Original Research Article

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Genetic Studies for Yield and Yield Components in Inter-Specific Hybrids (*G. hirsutum* × *G. barbadense*) of Cotton Over Environments

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ABSTRACT

The present study was conducted at three locations during *kharif* 2014-15 with 72 inter-specific hybrids along with their parents and two standard checks to elicit information on combining ability effects, gene action and heterosis of inter-specific hybrids over environments for yield and yield components. The pooled combining ability analysis of variance showed significant differences due to locations, parents, hybrids and various interactions indicating the existence of sufficient variation in the material under study. The *gca* and *sca* variances indicated the presence of additive gene action for number of bolls plant⁻¹, seed index and seed cotton yield plant⁻¹ whereas, days to 50% flowering, plant height, number of monopodia plant⁻¹, number of sympodia plant⁻¹, lint index and ginning out-turn were controlled by non-additive gene action. Both additive and non-additive gene actions were involved in the inheritance of boll weight. None of the line and tester was found to exhibit significant *gca* effects for all the characters studied. The lines, NDLH 1938, H 1442, ADB 542, ADB 532, MR 786, BS 37, L 762 and testers, GSB 40, DB 16, DB 11 and GSB 41, were found to be promising general combiners for seed cotton yield plant⁻¹ and other traits. Significant and desirable *sca* effects for seed cotton yield plant⁻¹ were exhibited by 22 hybrids. Based on *per se* performance, *sca* effects and standard heterosis, three cross combinations viz., H 1442 × GSB 41, H 1442 × DB 16 and TSH 0250 × GSB 40, were identified as superior for seed cotton yield plant⁻¹. Hence, these hybrids may also be considered for evaluation over more locations, seasons and years before they are being exploited commercially.

Keywords

Cotton, Inter-specific hybrids, Combining ability, Heterosis, Gene action and Over environments.

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Introduction

The knowledge of genetic structure and mode of inheritance of quantitative and qualitative traits helps the breeders to employ suitable breeding method for improvement of these traits. Combining ability analysis is an important tool for selection of the desirable parents together with the information regarding nature and magnitude of gene action controlling quantitative and qualitative traits. The information on gene action and combining ability over locations (pooled)

helps in identifying the best combiners which may be hybridized to produce superior stable heterotic cross combinations or to produce transgressive or recombinant segregants in F₂ and subsequent generations. The entire genetic variability observed in the analysis for each trait was partitioned into its components *i.e.*, general and specific combining ability (Sprague and Tatum, 1942). General combining ability (*gca*) is used to designate the average performance of a line in hybrid

combinations while specific combining ability (*sca*) define those cases in which certain combinations do relatively better or worse than expected on the basis of the average performance of the lines involved. The relative importance of general and specific combining ability can be assessed by estimating the components of variance and expressed in the ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ (Singh and Chaudhary, 1977). The closer the ratio to unity, greater is the magnitude of additive gene action and *vice versa*.

The purpose of this study was to determine the *gca* and *sca* effects for seed cotton yield plant⁻¹, yield contributing and fibre quality traits so as to choose appropriate parents and hybrids for the genetic enhancement. Study on the magnitude of heterosis in F₁s helps to assess the ability of the test genotypes to transmit the desirable characters to the F₁s upon hybridization. This facilitates in identification of genotypes that exhibit high amount of exploitable heterosis.

Materials and Methods

The present investigation was carried over three locations i.e., Regional Agricultural Research Station (RARS), Lam Farm, Agricultural Research Station (ARS), Jangamaheswarapuram and Agricultural College Farm, Bapatla during *kharif* 2014-15. During off-season 2013-14, 12 *hirsutum* lines viz., NDLH 1938, H 1442, ADB 542, ADB 532, WGCV 48, MR 786, TSH 0250, BS 37, SCS 793, MCU 5, L 1058, L 762 and six *barbadense* testers viz., GSB 40, DB 16, DB 11, GSB 41, TCB 37 and SUVIN were mated in line × tester fashion and obtained 72 inter-specific cross combinations. The hybrids along with their parents and two checks (DCH 32 and Mahalakshmi) i.e., 96 genotypes were evaluated in a Randomized Complete Block design with three replications. Each plot consisted of two rows of 10 m length spaced at 1.20 m apart with plant to plant distance of

60 cm. All the recommended agronomical practices and plant protection measures were followed as and when required to raise a good crop of cotton. The data was recorded from five randomly selected from each cross combination for yield and yield components. The data was subjected to statistical analysis for calculating combining ability variances and effects using line × tester method suggested by Kempthorne (1957) and detailed by Singh and Chaudhary (1985). Standard heterosis was calculated over both the checks by adopting methodology suggested by Meredith and Bridge (1972).

Results and Discussion

Line × tester pooled analysis for combining ability

The pooled analysis of variance for combining ability over three locations recorded significant differences for all the characters studied (Table 1). The differences among the parents, parents' vs. crosses and crosses were observed to be significant for all the characters studied. Partitioning of crosses into lines, testers and line × tester revealed that the variance due to lines was significant for all the characters whereas, for testers all the characters were found to be significant except for days to 50% flowering, number of monopodia plant⁻¹, number of bolls plant⁻¹ and seed index.. The interaction due to lines × testers were significant for all the traits evaluated. Interaction effect of locations × parents' vs. crosses, locations × crosses were significant for all the characters. Further, locations × line effect interaction showed significant differences for days to 50% flowering, plant height, number of monopodia plant⁻¹, number of sympodia plant⁻¹, number of bolls plant⁻¹ and seed cotton yield plant⁻¹. While, locations × tester effect interaction exhibited non-significant for all the characters except for number of monopodia plant⁻¹. Interaction effects of locations × line × testers

were significant for all the characters studied. General combining ability effects of parents and specific combining ability effects of crosses over locations (pooled) were estimated and presented in tables 2 and 3.

