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Line × tester analysis for fixed effect model in cotton (*Gossypium hirsutum* L.)

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Summary. The data from an experiment in cotton consisting of three testers and 12 lines selected deliberately have been analysed. The investigation showed higher specific combining ability variance for yield of seed cotton and number of bolls, indicating the predominance of non-additive gene action. Of parental lines, H777 was found to possess high g.c.a. effects for seed cotton yield, number of bolls and number of sympodes. Parent H842 contributed only for boll weight, whereas H655 was good general combiner for number of monopodes. There appeared to be better chances for increasing the yield by exploiting hybrid vigour for the number of bolls and boll weight. The presence of marked non-additive gene effects, in addition to additive gene effects, indicated the need for exploiting both the fixable and non-fixable components of genetic variance for increasing productivity in cotton.

Key words: Combining ability analysis – *Gossypium hirsutum* L.

Introduction

Combining ability analysis is the most widely used biometrical tool for identifying prospective parents and for formulating breeding procedures most likely to succeed. Line × tester analysis, which is a simple extension and application of the analysis of two factor factorial experiments given by Fisher (1926) and Yates (1937), has been very commonly used for combining ability analysis in plant breeding. With the above objective in mind, a line × tester design was adopted in cotton (*Gossypium hirsutum* L.) and the analysis presented with the help of experimental data.

Material and methods

Three testers H777, H655 and H842 and 12 lines (females) BARSP84, REBA-B50, BP68, Laxmi 7882, PL 807, H 807, 152F, Paymaster-303, Cocker 310, SV63, G.S.29 and H843 were deliberately selected, keeping in view the phenotypic and geographic diversity. Fifteen parents and 36 crosses were grown in a Randomized Block Design (RBD) with three replications during *kharif* 1981 at the Haryana Agricultural University Farm, Hisar.

Row to row spacing was kept at 75 cm and plant to plant spacing was 30 cm. Ten competitive plants were selected from F_1's and parents. Data was recorded on yield per plant (gm), boll number per plant, boll weight (gm), the number of monopodes and sympodes.

Regarding statistical analysis, the combined analysis of parents and crosses was done as suggested by Arunachanlam (1974) and for combining ability analysis, the following model was used:

$$Y_{ijk} = \mu + f_i + m_j + (mf)_{ij} + b_k + e_{ijk}$$
$$(i = 1, 2, \ldots l, j = 1, 2, \ldots t, k = 1, 2, \ldots r)$$

where Y_{ijk} denotes the observation recorded on the $(i \times j)$th cross in the k th replication; μ is the general effect; f_i is the effect of the i th line; m_j is the effect of the j th tester; s_{ij} is the specific combining ability (s.c.a.) effect of the $(i \times j)$th cross; b_k is the k th block effect and e_{ijk} is the environmental effect (random error) associated with the (ijk)th observation which is assumed to be normally and independently distributed with a mean of zero and variance (σ^2).

The estimates of male, female and interaction effects are obtained by using the usual least square theory. Male and female effects are obtained by taking the deviation of respective means from the overall mean, and the interaction effect is obtained after subtracting male and female effects from the cross effect. The sum of squares due to effects are obtained by the method of fitting constants (Table 1).

$\tilde{\sigma}_f^2$, $\tilde{\sigma}_m^2$ represent fixed type variances for lines and testers respectively. The weighted average of these two can be taken as an estimate of $\tilde{\sigma}^2_{g.c.a.}$, i.e.

$$\tilde{\sigma}^2_{g.c.a.} = [(l-1)\,\sigma_f^2 + (t-1)\,\sigma_m^2]/(l + t - 2).$$

The ratio $\tilde{\sigma}^2_{g.c.a.}/\tilde{\sigma}^2_{s.c.a.}$ will give an approximate idea about degree of dominance.

Table 1. ANOVA table for line × tester analysis (fixed effect model)

Source	d.f.	Sum of squares	M.S.	Expexted mean square	F
Blocks	$r-1$	$\frac{\sum_K Y^2_{..k}}{lt} - \frac{Y^2_{...}}{ltr}$			
Lines	$l-1$	$\frac{\sum_i Y^2_{i..}}{rt} - \frac{Y^2_{...}}{ltr}$	M_l	$\sigma^2 + rt \sum_i f_i^2/(l-1)$	M_l/M_e
Testers	$t-1$	$\frac{\sum_j Y^2_{.j.}}{rl} - \frac{Y^2_{...}}{ltr}$	M_t	$\sigma^2 + rl \sum_j m_j^2/(t-1)$	M_t/M_e
Line × tester	$(l-1) \times (t-1)$	$\frac{\sum_{i,j} Y^2_{ij.}}{r} - \frac{\sum_i Y^2_{i..}}{rt} - \frac{\sum_j Y^2_{.j.}}{lr} + \frac{Y^2_{...}}{ltr}$	$M_{l\times t}$	$\sigma^2 + \frac{i \sum_{i,j} (mf)^2_{ij}}{(l-1)(t-1)}$	$M_{l\times t}/M_e$
Error	$(lt-1) \times (r-1)$	$\sum_{i,j,k} Y^2_{ijk} - \sum_K Y^2_{..k/lt} - \sum_{i,j} Y^2_{ij./r} + Y^2_{...}/ltr$	M_e	σ^2	

