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Combining ability analysis over environments for yield and yield attributing traits in cotton (*G. hirsutum* L. × *G. barbadense* L.)

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Abstract
A study was carried out in interspecific cotton hybrids (*Gossypium hirsutum* L. × *Gossypium barbadense* L.) to assess the genetic potential and combining ability for yield and yield attributing characters at three different locations in Maharashtra. Twelve lines of *G. hirsutum* and five testers of *G. barbadense* were crossed in line × tester manner to develop 60 F_1 hybrids. All the traits showed significant differences for environment x crosses Analysis of variance for combining ability revealed the significant differences for all crosses, line effect and environment x crosses for all traits. Selection of suitable good general combiner parent through estimation of general combining ability (GCA) effects, and superior cross combinations were identified for commercial exploitation through estimation of specific combining ability (SCA) effects. Four lines of *G. hirsutum* exhibited significant GCA effects among these PH-1075 (0.182) revealed highest followed by PH348 (0.1140), RAH-1065 (0.093) and SCS-793 (0.051), whereas in tester lines of *G. barbadense* Sujata (0.178) showed significant positive GCA effect. Hybrid RAH-1065 x Sujata (0.190) showed highest significant positive SCA effect followed by PH348 x Sujata (0.184), LRA5166 x SB-425 YF (0.121), AKH081 x SB-425 YF (0.112). The best parental lines and interspecific cross combinations for seed cotton yield and other yield contributing traits could be utilized for hybrid development on the basis of positive GCA and SCA effects.

Keywords: *G. hirsutum* L. × *G. barbadense* L, environments

Introduction
Cotton is most important cash crop and widely cultivated as a source of fiber throughout the world. It is grown in tropical and sub-tropical regions globes. China, India, USA, Pakistan, Uzbekistan, Turkey, Brazil, Greece, Argentina, Australia and Egypt are major cotton producing countries contributing about 85% of global production. India has the largest area under cotton cultivation in the world (9.1 million ha.). All four cultivated species i.e., *G. hirsutum*, *G. barbadense*, *G. herbaceum* and *G. arboreum* are grown in India on commercial basis. The productivity of cotton in India is low due to its rainfed cultivation in major areas and inadequate use of quality inputs. Commercial cultivation of cotton hybrids was introduced by India to world. Cotton hybrids have 50% higher productivity than varieties. Most probably, hybrids have wider adaptability, high degree of tolerance to biotic and abiotic stresses and superior fibre quality. Hybrid - 4(H-4) was first intra-specific (H x H) released in 1971 from Main Cotton Research Station, Surat of G.A.U. by Dr. C.T. Patel. World first inter-specific hybrid Varalaxmi was released in 1972 from University of Agriculture Science, Dharwad by Dr. B.H. Katarki.

Continuous efforts have been made by plant breeders to increase seed cotton yield but focus remained on direct selection of genotypes on the basis of yield attributing traits such as number of bolls per plant, boll size and average boll weight which contributes for seed cotton yield. Combining ability is the potential of parents to transmit desirable characters to its progeny. By using combining ability analysis evaluation of genotypes in terms of their genetic value, in selection of suitable parents and selection of superior cross combinations in hybridization program. The concept of combining ability was proposed by Sprague and Tatum in 1942 to a measure of gene action. In this analysis, the total genetic variation is portioned into general combining ability (GCA) and specific combining ability (SCA) effects and variances. Selection of parental lines for genetic improvement in hybridization program is difficult task for plant breeder and it is essential to thorough screening before crossing the parents.

However, various biometrical evaluations can better helpful to the plant breeders in selection of desirable better parents. The line x Tester analysis method can be used to estimate combining ability in self and cross pollinated crops (Kempthorne, 1957) [7]. In hybrid development program, combining ability describes the breeding value of parental lines. Phenomenon of F1 hybrids heterosis can also reflect GCA of parental lines and SCA of specific crosses, and provide the basis for exploitation of valuable cross combinations and their future utilization. For significant improvement in genetic potential of genotypes for yield and fiber quality traits, the hybrid cotton is a good approach (Khan *et al*., 2009) [8].

