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Combining Ability Analysis for Seed Cotton Yield (Kapas Yield) and Its Components in Intra Hirsutum Hybrids and Forming Heterotic Boxes for Exploitation in Cotton

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Abstract An investigation was carried out during kharif 2008 in cotton (*G. hirsutum* L.) to evaluate intrahirsutum hybrids produced through Line x Tester mating design using 6 hirsutum non *Bt* lines (RAH 318, RAH 243, RAH 128, RAH 146, RAH 97 and RAH 124) and 8 hirsutum non *Bt* testers (SC 14, SC 18, SC 7, SC 68, RGR 32, RGR 24, RGR 58 and RGR 37) to generate information on combining ability effects in respect of kapas yield (seed cotton yield) and yield attributing characters and to for heterotic boxes. The 48 F1 hybrids were sown in a randomized complete block design (RCBD) with two replications at the Agricultural Research Station, Bavikere, UAS, Bangalore. From the estimates of additive and dominance variance, it is observed that dominance variance was predominant for all the characters and was maximum for kapas yield per plant followed by plant height and bolls per plant. However, both additive and dominance variance were found to be important in case of ginning per cent, monopodia per plant, mean boll weight, days to 50 per cent flowering, seed index and lint index. Among the lines, the mean sum of squares was significant for all characters except monopodia per plant and mean boll weight. The testers differed significantly for most of the characters except monopodia per plant, mean boll weight and seed index. However, the line x tester interaction was significant for all the characters except monopodia per plant, mean boll weight, seed index and lint index. Estimation of gca effects of lines and testers indicated that, no single line or tester was found to be a good general combiner for all the characters studied. However, the line RAH 146 exhibited significant gca effects in the desired direction for 5 characters (plant height, sympodia per plant, bolls per plant, kapas yield and ginning per cent) and was considered as best general combiner among lines. Among the testers, the tester RGR 32 was considered as the good general combiners, since it had high significant gca effects in the desirable direction for monopodia per plan, bolls per plant, mean boll weight and ginning per cent. The hybrid RAH 128 x RGR 37 exhibited significant specific combining ability for plant height, sympodia per plant and kapas yield; RAH 146 x SC14 for monopodia per plant, bolls per plant and kappa yield. The estimates of overall gca status of parents indicated that, the lines RAH 318, RAH 243 and RAH 124 were good general combiner as evident from its high (H) overall gca status. Among testers, testers SC 14, SC 7, SC 68 and RGR 24 were identified as good combiners with high (H) overall gca status. It also becomes important to determine whether a cross is a good specific combination across all the traits or not for the same reason, it is evident that 23 out of 48 hybrids had high (H) overall sca status, while remaining 25 crosses had low (L) overall sca status across all the traits studied.

Keywords Line x tester analysis; General combining ability; Specific combining ability; *Gossypium hirsutum* L.

Introduction

Cotton, being the king of fibers in preparing human apparel has played a key role in civilization of mankind. Cotton is providing livelihood directly and indirectly to over 60 million people and accounting for about 16 per cent of India's export earnings.

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Hybrids have occupied nearly 90% area of cotton cultivated in India. There is a constant need to develop more potential hybrids and adopt noval approaches for improving hybrid performance. In cross pollinated crops like maize heterotic populations are developed and exploited through population improvement schemes meant for improving combining ability. Such programmes are integral part of hybrid breeding programme and these populations are shared among breeders and used further to obtain more potential hybrids. Studies have shown that even in cotton it is possible to adopt these concepts with suitable modifications in the procedure to suit the mating system of self pollinated crops (Patil and Patil, 2003; Patil et al., 2007).

Exploiting heterosis is one of the methods used to increase cotton yields that have stagnated in recent years. The success of the hybridization is largely dependent on the correct selection of parents. Estimates of genetic variation and combining ability are useful in determining the breeding value of some populations and the appropriate procedures to use in a breeding program. The general combining ability effects are important indicators of the value of genotypes in hybrid combinations. Differences in general combining ability effects have been attributed to additive, additive x additive, and higher-order additive interactions, whereas differences in specific combining ability have been attributed to non-additive genetic variance (Falconer, 1960).

The concept of combining ability is important in designing plant breeding programmes. It is especially useful in testing procedures, where it is desired to study and compare the performance of lines in hybrid combinations. Combining ability or productivity in crosses is defined as the ability of parents or cultivars to combine amongst each other during the process of hybridization so that favourable genes/characters are transmitted to their progenies. Two types of combining ability, general and specific, have been recognized in quantitative genetics. Specific combining ability is defined as the deviation in the performance of hybrids from the expected productivity based upon the average performance of lines involved in the hybrid combination, whereas general combining ability is defined as average performance of a line in a series of crosses. According to Sprague and Tatum, general combining ability is due to genes which are largely additive in their effects and specific combining ability is due to the genes with dominance or epistatic effect. Rawlings and Thompson used line x tester analysis to estimate GCA and SCA of inbred parents. Since the development of new cultivars through hybridization is a continuous process, information on combining ability of new cultivars remains important. Desphande and Baig noted that though GCA and SCA variances were important, the magnitude of SCA was higher than GCA indicating the preponderance of dominant genes controlling number of bolls, ginning outturn%, seed index, lint index and seed cotton yield. Contrary to the above findings, Rokaya et al. found significance of GCA and SCA suggesting the importance of additive as well as dominant genes, nevertheless the ratio of GCA/SCA was greater than the unity further indicating the preponderance of additive genes in the inheritance of seed cotton yield, seed index and lint%.

