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Research Article

Combining ability analysis for yield & it's contributing traits based on multi-environment testing in upland cotton (*G. hirsutum* L.).

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Abstract
The experiment was aimed to study the combining ability of different parental lines in 8x8 diallel cross, carried out in Kharif 2016 at ICAR-CICR Regional Station, Sirsa, Haryana, India. Eight parental genotypes (RS-2013, RST-9, RS-810, F-1378, F-2164, F-2228, LH-2076 and LH-2108) were crossed in complete diallel fashion. Fifty-six F_1 hybrids along with their parents were grown during Kharif-2017. Genotypes showed significant ($p \leq 0.01$) differences for mean squares values for all the traits under study. Mean squares due to GCA were higher in magnitude than SCA for majority of the traits and their inheritance was mainly governed by additive type of gene action and partially by non-additive. F-2228, F-2164 and LH-2108 were the parents with best general combining abilities and their combinations produced best F_1 hybrids such as F-2228 x LH-2108, F-2164 x F-2228, RS-2013 x F-2228 and reciprocal hybrids like F-2228 x F-1378, F-2228 x RS-2013 and LH-2108 x F-2164 which performed very well in direct and reciprocal combinations.

Keywords
Combining ability, General combining ability, Specific combining ability, Seed cotton yield, *Gossypium hirsutum* L.

INTRODUCTION

Cotton is the foremost natural fibre crop of global importance grown commercially in more than 75 countries with a global area of 32.94 million hectares accounting for 118.5 million bales (170 kg) of production (USDA, 2019). In India, cotton is cultivated in an area of nearly 12.2 million hectares which is the largest in the world, with a production of 31.2 million bales (2018-19) which again is highest in the world (CAI (P) 2019). Cotton plays a key role in the national economy by way of its contribution in trade, industry, employment and foreign exchange earnings. The average productivity of cotton in India is very low compare to the other cotton-growing nations of the world so the genetic improvement efforts can play an important role in yield enhancement.

To improve the productivity, one of the most important steps in a breeding programme is the detection of suitable parents. Combining ability analysis is used in breeding programmes to compare performances of lines in hybrid combinations (Griffing, 1956). Combining ability analysis is used to determine hybrid vigour in a population and thereby aid in selecting parents for producing crosses and segregating populations (Wells & Meredith, 1984). In combining ability, the entire genetic variability of each trait can be partitioned into GCA and SCA as defined by Sprague & Tatum (1942) and reciprocal effects as sketched by Griffing's (1956). They stated that GCA effects administer the additive type of gene action whereas SCA effects are shown due to genes which are non-additive (dominant or epistatic) in nature. Sayal *et al.*, (1997) and Hassan *et al.*, (1999) reported the importance of non-additive type of gene action for different cotton traits.

In the current study combining ability analysis was used as a tool to differentiate good and poor combiners, followed by selection of appropriate crosses. One of the techniques widely used for this purpose in different crops, including cotton, is diallel analysis (Hayman, 1954; Dabholkar, 1992).

We used Diallel mating design for this study as it is one of the tools which help the breeder to identify the potential genotypes and the promising recombinants produced by combining the parental individuals through GCA and SCA. In diallel mating, the parents are crossed in all possible combinations to identify parents as best/poor general combiners through GCA and the specific cross combinations through SCA. It involves both direct as well as reciprocal crosses through which maternal effects can also be ascertained.

MATERIAL AND METHODS

The parental material multiplication and crossing program for the research was undertaken at ICAR-CICR, Regional Research Station, Sirsa. The experimental material was comprised of eight *G. hirsutum* lines viz., RS-2013, RST-9, RS-810, F-1378, F-2164, F-2228, LH-2076 & LH-2108. These eight parents were crossed in diallel manner with reciprocals to produce 56 F_1 hybrids at ICAR-CICR Regional Research Station, Sirsa during Kharif- 2016. Crossed seed was produced by emasculating the properly developed bud in the evening between 3.00 to 5.00 pm. The emasculated flowers were covered by butter red paper bags for avoiding out crossing as well as for easy identification at the time of crossing. The emasculated flowers were pollinated on the succeeding day morning between 9.30 am to 11.30 am by brushing the pollen from male on the stigmatic surface and covered with white paper bags to avoid contamination of pollen.

All F_1 crosses including all the eight parents were planted at three farmer field locations namely Sirsa (Village- Jodhka, Hisar road Sirsa, Grower- Suresh Kumar), Bathinda (Village- Jivan Singh Wala, Tehsil- Talwandi Sabo, Grower- Kulwinder Singh) and Abohar (Dhani- Karnail, Fazilka Road, Grower- Jeet Ram). 56 F_1 were developed using diallel mating of eight parents including reciprocals. The material was tested in Randomized Block Design with a spacing of 105x60 cm row to row and plant to plant spacing respectively during the Kharif-2017 season. Data for different traits under study was randomly collected from five plants from each plot.