In hybridization of Cotton, the various cotton genotypes were screened through combining ability to determine their GCA and SCA for development of new cross combinations. Many commercial cotton cultivars despite their high or low agronomic performance combine in a more significantly or poorly when used as a parental cultivar in cross combinations. Hence, the present study was made to analyze the interspecific F1 cross population for their genetic potential and combining ability effects for various yield and yield attributing traits in cotton.

Materials and Methods

In the present study, twelve pure lines of *G. hirsutum* L., *viz.* RAH1065, PH1075, P2151, GBHV170, SCS793, DHY286, AKH8828, AKH081, PKV RAJAT, LRA5166, PH348, and NH615 and five pure lines of *G. barbadense* L. *viz.* SB289E, Reba-B-50, SUJATA, Sb-425 YF, and Suvin with different morphological and agronomic characters were selected on the basis of per se performance. Sixty F_1 hybrids were made by crossing twelve lines of *G. hirsutum* and five testers of *G. barbadense* by line × tester manner during Kharif 2021. The resulting sixty F_1 hybrids along with parental lines and standard checks, *i.e.,* MRC 7918 and Varalaxmi were evaluated during Kharif 2022 in a randomized block design (RBD) with three replications at three different locations in Maharashtra. All needed agronomic practices were followed during the crop growth period to maintain good crop stand. Observations of five randomly selected plants in each entry were recorded for four yield and yield attributing traits including seed cotton yield per plot for each replication. The mean values were used for estimation of heterosis over mid parent, better parent, and standard checks as per the standard method. The analysis of recorded data was subjected to analysis of variance for all the characters reported by Panse and Sukhatme (1978) [11]. The analysis of combining ability was carried out by statistical method suggested by Kempthorne (1957) [7].

Result and Discussion

Analysis for variance (Table 1) exhibited significant differences for all the traits studied. Line effect showed significant differences for all the traits. Similarly significant variance showed by tester effect for all the characters. The significant variability for yield components was previously reported by Imran *et al.* (2012) [4] and Tang and Xiao (2013) [18]. Variability expressed in relation to the broad genetic base of the genotypes used to develop the progenies with desirable trait (Ali *et al*., 2015). Line x tester effect revealed significant differences for all yield and yield attributing characters studied. All the traits showed significant differences for environment x crosses. Significant variance showed due to environment x line effect, environment x tester and Environment x L x T for all the characters studied. Negative GCA variances for basic yield components also reported by Coyle and Smith (1997) [3]. Importance of additive and non-additive genetic components in the inheritance of various traits is reported in earlier studies by Neelima *et al*. (2004) [10], Pareetha and Raveendren (2008) and Pole *et al.* (2008) [14]. Significant variance due to environment, GCA x environment and SCA x environment for almost all the traits studied indicated interaction between the environment and combining ability significantly. It shows that the environment plays an important role in the manifestation of general and specific combining ability effects.

In general combining ability analysis (Table 2), female parental line PH348 exhibited highly significant GCA effect for Days to 50 % flowering (-2.131), Number of bolls per plant (4.416), Average boll weight (2.58), Seed cotton yield (0.1140). In male parents (Testers) SB289E showed negatively significant GCA effect for the trait Days to 50 % flowering (-2.691), Sujata exhibited significant GCA effects for number of bolls per plant (1.378), for the character average boll weight (0.326) and for seed cotton yield (0.178). Pavasia *et. al.* (1999) [13] and Ahuja and Dhayal (2007) [1] reported highest GCA effect in promising genotypes for days to fifty percent flowering. On the basis of above mentioned results the female parental line *i.e.*, PH348 as well as male parent (tester) Sujata being good general combiner for the studied characters and these lines could be utilized in breeding program for improvement of desirable traits in cotton.

