining ability variances indicate predominance of non-additive and dominance gene action. Combining ability analysis of cultivars and their filial generation combinations is thus important to exploit the relevant type of gene action in the particular breeding program.

Leghari *et al*., (2005) evaluated 12 F_1 intraspecific crosses belonging to *Gossypium hirsutum* L., for combining ability effects (general and specific) for three economic traits, viz., ginning out turn percentage, staple length and seed cotton yield per plant. Mean squares revealed that GOT% and seed cotton yield/plant were significant except staple length, which reflected non-significant differences. Variances for combining ability showed additive and dominant gene effects in all the characters. The parental variety Rehmani displayed maximum positive GCA effects in respect of seed cotton yield. The SCA effects were highly significant in hybrid Stoneville-213 x NIAB-78 in all the characters, whereas, Stoneville-213 x Shaheen showed significant reciprocal effects in two characters.

Adnan *et al*., (2006a) conducted combining ability analysis for seed cotton yield and other related characters in a set of diallel crosses involving five genotypes of upland cotton. Both additive and non-additive gene effects were important in the inheritance of most of the traits. The parent CIM-473, NIAB-999 and Acala 1517C and cross CIM-473 x NIAB-999 had high general combining ability (GCA) and specific combining ability (SCA) respectively, and were recommended to be utilized for further selection for high yield under Faisalabad conditions. In another study, Adnan *et al*., (2006b) crossed five genotypes of upland cotton (*Gossypium hirsutum* L.) in a complete diallel fashion to estimate the combining ability and heterosis in various quantitatively inherited traits using Griffing's (1956) technique, method I, model II. Highly significant mean squares for GCA and SCA were observed for most of the characters evaluated. It was found that variation due to SCA was greater in magnitude than due to GCA for all the characters except for fiber uniformity and micronaire indicating higher magnitude of non-additive type of gene action, whereas, GCA variance was high in magnitude for fiber uniformity and micronaire. Genotype MS-84 proved as the best general combiner for yield of seed cotton per plant, number of bolls per plant, boll weight and ginning out turn, while CRIS-379 in respect of fiber length, elongation, fiber strength and micronaire, and Coker-Improved was best general combiner for plant height. Cross MS-84 x CRIS-379 had high SCA effects for seed cotton yield per plant, boll number per plant, fibre uniformity and ginning out turn.

The purpose of the present investigation was, to obtain information regarding the combining abilities among drought tolerant and susceptible varieties and to identify those hybrids which possess superior combinations for drought tolerance in F_2 population of upland cotton for further utilization by cotton breeders while embarking upon any defined cotton breeding strategy.

Materials and Methods

Evolving crop cultivars with added or enhanced drought tolerance is the most successful and cheapest strategy to cope with drought. With that perspective in mind, an experiment was laid out on the experimental farm of Shah Abdul Latif University, Khairpur. Three commercial varieties CRIS-9, CRIS-134 and MARVI (drought tolerant) and three advance strains CRIS-52, CRIS-110 and CRIS-191 (drought susceptible) [Soomro unpublished data] were sown in kharif 2004 to make 6x6 diallel cross. This was done in non-replicated crossing block. All recommended agronomic and package of production technology practices were followed. At the time of peak flowering, fully mature buds were selected from each variety and emasculated in the evening. All emasculated buds were essentially butter-paper-bagged and pollinated individually with the desired pollen in the next morning. All pollinated buds were properly tagged and labeled to maintain the record. Thus all possible crossings were done including reciprocals. At maturity, the crossed bolls and selfs were harvested and their seeds collected to designate as F_0 seed for sowing in 2005. Also parents were selfed by tip-tying matured unopened buds with a red thread. Though cotton pollen is heavy and sticky and not wind-blown (Poehlman, 1952), yet it is often-cross pollinated crop and pollination is from 0 to 20% (www.ikisan.com).