In hybrid research study on cotton, large number of crosses involving varietal lines are used for assessing combining ability status. On constantly observing the most potential crosses attempts are made to infer about the causes of high heterosis. What are the combinations that give potential crosses? What would be the probable cause for high potentiality revealed by the F_1? What is the genetic base or is there any physiological mechanism linked to high productivity of F_1 etc., are the questions which are examined and on the basis of the information available, heterotic groups are developed (Patil et al., 2011).

The most potential crosses observed in present study have been examined and based on this the combining ability behavior (Pattern) of the line involved is determined. With the help of this information diverse groups are formed which are capable of giving potential hybrids between them. A study of set of hybrids involving the line as a common parent gives an idea about the combining ability pattern of the concerned line. The higher or lower performance of the hybrids is itself taken as reflection of genetic distance existing between the parents. It has been possible to identify heterotic combinations (potential crosses) based on their percent superiority over the commonly used check. When these crosses show up to be consistently potential, they are considered while forming heterotic groups involving parents of such crosses.

The exercise of identifying diverse groups is a continuous process because the new breeding lines developed and stabilized and those lines obtained from other sources are included in developing crosses and these lines could be added in different heterotic groups after studying their combining ability behavior (pattern) by crossing with representative genotypes of different groups. Thus the grouping of genotypes is continuously revised and refined. In the recent years, the concept of developing heterotic groups is put to test in self pollinated crops like cotton. Segregating populations based on diverse pairs of genotypes can be the ideal base material required for implementing procedures like reciprocal selection for improving combining ability (Patil and Paltil, 2003; Patil et al., 2011).

One of the problems in using heterosis in cotton involves defining a strategy for the selection of parents that will ultimately produce productive hybrids. The present study evaluated parents and hybrids produced from line x tester mating. The objective of this study was to estimate parental general combining ability effects, to compare performance among F_1 hybrids, and to identify those superior for lint yield and yield components.

1 Results and Discussion

ANOVA for combining ability in respect of ten characters is presented in Table 1. Among the lines, the mean sum of squares was significant for all characters except monopodia per plant and mean boll weight. The testers differed significantly for most of the characters except monopodia per plant, mean boll weight and seed index. However, the line x tester interaction was significant for all the characters except monopodia per plant, mean boll weight, seed index and lint index.

The estimates of variance due to general combining ability (GCA), variance due to specific combining ability (SCA), GCA and SCA ratio, additive variance (VA) and dominance variance (VD) were worked out for different characters and presented in Table 2. It is evident from the table that, the estimates of SCA variance was predominant for all the characters. The GCA and SCA variance ratio was wider for kapas yield per plant (1:199.86) followed by monopodia per plant (1:150.00) and bolls per plant (1:81.60). From the estimates of additive and dominance variance, it is observed that dominance variance was predominant for all the characters and was maximum for kapas yield per plant (266.24) followed by plant height (12.81) and bolls per plant (12.37). However, both additive and dominance variance were found to be important in case of ginning per cent, monopodia per plant, mean boll weight, days to 50 per cent flowering, seed index and lint index.

Table 2 Variance due to general and specific combining ability for kapas yield and its attributing characters of cotton hybrids (*G .hirsutum* L.)

Character	Variance due to GCA	Variance due to SCA	GCA:SCA ratio	V_A	V_D
1. Days to 50% flowering	0.04	1.27	1:31.75	0.09	0.77
2. Plant height (cm)	2.24	139.12	1:62.10	4.49	12.81
3 Monopodia per plant	0.0002	0.03	1:150.00	0.0004	0.02
4. Sympodia per plant	0.20	11.22	1:56.10	0.40	0.78
5. Bolls per plant	0.58	47.33	1:81.60	1.17	12.37
6. Mean boll weight (g)	0.0026	0.12	1:46.15	0.005	0.01
7. Kapas yield (g /plant)	1.89	377.75	1:199.86	3.78	266.24
8. Ginning per cent (%)	0.22	10.19	1:46.31	0.45	1.45
9. Seed index (g)	0.01	0.72	1:72.00	0.03	0.31
10. Lint index (g)	0.02	1.08	1:54.00	0.05	0.30

SCA variances were higher in magnitude compared to GCA variances for almost all characters, which indicated predominance of non-additive gene action suggesting good scope for heterosis breeding.

Higher SCA variance than GCA variance was reported by Shanmugavalli and Vijendradas (1995) for days to 50% flowering; Bhatade et al. (1980); Singh and Singh (1980); Virk and Kalsy (1982); Shanti and Selvaraj (1995); Kalsy et al.(1981) ; Gill and Singh (1982) for plant height; Hapase et al. (1987) for Mononpodia per plant; Singh and Gupta (1970); Kalsy andGarg (1980); Singh and Raut (1983) for sympodia per plant, Singh and Singh (1985); Hapase et al. (1987); Raut et al. (1989)for bolls per plant; Bhandari (1980); Jagtap (1986); Shanti and Selvaraj (1995); Panchal et al. (1995) for boll weight; Singh et al. (1983) for Seed cotton yield (g/plant); Deshpande and Bhale (1984) for ginning per cent; Chakreshkumar et al. (1984); Hapase et al. (1987) for seed index; Grakh and Choudhary (1983) for lint index.