In specific combining ability analysis (Table 3), the cross RAH-1065 x Sujata revealed highest negatively significant SCA effect (-2.289) for the trait days to 50 % flowering, in this hybrid, involved parent with low x low GCA effects indicates that non-additive x non-additive gene action would be responsible for high SCA effect. Preetha and Raveendran (2008) [15] recorded the character days to fifty percent flowering is governed by non-additive gene action. The cross between GBHV-170 and Sujata expressed highly significant SCA effect (10.753) for number of bolls per plant, for this cross involved parent with high x high GCA effects, indicating additive x additive type of gene action. Murthy and Rao (1998) [9] reported that the trait number of bolls per plant governed by additive gene action.

The cross DHY 286 x SB-425 YF (0.244) revealed highest SCA effect for the trait average boll weight, for this combination parents involved with low x low GCA effect which shows the non-additive gene action responsible for the trait boll weight. In earlier study Pavasia *et. al.* (1998) also reported that the trait boll weight governed by additive and non-additive type of gene action. Ahuja and Dhayal (2007) [1] recorded the highest GCA effect in parent CCH-526612 for boll weight.

Hybrid RAH-1065 x Sujata (0.190) and PH348 x Sujata (0.184) showed significant positive SCA effect for the trait seed cotton yield, parents involved for these crosses are with medium x high and high x high GCA effects which indicates that the highest SCA effects in hybrids due to additive and non-additive gene action. Preetha and Raveendran (2008) [15] observed the parent MCU 9 was best combiner for seed cotton yield and the cross combination TCH 1608 x TCH 1002 exhibited best SCA effect for seed cotton yield. Srinivas, *et. al.* (2014) [17] reported that the trait seed cotton yield showed predominance of additive gene action in their study.

Best performing lines (female parents) and testers (male parents) with good general combining ability could be utilized as one of the parents produced promising F1 population with significant SCA determination and mean performance for majority yield attributing traits. Additive gene action controlled the inheritance, and selection in such superior hybrids with desirable characters could be practiced in early segregating generations and some specific F1 hybrids could be identified and tested in large scale trials to confirm superiority for hybrid cotton production to enhance the seed cotton yield.

Table 1: Analysis of variances for combining ability of F1 crosses in Line x Tester sets

Source of variation	*d. f.*	Days to 50 % flowering	Number of bolls per plant	Average boll weight (g)	Seed cotton yield / plot (kg)
Environments	2	110.763	276.429	0.191	0.327
Crosses	59	57.266 **	295.146 **	0.915 **	0.241 **
Line effect	11	129.162 **	462.17	2.514 **	0.554 **
Tester effect	4	279.882 **	473.558	4.546 **	1.312 **
Line x Tester eff.	44	19.054 **	237.170 **	0.185 **	0.065 **
Env. x Crosses eff.	118	7.968 **	115.611 **	0.173 **	0.075 **
Env. x Line effect	22	13.492 **	163.928 *	0.24	0.129 **
Env. x Tester eff.	8	8.555	187.331	0.076	0.163 **
Env. x L x T effect	88	6.534 **	97.011 **	0.165 **	0.054 **
Error	354	0.692	1.626	0.003	0.007
σ^2 GCA		2.664	6.095	0.046	0.012
σ^2 SCA		2.040	26.172	0.020	0.006
A		5.329	12.189	0.092	0.024
D		2.040	26.172	0.020	0.006
σ2 GCA / σ2 SCA		1.306	0.233	2.271	1.891

Table 2: General combining ability effects for yield and yield attributing traits.