where $Y_{i...} = \sum_{j,k} Y_{ijk}$, $Y_{.j.} = \sum_{i,k} Y_{ijk}$, $Y_{...} = \sum_{i,j,k} Y_{ijk}$ and $Y_{..k} = \sum_{i,j} Y_{ijk}$

To evaluate the relative contribution of g.c.a. and s.c.a., fixed type of variances are obtained as follows:

$$\tilde{\sigma}_f^2 = \sum_i f_i^2/(l-1) = (M_l - M_e)/rt$$

$$\tilde{\sigma}_m^2 = \sum_j m_j^2/(t-1) = (M_t - M_e)/rl$$

$$\tilde{\sigma}^2_{s.c.a} = \sigma^2_{m\times f} = \sum_{i,j} (mf)^2_{ij}/(l-1)(t-1) = (M_{l\times t} - M_e)/r$$

$$\hat{\sigma}^2 = M_e$$

Table 2. ANOVA table for parents and crosses

Source	d.f.	Mean square				
		Yield	No. of bolls	Boll wt	No. of monopodes	No. of sympodia
Replications	2	2.338	99.261	0.1182	0.082	2.789
Hybrids	35	1280.037**	468.207**	0.976**	1.343**	37.526**
Parents	14	769.209**	297.305**	1.266**	4.835**	40.649**
Hybrids vs parents	1	2790.275**	1161.956**	0.683**	1.563**	1.418 NS
Error	100	57.607	17.371	0.055	0.208	2.619
Total	152					

Table 3. ANOVA for combining ability analysis

Source	d.f.	Mean squares				
		Yield	No. of bolls	Boll wt	No. of monopodes	No. of sympodes
Replication	2	112.5156	146.0417	0.2420	0.0395	0.7612
Line (female)	11	1615.8781**	731.3633**	2.5337**	3.3293**	61.8561**
Tester (males)	2	1031.7215**	77.4559**	0.3306**	1.2993**	2.9515**
Line × tester	22	1134.6920**	372.1526**	0.2563**	0.3540	28.5044**
Error	70	54.3963**	15.2492	0.0401	0.2310	2.3994
Total	107					

Results and discussion

The analysis of variance (Table 2) of the parents and crosses for five characters, viz. yield of seed cotton, number of bolls, boll weight, number of monopodia and number of sympodia indicated that no significant differences existed between replications, whereas differences between hybrids, parents and hybrids vs parents were significant for all characters except number of sympodes.

Analysis of variance for combining ability (Table 3) revealed that the differences due to female and male parents were highly significant for all characters studied except due to males for the number of sympodes. Contribution of male × female interaction was highly significant for all characters except number of monopodes. The differences due to males and females, when tested against interaction, as is done in a random effect model, turns out to be non-significant which is contrary to the conclusion drawn from a fixed effect model. Hence, gene effects though present are under-estimated or not detected in a random effect analysis when actual data pertains to a fixed effect model.

The estimates of $\tilde{\sigma}^2_{g.c.a.}$ and $\tilde{\sigma}^2_{s.c.a.}$ given in Table 4 revealed that the nature of the gene effects was predominantly non-additive for yield, number of bolls and sympodes. However, substantial additive gene action was noted for boll weight and the number of monopodes.

The comparative analysis of gca effects (Table 5) of the parents showed that among tester parents only H777 was a better general combiner for seed cotton yield and the number of bolls. Only four females, BAR-SP-84, Laxmi 7882, PL807 and H807, showed considerable positive g.c.a. effects for three important traits-yield, boll number and sympodia-giving little choice among females with respect to g.c.a. effects.

