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Line x Tester Analysis of Combining Ability and Its Interaction with Environment in American Cotton (*Gossypium hirsutum* L.)

D.R. BHANDARI[1]

The present studies reveal that general combining ability was more important as compared to specific combining ability in American cotton although latter was also operative. It would thus, be more appropriate first to concentrate additive genetic variance in the parents by selection procedures. This may be followed by a recurrent selection programme to utilize both additive and non-additive genetic variances in the segregating population. The g.c.a. component of variance was quite stable while s.c.a. was inconsistent from location to location except for halo length and ginning percentage for which both types of variances were stable. RS 455, H 297, RS 277 and PS 10 were overall the best parents for yield characters. TH 46, PS 10, CP 1998F, and Nectoriless were the best combining parents for ginning percentage, while RS 9, CPI 998F, RS 76, and SH 369 were superior parents for halo length. All crosses exhibiting the highest specific combining ability and mean, possess at least one parent which is a good or average combiner. Except for instance, in no case a low x low combiner exhibited high specific effects. General combining ability is thus, a good guide for initial selection of parents for improvement of various traits in cotton.

Studies on combining ability are useful in understanding the nature of genetic variance present in the material and selecting suitable parents for use in crossing programmes for developing superior F_1 hybrids or true breeding varieties. Combining ability is known to be influenced by environment (Rojas and Sprague, 1952; Marani, 1963, 1967; Lee *et al*. 1967). Such studies based on a single environment do not take into account genotype environment interactions, and results so obtained might be highly biased. Estimates of relative importance of general (g.c.a.) and specified combining ability (s.c.a.) respectively denoted by additive and non-additive genetic variance were obtained in the present study from comparison of variance components derived from line x tester analysis suggested by Kempthorne (1957) in three environments, involving twelve diverse female parents and four male parents of both inter and intraspecific origin as testers.

MATERIALS AND METHODS

The material consisted of twelve diverse female lines crossed to each of four unrelated male parents of inter and intraspecific origin. Of the four male parents, viz; RS 76, RS 455, SH 369 and TH 46, the last three had interspecific origin and were derivatives of *G. hirsu-*

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Cotton Botanist, Agricultural Research Station, Sriganganagar (Rajasthan).

tum, *G. barbadense* and *G. tharberi* respectively. Various female parents had American, Russian, Ceylonese or Indian origin. The forty eight F_1 hybrids along with sixteen parents were grown in a randomised block design with three replications at three locations in Rajasthan, i.e., Ajmer, Padampur and Sriganganagar. Individual plot consisted of one row, each 4.5 metre long, spaced 75 cm. apart. Plant to plant distance was maintained at 30 cm. Data were recorded from five randomly selected competitive plants in each plot for six characters, viz; seed cotton yield per plant, number of bolls per plant, boll weight, halo length, ginning percentage and seed index. General and specific combining ability variances and effects were determined using a line x tester method outlined by Kempthorne (1957).

RESULTS AND DISCUSSION

The estimates of general and specific combining ability components of variance for the three locations and pooled data along with combining ability x environment interaction components of variances are given in Table I.

Pooled analysis over locations revealed significant variances for general combining abitity for yield per plant, while at individual locations, the specific combining ability component of variance was much larger as compared to general combining ability, the latter being significant at one location only. However, the pooled analysis over location revealed, that much of the specific combining ability variance was subject to high genotype x environment interaction as evidenced by non-significant mean squares due to specific combining ability when tested against mean squares due to specific combining ability x location interaction. The component specific combining ability x location was very large. Compared to this, the general combining ability seems to be more stable as the component of variance due to g.c.a. was larger than g c.a. x location interaction.

A nearly similar trend was observed for another yield component number of bolls, but for other traits the trend was different. For boll weight specific combining ability was larger than the variance due to general combining ability in each case and it was unstable, as s.c.a. x location interaction was more as compared to the magnitude of s.c.a. variance component. For halo length and ginning percentage both g.c.a. and s.c.a. were stable and significant, although for the former g.c.a. and for the latter s.c.a. was more important. For seed index g.c a. was unstable and was significant at individual location only, while in pooled data s.c.a. was important.