Sr. No.	Genotypes	Days to 50 % flowering	Number of bolls per plant	Average boll weight (g)	Seed cotton yield / plot (kg)
Lines					
1	RAH-1065	0.335**	-0.424*	0.211**	0.093 **
2	PH-1075	-0.620**	3.229**	0.185**	0.182 **
3	P-2151	-0.154	-3.524**	0.138**	-0.023
4	GBHV-170	0.024	3.634**	0.054**	-0.034 **
5	SCS-793	2.491**	0.518**	0.002	0.051 **
6	DHY286	3.735**	-5.999**	-0.344**	-0.207 **
7	AKH8828	-0.620**	1.932**	-0.244**	0.01
8	AKH081	-1.598**	-0.742**	0.278**	0.014
9	PKV Rajat	0.846**	0.814**	-0.262**	-0.114 **
10	LRA5166	-1.020**	0.147	0.069**	0.006
11	PH348	-2.131**	4.416**	0.258**	0.140 **
12	NH615	-1.287**	-4.002**	-0.344**	-0.117 **
S.E. (gca)		0.124	0.0076	0.1901	0.0128
CD (gi-gj) @ 5 %		0.3448	0.015	0.5287	0.0357
CD (gi-gj) @ 1 %		0.454	0.0197	0.6963	0.047
Testers					
1	SB289E	-2.691***	-2.654**	-0.240**	-0.120 **
2	Reba-B-50	0.689***	-0.858**	0.002	-0.049 **
3	Sujata	0.022	1.378**	0.326**	0.178 **
4	SB-425 YF	1.578***	-0.604**	-0.053**	-0.002
5	Suvin	0.402***	2.738**	-0.036**	-0.008
S.E. (gca)		0.08	0.0049	0.1227	0.0083
CD (gi-gj) @ 5 %		0.2226	0.0097	0.3413	0.0231
CD (gi-gj) @ 1 %		0.2931	0.0127	0.4494	0.0304

*, ** significance at 5 % and 1 % level respectively

Table 3: Specific combining ability effects for yield and yield attributing traits.

Sr. No.	Crosses	Days to 50 % flowering	Boll number per plant	Average boll weight (g)	Seed cotton yield / plot (kg)
1	RAH-1065 x SB289E	-0.465	-4.535**	0.031	0.019
2	RAH-1065 x Reba-B-50	-1.733**	-3.664**	0.033	-0.052
3	RAH-1065 x Sujata	-2.289**	7.478**	0.131 **	0.190 **
4	RAH-1065 x SB-425 YF	1.822**	1.204**	-0.078 **	-0.072 *
5	RAH-1065 x Suvin	2.665**	-0.483	-0.118 **	-0.086 **
6	PH-1075 x SB289E	0.269	-1.955**	0.180 **	0.056
7	PH-1075 x Reba-B-50	0.222	-4.729**	-0.007	-0.109 **
8	PH-1075 x Sujata	0	-3.476**	-0.142 **	0.080 **
9	PH-1075 x SB-425 YF	0.889**	0.296	0.126 **	0.01
10	PH-1075 x Suvin	-1.380**	9.864**	-0.158 **	-0.037
11	P-2151 x SB289E	-0.198	-3.880**	0.049 **	0.072 *
12	P-2151 x Reba-B-50	-1.689**	0.069	-0.060 **	0.031
13	P-2151 x Sujata	2.200**	1.400**	0.016	-0.099 **
14	P-2151 x SB-425 YF	0.533	-1.918 **	-0.049 **	-0.022
15	P-2151 x Suvin	-0.846**	4.329 **	0.044 **	0.018