The crossed seed referred as F_0 generation of all the combinations along with their parental lines was sown as F_1 in the third week of May 2005. The F_1s and parents were harvested and ginned to get enough seed for sowing as F_2 during cotton season 2006. Thus, F_2 diallel cross was sown during the second week of May 2006 to record data on 9 parameters (leaf area, leaf fresh weight, leaf dry weight, leaf number per plant, number of sympodia, number of bolls per plant, boll weight, plant height and seed cotton yield per plant). Three seeds were dibbled per hill spaced at one foot; the rows were distanced at 2.5 feet apart. Later, one healthy plant was left per dibble. Three rows, each 10 feet, were provided to each entry in each replication in whole F_2 population. Ten plants were randomly selected per entry per replication and treated as index plants for recording observations on already mentioned 9 parameters. The whole trial of 3 irrigation regimes could have been laid out in one randomized block design but to avoid seepage or some infiltration of water from one channel or treatment to another, each irrigation regimes was conducted in separately agronomic trail at 25feet distance as buffer zone. The irrigation treatments are detailed as under:

Irrigation treatments (excluding soaking dose):

I_1 = Two Irrigations = 60 + 100 DAP (DAP= days after planting)
I_2 = Four Irrigations = 50 + 70 + 90 + 110 DAP.
I_3 = Seven Irrigations = 35 + 50 + 65 + 80 + 95 + 110 + 125 DAP

Four consecutive plants were selected from first row leaving two first plants as border effects; 3 plants from second row leaving first three plants as border effects and 3 plants from third row leaving first four plants in that row as border effects. This can also be termed as random index selection technique. This is random as the consecutive selected plants in that row may be weak or very healthy and tall or short. Nine parameter observations, recorded per plant per entry, are explained hereunder:

Leaf area: It was calculated in centimeters as length x breadth of three leaves taken from bottom, middle and upper portions of each indexed plant from each entry per treatment per replication and then average worked out.

Leaf fresh weight: Three leaves from bottom, middle and upper portions of plant were plucked from each indexed plant of each treatment and replication and weighed in grams on electronic digital balance (petiole detached from the base), and then averaged.

Leaf dry weight: Leaves used for fresh weight were dried for 48 hours at 90^oC and were weighed in grams on electronic digital balance.

Leaf number per plant: Leaves on each indexed plant from each entry, per treatment per replication were counted at 150 days after planting and then averages worked out. The leaves taken for fresh and dry weight were also included in this count.

Number of sympodia per plant: Sympodial branches from each indexed plant of each genotype, treatment and replication were counted and average were calculated.

Number of bolls per plant: The number of matured bolls (open and un-open) on each indexed plant from each entry, per treatment per replication was counted at 150 days after planting and then averages worked out.

Boll weight: Five opened bolls, with good opening, from each indexed plant per entry, per treatment and per replication were picked and seed cotton weighed in grams. Then average boll weight of each entry was used in the diallel table.

Plant height: Measured in centimeters from cotyledonary node to the apex (last tip) of the main stem at 150 days after planting. Each indexed plant of each entry, per treatment and per replication was measured and then averages worked out accordingly.

Seed cotton yield per plant: All the opened bolls with good opening were picked at maturity (150 days after planting) and seed cotton received was weighed in grams on electronic digital balance and then average weight of seed cotton yield per plant was calculated.

General combining ability (GCA) is used as average performance/contribution of the parent/line in hybrid combinations (Sprague & Tatum, 1942) and that is statistically measured as deviation of that particular entry's mean from the overall means of hybrid combinations involving that entry (parent). General and specific combining ability analyses were performed as described by Griffing (1956) using method-1 and model-2. F_2 diallel analyses following Hayman (1954a, 1954b) and Griffing (1956) were computed for all nine characters under study by developing Microsoft Excel Sheets program and plugging in the replicated data (average of 10 plants per entry) in the F_2 diallel tables for individual character under each irrigation treatment. The ultimate object was to pinpoint the extent of variation to which the combining ability estimates differed from each other for a particular character under study.

Results

Before estimating the general combining ability (GCA) and specific combining ability (SCA) effects of individual parents and hybrids respectively, the raw data of all the 3 replications under all irrigation treatments for F_2 diallel and for all the characters under study were subjected to analysis of variance for combining ability to determine whether general and specific combining ability variances were significant. Mean squares from such analysis of variance for F_2 diallel table during 2006 are given in Table 1 under all the three irrigation regimes and for all the characters under study. The mean squares for GCA and SCA were significant for all the characters and under all the irrigation treatments (Table 1) implying that in F_2 under stress conditions selection may be prioritized on the basis of GCA values and variances rather than SCA of hybrids as F_2 is the maximum segregating generation.