In the present investigation, since general combining ability was stable for all the characters, the study of general combining ability based on limited number of locations only might provide quite useful information. Contrary to this specific combining ability was inconsistent and subject to larger interaction with environment especially in case of yield, number of bolls and boll weight, and as such more locations would be necessary to obtain valid information about this parameter. Significant s.c.a. x environment interaction

TABLE I. Analysis of variance for combining ability

	DF	Yield/ plant	No. of bolls	Boll weight	Halo length	G.P	Seed index
			AJMER				
Females	11	2713.92	123.51	1.275*	2.91*	7.23*	1.74*
Males	3	2419.50	154.9	1.200	3.39*	4.444*	1.32
M x F	33	2039.40*	103.98*	0.816*	0.63	1.02*	0.51
Error	94	200.30	13.09	0.110	0.74	0.56	0.88
σ^2 g.c.a.		N.S.	N.S.	0.174	0.10	0.20	0.04
σ^2 s.c.a.		613.03	30.30	0.235	N.S.	0.15	N.S.
			PADAMPUR				
Females	11	2079.96	253.11	0.480	5.73*	4.86*	0.96
Males	3	5269.53*	528.12*	0.300	2.25	2.25*	3.99*
M x F	33	1279.08*	148.62*	0.400*	2.43*	0.63*	0.99
Error	94	106.02	22.77	0.090	1.80	0.28	0.93
σ^2 g.c.a.		99.82	10.08	N.S.	0.12	3.04	0.06
σ^2 s.c.a.		391.02	41.95	0.103	0.21	0.21	N.S.
			SRIGANGANAGAR				
Females	11	1118.40	256.68*	0.150	8.73*	0.69*	1.45*
Males	3	1390.95	188.05*	0.291	10.11*	10.08*	1.68*
M x F	33	737.46	6.51	0.309*	0.99	0.92*	0.52
Error	94	144.27	26.28	0.042	1.00	0.48	0.42
σ^2 g.c.a.		N.S.	8.99	N.S.	0.35	0.25	0.04
σ^2 s.c.a.		197.73	N.S.	0.890	N.S.	0.15	N.S.
			POOLED				
Females	11	1738.21	319.30	0.65	12.48*	13.21*	1.96
Males	3	6583.71*	574.79*	0.41	13.07*	11.81*	4.84
M x F	33	1247.31	99.68	0.71*	2.07*	1.62	0.98*
M x L	6	1216.44	105.55	0.65	1.13	1.11	1.70*
F x L	22	2081.41	148.07	0.60	2.70*	1.32	1.27*
M x F x L	66	1391.59*	105.46*	0.42*	1.01	0.74	0.73
Error	282	150.20	20.71	0.08	1.18	0.44	0.74
σ^2 g.c.a.		36.89	4.53	N.S.	0.13	0.14	N.S.
σ^2 s.c.a.		N.S.	N.S.	0.03	0.12	0.98	0.03
σ^2 g.c.a. x L		N.S.	N.S.	N.S.	0.04	0.02	0.31
σ^2 s.c.a. x L		413.80	28.25	0.11	N.S.	0.10	N.S.

* Significant at 5% level. M = Male, F = Female, L = Location

was also observed in corn by Rojas and Sprague (1952).

In cotton Miller & Marani (1963) did not find interactions of g.c.a. and s.c.a. of significance, but Marani (1963, 1967) observed both g.c.a. and s.c.a. interactions to be inconsistent from year to year. Lee *et al.* (1967), however reported significant g.c.a. and s.c.a. interaction with locations for lint yield and lint per cent, respectively.