1.1 Estimation combining ability effects of parents and hybrids

The estimates of general combining ability (gca) effects of 14 parents (6 lines and 8 testers) and specific combining ability for 48 F_1 hybrids for different characters are presented in Table 3, Table 4 respectively and briefly discussed below.

1.1.1 Days to 50 per cent flowering

None of the lines exhibited significant gca effect in desirable direction. However, line RAH 318 recorded maximum gca effect (-0.59) in desirable direction. On the other hand, the tester RGR 37 recorded positive and significant gca effect (1.39) in desirable direction among testers. Of 48 hybrids, none of the hybrids showed significant sca effects for this trait, indicating predominant role of additive gene action in the genetic control of this trait. Kolte and Thombre (1981); and Patil and Chopde (1983) reported similar findings in their study.

1.1.2 Plant height (cm)

Among the lines, line RAH 318 registered highest negative and significant gca effect (-9.56) followed by line RAH 124 (-7.58) recorded negative and significant gca effect. The line RAH146 showed positive and significant gca effect (8.59). On the other hand, the tester RGR 37 (-11.27) also recorded highest negative and significant gca effect. For this trait, only one hybrid viz. Hybrid RAH128 x RGR 37 (L_3T_8) manifested significant negative sca effect (-23.25) indicating non additive gene action in this cross and additive gene action in the remain crosses in the genetic control of this trait. Shanti and Selvaraj (1995) also reported similar results.

1.1.3 Monopodia per plant

None of the lines recorded significant gca effect in positive direction, but the line RAH 124 recorded negative and significant effect (-0.18). On the other hand, among testers the tester RGR 32 recorded positive significant gca effect (0.19). Two hybrids viz., RAH 243 x RGR 37 (L_2T_8) and RAH 146 x SC 14 (L_4T_1) expressed significant negative sca effects of (-0.48) and (-0.51) respectively, indicating predominant role of non additive gene action in these crosses and additive gene action in the remain crosses. The same result respect of this trait reported by Katanalli et al. (2004), Ahuja and Dhayal (2007).

1.1.4 Sympodia per plant

Among the lines, line RAH 146 recorded significant positive gca effect (1.68), but the line RAH 318 showed negative and significant effect (-4.46). Among testers, positive significant gca effect (1.94) was recorded by tester SC68. Only one out of 48 hybrids viz, RAH 128 x RGR 37 (L3T8) showed significant negative sca effect (-5.07) for this trait. This according to the result of Katanalli et al. (2004).

1.1.5 Bolls per plant

Among six lines, the line RAH 128 manifested highest positive and significant gca effect (3.57) followed by lines RAH 146 and RAH 243 were also exhibited significant positive gca effect (3.49) and (2.00) respectively, while the lines RAH 97(-6.56) and RAH 124 (-2.60) showed highest negative significant gca effect. Among all testers the tester RGR 58 showed highest positive and significant gca effect (3.47) followed by testers SC 18 (-2.30), RGR 32 (-2.17) which registered negative and significant gca effect. Eight out of 48 hybrids exhibited significant sca effects. The crosses, RAH 318 x RGR 24 (L_1T_6), RAH 128 x SC 68 (L_3T_4), RAH 124 x SC 14 (L_6T_1) and RAH 124 x SC 18 (L_6T_2) manifested highest positive and significant sca effect of (9.07), (7.26), (6.03) and (5.30) respectively. On the other hand, the crosses RAH 318 x SC 18 (L_1T_2), RAH 243 x SC 68 (L_2T_4), RAH 146 x SC 14 (L_4T_1) and RAH 124 x RGR 24 (L_6T_6) showed significant negative sca effects of (-5.30), (-5.77), (-5.65) and (-6.13) respectively, which were on par with one another. Nageshwara Rao and Shiva Santha Reddy (2002) reported similar findings in their study.

1.1.6 Mean boll weight (g)

The line RAH 97 recorded positive significant gca effect (0.40), while the line RAH 243 had highest negative significant gca effect (-0.21). Among testers, the tester RGR 32 exhibited significant and positive gca effect (0.30) and the tester SC 68 exhibited highest significant and negative gca effects (-0.29). Among 48 hybrids, hybrid RAH 97 x RGR 37 (L5T8) and hybrid RAH 124 x RGR 37 (L6T8) exhibited significant negative and positive sca effects of (-0.56) and (0.63) respectively. Patel et al. (2004) found the same result in respect of this trait.

1.1.7 Kapas yield (g/plant)

Highest positive significant gca effect (14.00) for this trait was recorded by the line, RAH 146 and highest negative and significant gca effect (-13.45) was registered by the line RAH 124. Among testers, the tester SC 18 recorded positive significant gca effect (8.64) followed by tester RGR 37 (8.38), but the tester SC 68 showed highest significant and negative gca effect (-14.18) followed by tester SC 14 (-7.27). Ten out of 48 crosses exhibited significant sca effects of which 4 were positive and 6 were negative. The crosses RAH 97 x SC 18 ($L_5 T_2$) and RAH 318 x RGR 24 (L_1T_6), recorded highest positive and significant sca effects of (62.53) and (30.53) respectively. Contrary to this, the crosses RAH 97 x RGR 24 (L_5T_6) followed by the cross RAH 146 x SC 14 (L_4T_1) exhibited highest negative and significant sca effect of (-27.71) and (-23.65) respectively. Nageshwara Rao and Shiva Santha Reddy (2002) reported the same findings.