For F_2 diallel sets under different irrigation conditions in 2006, the estimates of general and specific combining abilities for all the 9 characters under study have been presented in Tables 2, 3 and 4. The general combining ability estimates of parents in the F_2 diallel sets for all the characters under study and under all the irrigation treatments were highest for CRIS-134 except for boll weight under 4 irrigations where CRIS-52 excelled all the parents. Similarly, CRIS-9 followed CRIS-134 in GCA estimates scoring, and ranked second in all irrigation treatments and for all the characters except for boll weight under seven irrigations where MARVI was second highest, under 4 irrigations here CRIS-110 was second highest and under two irrigations where CRIS-52 was second highest. Thus GCA estimates of parents for boll weight are affected by drought conditions and therefore in the selection of desirable parents to give desirable combinations for boll weight, only those combinations be selected with highly significant difference for boll weight towards bigger boll size. Testing of such combinations is recommended to continue upto F_5 and F_6 generations to get homogeneity of high performing lines/advance strains. Invariably, CRIS-110 and CRIS-191 are being regarded as the poor combiners as GCA estimates of these cultivars for all the characters under study and in all the irrigation treatments were lowest or second lowest.

Table 1. Mean squares from the analysis of variance of general and specific combining ability of 6x6 F_2 complete cotton diallel cross for nine quantitative characters under three irrigation regimes during 2006 at Shah Abdul Latif University Farm, Khairpur.

Source of variation	D.F.	Leaves per plant	Leaf fresh weight	Leaf dry weight	Leaf area	Plant height	Sympodia per plant	Bolls per plant	Boll weight	Yield per plant
Seven irrigations										
Replications	2	18.46**	0.05*	0.00	52.09**	20.21**	105.36**	98.84**	0.07**	4.57
General combining ability	5	1421.32**	7.67**	0.42	692.26**	785.29**	94.83**	453.73**	0.02	8614.51**
Specific combining ability	9	177.18**	0.08**	0.13**	44.34**	74.18**	8.56**	54.85**	0.01	432.73**
Reciprocals	15	1.29	0.07**	0.03**	9.48**	3.64**	0.63**	24.21*	0.01	17.74**
Error	58	1.52	0.01	0.001	0.001	1.47	0.12	10.95	0.01	2.66
Variances of GCA	-	59.220	0.319	0.018	28.846	32.722	3.951	18.905	0.001	358.937
Variances of SCA	-	29.520	0.014	0.022	7.386	12.362	1.426	9.141	0.002	72.123
Four irrigations										
Replications	2	2.55	0.01**	0.00	61.41**	0.64	113.18**	104.21**	0.16**	1.03
General combining ability	5	1402.97**	6.87**	0.63	695.42**	875.97**	88.92**	486.68**	0.02*	7675.21**
Specific combining ability	9	157.82**	0.15**	0.42**	50.54**	53.40**	8.44**	20.14**	0.01	325.27**
Reciprocals	15	26.64**	0.07**	0.19**	3.02**	4.62**	5.60**	8.12*	0.01	158.70**
Error	58	2.49	0.001	0.001	1.19	1.88	0.21	3.46	0.01	1.24
Variances of GCA	-	58.450	0.286	0.026	28.977	36.499	3.705	20.278	0.001	319.800
Variances of SCA	-	26.300	0.025	0.070	8.421	8.990	1.406	3.357	0.001	54.214
Two irrigations										
Replications	2	3.16**	0.00	0.01**	338.32**	56.72**	111.97**	123.28**	0.11**	5.19
General combining ability	5	2519.37*	6.31**	0.39	861.12*	727.78**	94.81**	438.32**	0.05*	6323.26**
Specific combining ability	9	479.45**	0.15**	0.16**	167.16*	66.36**	5.53**	28.26**	0.01	301.19**
Reciprocals	15	17.32**	0.04**	0.05**	128.59*	2.58	1.06*	0.76	0.01	13.75**
Error	58	0.38	0.02	0.01	67.12	1.44	0.49	0.89	0.01	1.95
Variances of GCA	-	104.970	0.263	0.016	35.880	30.325	3.950	18.263	0.002	263.468
Variances of SCA	-	79.910	0.025	0.026	27.61	11.058	0.921	4.709	0.002	50.200

*= Significant at 5% probability level, **= Significant at 1% probability level

Table 2. General and specific combining ability estimates from 6x6 F_2 complete cotton diallel cross for nine quantitative characters under seven irrigations during 2006 at Shah Abdul Latif University Farm, Khairpur.