The analysis of 8x8 full diallel was done by using OP STAT software developed by CCSHAU, Hisar. Diallel theory was developed by Hayman (1954a, 1954b), Hayman (1958) and Jinks (1954) and it was also applied by Whitehouse *et al.* (1958) and Mather and Jink (1971, 1977 and 1982) to help the breeders to identify potential genotypes and promising recombinants produced by combining the parents through GCA and SCA. The data was subjected to analysis of variance (ANOVA) using OP STAT computer software for all the traits to test the null hypothesis of no difference between various F_1 crosses and their parental lines. Estimates of both GCA and SCA were computed according to (Griffing, 1956) designated Method-II and Model-I. The data for each character was tabulated and analysed on plot mean basis. The diallel analysis was used to evaluate traits that had a significant variation among parents. Simple additive-dominance model approach (Hayman, 1954, 1958) modified by Mather and Jinks (1982) was followed for genetic analysis and for estimation of the components of genetic variation.

RESULT AND DISCUSSION

Analysis of variance indicated highly significant differences due to treatments fulfilling the basic requirement to take the study forward (**Table1a and 1b**). The result suggests that there is enough variability in genetic material. The value of mean squares due to GCA, SCA, reciprocals, maternal effect, maternal interactions and GCA/SCA values for the number of monopods, the number of sympods, boll weight, plant height, seed cotton yield, GOT and seed index are given in **table 2a and 2b.** The mean square values of GCA were highly significant ($p \leq 0.01$) for the number of monopods, (0.506**), the number of sympods (6.369**), boll weight (0.497**), plant height (236.333**), seed cotton yield (0.17**), GOT (6.667**), and seed index (6.357**). The mean square values for SCA were also significant for all the traits except for the number of sympods (1.538). Mean square values due to maternal effect are non-significant for all the traits under study. Though maternal effects were non-significant but maternal interaction were seen significant for all the traits except for the number of sympods. Mean square values due to reciprocals were also found significant for the number of monopodia (0.258**), the number of sympodia (2.087**), plant height (125.42**), seed cotton yield (0.098**), GOT (0.183**) and for seed index (0.83**). Whereas the mean square values were found non-significant for boll weight (0.042) and the number of sympods (2.04) at two location out of three locations.

Table 1a. ANOVA table of Treatment effects for Monopods, Sympods & Boll weight traits

Traits		Monopods				Sympods				Boll Weight			
Locations		Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
Source of Variation	DF	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS
Replications	1	0.526*	0.013	0.025	0.045	23.463**	8.511	3.928	0.009	0.01	0.361	0.196*	0.132*
Treatments	63	0.517**	0.458**	0.312**	0.28**	3.596*	5.808**	2.632	2.319**	0.147**	0.251**	0.124**	0.116**
Error	63	0.08	0.098	0.105	0.037	2.447	3.4	2.14	1.197	0.045	0.067	0.042	0.032
Total	127												

Table 1b. ANOVA table of Treatment effects for Plant height, Seed cotton yield, GOT and Seed Index traits

Traits		Plant Height				Seed Cotton Yield				GOT		Seed Index	
Locations		Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Ac Locs	Abohar	Ac Locs
Source of Variation	DF	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS
Replications	1	-0.452	12.589	8.728	0.241	0.006	0.028	0.164*	0.047	5.796*	4.13	0.26	0.186
Treatments	63	921.78**	919.67**	972.45**	876.43**	0.389**	0.287**	0.255**	0.21**	4.474**	4.127**	1.385**	1.359**
Error	63	33.117	30.715	34.654	10.59	0.053	0.038	0.034	0.022	1.292	1.232	0.233	0.224
Total	127												

GCA/SCA ratio value show that an additive gene effect is more prevalent for the number of monopods, the number of sympods, boll weight and seed index traits with 2.057, 4.141, 5.287 and 9.948 respectively. For Seed cotton yield, Plant height and GOT the values of GCA/SCA are 0.650, 0.254 and 0.401 respectively indicating the importance of both additive and dominance variances in the population. These results support the findings of Ahuja and Tuteja (2000), Tuteja *et al.* (2003), Mert *et al.* (2003), El-Mansy *et al.* (2010).

Table 2a. Mean Squares for combining ability effects for Monopods, Sympods & Boll Weight

Traits		Monopods				Sympods				Boll Weight			
Locations		Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
Source of Variation	DF	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS
Due to GCA	7	0.418**	0.802**	0.872**	0.506**	6.1*	9.012*	7.682**	6.369**	0.487**	0.763**	0.437**	0.497**
Due to SCA	28	0.585**	0.322**	0.294**	0.246**	4.592*	5.035	1.958	1.538	0.104**	0.307**	0.106**	0.094**
Due to Reciprocals	28	0.474**	0.508**	0.19*	0.258**	1.975	5.78*	2.043	2.087*	0.105**	0.067	0.065	0.042
Maternal Effect	7	1.092**	0.357	0.204	0.335		11.032*		3.216	0.119			
Mater. Interaction	21	0.268**	0.558**	0.186*	0.233**		4.03		1.711	0.1**			
Error	63	0.08	0.098	0.105	0.037	2.447	3.4	2.14	1.197	0.045	0.067	0.042	0.032
GCA: SCA Ratio		0.715	2.491	2.966	2.057	1.356	1.790	3.923	4.141	4.683	2.510	4.123	5.287