16	GBHV-170 x SB289E	0.957**	-2.982 **	-0.022	-0.026
17	GBHV-170 x Reba-B-50	0.911**	5.667 **	0.191 **	0.047
18	GBHV-170 x Sujata	-1.756**	10.753 **	0.011	-0.034
19	GBHV-170 x SB-425 YF	-0.644*	-7.009 **	0.002	0.017
20	GBHV-170 x Suvin	0.531	-6.429 **	-0.182 **	-0.003
21	SCS-793 x SB289E	-1.509**	3.400 **	0.218 **	0.045
22	SCS-793 x Reba-B-50	1.333***	-3.184 **	-0.158 **	0.067 *
23	SCS-793 x Sujata	1.556**	4.380 **	0.129 **	-0.052
24	SCS-793 x SB-425 YF	-1.222**	-5.571 **	-0.125 **	-0.045
25	SCS-793 x Suvin	-0.157	0.975 *	-0.064 **	-0.014
26	DHY286 x SB289E	-2.087**	1.696 **	-0.246 **	-0.182 **
27	DHY286 x Reba-B-50	0.978**	0.734	-0.245 **	0.026
28	DHY286 x Sujata	0.867**	-5.425 **	0.120 **	0.03
29	DHY286 x SB-425 YF	-0.356	4.047 **	0.244 **	0.108 **
30	DHY286 x Suvin	0.598*	-1.051 *	0.127 **	0.017
31	AKH8828 x SB289E	-0.509	-0.602	-0.091 **	-0.039
32	AKH8828 x Reba-B-50	0.667*	8.047 **	0	0.019
33	AKH8828 x Sujata	-0.333	-3.322 **	-0.035 *	-0.070 *
34	AKH8828 x SB-425 YF	1.444**	1.471 **	0.022	0.012
35	AKH8828 x Suvin	-1.269**	-5.594 **	0.104 **	0.079 **
36	AKH081 x SB289E	0.357	-3.662 **	-0.213 **	-0.058 *
37	AKH081 x Reba-B-50	-1.133 **	2.265 **	0.011	-0.028
38	AKH081 x Sujata	-0.689 *	-3.827 **	0.087 **	0.003
39	AKH081 x SB-425 YF	-1.911 **	6.756 **	0.033	0.112 **
40	AKH081 x Suvin	3.376 **	-1.531 **	0.082 **	-0.029
41	PKV Rajat x SB289E	-1.309 **	2.194 **	0.227 **	0.032
42	PKV Rajat x Reba-B-50	1.089 **	2.754 **	0.006	0.019
43	PKV Rajat x Sujata	0.2	-1.205 **	-0.184 **	-0.038
44	PKV Rajat x SB-425 YF	0.533	-2.933 **	0.051 **	-0.068 *
45	PKV Rajat x Suvin	-0.513	-0.809	-0.100 **	0.055
46	LRA5166 x SB289E	0.335	5.060 **	-0.082 **	0.049
47	LRA5166 x Reba-B-50	0.4	-2.091 **	-0.002	-0.064 *
48	LRA5166 x Sujata	0.067	-5.827 **	-0.160 **	-0.143 **
49	LRA5166 x SB-425 YF	1.067 **	3.778 **	0.131 **	0.121 **
50	LRA5166 x Suvin	-1.869 **	-0.920 *	0.113 **	0.036
51	PH348 x SB289E	2.002 **	-1.475 **	-0.082 **	0.070 *
52	PH348 x Reba-B-50	-0.156	-7.915 **	0.053 **	-0.022
53	PH348 x Sujata	0.178	6.904 **	0.051 **	0.184 **
54	PH348 x SB-425 YF	-1.044 **	1.464 **	-0.169 **	-0.146 **
55	PH348 x Suvin	-0.980 **	1.022 *	0.147 **	-0.087 **
56	NH615 x SB289E	2.157 **	6.742 **	0.031	-0.038
57	NH615 x Reba-B-50	-0.889 **	2.047 **	0.178 **	0.064 *
58	NH615 x Sujata	0	-7.834 **	-0.024	-0.051
59	NH615 x SB-425 YF	-1.111 **	-1.584 **	-0.189 **	-0.027
60	NH615 x Suvin	-0.157	0.629	0.004	0.052
	S.E. (sca)	0.2772	0.017	0.4251	0.0287
	CD (S_{ij}-S_{ki}) @5%	0.771	0.0473	1.1823	0.0799
	CD (S_{ij}-S_{ki}) @ 1%	1.0153	0.0623	1.5569	0.1052

*, ** significance at 5 % and 1 % level respectively

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