The large magnitude of variance due to general combining ability in pooled data for yield, number of bolls, and halo length indicates that these traits are predominantly influenced by additive gene effects. At the same time for other yield components like boll weight, seed index and ginning percentage, specific combining ability was more important although, for the latter, general combining ability was also significant, which signifies that non-additive genetic variances were important for these characters. High magnitude of heterosis coupled with high and significant parent v/s hybrid variances at individual locations as well as in pooled data and also presence of significant variances for specific combining ability for yield and number of bolls at two to three locations indicate the presence of non- additive genetic variance as well. While few workers have reported preponderance of additive genetic variance for yield and most other characters (White and Richmond, 1963; Marani, 1963; Miller and Marani, 1963; Miller and Lee, 1964; Douglas and Adamson, 1966; Lee *et al.* 1967; Marani, 1968; Adl and Miller, 1971.), still others have observed both additive and non-additive variances to be important alough the relative magnitude of one over the other varied from study to study (White and Richmond, 1963; Singh *et al.* 1969; Singh and Gupta, 1970; Singh, Gupta and Phul, 1971; and Kumar *et al.* 1974). It is, thus, evident from the present study and also from other studies as mentioned above that in cotton both additive and non-additive genetic components of variance are operative although former seems to be relatively more important. If this should be so, the most efficient breeding method would be one that maximizes additive gene effects as well as heterotic effects. Under such a situation, it would be desirable first to proceed with selection in parental populations to increase the frequency of favourable genes with additive effects. As the favourable genes with additive effects became fixed, the parents may then be crossed to achieve high heterosis in F_1. Later, recurrent selection programme which may allow intermating of selections in different cycles would be effective in exploiting both types of gene effects. This may prove more important than conventional procedure of pedigree breeding in both fixing and increasing the frequency of pleiotropic genes and chromosome blocks of favourable link genes in superior lines. Both the parents selected for such programme should have high general combining ability which when crossed produce high heterosis and high to average specific effects. Such crosses may have additive x additive types of gene effects and therefore a large part of heterosis in F_1 would be fixable in segregating generations (Jink and Johnes, 1958).

It was observed that male parent RS 455 of interspecific origin and female parents H 297, RS 277 and PS 10 were good combining parents for yield and number of bolls and PS 10 for yield and ginning percentage (Table II). In addition to these, another male parent TH 46 was specifically the best combiner at Ajmer for yield, boll weight and ginning percentage and PS 10 for yield, number of bolls, boll weight and ginning percentage. Female parents 5143C and RS 105 were found to be superior at Srigangangar and Padampur respectively for yield and number of bolls. The parents should, therefore, be used judiciously for yield improvement in cotton. The important crosses involving such parents are PS 10 x TH 46 at Ajmer, RS 277 and H 297 crossed to RS 455 at Padampur, 5143C crossed to RS 455 at Sriganganagar, RS 277, PS 10 and H 297 crossed to RS 455 in pooled data. These crosses have given 24 to 98 per cent higher yield over the most superior parent, high to average specific effects and involve both parents which are good general combiners. These crosses, therefore, have good potentiality for use in future breeding programme. Parents CPI998F, Nectariless, TH 46 and PS 10 were the best combiners for ginning percentage while RS 9, RS 76, SH 369 and CP1998F were the best contributors of favourable genes for halo length. RS 445 was the best parent for seed index. For developing true breeding varieties combining high yield and quality characters, a multiple crossing programme might be most useful.

Among the two high yielding crosses at each location and in pooled data, one cross 5143C x RS 455 at Sriganganagar involved both parents which were high combiners while other crosses, i.e. PS 10 x RS 76 at Ajmer, H297 x TH46 and RS 67 x RS 455 at Padampur and H 297 x TH 46 and RS 277 x RS 455 involve only one parent which was a high combiner. These crosses may be useful for commercial exploitation in F_1 only as the fixable genes if any in such cases might be too small to be of practical value. Another two high yielding crosses, CP 1998F x SH 369 at Ajmer and CP1998F x RS 76 at Sriganganagar involve both parents which are average combiners. The average combiners may have balanced groupings of negative and positive alleles and hence may involve all sorts of interactions, especially when diverse in origin, thus, leading to high magnitude of heterosis. Such crosses in any case are also useful for commercial exploitation in F_1 only.