With regard to s.c.a. effects (Table 6) 17 cross combinations showed positive estimates of s.c.a. effects for the yield of seed cotton. Of these hybrids H842 × 152F, H655 × H807, H777 × H807, H842 × Paymaster 303 and H842 × SV63, in that order, were the best five combina-

Table 4. Estimation of fixed type variances for different traits

Estimate of variances (fixed type)	Yield	Boll wt	Boll no.	No. of monopodes	No. of sympodes
$\tilde{\sigma}^2 = M_e$	54.3963	0.0401	15.2492	0.2310	2.3994
$\tilde{\sigma}^2_{s.c.a.} = (M_{l \times t} - M_e)/3$	360.0986	0.0721	118.9678	0.0410	8.7017
$\tilde{\sigma}^2_f = (M_l - M_e)/9$	173.4980	0.2771	79.5682	0.3443	6.6063
$\tilde{\sigma}^2_m = (M_t - M_e)/36$	27.1479	0.0081	1.7280	0.0297	0.0153
$\tilde{\sigma}^2_{g.c.a} = (11\,\tilde{\sigma}^2_f + 2\,\tilde{\sigma}^2_m)/13$	150.9826	0.2357	67.5928	0.2959	5.5923
$\tilde{\sigma}^2_{s.c.a}/\tilde{\sigma}^2_{g.c.a.}$	2.3850	0.3059	1.7601	0.1386	1.5560

Table 5. g.c.a. effects of parents for different characters

Sr. no.	Parent	Yield	Boll no.	Boll wt	No. of monopodes	No. of sympodes
	Males					
1	H777	6.17	1.585	0.038	0.126	0.293
2	H655	− 2.76	− 0.276	− 0.109	0.092	− 0.013
3	H842	− 3.41	− 1.309	0.070	− 0.219	− 0.279
	Females					
4	BAR-SP-84	8.05	6.485	− 0.400	0.798	2.096
5	REBA-B-50	− 19.75	12.715	0.605	− 0.169	− 2.715
6	BP68	− 13.43	− 2.804	− 0.596	− 0.191	− 1.926
7	L7882	9.65	8.752	− 0.249	− 0.413	4.429
8	PL807	26.25	13.330	− 0.049	− 0.313	3.918
9	H807	14.97	12.096	− 0.306	− 0.124	3.057
10	152F	− 5.85	1.763	− 0.517	− 0.591	− 0.349
11	Paymaster 303	5.73	− 7.004	0.842	− 0.258	− 2.149
12	Cocker 310	− 6.97	− 10.693	0.816	− 0.102	− 1.738
13	S.V.63	− 13.45	− 5.315	− 0.249	− 0.313	− 2.349
14	G.S.29	0.85	4.352	− 0.366	1.598	− 1.060
15	H843	− 6.02	− 8.248	0.467	0.076	− 1.204

Table 6. s.c.a. effects of different crosses for different characters

Cross	Yield	Boll no.	Boll wt	No. of monopodes	No. of sympodes
1× 4	12.27	3.493	− 0.067	− 0.104	3.796
1× 5	− 11.10	− 2.707	0.131	0.163	0.207
1× 6	− 11.82	− 6.185	− 0.455	− 0.415	− 0.949
1× 7	− 0.70	− 4.507	0.326	− 0.326	− 1.071
1× 8	10.44	10.281	− 0.172	− 0.126	2.440
1× 9	23.65	15.915	− 0.128	0.185	3.074
1× 10	− 29.00	− 14.418	− 0.194	0.418	− 4.193
1× 11	− 6.71	− 7.585	0.254	0.519	− 0.259
1× 12	13.02	− 0.062	0.483	0.029	− 1.504
1× 13	− 7.63	− 2.040	− 0.212	− 0.260	0.441
1× 14	5.80	7.226	− 0.191	− 0.071	− 0.982
1× 15	1.74	0.593	0.202	− 0.015	− 1.004
2× 4	4.33	4.521	0.140	0.263	1.102
2× 5	− 2.47	− 1.646	0.028	− 0.570	− 1.421
2× 6	2.53	0.676	0.126	− 0.098	− 1.510
2× 7	1.50	0.954	− 0.038	0.108	2.069
2× 8	− 3.77	5.109	− 0.281	0.308	0.113
2× 9	26.48	11.310	0.279	− 0.219	3.147
2× 10	− 2.00	− 2.424	0.030	− 0.181	− 2.120
2× 11	− 15.28	− 3.657	− 0.182	− 0.381	− 0.287
2× 12	− 2.45	1.565	− 0.356	0.163	1.002
2× 13	− 6.90	− 9.146	0.152	0.274	0.113
2× 14	4.20	− 3.980	0.289	− 0.203	− 0.942
2× 15	− 6.26	− 3.280	− 0.187	0.052	− 1.265
3× 4	− 16.62	− 8.013	− 0.073	− 0.073	− 0.159
3× 5	13.55	4.384	− 0.158	0.408	1.212
3× 6	9.26	5.509	0.330	0.463	2.456
3× 7	− 0.82	3.553	− 0.314	0.219	− 0.999
3× 8	− 6.68	− 15.391	0.453	− 0.181	− 2.554
3× 9	− 50.14	− 27.224	− 0.150	− 0.404	− 6.221
3× 10	30.98	16.842	0.164	− 0.237	6.313
3× 11	22.00	11.243	− 0.071	− 0.136	0.546
3× 12	− 10.56	− 1.502	− 0.125	− 0.192	0.502
3× 13	14.51	11.187	0.060	− 0.015	− 0.554
3× 14	− 10.02	− 3.247	− 0.097	0.247	1.924
3× 15	4.52	2.687	− 0.013	− 0.037	2.268