Particulars	Leaves per plant	Leaf fresh weight	Leaf dry weight	Leaf area	Plant height	Sympodia per plant	Bolls per plant	Boll weight	Yield per plant
General combining ability									
CRIS-9	5.25	0.12	0.05	4.73	1.53	0.69	-1.17	-0.04	-6.44
CRIS-134	13.35	1.06	0.24	8.07	11.00	3.75	8.75	0.05	38.42
MARVI	-3.13	-0.04	-0.03	-0.67	-2.61	-0.95	-3.00	0.02	-7.04
CRIS-52	-4.85	-0.30	-0.07	-2.76	-2.72	-1.00	-1.39	-0.02	-6.70
CRIS-110	-4.71	-0.37	-0.07	-3.12	-3.60	-1.59	-2.10	-0.01	-11.99
CRIS-191	-5.90	-0.47	-0.12	-6.25	-3.61	-0.89	-1.09	0.01	-6.26
Specific combining ability									
CRIS-9 x CRIS-134	2.47	0.09	-0.28	-4.47	2.80	-0.08	4.12	-0.01	11.54
CRIS-9 x MARVI	0.53	0.08	0.22	-0.33	1.33	0.54	-0.76	-0.04	-10.19
CRIS-9 x CRIS-52	5.69	-0.08	0.05	-0.85	-5.21	-0.17	-0.97	-0.01	-1.47
CRIS-9 x CRIS-110	0.16	0.02	0.02	3.22	-1.60	0.50	-1.29	-0.01	-1.03
CRIS-9 x CRIS-191	-8.84	-0.11	0.00	2.44	2.67	-0.79	-1.10	0.07	1.93
CRIS-134 x MARVI	-7.25	-0.24	-0.03	1.63	1.43	-1.22	-6.25	0.02	-2.48
CRIS-134 x CRIS-52	-2.85	0.11	0.06	2.66	2.46	-0.01	0.31	0.02	2.85
CRIS-134 x CRIS-110	0.73	0.03	0.07	1.03	-0.45	-0.66	0.50	-0.03	-10.94
CRIS-134 x CRIS-191	6.89	0.01	0.18	-0.85	-6.25	1.97	1.32	0.01	-0.99
MARVI x CRIS 52	-0.82	0.02	0.00	1.15	-1.45	1.41	2.52	0.04	-2.87
MARVI x CRIS-110	2.34	0.05	-0.05	-0.53	-1.94	0.71	2.70	0.02	6.63
MARVI x CRIS-191	5.20	0.09	-0.14	-1.91	0.61	-1.43	1.79	-0.03	8.91
CRIS-52 x CRIS-110	-1.00	-0.08	-0.05	-3.50	2.61	-1.02	-0.89	0.01	8.74
CRIS-52 x CRIS-191	-1.02	-0.03	-0.05	0.53	1.59	-0.22	-0.98	-0.06	-7.25
CRIS-110 x CRIS-191	-2.23	-0.02	0.02	-0.21	1.38	0.48	-1.04	0.01	-2.60

Table 3. General and specific combining ability estimates from 6x6 F_2 complete cotton diallel cross for nine quantitative characters under four irrigations during 2006 at Shah Abdul Latif University Farm, Khairpur.