Table 2b. Mean Squares for combining ability effects for Plant height, Seed cotton yield, GOT and Seed Index

Traits		Plant Height				Seed Cotton Yield				GOT		Seed Index	
Locations		Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Ac Locs	Abohar	Ac Locs
Source of Variation	DF	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS	MSS
Due to GCA	7	799.182**	551.379**	236.333**	442.629**	0.685**	0.252**	0.119**	0.17**	4.289**	2.514	6.677**	6.357**
Due to SCA	28	1742.814**	1761.141**	2003.5**	1744.018**	0.447**	0.329**	0.411**	0.333**	6.603**	6.266**	0.633**	0.639**
Due to Reciprocals	28	131.418**	170.246**	125.427**	117.314**	0.257**	0.255**	0.132**	0.098**	2.39*	2.39*	0.813**	0.83**
Maternal Effect	7	161.716	129.676	98.745	91.331	0.285	0.566**	0.201	0.16	2.109	2.109	0.438	0.454
Mater. Interaction	21	121.319**	183.77**	134.321**	125.975**	0.248**	0.151**	0.109**	0.077**	2.483*	2.483*	0.938**	0.955**
Error	63	33.117	30.715	34.654	10.59	0.053	0.038	0.034	0.022	1.292	1.232	0.233	0.224
GCA: SCA Ratio		0.459	0.313	0.118	0.254	1.532	0.766	0.290	0.511	0.650	0.401	10.056	9.948

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Table 3a. GCA Effects of RS-2013, RST-9, RS-810 & F-1378 for Monopods, Sympods, Boll weight, Plant Height, Seed Cotton Yield, GOT and Seed Index

Parents	RS-2013				RST-9				RS-810				F-1378			
Traits \ Locations	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
Monopods	-0.008	-0.149	-0.198	-0.116	0.127	0.332	0.283	0.244	-0.173	-0.005	-0.03	-0.072	-0.117	-0.099	-0.042	-0.084
Sympods	-0.009	-0.12	-0.319	-0.145	-0.747	-0.558	-0.262	-0.507	-0.084	-0.414	-0.719	-0.441	-0.053	-0.145	-0.162	-0.116
Boll Weight	-0.241	-0.303	-0.184	-0.24	-0.06	0.006	-0.022	-0.018	-0.026	-0.147	-0.162	-0.105	0.024	0.031	0.084	0.035
Plant Height	2.166	2.773	3.012	2.65	4.797	7.736	1.3	4.613	-8.866	-4.389	-4.506	-5.925	-3.934	-5.533	-2.606	-4.019
Seed Cotton Yield	-0.093	0.04	0.002	-0.017	-0.115	-0.047	-0.007	-0.056	-0.125	-0.049	-0.125	-0.1	0.077	-0.125	0.011	-0.012
GOT	-0.669			-0.474	0.459			0.398	0.263			0.07	0.044			-0.03
Seed Index	-0.672			-0.638	-0.463			-0.46	-0.234			-0.282	0.08			0.08

Table 3b. GCA Effects of F-2164, F2228, LH-2076 & LH-2108 for Monopods, Sympods, Boll weight, Plant Height, Seed Cotton Yield, GOT and Seed Index

Parents	F-2164				F-2228				LH-2076				LH-2108			
Traits \ Locations	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
Monopods	-0.023	-0.093	-0.211	-0.109	-0.042	0.038	0.033	0.003	0.095	0.095	0.152	0.116	0.142	-0.118	0.014	0.019
Sympods	0.266	0.705	0.288	0.434	0.741	0.342	0.613	0.571	-0.322	-0.545	-0.137	-0.329	0.209	0.736	0.7	0.534
Boll Weight	0.012	0.028	0.022	0.02	0.187	0.134	0.1	0.141	0.09	0.159	0.125	0.129	0.015	0.091	0.038	0.038
Plant Height	6.284	1.048	3.456	3.6	2.584	0.211	0.862	1.219	-0.447	-0.477	-0.75	-0.556	-2.584	-1.37	-0.769	-1.581
Seed Cotton Yield	0.247	-0.074	0.082	0.085	-0.017	0.081	0.032	0.032	-0.136	0.029	-0.032	-0.046	0.163	0.143	0.038	0.115
GOT	-0.316			-0.152	0.091			0.104	-0.153			-0.209	0.281			0.295
Seed Index	0.055			0.084	0.795			0.755	0.176			0.202	0.262			0.259

GCA of Parental lines: The GCA effects of all eight parents are given in **table 3a and 3b**. Traits for GCA comparison are the number of monopods, the number of sympods, boll weight, plant height, seed cotton yield, ginning out-turns and seed index. Out of eight parents LH-2108 gave highest GCA effects with mean value of 0.115 with positive GCA effects at all the three testing locations, followed by F-2164 (0.085) and F-2228 (0.32) which gave positive GCA effects on two location out of three. For boll weight maximum five parents gave positive GCA values. F-2228 (0.141) was the highest GCA parent for boll weight followed by LH-2076 (0.129), LH-2128 (0.038), F-1378 (0.035) and F-2164 (0.02). All these five parents showed positive effects across all the three locations.