Days to 50% flowering

General combining ability effects for days to 50% flowering in pooled analysis varied from -2.88 (L 762) to 2.12 (BS 37) in lines and from -1.09 (DB 16) to 1.15 (TCB 37) in testers. The lines, L 762 (-2.88), H 1442 (-1.90) and NDLH 1938 (-0.64) and the testers DB 16 (-1.09*) and GSB 41 (-0.45) recorded significant *gca* effects in desired direction for this trait and these parents were good general combiners with favourable genes for earliness over locations. In pooled analysis, estimates of specific combining ability effects for this trait ranged from -5.72 (H 1442 × GSB 41) to 5.70 (L 1058 × DB 16). Out of 72 cross combinations evaluated, seventeen hybrids recorded significant negative *sca* effects. When compared over their *per se* performance and *sca* effects the crosses, H 1442 × GSB 41 (High × High), TSH 0250 × GSB 40 (Low × Low) and NDLH 1938 × DB 11 (High × Low) were identified as best specific cross combinations for this trait.

Days to 50% flowering in pooled analysis recorded significant negative standard heterosis over both the checks was recorded by H 1442 × GSB 41 (55.67) and L 762 × DB 16 (58.11) and superiority of these hybrids was further confirmed by their *per se* performance and high *sca* effects. These results are in agreement with the reports of Amalabalu *et al.*, (2012) for heterosis over standard check.

Plant height (cm)

The *gca* effects ranged from -8.56 (MCU 5) to 9.32 (NDLH 1938) in lines and from -6.12

(SUVIN) to 5.96 (GSB 40) in testers for plant height across the locations. Significant positive *gca* effects desirable for this trait was recorded by the lines, NDLH 1938 (9.32**), MR 786 (7.35) and ADB 542 (3.32) and the tester GSB 40 (5.96). These parents can be utilized in basic breeding programmes for improvement of this trait. The estimates of *sca* effects for plant height varied from -20.14 (NDLH 1938 × DB 11) to 19.74 (ADB 532 × DB 16).

Significant positive *sca* effects in desirable direction was exhibited by ten cross combinations and the top five cross combinations were, ADB 532 × DB 16 (19.74), H 1442 × DB 11 (16.57), TSH 0250 × GSB 40 (10.79), L 1058 × SUVIN (10.37) and NDLH 1938 × TCB 37 (9.36). The superior cross combinations identified based on their *per se* performance and *sca* effects were, H 1442 × DB 11 (Low × Low), TSH 0250 × GSB 40 (Low × High) and NDLH 1938 × TCB 37 (High × Low). The crosses between two low combiners producing crosses with significant *sca* effect indicating the presence of non-additive inter-allelic interaction.

Standard heterosis over DCH 32 and Mahalakshmi ranged from -6.56 (ADB 532 × TCB 37) to 21.36 (NDLH 1938 × GSB 40) and from -16.31 (ADB 532 × TCB 37) to 8.70 (NDLH 1938 × GSB 40), respectively. Forty two hybrids over DCH 32 and seventeen hybrids over Mahalakshmi showed significant positive heterosis. Based on overall performance (*per se*, *sca* effects and standard heterosis) the top three specific combiners identified for this trait were, NDLH 1938 × GSB 40 (194.54), NDLH 1938 × GSB 41 (190.59) and H 1442 × DB 11 (189.85). These results are in agreement with the reports of Amalabalu *et al.*, (2012), Kumar *et al.*, (2013) and Nirania *et al.*, (2014) for heterosis over standard check.

Number of monopodia plant⁻¹

A range of -0.31 (NDLH 1938) to 0.51 (BS 37) *gca* effects was observed for lines. Whereas, testers recorded a range from -0.09 (DB 16) to 0.07 (GSB 40 and SUVIN). Among the lines, BS 37 (0.51), WGCV 48 (0.36), ADB 532 (0.18), ADB 542 (0.10) and L 1058 (0.07) while, in testers GSB 40 (0.07), SUVIN (0.07) and GSB 41 (0.04) showed significant positive *gca* effects over locations. These parents may serve as useful source for improvement of this trait in hybridization programmes. Lowest and highest *sca* effects recorded in pooled analysis were -0.80 (MCU 5 × GSB 41) and 0.74 (TSH 0250 × GSB 40). The variance due to *gca* (-0.005) was very low and negative than variance due to *sca* (0.041) and both were non-significant. The crosses, ADB 532 × GSB 41 (High × High), TSH 0250 × GSB 40 (Low × High) and MCU 5 × GSB 40 (Low × High) were identified as best specific combiners as per their *per se* performance and *sca* effects.

Standard heterosis over DCH 32 and Mahalakshmi ranged from -15.19 (TSH 0250 × TCB 37) to 87.94 (ADB 532 × GSB 41) and -47.26 (TSH 0250 × TCB 37) to 16.86 (ADB 532 × GSB 41), respectively. Sixty two and eight hybrids showed significant positive heterosis over DCH 32 and Mahalakshmi, respectively. The best heterotic hybrids identified based on *per se* and *sca* effects were, ADB 532 × GSB 41 (3.20) followed by BS 37 × GSB 40 (3.18) and WGCV 48 × TCB 37 (3.03). These results are in agreement with the reports of Nirania *et al.*, (2014) and Tuteja (2014) for heterosis over standard check.

Number of sympodia plant⁻¹

In pooled analysis *gca* effects for number of sympodia plant⁻¹ varied from -1.91 (MCU 5) to 1.72 (MR 786) in lines and from -1.24

(TCB 37) to 0.95 (DB 16) in testers. The lines, MR 786 (1.72), SCS 793 (1.06), H 1442 (0.91) and NDLH 1938 (0.40) and the testers DB 16 (0.95), GSB 41 (0.69) and GSB 40 (0.33*) exhibited significant and positive *gca* effects for this trait. *Sca* effects for this trait ranged from -2.91 (WGCV 48 × GSB 41) to 5.60 (MR 786 × GSB 41).

The best specific cross combinations identified based on their *per se* performance and *sca* effects were MR 786 × GSB 41 (High × High), ADB 542 × DB 16 (Low × High) and H 1442 × DB 16 (High × High).