tions. It is interesting to note that all five crosses showing higher s.c.a. effects for yield of seed cotton also recorded the greater values of s.c.a. effects for boll number. The s.c.a. for yield of seed cotton and boll number had almost a parallel trend. Sixteen cross combinations exhibited positive estimates of s.c.a. effects for boll weight, the maximum being in case of H777× Cocker 310, (0.483) followed by H842×PL807 (0.453), H842×BP68 (0.33), H777×Laxmi 7882 (0.326). Eighteen crosses possessed positive s.c.a. effects for number of sympodes, H842×152F having the maximum s.c.a. value (6.313) closely followed by H777×BAR SP84 (3.796), H655×H807 (3.14) and H777×H807 (3.074). Hybrid H842×152F, possessing the highest s.c.a. effect for number of sympodia, also possessed the highest s.c.a. effect for seed cotton yield.

Heterotic effects

Heterotic effects were estimated as the deviations of the F_1's from mid-parental values (MP) and the deviations from its better parent (BP), with respect to five traits of American cotton.

Sixteen crosses manifested heterosis over the mid-parent for seed cotton yield. Cross H842×H807 (69.81) followed by H777×PL807 (61.81) and H842×152F (61.57) exhibited even more than 50% heterosis over the mid-parent. Only eight hybrids showed positive heterosis over the better parent for seed cotton yield. Two cross combinations, H777×H807 (42.9%) and H777×PL807 (40.2), recorded more than 40% heterosis over the better parent (H777), the most commonly cultivated cotton variety of the zone.

Similarly, 16 crosses exhibited positive hybrid vigour (MP) for number of bolls, ranging between 8.0 to 85.2 (H655×H807) per cent. Twelve crosses recorded heterosis over BP for boll number. Hybrids H655× H807 (74.0%), H655×PL807 (53.5%) and H655× BAR SP (51.4%), recorded more than 50% heterosis over BP for boll number. Eleven crosses were found to be superior for boll weight over their better parents.

Heaviest boll weight was produced by the crosses H777×Laxmi 7882 (16.5%), followed by H842×PL807 (11.9%) and H777×H807 (10.5%). More than 50% hybrid vigour (BP) was recorded for number of monopodes in two crosses, H842×BP68 (52.2%) and H842×Reba-B50 (50.8%). Only six crosses recorded higher number of sympodia (BP), ranging between 3.0% (H655×H807) to 28.0% (H777×H807).

The degree of heterosis varied considerably for different characters with the maximum heterosis for the number of bolls per plant, yield of seed cotton and boll weight. Therefore, there appears to be good possibilities of increasing the yield by exploiting hybrid vigour through the number of bolls and boll weight. These results are in confirmity with earlier reports (White and Richmond 1963; Miller and Marani 1963; Marani 1967; Singh and Murty 1971; Singh 1974). For yield of seed cotton, the three best crosses were H842×152F, H655×H807 and H777×H807. These crosses were also best for boll number and the number of both types of branches. Crosses involving parents H842, H807 and 152F exhibited higher degree of heterosis for yield of seed cotton and other component characters of yield in this study. The best combinations (H777×PL807 and H777×H807), as judged from the s.c.a. estimates of seed cotton, involved the best general combiners (Table 6). Therefore, there may be a good chance of success for getting high yielding segregants and it equally may be possible of developing a hybrid involving the parents H777, PL807 and H807. These results are in general agreement with those reported by Turner (1953); Marani (1963, 1964); Gururaja Rao (1975) and Bhallala (1976). In order to exploit the type of gene effects operative in the population developed by involving H777, H807 and PL807, a breeding procedure which takes care of both additive and non-additive gene effects might prove the most efficient in improving the population. Similar findings have also been reported by Gupta and Singh 1970; Singh 1974; Chandermathi and Menon 1973 and Mirza and Khan 1976.

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