For plant height RST-9 (4.613) was the highest across location GCA parent followed by F-2164 (3.60), RS-2013 (2.65) and F-2228 with GCA effect of 1.219 which also gave positive GCA at all the three test locations. For the number of sympodia per plant F-2228 was the highest GCA parent with 0.571 GCA value followed by LH-2108 (0.534) and F-2164 (0.434), which gave positive GCA effects at the three test locations. For the number of monopodia per plant RST-9 (0.244) was at the top followed by LH-2076 (0.116) and both parents showed positive GCA effects at all the three locations, whereas LH-2108 (0.019) and F-2228 (0.003) gave positive GCA values at two locations each. The Seed Index and GOT data points were captured from Abohar location and for seed index F-2228 (0.755), LH-2108 (0.259), LH-2076 (0.202), F-2164 (0.084) and F-1378 (0.080) had positive GCA effects. RST-9 (0.398), LH-2108 (0.295), F-2228 (0.104) and RS-810 (0.070) gave positive GCA effects for ginning out turn. Based on the GCA effects three lines were found most potential parents. F-2228, LH-2108 and F-2164 were the top three general combiners with positive GCA effects for seven, six and five traits respectively.

Table 4a. SCA Effects for F_1 combination at different locations for Monopods, Sympods & Boll weight

Traits	Monopods				Sympods				Boll Weight			
Pedigree \ Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
RS-2013 x RST-9	-0.30	-0.05	-0.23	-0.20	0.70	0.20	0.06	-0.30	0.13	0.26	0.14	0.17
RS-2013 x RS-810	-0.05	-0.21	0.18	-0.03	0.50	0.50	0.27	0.11	-0.18	0.13	0.06	0.01
RS-2013 x F-1378	0.15	0.18	-0.26	0.03	-0.90	0.03	-0.84	-0.12	-0.10	-0.07	-0.14	-0.11
RS-2013 x F-2164	0.55	0.07	-0.09	0.18	1.15	-0.37	-0.19	-0.09	0.09	-0.27	-0.03	-0.07
RS-2013 x F-2228	0.42	-0.26	0.27	0.14	0.30	1.00	0.89	0.45	0.19	0.35	0.25	0.29
RS-2013 x LH-2076	0.06	0.29	-0.10	0.08	0.95	-0.87	0.44	0.07	0.18	0.25	0.17	0.20
RS-2013 x LH-2108	-0.69	-0.10	-0.26	-0.35	0.15	2.55	1.25	1.34	-0.14	-0.40	-0.12	-0.24
RST-9 x RS-810	-0.38	-0.10	-0.05	-0.17	-0.15	1.34	0.86	0.87	-0.06	-0.03	0.07	-0.01
RST-9 x F-1378	-0.11	-0.25	0.01	-0.13	-0.55	-0.63	-0.29	-0.50	-0.03	0.25	0.10	0.10
RST-9 x F-2164	0.49	0.39	0.28	0.39	-0.05	0.62	0.26	-0.35	-0.12	0.00	-0.06	-0.06
RST-9 x F-2228	0.06	0.01	-0.26	-0.04	0.50	0.23	0.08	0.21	0.03	0.09	0.08	0.07
RST-9 x LH-2076	-0.65	-0.30	-0.18	-0.38	0.10	-0.78	-0.72	-0.37	-0.02	0.14	-0.17	-0.02
RST-9 x LH-2108	-0.30	-0.13	-0.20	-0.21	0.40	-0.31	0.24	0.37	0.05	0.01	-0.05	0.02
RS-810 x F-1378	0.11	-0.06	0.02	0.01	0.75	-0.67	-0.34	-0.49	0.06	-0.03	0.07	0.03
RS-810 x F-2164	0.14	-0.27	-0.61	-0.24	0.00	-0.22	0.51	-0.07	-0.21	0.23	0.18	0.02
RS-810 x F-2228	0.11	0.20	0.00	0.10	0.15	-0.41	-0.11	-0.33	-0.11	-0.05	0.08	-0.02
RS-810 x LH-2076	0.15	-0.11	0.03	0.03	-0.55	-0.12	0.19	-0.33	-0.03	-0.23	0.00	-0.09
RS-810 x LH-2108	0.23	0.56	0.47	0.43	-1.45	-1.46	-0.80	-0.74	0.02	0.09	0.14	0.08
F-1378 x F-2164	0.04	0.37	0.06	0.17	-0.90	-0.44	-0.19	-0.09	-0.03	0.08	-0.04	0.01
F-1378 x F-2228	0.13	0.24	0.11	0.16	1.55	1.67	1.08	0.52	-0.28	0.07	-0.07	-0.09
F-1378 x LH-2076	0.24	0.14	-0.06	0.10	-0.65	1.16	0.43	0.15	0.19	-0.01	0.13	0.10
F-1378 x LH-2108	0.07	0.00	-0.07	0.02	0.20	-0.62	-0.16	-0.59	0.29	0.29	0.04	0.22
F-2164 x F-2228	-0.29	-0.01	-0.02	-0.12	0.05	0.77	0.18	0.52	0.13	0.10	0.09	0.10
F-2164 x LH-2076	-0.30	0.08	0.41	0.07	-0.50	0.31	0.03	-0.03	0.00	0.12	0.04	0.07
F-2164 x LH-2108	-0.12	-0.21	0.05	-0.11	-0.30	-0.47	-0.01	-0.67	-0.15	0.02	-0.07	-0.10
F-2228 x LH-2076	0.02	0.45	0.37	0.28	1.10	-0.93	-1.44	-0.89	0.05	0.27	0.06	0.12
F-2228 x LH-2108	0.12	0.11	0.11	0.11	0.40	0.64	0.07	0.07	0.00	0.11	0.08	0.06
LH-2076 x LH-2108	-0.07	-0.25	-0.06	-0.13	-0.90	1.43	0.82	1.00	-0.20	0.13	-0.08	-0.03