Heterosis over standard checks DCH 32 and Mahalakshmi ranged from -12.52 (MCU 5 × TCB 37) to 36.96 (MR 786 × GSB 41) and -21.46 (MCU 5 × TCB 37) to 22.97 (MR 786 × GSB 41), respectively. Among seventy two hybrids studied, twenty one and four hybrids exhibited significant positive values over DCH 32 and Mahalakshmi, respectively. Based on *per se* performance, *sca* effects and standard heterosis the hybrids *viz.*, MR 786 × GSB 41 (31.43), ADB 542 × DB 16 (28.02) and H 1442 × DB 16 (27.29) were found to be superior. Nirania *et al.*, (2014) and Tuteja (2014) for heterosis over standard check.

Number of bolls plant⁻¹

Among the lines *gca* effects ranged from -14.61 (MCU 5) to 6.54 (H 1442) and among the testers, *gca* effects varied from -2.95 (TCB 37) to GSB 41 (2.71). The lines, H 1442 (6.54), NDLH 1938 (6.43), L 762 (4.41), SCS 793 (3.68), BS 37 (2.68), MR 786 (1.60) and ADB 542 (1.16) and the testers GSB 41 (2.71), DB 16 (2.46) and DB 11 (1.42) recorded significant positive *gca* effects in pooled analysis. The range of *sca* effects was from -13.96 (TSH 0250 × TCB 37) to 14.26 (BS 37 × SUVIN). The crosses, BS 37 × SUVIN (High × Low), BS 37 × GSB

41 (High $\times$ High) and ADB 542 $\times$ DB 16 (High $\times$ High) were identified as best specific cross combinations based on their *sca* effects and *per se* performance.

Standard heterosis over DCH 32 and Mahalakshmi ranged from -27.95 (TSH 0250 $\times$ TCB 37) to 30.09 (BS 37 $\times$ SUVIN) and -38.84 (TSH 0250 $\times$ TCB 37) to 10.43 (BS 37 $\times$ SUVIN), respectively. Forty one hybrids over DCH 32 and six hybrids over Mahalakshmi showed positive significant heterosis. The potential hybrids identified as *per se* performance, *sca* effects and standard heterosis were, BS 37 $\times$ SUVIN (79.98), H 1442 $\times$ DB 16 (78.91) and BS 37 $\times$ GSB 41 (77.89). Similar results for number of bolls plant⁻¹ were earlier reported by Amalabalu *et al.*, (2012) and Kumar *et al.*, (2013) for heterosis over standard check.

Boll weight (g)

Estimates of *gca* effects in pooled analysis ranged from -0.33 (MCU 5) to 0.23 (MR 786) among lines and from -0.27 (SUVIN) to 0.20 (GSB 40) among testers. *gca* effects were positive and significant for the lines, MR 786 (0.23), ADB 532 (0.21), NDLH 1938 (0.14), ADB 542 (0.13), H 1442 (0.12) and BS 37 (0.08) and in the testers GSB 40 (0.20), DB 16 (0.16) and DB 11 (0.03). The *sca* effects varied from -0.53 (L 762 $\times$ GSB 41) to 0.86 (TSH 0250 $\times$ GSB 40). Based on *per se* performance and *sca* effects the crosses *viz.*, TSH 0250 $\times$ GSB 40 (Low $\times$ High), H 1442 $\times$ GSB 41 (High $\times$ Low) and ADB 542 $\times$ DB 11 (High $\times$ High) were noticed as superior hybrids for boll weight.

Standard heterosis over DCH 32 and Mahalakshmi ranged from -23.36 (SCS 793 $\times$ TCB 37) to 23.29 (TSH 0250 $\times$ GSB 40) and -30.60 (SCS 793 $\times$ TCB 37) to 11.63 (TSH 0250 $\times$ GSB 40), respectively. Standard heterosis in desirable direction was observed

in seventeen hybrids over DCH 32 and two hybrids over Mahalakshmi. Based on overall performance (*per se* performance, *sca* effects and standard heterosis) the best specific cross combinations identified were, TSH 0250 $\times$ GSB 40 (4.21), H 1442 $\times$ GSB 41 (3.97) and ADB 532 $\times$ GSB 40 (3.84). These results are in conformity with the reports of Kumar *et al.*, (2013) and Nirania *et al.*, (2014) over standard check.

Lint index (g)

Range of *gca* effects over locations for lint index was from -0.45 (BS 37) to 0.50 (L 1058) among lines and from -0.26 (SUVIN) to 0.38 (DB 16) among testers. Out of 12 lines, L 1058 (0.50), MR 786 (0.29), L 762 (0.24), ADB 532 (0.15) and H 1442 (0.10) recorded significant positive *gca* effects.

Whereas, in the testers DB 16 (0.38), GSB 41 (0.12) and GSB 40 (0.06**) exhibited significant *gca* effects in desired direction for this character. The *sca* effects for lint index varied from -0.65 (MR 786 $\times$ DB 11) to 0.92 (TSH 0250 $\times$ GSB 40). Estimated component of variance due to general combining ability (0.049) was lower than due to specific combining ability (0.058). Based on *per se* performance and *sca* effects, the crosses, TSH 0250 $\times$ GSB 40 (Low $\times$ High), L 762 $\times$ SUVIN (High $\times$ Low) and WGCV 48 $\times$ SUVIN (Low $\times$ Low) were detected as promising specific cross combinations.

Standard heterosis over DCH 32 was found in thirty two hybrids and over Mahalakshmi in one hybrid (L 1058 $\times$ DB 16). The best performing hybrids identified based on *per se* performance, *sca* effects and standard heterosis were ADB 532 $\times$ DB 16 (6.02) and TSH 0250 $\times$ GSB 40 (5.93). These results are in conformity with the reports of Amalabalu *et al.*, (2012) and Kumar *et al.*, (2013) for heterosis over standard check.