1.1.8 Ginning per cent (%)

Among the lines, the line RAH 146 manifested positive significant gca effect (2.19) while, the line RAH 243 recorded negative significant gca effect (-2.20). Among testers, the tester RGR 32 exhibited positive and significant gca effect (2.64) while tester SC 7 recorded negative significant gca effect (-2.42). Only one cross viz, RAH 318 x RGR 37 (L_1T_8) out of 48 crosses exhibited significant positive sca effect (5.88) indicates role of additive gene action. Kalsy et al. (1981); Bains et al. (1982); Singh et al. (1988); Panchal et al. (1995) reported the same findings.

1.1.9 Seed index (g)

Only the line RAH 97, among the lines recorded positive significant gca effect (1.16). On the other hand, only the tester RGR 24 manifested positive significant gca effect (0.75). Of 48 hybrids, none of the hybrids showed significant sca effects for this trait indicates predominant role of additive gene action. Singh and Singh (1980); Bhatade and Bhale (1983) reported the same results.

1.1.10 Lint index (g)

Among the lines also, two out of six lines viz, line RAH 97 and line RAH 243 expressed highest significant positive and negative gca effects of (1.07) and (-0.72) respectively. However, none of the testers exhibited significant gca effects for this trait. Of 48 hybrids, none of the hybrids showed significant sca effects for this trait reveals predominant role of additive gene action. Similar results was reported by Gururaja Rao et al. (1977).

1.2 Overall general combining ability status of lines and testers

Since the different traits are both positively and negatively correlated, it is usual to find, for a particular parent, gca in the desirable direction for some characters and in undesirable direction for the others. Hence, it becomes important to decide whether a parent is a good general combiner across all the characters or not. In this context, the method proposed by Arunachalam and Bandyopadhyay (1979) with slight modification as suggested by Mohan Rao (2001) was used in the present investigation to determine the overall general combining ability status of a line or a tester for its gca effects across the traits. The results of the same are presented in Table 5.

Table 5 Overall general combining ability status of parents in Cotton hybrids

Lines	Across traits	Overall Status
L_1- RAH 318	47	H
L_2- RAH 243	48	H
L_3- RAH128	35	L
L_4- RAH146	17	L
L_5- RAH 97	37	L
L_6- RAH 124	47	H
Final Mean = 38.5		
Testers	Across traits	Overall Status
T_1- SC 14	60	H
T_2- SC 18	46	L
T_3- SC 7	58.5	H
T_4- SC 68	59.5	H
T_5- RGR 32	34	L
T_6- RGR 24	51.5	H
T_7- RGR 58	46.5	L
T_8- RGR 37	40	L
Final Mean=49.5		

Note: H= High gca status; L = Low gca status

It is clear from the table that, the lines RAH 318, RAH 243 and RAH 124 among the lines recorded high (H) overall gca status, the line RAH 128, RAH 146 and RAH 97 exhibited low (L) overall gca status. Among the testers, SC 18, RGR 32, RGR 58 and RGR 37 recorded low (L) overall gca status, while the remaining four testers exhibited high (H) overall gca status.

1.3 Overall specific combining ability status of crosses

It also becomes important to determine whether a cross is a good specific combination across all the traits or not for the same reason explained above. The overall sca status of all the 48 hybrids was determined and the same has been depicted in Table 6.

From the table, it is evident that 23 out of 48 hybrids had high (H) overall sca status, while remaining 25 crosses had low (L) overall sca status across all the traits studied. The highest total score over the final norm was recorded by the hybrid 149 followed by 150, 111 and 141. Hence, these crosses can be utilized for heterosis breeding.

1.4 Proportional contribution of lines, testers and line x tester interaction to the total variance in hybrids

The per cent contribution of lines towards total variation in the hybrids (Table 7 and Figure 1) was higher from seed index (52.64%), followed by sympodia per plant (50.28%) and lint index (47.88%). On the other hand, per cent contribution of line x tester interaction to the total variance was higher for monopodia per plant (70.47%), kapas yield per plant (66.73%), plant height (51.98%), days to 50% flowering (48.82), bolls per plant (44.62%), mean boll weight (39.76%) and sympodia per plant (37.62%).

The per cent contribution of both tester and line and their interaction is dominant on par and important per cent contribution of line with respect to ginning per cent.

Table 7 Proportional contribution of lines, testers and their interactions to the total variance in Cotton (*G. hirsutum* L.)

Characters	Contribution of		
	Lines	Testers	Line x Tester Interaction
1. Days to 50% flowering	13.05	38.13	48.82
2. Plant height (cm)	29.97	18.05	51.98
3. Monopodia per plant	15.65	13.88	70.47
4. Sympodia per plant	50.28	12.10	37.62
5. Bolls per plant	43.85	11.52	44.62
6. Mean boll weight (g)	36.36	23.88	39.76
7. Kapas yield (g/plant)	18.82	14.45	66.73
8. Ginning per cent (%)	28.61	35.20	36.19
9. Seed index (g)	52.64	20.26	27.09
10. Lint index(g)	47.88	26.86	25.26