The specific combining ability values for different F_1 hybrid combination for different traits under study are provided in **table 4a and 4b**. Positive SCA range for seed cotton yield was 0.01 to 0.34. Out of total 28 F_1 hybrids 21 F_1 combination showed positive SCA effects for across location mean. The top five F_1 hybrid were RST-9 x F-2164 (0.34), RS-810 x F-2164 (0.29), RS-2013 x F-1378 (0.28), F-1378 x LH-2108 (0.27) and LH-2076 x LH-2108 (0.25) which gave positive SCA effects at all the three test locations. The SCA effects for boll weight had a positive range from 0.01 to 0.29. RS-2013 x F-2228 was the F_1 combination with the highest SCA value of 0.29 followed by F-1378 x LH-2108 (0.22), RS-2013 x LH-2076 (0.20), RS-2013 x RST-9 (0.17) and F-2228 x LH-2076 (0.12) were the top 5 performers showing positive values at all the locations. For the number of monopodia 16 F_1 hybrids showed positive SCA effects with a range of 0.01 to 0.43. RS-810 x LH-2108 (0.43), RST-9 x F-2164 (0.39), F-2228 x LH-2076 (0.28), RS-2013 x F-2164 (0.18) and F-1378 x F-2164 (0.17) were the top five F_1 hybrids. For the number of sympodia per plant 12 F_1 hybrid showed positive SCA effects with a range from 0.07 to 1.34. Best five F_1 hybrids for SCA effects were RS-2013 x LH-2108 (1.34), LH-2076 x LH-2108 (1.00), RST-9 x RS-810 (0.87), F-1378 x F-2228 (0.52) and F-2164 x F-2228 (0.52). All top performers gave positive SCA values at all locations under test.

Table 4b. SCA Effects for F_1 combinations at different locations for Plant height, Seed cotton yield, GOT & Seed Index