Table.1 Analysis of variance of combining ability for different characters in inter-specific hybrids of cotton (*G. hirsutum* L. × *G. barbadense* L.) Over three locations (pooled) during *kharif*, 2014-15

Source of variation	d.f	Days to 50% flowering	Plant height (cm)	No. of monopodia plant ⁻¹	No. of sympodia plant ⁻¹	No. of bolls plant ⁻¹	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning out-turn (%)	Seed cotton yield plant ⁻¹ (g)
Replications	2	0.55	12.87	0.02	1.75	6.53	0.03	0.01	0.14	0.88	17.03
Environments	2	989.97**	27421.73**	6.83**	3763.31**	13552.86**	7.24**	21.02**	794.63**	849.38**	50063.40**
Rep × Env.	4	1.86	87.39	0.00	1.23	18.03	0.01	0.02	0.12	0.78	52.96
Treatments	89	120.90**	3391.81**	2.45**	94.80**	1316.79**	1.48**	2.23**	13.73**	47.86**	13620.91**
Parents	17	397.79**	1024.64**	0.97**	14.62**	390.94**	3.59**	1.96**	9.82**	24.09**	3930.51**
Parents (Line)	11	145.89**	471.73**	1.06**	15.55**	371.73**	0.16**	0.85**	3.66**	12.17**	2614.58**
Parents(Testers)	5	32.79**	730.54**	0.88**	13.62**	164.07**	0.35**	2.69**	3.41**	46.68**	1471.83**
Parents (L vs T)	1	4993.78**	8577.13**	0.33**	9.33*	1736.48**	57.55**	10.51**	109.56**	42.29**	30699.13**
Parent vs Crosses	1	275.04**	226538.63**	87.55**	5874.75**	69282.50**	4.12**	25.12**	720.54**	777.65**	451974.84**
Crosses	71	52.43**	815.68**	1.61**	32.59**	581.21**	0.93**	1.97**	4.71**	43.27**	9767.15**
Line effect	11	110.73**	1548.47**	3.52**	54.00*	1880.81**	1.87**	4.38**	11.73**	106.79**	27448.06**
Tester effect	5	67.41	2364.03**	0.56	74.91*	691.19	3.34**	6.00**	5.41	107.24**	25580.27**
Line × Tester effect	55	39.41**	528.37**	1.32**	24.45**	311.29**	0.53**	1.12**	3.25**	24.75**	4793.40**
Env × Treatments	178	17.55**	618.07**	1.21**	22.67**	372.60**	0.30**	0.57**	4.64**	11.37**	3385.54**
Env × Parents	34	8.51**	144.54	0.59**	12.17**	77.93**	0.14**	0.36**	2.73**	12.00**	670.42**
Env × Parents (L)	22	4.38	126.41	0.38**	11.53**	78.65**	0.14**	0.19**	0.99**	9.33**	774.10**
Env × Parents (T)	10	3.02	207.80*	0.67**	12.40**	85.92**	0.14**	0.71**	4.05**	17.34**	512.51**
Env × PAR (L vs T)	2	81.33**	27.69	2.40**	18.18**	30.10	0.06*	0.58**	15.26**	14.77**	319.42
Env × Parent vs Cross	2	103.56**	21608.40**	12.05**	620.45**	4632.61**	2.61**	1.92**	56.53**	54.76**	26339.47**
Env × Crosses	142	18.51**	435.81**	1.21**	16.76**	383.15**	0.31**	0.60**	4.36**	10.61**	3712.35**
Env × Line effect	22	29.24*	1022.23**	2.20**	27.13*	749.16**	0.29	0.65	3.55	12.89	6011.89*
Env × Tester effect	10	18.04	127.42	1.90*	19.30	540.70	0.49	0.60	6.29	9.93	4450.07
Env × L × T effect	110	16.40***	346.56**	0.95**	14.45**	295.63**	0.29**	0.59**	4.35**	10.21**	3185.38**
Error	534	3.08	108.21	0.05	1.73	11.02	0.02	0.03	0.20	1.06	200.62

* Significant at 5% level, **Significant at 1% level

Table.2 General combining ability effects of parents for different characters in cotton over three locations (pooled)
During *kharif*, 2014-15

	Days to 50% flowering	Plant height (cm)	No. of monopodia plant ⁻¹	No. of sympodia plant ⁻¹	No. of bolls plant ⁻¹	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning out- turn (%)	Seed cotton yield plant ⁻¹ (g)
LINES										
NDLH 1938	-0.64*	9.32**	-0.31**	0.40*	6.43**	0.14**	-0.04	-0.49**	0.65**	25.23**
H 1442	-1.90**	-0.28	-0.22**	0.91**	6.54**	0.12**	0.10**	-0.49**	1.21**	25.40**
ADB 542	0.96**	3.32*	0.10**	0.11	1.16*	0.13**	0.03	-0.23**	0.58**	11.21**
ADB 532	-0.12	-5.21**	0.18**	-0.99**	-2.49**	0.21**	0.15**	0.89**	-0.80**	4.22*
WGCV 48	0.12	-7.63**	0.36**	-0.48*	-1.16*	-0.05**	0.03	0.04	0.23	-7.19**
MR 786	-0.28	7.35**	-0.15**	1.72**	1.60**	0.23**	0.29**	0.22**	0.73**	16.75**
TSH 0250	-0.27	0.17	-0.24**	-1.01**	-4.43**	-0.15**	-0.18**	-0.13*	-0.56**	-20.20**
BS 37	2.12**	-0.42	0.51**	0.14	2.68**	0.08**	-0.45**	-0.01	-1.84**	10.51**
SCS 793	-0.14	-0.67	0.03	1.06**	3.68**	-0.30**	-0.37**	0.21**	-1.73**	-7.09**
MCU 5	1.23**	-8.56**	-0.12**	-1.91**	-14.61**	-0.33**	-0.31**	0.50**	-2.15**	-55.60**
L 1058	1.77**	0.73	0.07*	0.14	-3.81**	-0.02	0.50**	0.28**	1.45**	-10.81**
L 762	-2.88**	1.89	-0.21**	-0.12	4.41**	-0.07**	0.24**	-0.79**	2.22**	7.56**
SE (gi)	0.25	1.49	0.03	0.19	0.48	0.02	0.02	0.06	0.14	2.03
TESTERS										
GSB 40	0.25	5.96**	0.07**	0.33*	-1.05**	0.20**	0.06**	0.28**	-0.16	7.58**
DB 16	-1.09**	1.84	-0.09**	0.95**	2.46**	0.16**	0.38**	0.06	1.35**	16.62**
DB 11	-0.34	2.00	-0.08**	-0.07	1.42**	0.03*	-0.14**	-0.08	-0.38**	4.83**
GSB 41	-0.45*	1.50	0.04*	0.69**	2.71**	0.01	0.12**	-0.38**	1.08**	8.90**
TCB 37	1.15**	-5.18**	-0.01	-1.24**	-2.95**	-0.13**	-0.16**	0.15**	-0.84**	-15.20**
SUVIN	0.48**	-6.12**	0.07**	-0.66**	-2.59**	-0.27**	-0.26**	-0.03	-1.05**	-22.73**
SE (gj)	0.18	1.05	0.02	0.13	0.34	0.01	0.02	0.04	0.10	1.43
σ^2_{gca}	0.523*	14.810*	-0.005	0.385*	7.721	0.024*	0.049*	0.058	1.000**	242.903**
σ^2_{sca}	2.557**	20.200*	0.041	1.111*	1.740	0.025*	0.058**	-0.122	1.615**	178.669*
$\sigma^2_{gca}/\sigma^2_{sca}$	0.204	0.733	-0.121	0.346	4.437	0.96	0.844	-0.475	0.619	1.359