Particulars	Leaves per plant	Leaf fresh weight	Leaf dry weight	Leaf area	Plant height	Sympodia per plant	Bolls per plant	Boll weight	Yield per plant
General combining ability									
CRIS-9	5.15	0.11	0.11	4.90	1.95	0.21	-0.99	-0.05	-2.76
CRIS-134	13.40	1.00	0.28	8.18	11.50	3.65	9.14	-0.02	36.10
MARVI	-4.93	0.00	-0.10	-0.65	-3.06	-0.11	-2.34	0.01	-8.25
CRIS-52	-4.66	-0.39	-0.11	-3.25	-2.59	-0.72	-1.92	0.04	-7.75
CRIS-110	-4.65	-0.29	-0.09	-4.01	-3.87	-1.64	-2.14	0.02	-10.87
CRIS-191	-4.31	-0.43	-0.09	-5018	-3.93	-1.39	-1.76	-0.01	-6.47
Specific combining ability									
CRIS-9 x CRIS-134	0.78	-0.01	-0.53	-4.68	2.34	-0.37	3.01	0.00	5.04
CRIS-9 x MARVI	3.55	0.13	0.22	0.30	0.48	0.18	-1.58	0.00	-10.97
CRIS-9 x CRIS-52	5.86	-0.26	-0.08	-1.23	-3.96	-0.46	-1.41	0.02	-3.08
CRIS-9 x CRIS-110	-3.23	0.08	0.21	4.03	-1.43	0.84	-1.52	-0.01	-0.91
CRIS-9 x CRIS-191	-6.95	0.06	0.17	10.58	20.57	-0.20	1.50	-0.01	9.91
CRIS-134 x MARVI	-6.04	-0.21	0.09	0.49	0.88	-1.31	-1.71	-0.01	2.27
CRIS-134 x CRIS-52	-1.91	0.17	0.11	2.89	2.31	0.70	-0.54	0.02	2.74
CRIS-134 x CRIS-110	2.47	0.11	0.02	0.52	0.21	0.07	-0.27	0.02	-6.45
CRIS-134 x CRIS-191	4.69	-0.07	0.30	0.78	-5.75	0.91	-0.50	-0.03	-3.61
MARVI x CRIS 52	-4.59	0.03	0.01	1.94	-0.88	2.03	-0.96	-0.04	-0.63
MARVI x CRIS-110	1.61	-0.06	-0.12	-0.43	-1.79	-0.05	1.38	0.03	4.41
MARVI x CRIS-191	5.48	0.10	-0.21	-2.30	1.32	0.84	0.95	0.02	4.92
CRIS-52 x CRIS-110	1.51	0.01	0.05	-3.83	1.83	-1.62	1.68	-0.03	7.56
CRIS-52 x CRIS-191	-0.86	0.05	-0.10	0.23	0.70	-0.65	-0.69	0.03	-6.60
CRIS-110 x CRIS-191	-2.36	-0.14	-0.16	-0.29	1.17	0.77	-1.26	-0.01	-4.62

Table 4. General and specific combining ability estimates from 6x6 F_2 complete cotton diallel cross for nine quantitative characters under two irrigations during 2006 at Shah Abdul Latif University Farm, Khairpur.

Particulars	Leaves per plant	Leaf fresh weight	Leaf dry weight	Leaf area	Plant height	Sympodia per plant	Bolls per plant	Boll weight	Yield per plant
General combining ability									
CRIS-9	7.41	0.05	0.06	1.58	1.53	0.59	-1.47	0.00	-3.37
CRIS-134	16.74	0.97	0.22	10.25	10.60	3.74	8.70	0.08	32.82
MARVI	-1.62	0.02	-0.02	1.33	-3.08	-0.71	-1.45	-0.01	-6.32
CRIS-52	-5.95	-0.28	-0.04	-6.56	-2.79	-1.23	-1.84	0.04	-6.33
CRIS-110	-5.65	-0.35	-0.09	-1.71	-3.11	-1.73	-2.28	-0.05	-10.40
CRIS-191	-10.93	-0.41	-0.13	-4.90	-3.15	-0.66	-1.66	0.01	-6.40
Specific combining ability									
CRIS-9 x CRIS-134	-12.24	-0.08	-0.32	-1.97	2.97	-1.01	4.36	-0.04	12.35
CRIS-9 x MARVI	5.09	0.31	0.24	3.35	2.49	0.89	-1.19	-0.03	-7.10
CRIS-9 x CRIS-52	7.97	0.11	0.12	-10.84	-5.14	-0.31	-1.32	0.00	-1.02
CRIS-9 x CRIS-110	2.17	0.04	0.01	4.41	-2.41	0.59	-1.78	0.05	-3.24
CRIS-9 x CRIS-191	-2.98	-0.16	-0.04	5.05	2.10	-0.16	-0.08	0.02	-0.99
CRIS-134 x MARVI	-9.39	-0.10	0.02	-2.04	-0.97	-1.03	-1.54	0.05	-3.78
CRIS-134 x CRIS-52	1.16	0.16	0.06	5.82	2.97	1.00	-0.49	0.06	0.37
CRIS-134 x CRIS-110	7.29	-0.03	0.08	-0.98	0.43	-0.12	-1.42	-0.05	-8.50
CRIS-134 x CRIS-191	13.21	0.05	0.17	-0.84	-5.40	1.17	-0.91	-0.01	-0.43
MARVI x CRIS 52	-0.94	-0.11	-0.09	3.06	-0.69	0.58	-0.37	-0.04	-2.15
MARVI x CRIS-110	0.02	-0.14	-0.08	-0.82	-1.16	0.48	1.27	0.00	6.46
MARVI x CRIS-191	5.22	0.05	-0.09	-3.55	0.34	-0.92	1.83	0.02	6.57
CRIS-52 x CRIS-110	-1.09	0.07	-0.03	0.00	1.52	-1.06	2.47	0.01	6.61
CRIS-52 x CRIS-191	-7.09	-0.01	-0.05	1.96	1.34	-0.20	-0.30	-0.04	-3.81
CRIS-110 x CRIS-191	-8.36	0.07	0.02	-2.62	1.63	0.11	-0.54	0.00	-1.33