Traits	Plant Height				Seed Cotton Yield				Ginning out Turn		Seed Index	
Pedigree \ Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Abohar	Ac Locs
RS-2013 x RST-9	-1.22	1.76	6.41	2.33	0.12	0.154	0.190	0.15	0.77	0.64	0.22	0.23
RS-2013 x RS-810	-5.86	-6.71	-4.43	-5.66	-0.22	-0.046	-0.087	-0.12	0.17	0.17	0.02	0.02
RS-2013 x F-1378	3.81	-6.82	-6.38	-3.14	0.32	0.262	0.258	0.28	0.23	0.12	-0.39	-0.42
RS-2013 x F-2164	0.04	2.15	1.66	1.29	0.16	-0.046	0.138	0.08	0.24	-0.11	0.25	0.21
RS-2013 x F-2228	1.14	9.04	7.85	5.99	-0.04	0.336	0.182	0.16	1.34	1.14	-0.01	0.01
RS-2013 x LH-2076	-2.48	5.53	6.56	3.22	0.36	0.007	0.214	0.19	1.48	1.35	0.69	0.64
RS-2013 x LH-2108	5.11	12.22	10.73	9.37	0.09	0.115	0.056	0.09	-0.33	-0.53	-0.51	-0.52
RST-9 x RS-810	0.21	-2.02	10.83	3.03	0.03	0.056	-0.014	0.02	-1.11	-0.85	-0.08	-0.03
RST-9 x F-1378	0.38	8.17	11.48	6.67	0.01	-0.035	0.042	0.01	0.63	0.77	-0.04	-0.04
RST-9 x F-2164	8.51	1.29	9.12	6.30	0.34	0.299	0.378	0.34	0.29	0.20	-0.38	-0.37
RST-9 x F-2228	0.21	8.38	10.56	6.38	-0.10	-0.199	-0.162	-0.15	1.16	1.22	0.02	0.08
RST-9 x LH-2076	6.19	14.16	17.18	12.51	-0.19	0.295	0.222	0.11	1.13	1.25	-0.31	-0.32
RST-9 x LH-2108	-2.17	-10.04	-3.21	-5.14	0.09	0.147	0.080	0.11	0.59	0.65	-0.40	-0.37
RS-810 x F-1378	9.54	16.00	6.44	10.66	-0.15	-0.251	-0.090	-0.17	0.85	1.13	-0.03	0.03
RS-810 x LH-2108	10.37	10.16	7.43	9.29	0.32	0.303	0.255	0.29	1.91	1.95	-0.14	-0.10
RS-810 x F-2228	15.32	12.25	11.17	12.94	0.17	0.154	0.254	0.19	0.41	0.59	-0.18	-0.10
RS-810 x LH-2076	1.75	-0.06	2.38	1.37	0.13	0.100	0.340	0.19	-0.78	-0.52	-0.37	-0.34
RS-810 x LH-2108	15.64	8.53	13.25	12.47	-0.08	-0.061	-0.012	-0.05	-0.33	-0.15	0.40	0.45
F-1378 x F-2164	17.84	7.16	14.93	13.31	0.31	-0.302	0.176	0.06	0.18	0.10	-0.08	-0.09
F-1378 x F-2228	4.29	8.15	9.07	7.16	-0.15	0.229	0.045	0.04	-0.70	-0.63	-0.36	-0.31
F-1378 x LH-2076	5.62	7.63	2.38	5.21	-0.13	-0.062	-0.126	-0.11	-0.53	-0.40	0.55	0.55
F-1378 x LH-2108	10.06	7.88	5.55	7.84	0.39	0.251	0.172	0.27	1.11	1.18	0.44	0.44
F-2164 x F-2228	20.17	10.96	12.26	14.47	0.33	0.146	0.076	0.19	0.48	0.32	0.49	0.51
F-2164 x LH-2076	5.35	9.25	7.97	7.52	-0.48	-0.064	-0.185	-0.24	0.53	0.43	-0.21	-0.26
F-2164 x LH-2108	6.99	15.15	12.24	11.47	0.00	-0.075	-0.051	-0.04	0.12	-0.05	0.14	0.11
F-2228 x LH-2076	15.45	10.49	6.26	10.75	0.22	-0.004	0.027	0.08	-0.43	-0.38	0.52	0.52
F-2228 x LH-2108	7.89	12.98	6.13	8.98	0.03	0.141	0.226	0.13	0.26	0.24	0.43	0.49
LH-2076 x LH-2108	15.32	11.47	12.84	13.20	0.38	0.211	0.169	0.25	0.18	0.23	-0.42	-0.43

For plant height maximum number of hybrids i.e. 25 F_1 combination showed positive SCA effects with a range of 1.29 to 14.47. F-2164 x F-2228 (14.47), F-1378 x F-2164 (13.31), LH-2076 x LH-2108 (13.20) RS-810 x F-2228 (12.94) and RS-810 x LH-2108 (12.47) were the top five F_1 hybrids with highest SCA effects and positive SCA values at all the locations under test for plant height. For ginning out turn 19 F_1 combinations give positive SCA effects with a range of 0.10 to 1.92. RS-810 x LH-2108 was the best combination with 1.92 SCA value. RS-2013 x LH-2076 (1.35), RST-9 x LH-2076 (1.25), RST-9 x F-2228 (1.22) and F-1378 x LH-2108 (1.18) are the F1 combination with top five highest SCA values. As far as the seed index trait is concerned 14 hybrid combinations have given positive SCA values out of total 28. The range of positive SCA values for seed index is 0.01 to 0.64.

The best F1 combination for seed index was RS-2013 x LH-2076 (0.64), followed by F-1378 x LH-2076 (0.55), F-2228 x LH-2076 (0.52), F-2164 x LH-2076 (0.51), F-2228 x LH-2108 (0.49). F1 hybrid combinations RS-2013 x F-2228, RS-2013 x LH-2076 and F-2228 x LH-2108 gave positive SCA effects for all the seven traits whereas F-1378 x LH-2108 and F-2164 x F-2228 gave positive SCA effects for six traits under study.

Reciprocal Effects: - Table 5a and 5b enlist the reciprocal effects for different traits under study. The table value suggests that the parents with good GCA which produced high SCA effects for F_1 hybrid combination also produced good hybrids with reciprocal combinations. F-2228 x RS-2013 produced positive SCA effects also produced positive reciprocal values for 6 traits and LH-2076 x RS-2013 similarly produced positive reciprocal effects for six traits whereas its straits combination produced good SCA effects for seven traits. F-2228 x F-1378, LH-2108 x F-2164, F-2228 x RS-2013 are some other reciprocal combinations of good GCA parents which did well in strait as well as reciprocal crosses.