*Significant at 5% level, **Significant at 1% level

Table.3 Specific combining ability effects of 72 inter-specific hybrids of cotton (*G. hirsutum* L. × *G. barbadense* L.) for days to 50% flowering, plant height, no. of monopodia plant⁻¹, no. of sympodia plant⁻¹, no. of bolls plant⁻¹ and boll weight over three locations (Pooled) during *kharif*, 2014-15

	Days to 50% flowering	Plant height (cm)	No. of monopodia plant ⁻¹	No. of sympodia plant ⁻¹	No. of bolls plant ⁻¹	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning out-turn (%)	Seed cotton yield plant ⁻¹ (g)
NDLH 1938 × GSB 40	1.43*	7.70*	0.15*	-0.83	0.01	0.08	-0.05	-0.44**	0.28	6.26
NDLH 1938 × DB 16	0.55	-6.17	0.46**	-0.33	-1.39	0.06	-0.34**	0.19	-1.57**	0.57
NDLH 1938 × DB 11	-2.42**	-20.14**	0.07	-1.48**	-1.55	0.09*	0.30**	-0.65**	2.42**	-0.14
NDLH 1938 × GSB 41	0.69	8.21*	-0.42**	1.22**	2.14	0.03	0.18**	0.05	0.57	7.00
NDLH 1938 × TCB 37	1.76**	9.36*	-0.07	0.34	4.90**	-0.18**	0.35**	0.08	1.43**	1.01
NDLH 1938 × SUVIN	-2.01**	1.04	-0.18*	1.09*	-4.12**	-0.07	-0.43**	0.77**	-3.14**	-14.71**
H 1442 × GSB 40	1.80**	7.32*	0.35**	0.06	2.61*	-0.26**	-0.02	0.62**	-0.79*	-10.38*
H 1442 × DB 16	-1.85**	-19.10**	-0.34**	2.03**	4.27**	0.16**	-0.27**	-0.37*	-0.51	25.28**
H 1442 × DB 11	1.84**	16.57**	0.35**	-0.90	1.66	-0.33**	-0.14*	-0.16	-0.31	-16.70**
H 1442 × GSB 41	-5.72**	-0.54	0.08	0.15	0.30	0.54**	0.37**	-0.16	1.67**	34.97**
H 1442 × TCB 37	0.90	1.33	0.13	-0.78	-6.72**	0.02	0.13*	-0.08	0.51	-21.01**
H 1442 × SUVIN	3.02**	-5.57	-0.57**	-0.55	-2.12	-0.10*	-0.07	0.14	-0.57	-12.15*
ADB 542 × GSB 40	0.28	-5.96	-0.78**	-1.88**	6.49**	-0.33**	-0.06	0.22	-0.59	-0.50
ADB 542 × DB 16	-1.93**	6.52	0.26**	3.55**	7.25**	0.11*	0.19**	-0.88**	2.13**	28.56**
ADB 542 × DB 11	-0.01	3.08	0.44**	-0.14	1.84	0.32**	-0.18**	0.42**	-1.24**	24.33**
ADB 542 × GSB 41	1.43*	0.18	0.02	-0.14	-9.14**	0.17**	0.33**	0.78**	-0.06	-19.14**
ADB 542 × TCB 37	-0.73	4.81	0.18*	0.37	6.06**	-0.14**	-0.23**	-0.11	-0.80*	7.63
ADB 542 × SUVIN	0.95	-8.63*	-0.12	-1.75**	-12.50**	-0.13**	-0.05	-0.41**	0.56	-40.88**
ADB 532 × GSB 40	-2.31**	-0.51	-0.17*	1.79**	4.86**	0.13**	0.33**	0.53**	0.42	23.70**
ADB 532 × DB 16	-0.63	19.74**	-0.67**	1.81**	-6.84**	0.14**	0.36**	0.62**	0.21	-15.22**
ADB 532 × DB 11	-0.94	3.43	0.06	0.64	1.36	-0.07	-0.39**	-0.57**	-0.71*	2.43
ADB 532 × GSB 41	1.17	-5.81	0.55**	-2.76**	-2.79*	-0.09*	0.04	-0.42**	0.68*	-14.10**
ADB 532 × TCB 37	2.79**	-11.39**	0.21**	-1.09*	2.89*	-0.16**	-0.37**	-0.18	-0.95**	-0.69
ADB 532 × SUVIN	-0.09	-5.45	0.02	-0.39	0.52	0.05	0.03	0.02	0.34	3.89
WGCV 48 × GSB 40	-0.77	-1.38	-0.49**	1.46**	-0.73	0.05	-0.20**	0.18	-0.99**	-3.85
WGCV 48 × DB 16	-1.10	9.13*	0.30**	0.88	0.07	-0.03	-0.28**	0.03	-1.21**	-1.48
WGCV 48 × DB 11	-0.29	-0.70	0.14	1.91**	8.23**	-0.07	0.19**	-0.54**	1.77**	20.56**
WGCV 48 × GSB 41	2.04**	-2.03	-0.02	-2.91**	0.70	-0.09*	-0.38**	-0.37*	-0.95**	-4.52

