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Ratooning and Combining Ability Analysis through Line × Tester Mating Design in Interspecific Cotton Hybrids (*G. hirsutum* × *G. barbadense*)

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ABSTRACT

Cotton (*Gossypium* spp.) is an important fibre crop and plays a vital role as a cash crop in commerce of many countries in the world. The development of cotton hybrids which can offer the great yields and quality fibre is the current research in cotton breeding. For the first time, here we investigated the mean performance and ratooning ability of thirty novel cotton hybrids. In addition, we also analyzed the expression of general combining ability (GCA) of the parents and specific combining ability (SCA) of hybrids in order to develop high yielding and better quality cotton cultivars in both first crop and ratoon crop. L × T analysis revealed that the significant GCA and SCA effects for all the studied traits. The significant range of variability was observed in all the traits except for boll weight and elongation percentage in parents and hybrids. Based on mean performance, the evaluated hybrids varied significantly ($p \leq 0.05$) in first crop and ratoon crop for the all studied traits. The predominance of additive gene action was estimated for the number of bolls per plant and fibre bundle strength in first crop which were found to be controlled by additive gene action due to high GCA variance. In ratoon crop, the predominance of dominant gene action was estimated for all the studied traits which were found to be controlled by non-additive gene action due to high SCA variance. Among the parents, TCH 1819 was found to be a good combiner for all the investigated traits except for boll weight. The hybrids, MCU 13 × SUVIN and TCH 1819 × TCB 209 were found to be the best specific combinations for fibre bundle strength.

Highlights:

- The analysis of combining ability in first crop and ratoon crop was revealed the best cotton hybrids for the yield and fibre quality traits.

Keywords: *Gossypium* spp., Mean performance, Ratoon crop, Combining ability, Hybrids

Cotton, the king of fibre is an important cash crop which influences economics and social affairs of the world to a great extent. It is popularly known as “White Gold”. In India, cotton was grown in 105 lakh ha with a productivity of 568 kg ha^{-1} (AICCIP, annual report 2016-17), thereby contributing nearly 65% of the total raw material demand of the textile industry of the country (Patel *et al.* 2014). However, in the view of a low production per unit area and low fibre quality traits compared to other advanced cotton growing countries of the world the need for continued genetic improvement of cotton for yield and quality traits is high,. Therefore, the development of hybrids as a commercial variety gets much importance. Simpson (1954) classified cotton as predominantly self-pollinated and often cross-pollinated crop amenable for both heterosis breeding as well as hybridization followed by selection in subsequent generations.

Exploitation of heterosis on a commercial scale and varietal improvement through hybridization are the main focus areas to increase cotton production. Besides yield, improvement in the fibre quality has also become increasingly important. *Gossypium* *barbadense* cotton are well known for their quality of fibres especially fibre length and fibre strength. On the other hand, *Gossypium hirsutum* cotton possesses early maturity, bigger bolls, good boll opening and high seed cotton yield. In order to develop high yielding cotton varieties or hybrids with superior fibre quality, there must be an involvement of *G. barbadense* lines as one of the parents in hybridization programme with *G. hirsutum* (Patel *et al.* 2014). Interspecific hybrids give rise to a larger range of heterosis than do intraspecific hybrids for seed cotton yield. Interspecific hybrids (*G. hirsutum* x *G. barbadense*) displayed 157.2% heterosis, while intraspecific (i.e., intra-*hirsutum* and intra-*barbadense*) hybrids resulted in 33.7 and 28.3% heterosis, respectively (Soomro *et al.* 1996).

The line × tester analysis is one of the important biometrical techniques which provides valuable information about general and specific combining ability variances and effects, thus helps in identification of good general combiners and specific promising cross combinations (Muthuswamy *et al.* 2003). It helps in detection of appropriate parents and crosses superior in terms of the investigated characters, and so the application of the analysis has been widely used by plant breeders to selection in early generations. This method was applied to improve self and cross-pollinated plants (Kempthorne 1957). In view of the importance of knowing the combining ability of the parents, thereby determining the types of gene action involved in the expression of various plant characters in cotton, the line × tester analysis is requisite to decide for efficient breeding strategies to improve the valuable characters (Kempthorne 1957).