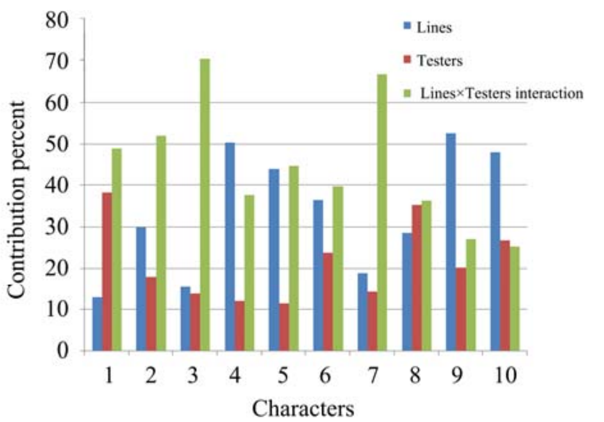

Figure 1 Proportional contribution of lines, testers and their interactions to the variance in hybrids of cotton (*G. hirsutum* L.)
Note: 1 Days to 50 % flowering; 2 Plnt height (cm); 3 Monopodia per plant; 4 Sympodia per plant; 5 Bolls per plant; 6 Mean boll weight (g); 7 Kapas yield per plant (g / plant); 8 Ginning per cent (%); 9 Seed index (g); 10 Lint index (g)

2 Conclusions and Recommendations

The term heterotic group refers to “a group of related or unrelated genotypes from the same or different populations, which display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups” (Melchinger and Gumber, 1998). In the recent years the concept of developing heterotic populations is put to test in self pollinated crops like cotton, segregating populations based on diverse pairs of genotypes can be the ideal base material required for implementing procedures like reciprocal selection for improving combining ability (Patil and Paltil, 2003; Patil et al., 2011). In hybrid research study on cotton, a large number of crosses involving varietal lines are used for assessing combining ability status. On constantly observing the most potential crosses attempts are made to infer about the causes of high heterosis.

If more lines are found to be giving superior crosses with a tester then it is possible to initiate multiple crosses among such lines selected for combining ability and this can lead to creation broad gene pool of recombination variability for combining ability as the population developed in this manner based on number of components improved in ability to combine with the tester. This heterotic gene pool can be exploited for developing superior hybrid combinations with the tester concerned.

Utilization of heterosis depends on genetic diversity existing between the parents, magnitude of dominance at the yield influencing loci and the genetic distance between the chosen parental genotypes. It is possible to maximize heterosis by enhancing genetic distance between two chosen parental populations. Many population improvement schemes are followed in cross pollinated crops to increase genetic diversity, to create heterotic groups and exploit them. These schemes can be extended to self pollinated crops by introducing slight modifications in the procedures to suit the crossing system of self pollinated crops. In present study heterotic box was developed by involving barbadense and hirsutum varieties and it was exploited by creating recombinational variability for combining ability. If two lines A and B are found to give potential crosses with testers T_1 and T_2, it is possible to increase the genetic distance between these opposite pairs A, B vs, T_1 and T_2 by following population improvement scheme for improving combining ability defined in cross pollinated crops by introducing suitable changes to match the crossing system seen in self pollinated crops. The recombinational variability realized in a segregating generation like F_3/F_4 can be evaluated by crossing these lines with opposite testers representing opposite heterotic group.

Based on the principle of suggested by Patil and Patil (2003) predicted double cross performance and two pairs of crosses mentioned in table 8 and 9 are selected to form heterotic boxes. These opposite F_1s are advanced to F_2 and the material is ready for initiating reciprocal selection for combining ability. These crosses are confirmed for consistency of performance and based on this information one out of these heterotic boxes will be selected.

Table 8 Mean performance of best hybrids for different characters

Crosses	Bolls per plant	Mean boll weight (g)	Kapas yield (g/plant)	Ginning per cent (%)
(L_5T_2)	16.1	3.52	139.96	35.74
RCH2 *Bt*	31.6	3.32	107.58	32.25
(L_4 T_8)	29.5	2.89	106.18	36.87
(L_4 T_7)	33.8	2.98	104.9	41.37
(L_1 T_6)	33.2	2.98	103.6	35.06
(L_4 T_3)	31.1	2.87	95.26	36.23
(L_2 T_3)	31.4	2.91	91.61	31.6
(L_3 T_6)	31.1	2.97	91.16	31.38
BUNNY *Bt*	26.4	3.3	91.14	34.88
(L_3 T_7)	30.1	2.97	89.2	36.09
(L_2 T_6)	28.5	3.05	89.09	33.44
(L_4 T_5)	25.9	3.44	88.96	42.23
(L_1 T_8)	26.1	3.08	86.53	37.31
(L_1 T_7)	31.3	3.23	82.33	36.54
RAHH 95	30.6	2.31	68.15	37.54

Table 9 Identifying diverse pairs of crosses based on predicted performance of double cross combinations

Crosss	Predicted means
RAH 146 x SC 18 (L4 T2)	78.48
RAH 97 x SC 18 (L5 T2)	139.96
RAH 146 x SC 7 (L4 T3)	95.26
RAH 97 x SC 7 (L5 T3)	66.52
Mean	95.06
RAH 146 x RGR 37 (L4 T8)	106.18
RAH 146 x RGR 58 (L4T7)	104.9
RAH 318 x RGR 37 (L1 T8)	86.53
RAH 318 x RGR 58 (L1 T7)	82.33
Mean	94.985

3 Materials and Methods

The plant materials used in the present study were obtained by line x tester crossing. According to this method, RAH 318, RAH 243, RAH 128, RAH 146, RAH 97 and RAH 124 were crossed as the lines with SC 14, SC 18, SC 7, SC 68, RGR 32, RGR 24, RGR 58 and RGR 37 as the testers. The six hirsutum lines representing Robust plant type classes but differing in efficiency of physiological processes like photosynthesis, were selected and crossed to a set of eight testers representing compact types and faster growth rate. The seeds of the hybrids were supplied by Dr. S.S. Patil, Senior Cotton Breeder, Agricultural Research Station, Dharwad Farm, Karnataka, India, in 2008. The experiment comprising of 48 experimental hybrids along with 3 checks (BUNNY *Bt*, RCH2 *Bt*, RAHH 95) (one repeated two times) was laid out in Randomized Complete Block Design (RCBD) with two replications. Each entry was sown in 3 row plots of 6 m length spaced at 90 cm with recommended dose of fertilizer and treatment of seeds with Imidochloprid were sown on 10-7-2008, 2~3 seeds were dibbled per spot in each row and thinning was attended to retain one healthy plant per hill at 25 days after sowing. All the recommended package of practices were followed to rise healthy crop.