WGCV 48 × TCB 37	0.11	-3.22	0.26***	0.38	0.52	-0.01	0.07	-0.05	0.14	1.42
WGCV 48 × SUVIN	0.01	-1.78	-0.19**	-1.74**	-8.79**	0.14**	0.61**	0.76**	1.23**	-12.12*
MR 786 × GSB 40	0.41	5.19	-0.17*	-1.19**	-4.56***	-0.06	-0.04	0.16	-0.51	-19.65**
MR 786 × DB 16	0.09	-4.15	-0.04	-2.70**	-2.46*	-0.01	0.09	0.15	0.09	-7.02
MR 786 × DB 11	0.67	-1.31	0.13	-0.76	-0.44	-0.12**	-0.65**	0.01	-2.77**	-6.70
MR 786 × GSB 41	-2.10**	-2.39	-0.11	5.60**	2.73*	0.09*	0.18**	-0.95**	2.29**	14.50**
MR 786 × TCB 37	-1.93**	0.41	-0.05	0.06	4.73**	-0.02	0.13*	1.18**	-1.23**	10.26*
MR 786 × SUVIN	2.86**	2.25	0.24**	-1.00*	0.01	0.13**	0.30**	-0.55**	2.13**	8.60

	Days to 50% flowering	Plant height (cm)	No. of monopodia plant⁻¹	No. of sympodia plant⁻¹	No. of bolls plant⁻¹	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning out turn (%)	Seed cotton yield plant⁻¹ (g)
TSH 0250 × GSB 40	-4.27**	10.79**	0.74**	1.94**	9.14**	0.86**	0.92**	- 1.00**	5.17**	76.56**
TSH 0250 × DB 16	0.40	3.84	0.46**	-1.44**	-0.65	-0.25**	0.06	0.09	0.26	-14.42**
TSH 0250 × DB 11	1.43*	-2.66	-0.44**	1.02*	3.58**	-0.25**	0.18**	0.85**	-0.43	-4.08
TSH 0250 × GSB 41	1.99**	-6.12	-0.05	-0.17	2.92*	-0.26**	- 0.16**	-0.05	-0.49	-7.36
TSH 0250 × TCB 37	1.50*	-8.22*	-0.73**	-0.82	-13.96**	0.01	0.39**	-0.20	-1.32**	-41.37**
TSH 0250 × SUVIN	-1.05	2.37	0.02	-0.53	-1.02	-0.11*	0.62**	0.31*	-3.20**	-9.33
BS 37 × GSB 40	2.12**	-6.82	0.18*	0.29	0.58	0.12**	0.44**	-0.29	2.56**	11.66*
BS 37 × DB 16	-0.87	1.05	-0.03	-0.46	-4.56**	-0.16**	-0.11	0.21	-0.78*	-22.53**
BS 37 × DB 11	0.38	-1.99	-0.17*	-2.08**	-10.99**	0.24**	- 0.17**	0.05	-1.01**	-23.42**
BS 37 × GSB 41	-1.51*	2.29	-0.09	1.57**	6.86**	-0.03	0.32**	0.74**	0.19	18.96**
BS 37 × TCB 37	-0.11	-1.67	0.04	0.58	-6.16**	-0.02	0.32**	0.80**	-2.56**	-13.30**
BS 37 × SUVIN	0.01	7.14	0.07	0.11	14.26**	-0.14**	- 0.16**	- 1.52**	1.60**	28.63**
SCS 793 × GSB 40	2.60**	-4.53	-0.23**	-0.17	-9.31**	-0.15**	- 0.47**	- 0.56**	-0.62	-30.63**
SCS 793 × DB 16	1.72**	4.85	-0.33**	-2.12**	1.04	0.16**	0.36**	0.14	1.14**	11.52*
SCS 793 × DB 11	-1.25*	2.57	0.25**	-0.29	2.80*	0.18**	0.50**	0.55**	1.10**	16.08**

SCS 793 × GSB 41	-2.03**	1.37	-0.02	-1.13*	3.72**	0.12**	-	0.36**	0.63**	-2.30**	16.64**
SCS 793 × TCB 37	-1.19	0.65	-0.04	0.49	-4.25**	-0.26**	0.33**	-0.24	1.62**		-24.02**
SCS 793 × SUVIN	0.15	-4.91	0.36**	3.22**	6.00**	-0.05	0.37**	0.51**	-0.93**		10.40*
MCU 5 × GSB 40	1.56*	-3.66	0.58**	0.41	-3.67**	-0.06	0.53**	-0.19	-2.17**		-17.65**
MCU 5 × DB 16	-0.43	1.80	0.04	0.14	1.11	0.18**	0.17**	0.97**	-0.81*		7.89
MCU 5 × DB 11	1.60*	-1.87	-0.53**	0.56	-6.84**	-0.17**	0.09	0.76**	1.64**		-23.98**
MCU 5 × GSB 41	1.49*	4.97	-0.80**	-1.18*	-0.39	-0.06	0.02	-0.03	0.07		-4.25
MCU 5 × TCB 37	-3.11**	0.15	0.59**	-0.19	5.27**	0.16**	-0.04	0.55**	0.77*		23.91**
MCU 5 × SUVIN	-1.10	-1.39	0.13	0.25	4.52**	-0.05	0.29**	0.56**	0.50		14.08**
L 1058 × GSB 40	-2.42**	-4.28	0.17*	-1.88**	-1.46	-0.24**	0.03	0.75**	-1.18**		-17.38**
L 1058 × DB 16	5.70**	11.79**	0.11	-0.37	-0.53	-0.24**	0.07	0.69**	1.40**		-13.36**
L 1058 × DB 11	-1.83**	1.68	-0.42**	0.18	-0.01	0.21**	0.06	0.15	-0.14		13.11**
L 1058 × GSB 41	0.06	-3.56	0.38**	0.47	-1.24	0.11*	0.36**	-0.22	-1.07**		0.53
L 1058 × TCB 37	0.24	7.58*	-0.15*	0.45	0.74	0.06	0.20**	-0.01	0.67*		6.59
L 1058 × SUVIN	-1.75**	10.37**	-0.09	1.14*	2.51*	0.10*	0.00	0.02	0.32		10.50*
L 762 × GSB 40	-0.44	-3.85	-0.33**	0.10	-3.96**	-0.14**	0.35**	0.03	-1.58**		-18.14**
L 762 × DB 16	-1.65**	-5.73	-0.21**	-0.98*	2.69*	-0.12**	0.32**	0.45**	-0.36		0.22
L 762 × DB 11	0.82	1.35	0.12	1.33**	0.37	-0.03	0.23**	0.64**	-0.32		-1.50
L 762 × GSB 41	2.49**	3.44	0.48**	-0.73	-5.80**	-0.53**	0.17**	-0.01	-0.58		-43.25**
L 762 × TCB 37	-0.23	0.21	-0.36**	0.21	5.96**	0.57**	0.14*	0.64**	1.71**		49.58**
L 762 × SUVIN	-0.99	4.58	0.30**	0.16	0.73	0.24**	0.47**	0.43**	1.13**		13.08**
SE (s _{ij})	0.62	3.64	0.07	0.46	1.17	0.04	0.06	0.16	0.34		4.98