Table 5a: Reciprocal Effects for monopods, sympods & boll weight

Traits	Monopods				Sympods				Boll Weight			
Pedigree \ Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs
RST-9 x RS-2013	-0.08	-0.15	-0.05	-0.10	-1.00	-0.30	-0.10	0.10	-0.03	0.03	0.05	0.00
RS-810 x RS-2013	0.53	0.35	0.15	0.35	-0.46	0.45	0.35	0.43	-0.05	-0.10	-0.08	-0.05
RS-810 x RST-9	0.38	-0.15	0.20	0.13	0.43	0.45	0.20	0.18	0.00	-0.15	-0.05	-0.05
F-1378 x RS-2013	0.03	0.15	0.10	0.10	0.51	2.35	0.90	0.78	-0.13	-0.18	-0.23	-0.23
F-1378 x RST-9	0.00	-0.20	0.05	-0.05	-0.50	-0.65	-0.80	-0.68	0.23	-0.10	0.33	0.15
F-1378 x RS-810	-0.58	-0.65	-0.25	-0.48	-0.57	0.15	0.10	0.35	-0.10	-0.08	-0.10	-0.10
F-2164 x RS-2013	-0.08	-0.15	0.00	-0.08	0.34	2.40	0.80	1.45	0.20	0.03	0.13	0.15
F-2164 x RST-9	-0.35	-0.35	-0.25	-0.30	-1.82	-1.25	-0.50	-0.63	-0.18	0.10	-0.15	-0.08
F-2164 x RS-810	-0.35	-0.25	0.05	-0.20	-0.53	0.15	0.00	0.03	-0.13	-0.13	0.00	-0.08
F-2164 x F-1378	-0.20	0.10	0.10	0.00	0.43	-1.60	-0.65	-1.08	0.25	0.10	0.28	0.20
F-2228 x RS-2013	-0.43	0.55	0.10	0.10	-0.48	2.10	0.90	1.13	-0.18	0.10	-0.03	-0.03
F-2228 x RST-9	-0.20	0.30	0.25	0.13	0.45	-1.00	-1.35	-0.63	-0.10	0.15	-0.08	-0.03
F-2228 x RS-810	-0.35	0.05	0.00	-0.10	-0.46	-0.20	0.00	0.00	0.05	-0.10	-0.08	-0.05
F-2228 x F-1378	-0.38	0.30	0.20	0.05	-1.09	1.05	1.05	1.23	0.13	0.00	0.13	0.08
F-2228 x F-2164	0.25	0.25	0.30	0.25	0.69	0.10	-0.50	-0.13	0.18	-0.23	0.03	0.00
LH-2076 x RS-2013	0.65	0.55	0.45	0.55	0.73	1.35	0.80	1.05	0.23	-0.18	0.13	0.08
LH-2076 x RST-9	-0.13	-0.15	0.05	-0.10	0.52	0.40	0.10	0.20	0.00	0.08	-0.20	-0.08
LH-2076 x RS-810	-0.53	0.20	0.15	-0.05	-1.10	-1.10	-0.85	-0.85	-0.08	0.00	-0.03	-0.03
LH-2076 x F-1378	0.18	0.05	0.05	0.10	-1.13	-0.45	0.15	-0.30	0.30	-0.10	0.05	0.10
LH-2076 x F-2164	0.28	-0.20	0.05	0.05	-0.30	1.15	0.20	0.28	-0.05	0.23	0.00	0.10
LH-2076 x F-2228	0.48	0.30	0.15	0.33	-0.27	0.95	1.05	1.05	-0.08	0.08	0.05	0.03
LH-2108 x RS-2013	-0.55	-0.95	-0.45	-0.68	0.15	2.05	0.15	0.78	0.125	0.15	0.00	0.10
LH-2108 x RST-9	-0.475	-0.50	0.00	-0.33	0.4	-0.95	-0.90	-0.50	-0.05	0.03	0.03	-0.03
LH-2108 x RS-810	-0.15	-0.15	-0.15	-0.15	-1.45	-0.85	-0.80	-1.05	-0.15	-0.20	-0.23	-0.20
LH-2108 x F-1378	0.15	0.00	-0.50	-0.13	0.2	0.25	0.20	0.23	0.275	0.08	0.08	0.13
LH-2108 x F-2164	0.3	0.20	0.35	0.28	-0.3	1.85	1.00	0.85	0.375	-0.15	0.10	0.10
LH-2108 x F-2228	-0.075	0.35	-0.15	0.05	0.4	-0.80	-0.60	-0.33	0.05	0.25	0.08	0.13
LH-2108 x LH-2076	0.125	0.55	0.20	0.28	-0.9	1.40	1.40	0.65	-0.05	0.05	0.05	0.03

Three lines were found most potential parents, F-2228 was the best parent which showed positive GCA effects for all the seven traits under study. LH-2108 was the second-best parent which showed positive GCA effect for six traits followed by F-2164 which came out in top three with positive GCA effects for five traits. Mean squares due to GCA were higher in magnitude than SCA for majority of the traits and their inheritance was mainly governed by additive type of gene action and partially by non-additive. Selection in such promising hybrids could be used in segregating generations, and some specific cross combinations can be used for hybrid cotton production to increase the seed cotton yield. For seed cotton yield best F_1 hybrids RST-9 x F-2164 (0.34), RS-810 x F-2164 (0.29), F-1378 x LH-2108 (0.27) and LH-2076 x LH-2108 (0.25) were made with the two of our best combiner parents. F_1 hybrid combinations RS-2013 x F-2228, RS-2013 x LH-2076 and F-2228 x LH-2108 gave positive SCA effects for all the seven traits whereas F-1378 x LH-2108 and F2164 x F-2228 gave positive SCA effects for six traits under study. It was also visible that reciprocal cross combinations of best general combiners produced high SCA effects.