Samples containing 20 bolls were hand-harvested from each plot prior to picking. The days to 50 per cent flowering recorded by the number of days taken from the date of sowing to the date when the first flower opens in 50 per cent of the plants. The number of monopodia per plant are the number of branches on main stem which were lateral and axillary in position with vertical growth in acropetal succession was counted at maturity stage , avoiding small sprouts, but the number of sympodia per plant are branches which are extra-axillary in position and normally horizontal with zig -zag pattern of fruiting points were taken as sympodia. The number of such sympodia on main stem were counted at maturity stage. The boll samples were weighed to determine seed cotton weight per boll values, and ginned on a roller using laboratory gin for lint percentage (100 x lint weight/seed cotton weight) and 100-seed weight calculations (seed index). The ginned lint from each plot was weighed and divided by the number of plants within each plot to determine lint yield per plant. Five plants were selected randomly from each genotype to find the boll number per plant. The general combining ability variance of parents and the specific ability variance of hybrids were estimated via line x tester variance analysis according to Singh and Chaudhary (1977). The Microsoft Excel computer program was used to analyze the data. The line x tester mating design can provide information regarding the usefulness of male and female inbreds as parents for hybridization to generate segregating populations, which is expected to give prodigious selections. The general (GCA) and specific combining ability (SCA) effects were estimated using a 2-way table with the following formulae:

GCA_{lines} = (Xi../tr) - (XÉ/ltr)

$GCA_{testers}$ = (X.j./lr) Ð (XÉ/ltr)

SCA = (Xij./r) - (Xi../tr) - (X.j./lr) + (XÉ/ltr)

where Xi.. is the sum of columns; X.j. is the sum of rows; Xij. is the total value of hybrids over replications; XÉ is the grand total; and l, t and r are the number of lines, testers and replications.

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Table 1 Combining ability analysis of variance as per Kempthorne (1957) in respect of kapas yield and its attributing characters of cotton hybrids (*G .hirsutum* L.)

Source of variation	Mean Squares										
	Df	Days to 50% flowering	Plant height (cm)	Monopodia per plant	Sympodia per plant	Bolls per plant	Mean boll weight (g)	Kapas yield per plant (g/plant)	Ginning per cent	Seed Index (g)	Lint Index (g)
Replication	1	33.84**	148.00**	0.72	0.22	29.04**	0.22	7.96**	0.008	1.76	0.57
Cross	47	5.47**	311.77**	0.16	17.15**	61.15**	0.23	762.36**	18.69**	1.20	1.60**
Lines(c)	5	6.71**	878.26**	0.23	81.10**	252.09**	0.78	1348.67**	50.28**	5.97**	7.22**
Testers(c)	7	14.02**	377.85**	0.14	13.94**	47.30**	0.36	739.63**	44.19**	1.64	2.89**
L × T (c)	35	3.59**	217.63**	0.15	8.66**	36.64**	0.12	683.14**	9.08**	0.43	0.54
Error	47	5.14	192.00	0.10	10.23	11.89	0.14	150.65	11.99	1.07	1.15
Total	95	-	-	-	-	-	-	-	-	-	-

Table 3 General combining ability effects of parents (lines and testers) in respect of kapas yield and its attributing characters of cotton (*G .hirsutum* L.)