*Significant at 5% level, **Significant at 1% level

Table.4 The best heterotic inter-specific cotton hybrids identified for different characters based on overall performance over three Locations during *kharif*, 2014-15

Character	hybrids	Per se performance	SCA effect	Standard heterosis	
				DCH 32	Mahalakshmi
Days to 50% flowering	H 1442 × GSB 41	55.67	-5.72**	-7.22**	-7.73**
	L 762 × DB 16	58.11	-1.65**	-3.15*	-3.68*
Plant height (cm)	NDLH 1938 × GSB 40	194.54	7.70*	21.36**	8.70**
	NDLH 1938 × GSB 41	190.59	8.21*	18.90**	6.50*
	H 1442 × DB 11	189.85	16.57**	18.44**	6.08*
No. of monopodia plant ⁻¹	ADB 532 × GSB 41	3.20	0.55*	87.94**	16.86**
	BS 37 × GSB 40	3.18	0.18*	86.96**	16.25**
	WGCV 48 × TCB 37	3.03	0.26**	78.23**	10.82**
No. of sympodia plant ⁻¹	MR 786 × GSB 41	31.43	5.60**	36.96**	22.97**
	ADB 542 × DB 16	28.02	3.55**	22.12**	9.64**
	H 1442 × DB 16	27.29	2.03**	18.96**	6.81**
No. of bolls plant ⁻¹	BS 37 × SUVIN	79.98	14.26**	30.09**	10.43**
	H 1442 × DB 16	78.91	4.27**	28.34**	8.95**
	BS 37 × GSB 41	77.89	6.86**	26.69**	7.54**
Boll weight (g)	TSH 0250 × GSB 40	4.21	0.86**	23.29**	11.63**
	H 1442 × GSB 41	3.97	0.54**	16.14**	5.15**
	ADB 532 × GSB 40	3.84	0.13**	12.39**	1.77
Lint index (g)	ADB 532 × DB 16	6.02	0.36**	18.69**	2.71
	TSH 0250 × GSB 40	5.93	0.92**	17.06**	1.31
Seed index (g)	ADB 532 × GSB 40	14.34	0.53**	24.59**	3.73*
	ADB 532 × DB 16	14.22	0.62**	23.57**	2.88
	MR 786 × TCB 37	14.19.	1.18**	23.33**	2.68
Ginning out-turn (%)	TSH 0250 × GSB 40	33.49	5.17**	9.43**	11.92**
	L 1058 × DB 16	33.24	1.40**	8.61**	11.07**
	MR 786 × GSB 41	33.13.	2.29**	8.27**	10.73**
Seed cotton yield plant ⁻¹ (g)	H 1442 × GSB 41	253.36	34.97**	45.61**	27.18**
	H 1442 × DB 16	251.38	25.28**	44.47**	26.18**
	TSH 0250 × GSB 40	248.02	75.56**	42.54**	24.50**

*Significant at 5% level, **Significant at 1% level

Seed index (g)

General combining ability effects for seed index in pooled analysis varied from -0.79 (L 762) to 0.89 (ADB 532) in lines and in testers it ranged from -0.38 (GSB 41) to 0.28 (GSB 40). The lines, ADB 532 (0.89), MCU 5 (0.50), L 1058 (0.28), MR 786 (0.22) and SCS 793 (0.21) and the testers GSB 40 (0.28) and TCB 37 (0.15) possessed significant positive *gca* effects for this character. The cross combination, BS 37 × SUVIN (-1.52) recorded lowest *sca* effect whereas, the highest was exhibited by MR 786 × TCB 37 (1.18). The crosses, MR 786 × TCB 37 (High × High), MCU 5 × DB 16 (High × Low) and BS 37 × TCB 37 (Low × High) were registered as good specific cross combinations as per their *per se* performance and *sca* effects.

The significant positive heterosis was detected in fifty nine hybrids over DCH 32 and it varied from -3.59 (BS 37 × SUVIN) to 24.59 (ADB 532 × GSB 40), one hybrid (ADB 532 × GSB 40) over Mahalakshmi and it ranged from -19.73 (BS 37 × SUVIN) to 3.73 (ADB 532 × GSB 40). Based on *per se* performance, positive *sca* effects and standard heterosis superior cross combinations identified were, ADB 532 × GSB 40 (14.34), ADB 532 × DB 16 (14.22) and MR 786 × TCB 37 (14.19). Similar type of results were earlier reported by Amalabalu *et al.*, (2012), Kumar *et al.*, (2013), Nirania *et al.*, (2014) and Tuteja (2014) for heterosis over standard check.