The primary application of cotton ratooning is the achievement of high seed yield, in order to minimize the cost burden on the procurement of seed material. Unlike sugarcane, cotton can be allowed for a single ratoon crop, since the cotton is not propagated by vegetative reproduction. The costs of growing a ratoon crop of cotton are less than the costs of growing a first crop and also the time required for flowering is less in ratoon crop than the first crop. However, the yield of ratoon crop generally is not the same as that of the first crop and less yield is common due to various reasons. Nevertheless, in the practice of ratooning, the major contributing factor is choice of varieties with better ratooning capabilities. The genotypic and morphological differences of traits in varieties, acting either singly or in combination are the major reasons for the decline in yield of the ratoon crops (Milligan *et al.* 1996). A variety can be considered to have good ratooning ability when it can maintain a stable yield and/or it has a high yield potential over the normal crop cycle (Milligan *et al.* 1996)

In the present study, for the first time, we attempted to investigate the *per se* performance and ratooning ability of F_1 interspecific hybrids generated from *G. hirsutum* × *G. barbadense* crosses for their yield and fibre quality traits. In addition, the results of this study would provide insights into the understanding of the behavior of best performing F_1 crosses upon ratooning and the nature of combining ability for seed cotton yield and its fibre quality parameters in cotton with a view to identifying good combining parents.

MATERIALS AND METHODS

Selection of Parental lines and testers

The parental lines to be used in the present study were selected based on their agronomical superiority and five female lines *viz:* MCU 13, TCH 1777, TCH 1819, TSH 0250 and VS 9-S11-1 and six male testers *viz:* CCB 36, DB 3, SUVIN, TCB 26, TCB 37 and TCB 209 were selected.

Hybrid development

All the parental lines (5) were crossed with all the six male parents in Line × Tester fashion. When the parental lines started to flower, these were crossed in line × tester fashion. Some of the buds of parents were also selfed. Maximum numbers of crosses were made to develop sufficient F_1 seed. The following necessary precautions were taken at the time of emasculation and pollination: (1) Emasculation was done before the anthers were mature and the stigma has become receptive to minimize self-pollination. (2) The flowers selected for emasculation were likely to open the next morning. (3) Care was taken that all the anthers are removed. (4) The gynoecium must not be injured and (5) Bagging of emasculated buds before and after pollination.

Field layout and procedure

30 hybrids and 11 parents with single check DCH

32 were planted in the field at the Department of cotton, Tamil Nadu Agricultural University, Tamil Nadu (India). Each entry was sown in a randomized block design (RBD) with two replications. Each genotype was grown in a 9 m length row with a spacing of 90 cm between rows and 60 cm between the plants in a row, to have 13 plants per row and it was considered as a first crop. After harvesting, the first crop was pruned with garden shears at a height of 30 cm above ground level. Weak and dried shoots were thinned out from the pruned stumps and then earthed up and it was considered as a ratoon crop. The plant protection measures taken for the ratoon crop were similar to the first crop.

Data analysis

Data were recorded on five randomly selected plants per replication for all the six characters *viz.*, Number of bolls per plant, boll weight (g), seed cotton yield per plant (g), 2.5% span length (mm), fibre bundle strength (g/tex) and elongation percentage. The means for all the observed parameters were worked out and further subjected to Analysis of variance from the replicated data worked out using the AGRISTAT statistical analysis software. The Line × Tester analysis of combining ability analysis of the data was done as suggested by Kempthorne (1957).

Calculation of ratooning ability

Ratooning ability (RA) is defined as $RA_i = 100\ RC_i / FC_i$ for cotton. The RA of trait 'i' is defined as the ratio of the ratoon crop (RC) yield for trait 'i' to the first crop yield (FC) for trait 'i' and expressed as a percentage. A modified form of sugarcane ratooning ability equation was applied to cotton, because here cotton was allowed for a single ratoon crop. Therefore, the second ratoon (SR) present in the sugarcane ratooning ability equation is replaced by ratoon crop (RC) of cotton to calculate the cotton ratooning ability (Milligan *et al.* 1996).