With respect to specific combining ability estimates of F_2 diallel sets under seven irrigations (Table 2), hybrid CRIS-134 x CRIS-191 recorded the highest SCA values for number of leaves per plant (SCA= 6.89) while CRIS-9 x CRIS-191 was the lowest (SCA value= -8.84). The second lowest SCA scoring hybrid CRIS-134 x MARVI (SCA= -7.25) had one parent CRIS-134 with highest GCA value (13.35) for this character suggesting that parents with highest general combining ability values may give hybrids with lowest specific combining ability estimates. For leaf fresh weight, the highest scoring hybrid was CRIS-134 x CRIS-52 (SCA= 0.11) while CRIS-134 x MARVI was the lowest with SCA estimates of -0.24. For leaf dry weight, the highest SCA estimates were scored by hybrid CRIS-9 x MARVI (SCA= 0.22) while cross CRIS-9 x CRIS-134 was the lowest (SCA value= -0.28). In case of leaf area, hybrid CRIS-9 x CRIS-110 recorded the highest SCA value of 3.22 while cross CRIS-9 x CRIS-134 was the lowest (SCA= -4.47). For plant height, hybrid CRIS-9 x CRIS-134 scored the highest specific combining ability estimates of 2.80 and the lowest was CRIS-134 x CRIS-191 with SCA value of -6.25. It will be appropriate to mention here that high values of general combining ability for parents and specific combining ability of hybrids for plant height are absolutely undesirable in selecting cotton plant type as the cotton breeders would definitely not prefer taller plants to extend growing period which will distort cotton-wheat-cotton rotation fitness under our crop rotational system in intensive cotton growing areas of the country. Therefore low GCA and SCA estimates be preferred over high ones, if plant height in cotton is targeted during selection procedure. For number of sympodial branches per plant, highest SCA estimates were scored by CRIS-134 x CRIS-191 (SCA= 1.97) followed by MARVI x CRIS-52 (SCA= 1.44) while the lowest SCA scoring hybrid was MARVI x CRIS-110 (SCA= -1.43). For number of bolls per plant, highest SCA estimates were given by hybrid CRIS-9 x CRIS-134 (SCA= 4.12) and the lowest by hybrid CRIS-134 x MARVI (SCA= -6.25). In case of boll weight, highest SCA scoring hybrid was CRIS-9 x CRIS-191 (SCA= 0.07) and the lowest was CRIS-52 x CRIS-191 (SCA= -0.06). Finally, for seed cotton yield per plant, hybrid CRIS-9 x CRIS-134 secured maximum SCA estimates (11.54) and CRIS-134 x CRIS-110 was the lowest (SCA= -10.94) followed by CRIS-9 x MARVI (SCA= -10.19) at the second bottom.