In the present study, the crosses of high x high combining parents in most cases have exhibited average specific combining ability. Such crosses showing high combining ability were, however, rare. These results are in agreement with Bains, *et al.* (1967) in pearl millet, and Singh, *et al.* (1971) in cotton. It was further observed that the two highest yielding crosses at each location also exhibited high specific combining ability as well. The data further reveal that crosses showing high s.c.a. effects involve at least one parent which is high or average general combiner except for one cross CPI 998F x

TABLE II. Estimates of general combining ability effects for parents

	Yield/plant				No. of bolls				boll weight			
(1)	Ajm. (2)	Pad. (3)	SGNR (4)	Pooled (5)	Ajm. (6)	Pad. (7)	SGNR (8)	Pooled (9)	Ajm. (10)	Pad. (11)	SGNR (12)	Pooled (13)
Males												
SH 369	−2.11	−0.46	−1.62	−1.23	1.71	−0.42	0.73	0.55	−0.26	0.80	−0.09	−0.08
RS 455	3.48	14.28**	9.17**	8.90**	0.22	4.20**	2.80**	2.41**	0.06	0.07	0.07	0.06*
TH 46	8.91**	1.45	−3.15	2.34	1.10	1.13	−0.92	0.17	0.18**	−0.11	−0.06	0.00
RS 76	−10.28**	15.26**	−3.39	−10.00**	−3.03	−4.91**	−2.61*	−3.13**	0.12	−0.04	−0.09*	0.01
S.E. ±	1.95	1.77	1.99	1.29	0.51	0.61	0.72	0.37	0.048	0.046	0.009	0.020
C.D. 5%	5.50	4.99	5.62	3.64	1.44	1.72	2.03	1.05	0.13	0.12	0.225	0.06
C.D. 1%	7.23	6.56	7.39	4.79	1.89	2.26	2.67	1.37	0.17	0.15	0.033	0.08
Females												
RS 295	−8.98	−1.62	16.90**	1.97	1.52	−3.13	6.83**	1.66	−0.41**	0.24*	0.01	−0.05
RS 105	−16.39**	8.38*	7.44	−0.26	−0.65	3.06	4.00*	1.82	−0.36**	0.00	−0.10	−0.12
RS 273	−1.47	0.38	1.44	0.01	−0.82	−0.70	0.94	−0.46	0.10	0.08	0.01	0.06
RS 277	9.50	18.65**	−4.21	7.91*	2.25	7.72**	−2.02	2.52*	0.40**	−0.07	−0.01	0.01
H 297	−3.18	25.89**	5.09	9.21*	0.53	7.11**	3.35	3.54**	−0.17	0.10	−0.07	−0.04
5143 C	3.64	−10.55**	9.96*	1.62	4.12**	0.92	3.90*	2.85**	−0.38**	−0.39**	−0.01	−0.26**
RS 67	2.46	0.68	3.97	2.32	2.70	−1.12	1.32	0.82	−0.13	0.02	0.06	0.01
Nect.	7.50	−1.51	−13.64**	−2.62	−4.13**	−0.12	−4.21*	−2.37*	0.67**	0.02	−0.12	0.19**
PS 10	35.68**	0.40	−0.80	9.19**	4.40**	−0.81	−2.84	0.45	0.34**	−0.02	−0.10	0.07
D 33	−8.97	12.73**	−3.69	−8.51*	−4.13**	−1.82	−1.63	−1.72	0.25*	−0.28*	0.06	−0.01
RS 9	−24.23**	−5.13**	0.99	−9.48**	−5.15**	−1.31	0.91	−2.00	−0.12	−0.04	−0.02	−0.05
CP 1998 F	4.45	−22.64**	−15.92**	−11.36**	−0.62	−9.80**	−10.55**	−7.11**	0.18	0.33**	0.30**	0.24**
S.E. ±	3.86	2.81	3.28	2.47	0.98	1.29	1.39	0.71	0.090	0.081	0.060	0.046
C.D. 5%	10.91	7.93	9.25	6.97	2.78	3.66	3.93	2.01	0.25	0.23	0.16	0.12
C.D. 1%	14.34	10.43	12.15	9.17	3.65	4.81	5.17	2.64	0.33	0.30	0.20	0.16

[Contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Males												
SH 369	0.29	0.20	0.21	0.25*	0.07	—0.07	0.07	0.02	—1.67**	—0.23	—0.12	—0.19*
RS 455	—0.29	—0.25	—0.43*	—0.30*	0.17	0.03	—0.25	—0.03	1.48**	0.49**	0.27*	0.29**
TH 46	—0.25	—0.17	—0.33*	—0.29*	0.32*	—0.28*	0.54**	0.40**	1.48**	0.07	—0.21	0.01
RS 76	0.24	0.23	0.65**	0.35**	—0.56**	0.28*	—0.37*	—0.39**	—1.64**	0.18	0.06	—0.11
S.E.±	0.118	0.187	0.138	0.083	0.104	0.069	0.097	0.055	0.132	0.132	0.090	0.069
C.D. 5%	0.33	0.53	0.39	0.24	0.29	0.10	0.27	0.15	0.37	0.37	0.25	0.19
C.D. 1%	0.43	0.69	0.51	0.33	0.38	0.25	0.36	0.20	0.49	0.49	0.33	0.25
Females												
RS 295	0.03	0.37	0.43	0.26	—0.08	—0.33	0.19	—0.08	—0.73*	—0.26	—0.01	—0.36
RS 105	—0.55	0.32	0.04	—0.03	—0.37	—0.33	—0.12	—0.27	—0.39	0.05	0.21	—0.09
RS 273	0.45	0.08	0.17	0.28	—0.60*	—0.57**	0.70**	—0.70**	0.77*	0.24	0.49*	0.48*
RS 277	0.13	0.08	0.20	0.09	—0.60*	—0.04	0.13	—0.01	—0.37	0.17	0.48	0.31
H 297	0.18	0.57	0.32	0.43	—0.41	—0.43*	—0.16	—0.33	—0.21	0.25	—0.03	—0.01
5143 C	—0.83*	—1.48**	—0.45	—0.92**	0.40	—0.25	0.72**	—0.01	—0.06	0.07	—0.03	—0.03
RS 67	0.08	—0.32	—0.18	0.03	—0.40	0.08	—0.39	—0.23	—0.12	0.07	0.03	—0.04
PS 10	—0.10	—0.20	—1.48**	—0.60*	1.18**	0.57**	0.72**	0.83**	—0.18	0.44	—0.63*	—0.01
Nect.	—0.63	—0.83	—1.42**	—0.98**	1.73**	0.61**	0.73**	0.96**	0.00	—0.42	—0.33	—0.06
D 33	0.08	—0.40	—0.14	—0.13	0.03	0.56**	—0.11	0.15	0.31	0.37	0.13	0.00
RS 9	1.00**	—0.50	1.25**	0.71**	—0.99**	—1.09**	—0.05**	—1.04**	0.01	0.21	0.23	0.13
CPI 1998F	0.15	1.22*	1.26**	0.86**	0.37	1.21**	0.69**	0.75**	—0.13	—0.32	—0.48	—0.31
S.E. ±	0.09	0.361	0.271	0.166	0.201	0.145	0.187	0.104	0.257	0.264	0.173	0.132
C.D. 5%	0.66	1.01	0.76	0.47	0.56	0.41	0.53	0.29	0.72	0.74	0.49	0.38
C.D. 1%	0.87	1.33	1.00	0.62	0.74	0.54	0.69	0.39	0.95	0.97	0.64	0.60

* Significant at 5 per cent level ** Significant at 1 per cent level

SH 369 pertaining to number of bolls at Sriganganagar. Except for one instance, in no case a cross of low x low combining parents exhibited high s.c.a. effects. Furthermore, the crosses exhibiting the highest yield in most cases also possess at least one, and in some cases both the parents which are high combiners. Thus, combining ability seems to be a good guide for initial selection of parents with further selection guided by evaluation of specific effects.

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