Lines	Days to 50% flowering	Plant height (cm)	Monopodia per plant	Sympodia per plant	Bolls per plant	Mean boll weight(g)	Kapas yield (g plant)	Ginning per cent (%)	Seed index(g)	Lint index(g)
L_1- RAH318	-0.59	-9.56 **	0.11	-4.46 **	0.10	0.00	-0.76	-0.67	-0.38	-0.37
L_2- RAH243	-0.41	4.24	0.07	1.00	2.00 *	-0.21 *	-2.02	-2.20 *	-0.41	-0.72 **
L_3- RAH128	-0.34	5.65	-0.08	1.22	3.57 **	-0.07	5.43	-1.61	-0.28	-0.54
L_4- RAH146	1.09	8.59 *	0.12	1.68 *	3.49 **	0.06	14.00 **	2.19 *	-0.31	0.32
L_5- RAH97	-0.22	-1.35	-0.03	0.20	-6.56 **	0.40 **	-3.20	1.61	1.16 **	1.07 **
L_6- RAH 124	0.47	-7.58 *	-0.18 *	0.36	-2.60 **	-0.19	-13.45 **	0.68	0.22	0.25
S.Em.±	0.5669	3.46	0.08	0.79	0.86	0.09	3.06	0.86	0.25	0.26
CD ($\hat{g}_i - \hat{g}_j$) at 5%	1.61	9.84	0.23	2.27	2.45	0.27	8.72	2.46	0.73	0.76
CD ($\hat{g}_i - \hat{g}_j$) at 1%	2.14	13.12	0.31	3.03	3.26	0.36	11.62	3.28	0.98	1.01
Testers										
T_1- SC14	1.14	-0.82	-0.00	0.24	-0.53	-0.16	-7.27 *	-1.80	-0.42	-0.61
T_2- SC18	1.30	3.46	-0.05	0.14	-2.30 *	0.11	8.64 *	-1.70	0.17	-0.29
T_3- SC7	-0.86	3.23	-0.18	0.22	1.25	-0.02	1.96	-2.42 *	-0.08	-0.62
T_4- SC68	-0.78	5.73	-0.03	1.94 *	-1.33	-0.29 *	-14.18 **	0.24	-0.42	-0.21
T_5- RGR32	-0.53	4.28	0.19 *	0.15	-2.17 *	0.30 **	-3.24	2.64 *	0.00	0.59
T_6- RGR24	-0.45	-0.24	-0.05	-1.08	0.23	0.06	1.85	-0.53	0.75 *	0.32
T_7- RGR58	-1.20	-4.37	0.00	0.14	3.47 **	-0.04	3.86	1.62	-0.08	0.33
T_8- RGR37	1.39 *	-11.27 **	0.11	-1.75	1.38	0.04	8.38 *	1.95	0.08	0.49
S.Em.±	0.65	4.0001	0.09	0.92	0.99	0.11	3.54	0.99	0.29	0.30
CD ($\hat{g}_i - \hat{g}_j$) at 5%	1.86	11.37	0.26	2.62	2.82	0.31	10.07	2.84	0.85	0.88
CD ($\hat{g}_i - \hat{g}_j$) at 1%	2.48	15.16	0.35	3.50	3.77	0.41	13.42	3.78	1.13	1.17

Note: *Significant at P = 0.05; ** Significant at P = 0.01

Table 4 Specific combining ability effects of hybrids in respect of kapas yield and their attributing characters in cotton (*G. hirsutum* L.)

Crosses	Days to 50% flowering	Plant height (cm)	Monopodia per plant	Sympodia per plant	Bolls per plant	Mean boll weight(g)	Kapas yield (g/plant)	Ginning percent	Seed index (g)	Lint index (g)
1	2	3	4	5	6	7	8	9	10	11
(L_1 T_1)	0.93	-3.59	0.19	-1.07	0.33	-0.04	2.20	-1.55	0.17	-0.21
(L_1 T_2)	0.76	1.42	0.14	-3.97	-5.30 *	0.12	-19.59 *	-0.40	0.58	0.18
(L_1 T_3)	-0.07	2.66	0.07	1.04	-1.65	-0.17	-7.27	0.01	-0.17	-0.06
(L_1 T_4)	-1.16	5.36	-0.18	2.82	-4.57	-0.22	-12.70	-0.99	-0.08	-0.23
(L_1 T_5)	1.09	0.41	-0.12	1.21	-2.63	0.02	-7.33	-3.42	0.25	-0.67
(L_1 T_6)	0.51	-9.77	-0.26	-0.96	9.07 **	-0.05	30.53 **	0.56	0.00	0.06
(L_1 T_7)	-1.24	13.36	0.39	1.83	3.93	0.29	7.24	-0.10	0.33	0.14
(L_1 T_8)	-0.82	-9.84	-0.22	-0.89	0.82	0.06	6.93	5.88 *	-1.08	0.80
(L_2 T_1)	-1.76	-12.69	0.29	-1.93	0.03	-0.07	1.17	0.18	-0.30	-0.09
(L_2 T_2)	1.07	1.13	-0.02	-0.58	-1.90	-0.04	-14.18	-3.00	-0.39	-0.68
(L_2 T_3)	-1.26	7.36	0.11	-1.01	4.35	0.17	19.69 *	0.33	0.36	0.30
(L_2 T_4)	2.16	7.46	0.36	0.77	-5.77 *	0.05	-8.45	1.16	0.45	0.49
(L_2 T_5)	-2.09	-4.79	-0.26	0.15	-1.13	-0.19	-1.54	0.90	0.03	0.15
(L_2 T_6)	0.32	0.02	0.38	0.49	2.47	0.23	17.27	0.45	0.03	0.01
(L_2 T_7)	1.57	-0.14	-0.37	0.77	0.23	-0.25	-7.73	-1.78	-0.39	-0.63
(L_2 T_8)	-0.01	1.66	-0.48 *	1.35	1.72	0.10	-6.23	1.76	0.20	0.45
(L_3 T_1)	1.68	14.50	-0.11	2.35	-3.04	-0.07	-0.65	-0.47	0.32	0.10
(L_3 T_2)	0.51	-6.39	0.13	-1.75	2.43	-0.14	-8.28	3.52	-0.26	0.63
(L_3 T_3)	1.68	4.35	-0.23	1.17	-2.23	-0.01	-3.21	0.89	-0.76	-0.14
(L_3 T_4)	-0.41	-2.85	-0.18	-0.15	7.26 **	0.21	16.70	-1.46	-0.18	-0.36
(L_3 T_5)	-1.16	6.00	-0.01	-0.07	-2.31	-0.06	-2.20	1.85	-0.09	0.35
(L_3 T_6)	-2.24	13.51	0.03	2.47	3.49	0.01	11.89	-2.35	0.16	-0.53
(L_3 T_7)	-0.99	-5.85	0.18	1.05	-0.74	0.10	7.92	0.59	-0.26	-0.03
(L_3 T_8)	0.93	-23.25 *	0.18	-5.07 *	-4.86	-0.03	-22.17 *	-2.56	1.07	-0.01
(L_4 T_1)	-0.76	-12.74	-0.51 *	-1.21	-5.65 *	-0.26	-23.65 **	-0.60	-0.15	-0.32
(L_4 T_2)	-0.93	-13.43	-0.07	1.49	-1.69	0.21	-16.15	0.64	-0.23	0.00
(L_4 T_3)	-0.76	-4.99	0.17	0.30	2.56	-0.15	7.31	0.82	-0.48	-0.15
(L_4 T_4)	1.16	-0.49	0.02	-0.81	4.75	0.01	9.66	2.06	0.35	0.67
(L_4 T_5)	1.41	-4.74	-0.31	-2.73	0.78	0.10	6.21	1.51	0.19	0.54
(L_4 T_6)	0.32	15.37	0.13	-0.80	-4.62	0.30	-10.26	-2.15	0.19	-0.44
(L_4 T_7)	0.07	10.41	0.18	1.59	3.05	-0.02	15.05	1.63	0.52	0.73