As regards to SCA estimates of F_2 diallel sets under 4 irrigations treatment, the estimates are presented in Table 3 and highest SCA score of 5.86 was given by hybrid CRIS-9 x CRIS-52 followed by second highest (SCA= 5.48) in hybrid MARVI x CRIS-191 for number of leaves per plant and the lowest SCA scoring hybrid was CRIS-9 x CRIS-191 (SCA= -6.95) followed by CRIS-134 x MARVI (SCA= -6.04). For leaf fresh weight, the highest SCA score was given by hybrid CRIS-134 x CRIS-52 (SCA= 0.17) and the lowest was CRIS-9 x CRIS-52 (SCA= -0.26). In case of leaf area, highest SCA estimates were exhibited by hybrid CRIS-9 x CRIS-191 (SCA= 10.58) while the lowest SCA scoring hybrid was CRIS-9 x CRIS-134 (SCA= -4.68). For leaf dry weight, highest SCA estimates were given by cross CRIS-134 x CRIS-191 (SCA= 0.30) and the lowest by CRIS-9 x CRIS-134 (SCA= -0.53). For plant height, highest SCA estimates of 20.57 were given by cross CRIS-9 x CRIS-191 while hybrid CRIS-134 x CRIS-191 with SCA value of -5.75 ranked the lowest. In case of sympodial branches per plant, the highest SCA estimates were given by MARVI x CRIS-52 (SCA= 2.03) and the lowest were -1.62 for CRIS-52 x CRIS-110 followed by CRIS-134 x MARVI (SCA= -1.31). For number of bolls per plant, hybrid CRIS-9 x CRIS-134 exhibited the highest value of SCA (3.01) followed by CRIS-52 x CRIS-110 with 1.68 SCA while the lowest ranking hybrid for this character was CRIS-134 x MARVI (SCA= -1.71) followed by CRIS-9 x MARVI (SCA= -1.58). Boll weight SCA estimates were highest for MARVI x CRIS-110 and CRIS-52 x CRIS-191 (both the values SCA= 0.03) while hybrid MARVI x CRIS-52 scored the lowest SCA value of -0.04. Finally, for seed cotton yield per plant, the highest SCA estimates scoring hybrid was CRIS-9 x CRIS-191 (SCA= 9.91) followed by second highest (SCA=7.56) hybrid CRIS-52 x CRIS-110, while the lowest hybrid was CRIS-9 x MARVI with -10.97 SCA value followed by CRIS-52 x CRIS-191 with second lowest SCA value of -6.60.

For specific combining ability estimates of F_2 diallel sets under stress conditions of two irrigations only throughout the growing period, the results have been shown in Table 4 for all the characters. In case of number of leaves per plant, the highest SCA estimates were secured by hybrid CRIS-134 x CRIS-191 (SCA= 13.21) followed by value of 7.97 for hybrid CRIS-9 x CRIS-52. On the other hand, the lowest SCA estimates were displayed by hybrid CRIS-9 x CRIS-134 (SCA= -12.24) followed by second lowest value of -9.39 by hybrid CRIS-134 x MARVI. For leaf fresh weight, hybrid CRIS-9 x MARVI scored the highest SCA estimates (SCA= 0.31) and the lowest by CRIS-9 x CRIS191 (SCA= -0.16). In case of leaf dry weight, highest SCA securing hybrid was CRIS-9 x MARVI (SCA= 0.24) followed by CRIS-134 x CRIS-191 (SCA= 0.17) and the lowest ranking hybrid was CRIS-9 x CRIS-134 (SCA= -0.32) followed by MARVI x CRIS-52 (SCA value= -0.09). In case of leaf area, the highest, the SCA scoring hybrid was CRIS-134 x CRIS-52 (SCA= 5.82) followed by value of 5.05 of CRIS-9 x CRIS-191 while the lowest SCA scoring hybrid for leaf area was CRIS-9 x CRIS-52 (with SCA= -10.84) followed by MARVI x CRIS-191 (SCA= -3.55). For plant height, hybrids CRIS-9 x CRIS-134 and CRIS-134 x CRIS-52 scored highest SCA value of 2.97 followed by 2.49 of CRIS-9 x MARVI while the lowest SCA value of -5.40 was given by hybrid CRIS-134 x CRIS-191 followed by CRIS-9 x CRIS-52 with -5.14 SCA value. For number of sympodia per plant, hybrid CRIS-134 x CRIS-191 secured the highest SCA estimates (SCA= 1.17) followed by CRIS-134 x CRIS-52 (SCA= 1.00) and the lowest by hybrid CRIS-52 x CRIS-110 (SCA= -1.06) followed by CRIS-134 x MARVI (SCA= -1.03). In case of bolls per plant, hybrid CRIS-9 x CRIS-134 exhibited the highest SCA estimates (4.36) followed by CRIS-52 x CRIS-110 (SCA= 2.47), the lowest values were for hybrid CRIS-9 x CRIS-110 (SCA= -1.78) followed by -1.42 for hybrid CRIS-134 x CRIS-110. For boll weight, the maximum SCA estimates were scored by hybrid CRIS-134 x CRIS-52 (SCA= 0.06) and the lowest by CRIS-134 x CRIS-110 (SCA=-0.05) followed by three hybrids simultaneously, viz. CRIS-9 x CRIS-134, MARVI x CRIS-52 and CRIS-52 x CRIS-191 by giving the SCA estimates of -0.04. Finally, in case of seed cotton yield per plant, the highest SCA scoring hybrid was CRIS-9 x CRIS-134 (12.35) followed by second highest CRIS-52 x CRIS-191 (SCA= 6.61) and the lowest was CRIS-134 x CRIS-110 with -8.50 SCA followed by second lowest value of -7.10 for hybrid CRIS-9 x MARVI.