Ginning out-turn (%)

In pooled analysis *gca* effects for lines ranged from -2.15 (MCU 5) to L 762 (2.22) whereas, for testers it was from -1.05 (SUVIN) to 1.35 (DB 16). Significant positive *gca* effects was recorded by L 762 (2.22), L 1058 (1.45), H 1442 (1.21), MR 786 (0.73), NDLH 1938 (0.65) and ADB 542 (0.58) in lines and DB 16 (1.35) and GSB 41 (1.08) in testers. Among the crosses *sca* effects varied from -3.20 (TSH 0250 × SUVIN) to 5.17 (TSH 0250 × GSB 40). The superior specific cross combinations identified based on their *per se* performance and *sca*

effects were, TSH 0250 × GSB 40 (Low × Low), MR 786 × GSB 41 (High × High) and ADB 542 × DB 16 (High × High).

The heterosis over DCH 32 and Mahalakshmi ranged from -22.21 (BS 37 × TCB 37) to 9.43 (TSH 0250 × GSB 40) and -20.45 (BS 37 × TCB 37) to 11.92 (TSH 0250 × GSB 40), respectively. Among 72 hybrids studied, nine hybrids over DCH 32 and twelve hybrids over Mahalakshmi exhibited significant positive heterosis. Best specific cross combinations detected based on overall performance for this trait were, TSH 0250 × GSB 40 (33.49), L 1058 × DB 16 (33.24) and MR 786 × GSB 41 (33.13). These results are in conformity with the reports of Amalabalu *et al.*, (2012) and Patel *et al.*, (2012).

Seed cotton yield Plant⁻¹ (g)

The *gca* effects among the lines ranged from -55.60 (MCU 5) to 25.40 (H 1442) and from -22.73 (SUVIN) to 16.62 (DB 16) in testers. Significant and positive *gca* effects were desirable for this trait and were noticed in the lines, H 1442 (25.40), NDLH 1938 (25.23), MR 786 (16.75), ADB 542 (11.21), BS 37 (10.51), L 762 (7.56) and ADB 532 (4.22) and the testers *viz.*, DB 16 (16.62), GSB 41 (8.90), GSB 40 (7.58) and DB 11 (4.83). Among the cross combinations, *sca* effects varied from -43.25 (L 762 × GSB 41) to 76.56 (TSH 0250 × GSB 40). The crosses, H 1442 × GSB 41 (High × High), TSH 0250 × GSB 40 (Low × High) and ADB 542 × DB 16 (High × High) were identified as best specific cross combinations as per their *per se* performance and *sca* effects.

Thirty four hybrids over DCH 32 and thirteen hybrids over Mahalakshmi showed significant positive heterosis. Based on *per se* performance, *sca* effects and standard heterosis superior specific cross combinations identified were, H 1442 × GSB 41 (253.36), H 1442 × DB 16 (251.38) and TSH 0250 × GSB 40 (248.02). Similar results for significant positive standard heterosis over check were reported by Nirania *et al.*, (2014) and Tuteja (2014).

The crosses between two low combiners producing crosses with significant *sca* effect revealed the role of non-additive inter-allelic interaction. This may be due to high nicking ability/genetic diversity of parents involved. This component may be exploited through heterosis breeding. The crosses between high $\times$ low or low $\times$ high combiners resulted in superior cross combinations due to complementary gene action which has arisen out of both additive and non-additive gene action. These crosses may likely to throw superior transgressive segregants for desirable traits. These components may be exploited by adopting breeding procedures like cyclic hybridization, biparental mating and diallel selective mating system. The cross combinations involving high $\times$ high general combiners producing crosses with significant *sca* effect revealed the role of additive and additive $\times$ additive genetic component of variance which could be easily improved through simple selection procedures.

Combining Ability Variances and Gene Action

The estimate of *gca* and *sca* variances in pooled analysis is presented in table 4. General combining ability is generally associated with additive gene action, while specific combining ability is due to dominance and epistasis. In the present study *sca* variances were higher than *gca* variances in pooled analysis for days to 50% flowering, plant height, number of monopodia plant⁻¹, number of sympodia plant⁻¹, lint index, ginning out-turn, micronaire value, bundle strength, fibre elongation and lint yield plant⁻¹ indicating the predominance of non-additive gene action for these characters and boll weight was controlled by both additive and non-additive gene actions whereas, additive gene action controls the remaining traits. Deosarkar *et al.*, (2014), Yanal *et al.*, (2013), Rajamani *et al.*, (2014), Simon *et al.*, (2013), Patel *et al.*, (2014), Usharani *et al.*, (2014), Patel *et al.*, (2012), Baloch *et al.*, (2014). The traits which are controlling by non-additive gene action may be exploited by biparental

mating or diallel selective mating or heterosis breeding. For improvement of number bolls plant⁻¹, breeding programmes like population improvement as well as heterosis breeding can be employed for exploitation as it is under the control of both additive and non-additive gene actions.

Based on overall performance (*per se* performance, significant *sca* effects and standard heterosis) for seed cotton yield plant⁻¹ in pooled analysis the hybrids, H 1442 $\times$ GSB 41, H 1442 $\times$ DB 16 and TSH 0250 $\times$ GSB 40 recorded high *per se* performance (253.36, 251.38 and 248.02), significant *sca* effects (34.97, 25.28 and 76.56) and standard heterosis over DCH 32 and Mahalakshmi (45.61% & 27.18%, 44.47% & 26.18%, 42.54 % & 24.50%). Besides seed cotton yield plant⁻¹ the hybrids exhibited good *per se* performance, significant *sca* effects and standard heterosis for other important yield contributing characters *viz.*, number of sympodia plant⁻¹, number of boll plant⁻¹, boll weight and ginning out-turn and fibre quality traits like 2.5% span length and micronaire value. The best heterotic cross combinations identified based on overall performance for different characters and these can be tested over seasons, location and years before their commercial cultivation are presented in table 4.

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