Continuing table 4

Crosses	Days to 50% flowering	Plant height (cm)	Monopodia per plant	Sympodia per plant	Bolls per plant	Mean boll weight(g)	Kapas yield (g/plant)	Ginning percent	Seed index (g)	Lint index (g)
(L_4 T_8)	-0.51	10.61	0.38	2.17	0.83	-0.19	11.81	-3.91	-0.40	-1.04
(L_5 T_1)	1.05	9.20	0.24	1.06	2.30	0.38	3.20	0.74	0.14	0.15
(L_5 T_2)	0.89	11.31	-0.12	1.06	1.16	0.04	62.53 **	0.14	-0.20	-0.15
(L_5 T_3)	0.55	-1.15	0.22	0.38	-0.59	0.41	-4.23	-1.11	0.30	-0.16
(L_5 T_4)	-2.53	0.75	-0.13	-0.54	-2.80	-0.25	-17.68 *	-0.47	-0.61	-0.54
(L_5 T_5)	0.22	-3.00	0.34	0.65	2.03	0.08	-7.30	-0.74	-0.28	-0.30
(L_5 T_6)	-0.36	-10.89	-0.32	0.38	-4.27	-0.16	-27.71 **	4.13	0.22	1.45
(L_5 T_7)	-0.11	-16.35	-0.27	-3.44	-2.20	0.08	-9.55	-1.09	0.30	-0.10
(L_5 T_8)	0.30	10.15	0.03	0.45	4.38	-0.56 *	0.74	-1.60	0.14	-0.35
(L_6 T_1)	-1.14	5.33	-0.11	0.81	6.03 *	0.07	17.73 *	1.70	-0.18	0.36
(L_6 T_2)	-2.30	5.95	-0.07	3.76	5.30 *	-0.18	-4.33	-0.90	0.49	0.02
(L_6 T_3)	-0.14	-8.22	-0.33	-1.88	-2.45	-0.25	-12.29	-0.94	0.74	0.22
(L_6 T_4)	0.78	-10.22	0.12	-2.09	1.13	0.21	12.48	-0.30	0.07	-0.04
(L_6 T_5)	0.53	6.13	0.34	0.79	3.27	0.05	12.16	-0.10	-0.09	-0.06
(L_6 T_6)	1.45	-8.25	0.03	-1.58	-6.13 *	-0.32	-21.73 *	-0.64	-0.59	-0.56
(L_6 T_7)	0.70	-1.42	-0.12	-1.79	-4.27	-0.20	-12.93	0.74	-0.51	-0.12
(L_6 T_8)	0.11	10.68	0.13	1.99	-2.88	0.63 *	8.92	0.43	0.07	0.17
S.Em.±	1.603	9.798	0.232	2.262	2.438	0.270	8.6790	2.4489	0.732	0.7588
CD at 5% (s_{ij}-s_{kl})	4.55	27.85	0.66	6.43	6.93	0.76	24.67	6.96	2.08	2.15
CD at 1% (s_{ij}-s_{kl})	6.07	37.13	0.88	8.57	9.24	1.02	32.89	9.28	2.77	2.87

Note: *Significant at P = 0.05; ** Significant at P = 0.01

Table 6 Overall specific combining ability status of cotton hybrids

Testers	RAH 318 (H)		RAH 243 (H)		RAH 128 (L)		RAH 146 (L)		RAH 97(L)		RAH 124 (H)	
	Total score	Overall staus	Total score	Overall staus	Total score	Overall staus	Total score	Overall staus	Total score	Overall staus	Total score	Overall staus
SC 14 (H)	277	H	328.5	H	222	L	451.5	H	130	L	194	L
SC 18 (L)	278.5	H	366	H	253.5	L	305	H	210.5	L	228.5	L
SC 7 (L)	303.5	H	177	L	273	H	290	H	244.5	L	332.5	H
SC 68 (H)	363	H	171	L	278.5	H	161.5	L	411	L	238	L
RGR 32 (L)	305.5	H	310	H	257	L	231	L	292.5	H	182.5	L
RGR 24 (H)	233	L	184.5	L	251	L	261.5	L	328	H	413.5	H
RGR 58 (L)	153.5	L	349.5	H	247.5	L	115.5	L	365.5	H	373.5	H
RGR 37 (L)	261	L	226.5	L	343	H	292.5	H	258	L	201	L