Discussion

Basically the material consisted of prescreened 6 cotton (*Gossypium hirsutum* L.) varieties, viz., CRIS-9, CRIS-134, MARVI, CRIS-52, CRIS-110 and CRIS-191, first three being prescreened as drought tolerant and last 3 as drought susceptible varieties. Normally in Sindh province, under recommended package of cotton production technology, 7 irrigations are given sowing dose throughout the cotton growing period. Thus 7 irrigations treatment was considered as non stress condition. Four irrigations were considered as medium stress conditions and only 2 irrigations as water stress or drought conditions. Therefore, all these quantitative genetic analyses were individually performed on F_2 (in 2005) for each quantitative character and under each irrigation treatment.

Griffing (1956) proposed diallel cross technique for determining the combining ability of parental and hybrid lines and characterizing the nature and extent of gene action in both plants and animals. Since its formulation, Griffing’s analysis has been widely used in plant breeding programmes. Griffing’s analysis allows the option to test for fixed (Model-1) or random (Model-2) effects. Griffing’s analysis on combining ability requires no genetic assumptions and has been shown to convey reliable information on the combining potential of parents. Once identified, the best parental combiners can be crossed to identify the optimal hybrid combinations or hybridized with the intent of selecting promising genotypes within the segregating generation. In recurrent selection techniques, parents possessing high combining ability can be crossed with one another in an attempt to accumulate desirable alleles within the base population.

In the present case, exactly the same procedure has been applied to estimate the values of general combining abilities of parents and specific combining abilities of the hybrids and the results have been presented accordingly in Tables 2 to 4. The ultimate object of whole combining ability analysis is to select and isolate the parents with good general combining ability values (commonly known as best combiners) and hybrids with high specific combining ability values with respect to a particular character under study. But from the combining ability analysis results in Tables 2 to 4, it has been seen/noted that the parent with high general combining ability estimate for a particular character does not always produce hybrids with high specific combining ability values for that character which means that the general combining ability is not circumstances, selection of parents to use them further in cultivar development program becomes comparatively less efficient and require higher selection pressure for targeted results.

Parent CRIS-134 with highest mean performance for yield under all irrigation treatments also gave highest general combining ability values under stress and non-stress conditions. So was the case with CRIS-110 with lowest mean yield giving lowest GCA values for yield under all three irrigation treatments. But the highest scoring GCA hybrid for yield CRIS-9 x CRIS-134 under seven irrigations did not give highest SCA under four irrigations conditions of stress. Similar was the condition with lowest SCA scoring hybrid CRIS-134 x CRIS-110 under seven, four and two irrigation treatments, respectively. Similar examples of other parents and their hybrids can be explained with respect to drought effects on the estimates of general and specific combining abilities that are affected by drought conditions because the variances for general and specific combining abilities tend to vary with the stress and non-stress conditions. Such results are in conformation with those of Zangi (2005) and Mahmood *et al*., (2006) who correlated performance of cotton cultivars to irrigation stress and non-stress conditions. According to them the varieties showed distinct response to moisture deficit and productivity traits provided some manifestation to drought tolerance. Mohammad *et al*., (2009) reported that even the parental order of dominance in Egyptian cotton cultivars was reversed under drought conditions and proportion of dominant to recessive genes in the parents also changed due to irrigation stress conditions. Selvam *et al*., (2009) have identified a novel drought tolerance gene in KC3 variety of upland cotton in India. According to the authors this novel drought tolerance conferring gene, cDNA, tested through RAPD approach, present in variety KC3 of *Gossypium hirsutum* offers drought tolerance as this variety is well adapted in rain-fed tracts of Tamil Nadu, India as compared to 25 other cultivars grown with KC3. The authors have suggested that further characterization of this gene through genetic engineering and/or marker aided selection (MAS) technique will improve its drought resistance attribute. Pettigrew (2004) proved that under water stress, decrease in seed cotton yield is primarily due to reduction in number of bolls. Water stress in late-bloom stages will reduce late-developing bolls and fiber strength in mid-canopy bolls.

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