Table 5b. Reciprocal Effects for Plant height, Seed cotton yield, GOT & Seed Index

Traits	Plant Height				Seed Cotton Yield				GOT		Seed Index	
Pedigree \ Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Bathinda	Sirsa	Ac Locs	Abohar	Ac Locs	Abohar	Ac Locs
RST-9 x RS-2013	-8.95	-11.50	-10.40	-10.28	0.11	0.138	0.164	0.14	-0.45	-0.45	0.02	0.03
RS-810 x RS-2013	1.55	4.50	-0.65	1.80	-0.07	0.038	0.189	0.05	-0.15	-0.15	0.01	0.00
RS-810 x RST-9	10.45	6.05	11.50	9.35	-0.06	0.076	0.104	0.04	-0.30	-0.30	-0.39	-0.38
F-1378 x RS-2013	-5.85	-1.05	0.60	-2.08	-0.27	0.460	0.020	0.07	-0.75	-0.75	-0.62	-0.63
F-1378 x RST-9	3.25	9.40	3.05	5.25	-0.13	0.266	-0.023	0.04	0.53	0.53	-0.31	-0.33
F-1378 x RS-810	0.75	7.90	7.80	5.50	0.07	-0.163	0.010	-0.03	-0.80	-0.80	-0.07	-0.08
F-2164 x RS-2013	0.50	4.00	1.00	1.83	-0.09	0.415	-0.050	0.09	-1.00	-1.00	0.56	0.55
F-2164 x RST-9	9.50	5.80	1.25	5.50	-0.12	0.331	0.014	0.08	0.53	0.53	0.18	0.20
F-2164 x RS-810	2.70	1.45	-0.85	1.10	0.04	0.131	-0.029	0.05	0.45	0.45	1.12	1.10
F-2164 x F-1378	2.40	-6.40	2.85	-0.38	-0.33	-0.090	-0.275	-0.23	-0.90	-0.90	0.31	0.33
F-2228 x RS-2013	4.70	7.15	6.80	6.20	-0.18	0.119	0.095	0.01	0.30	0.30	-0.09	-0.08
F-2228 x RST-9	-2.40	-9.55	-8.20	-6.70	-0.31	0.080	0.011	-0.07	-0.25	-0.25	-0.66	-0.68
F-2228 x RS-810	7.95	-1.50	0.50	2.33	0.01	0.033	0.037	0.03	-0.60	-0.60	0.11	0.13
F-2228 x F-1378	5.75	1.85	2.60	3.40	0.53	0.345	0.248	0.38	0.98	0.98	0.29	0.33
F-2228 x F-2164	0.65	-1.75	-0.95	-0.68	-0.01	-0.180	-0.092	-0.09	0.45	0.45	1.12	1.15
LH-2076 x RS-2013	10.05	16.65	11.20	12.65	0.69	0.186	0.302	0.39	0.85	0.85	-0.18	-0.20
LH-2076 x RST-9	-3.25	-6.55	0.10	-3.25	-0.08	0.561	0.543	0.34	-0.73	-0.73	0.57	0.58
LH-2076 x RS-810	-6.45	-0.20	-0.90	-2.53	0.18	-0.048	-0.133	0.00	-1.23	-1.23	0.24	0.23
LH-2076 x F-1378	-0.85	4.85	7.40	3.83	0.08	0.235	0.209	0.18	1.10	1.10	-0.07	-0.08
LH-2076 x F-2164	-13.60	-3.95	-7.85	-8.45	-0.17	0.266	0.005	0.03	-0.20	-0.20	0.66	0.68
LH-2076 x F-2228	0.30	0.75	1.65	0.90	0.03	0.334	0.253	0.21	1.00	1.00	0.01	0.03
LH-2108 x RS-2013	4.7	10.95	11.05	8.88	-0.323	0.378	0.213	0.09	-0.725	-0.73	0.485	0.50
LH-2108 x RST-9	1.05	1.55	3.00	1.88	-0.432	-0.081	-0.189	-0.23	-1.575	-1.58	0.082	0.08
LH-2108 x RS-810	-0.7	-0.60	1.65	0.10	-0.032	-0.091	-0.033	-0.05	-0.15	-0.15	-0.54	-0.53
LH-2108 x F-1378	3.85	3.00	2.35	3.08	0.079	-0.169	-0.051	-0.05	-1.125	-1.13	-0.06	-0.08
LH-2108 x F-2164	7.4	5.45	4.70	5.88	0.061	0.244	0.030	0.11	-0.725	-0.73	0.405	0.40
LH-2108 x F-2228	-4.7	-7.95	-5.20	-5.95	-0.519	0.234	0.305	0.01	-0.775	-0.78	0.18	0.15
LH-2108 x LH-2076	0.7	-4.75	0.10	-1.30	0.148	-0.285	-0.019	-0.05	0.75	0.75	0.005	0.03

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