RESULTS AND DISCUSSION

Mean performance and ratooning ability for yield contributing traits

Promising hybrids (or) cross combinations were expressed significant differences in the mean performance for the number of bolls per plant, boll weight (g) and seed cotton yield per plant (g) in both first crop and ratoon crop (Table 1). In cotton plants, as the number of bolls per plant increases, the yield increases correspondingly. Thus, there is a close and positive association between these parameters. In the first crop, on an average, the hybrid MCU 13 × TCB 26 (58.70), exhibited the highest number of bolls per plant while MCU 13 × DB 3 (32.60) had the lowest number of bolls per plant (Table 1). In case of the ratoon crop, the same hybrid MCU 13 × DB 3 expressed the lowest number of bolls per plant (20.56) and MCU 13 × CCB 36 had the highest number of bolls per plant (39.79) (Table 1). Six hybrids in first crop and seven hybrids in ratoon crop significant than the overall mean for this trait. The hybrid VS 9-S11-1 × TCB 37 showed the highest ratooning ability of 95.94%, whereas MCU 13 × TCB 26 exhibited the lowest ratooning ability of 45.81%. Three hybrids TCH 1819 × TCB 209 (92.36%), VS 9-S11-1 × TCB 37 (95.94%) and VS 9-S11-1 × TCB 209 (91.74%) expressed higher ratooning ability than the check (87.24%) (Table 1).

In cotton, boll weight and number of bolls per plant in interspecific hybrids are reported as major components of heterosis in yield (Pavasia *et al.* 1999). The highest boll weight was observed in the hybrid VS 9-S11-1 × TCB 26 (4.01 g) and the lowest boll weight was expressed by TSH 0250 × DB 3 (2.28 g). In the case of ratoon crop, the same hybrid TSH 0250 × DB 2 (2.03 g) expressed the lowest boll weight and TCH 1819 × DB 3 (3.21 g) exhibited the highest boll weight (Table 1). Five hybrids in first crop and seven hybrids in ratoon crop were significant for boll weight as compared to the overall mean value. The hybrid VS 9-S11-1 × CCB 36 (97.55%) was showed highest ratooning ability and VS 9-S11-1 × TCB 26 showed lowest ratooning ability for this trait. Among the thirty hybrids, twenty-five hybrids were showed higher ratooning ability than the check (80.25%) for boll weight (Table 1).

Seed cotton yield per plant in the first crop ranged from 112.29 g (MUC 13 × DB 3) to 230.74 g (TCH 1819 × TCB 37). In case of ratoon crop, the same cross combination MCU 13 × DB 3 exhibited lowest rank (89.34 g) and highest yield was recorded in VS 9-S11-1 × TCB 37 (139.99 g) (Table 1). Fourteen hybrids in first crop and thirteen hybrids in ratoon crop showed significant differences over mean value. The ratooning ability ranged from 55.69 % (TCH 1819 × TCB 37) to 97.80% (TCH 1819 × SUVIN)

Table 1: Mean performance and ratooning ability of thirty cotton hybrids for yield component traits

Hybrid	Number of Bolls per Plant			Boll Weight (g)			Seed Cotton Yield per Plant (g)		
	FC	RC	RA%	FC	RC	RA%	FC	RC	RA%
MCU 13 × CCB 36	57.60*	39.79*	69.08	3.10	2.90	93.55	121.04	99.67	82.34
MCU 13 × DB 3	32.60	20.56	63.07	3.30	2.80	84.85	112.29	89.34	79.57
MCU 13 × SUVIN	55.40*	25.67	46.34	2.67	2.40	89.89	114.26	91.23	79.84
MCU 13 × TCB 26	58.70*	26.89	45.81	2.90	2.40	82.76	116.96	94.34	80.66
MCU 13 × TCB 37	38.40	28.95	75.39	2.59	2.49	96.14	134.69*	94.27	69.99
MCU 13 × TCB 209	51.70	26.78	51.80	3.20	2.51	78.56	133.98*	95.10	70.98
TCH 1777 × CCB 36	44.60	32.67	73.25	2.77	2.24	80.87	127.47	111.23	87.26
TCH 1777 × DB 3	51.70	34.45	66.63	3.32	2.56	77.11	116.64	110.45	94.69
TCH 1777 × SUVIN	52.00	36.80*	70.77	2.77	2.34	84.63	115.62	109.86	95.02
TCH 1777 × TCB 26	46.30	39.23*	84.73	4.00*	3.13*	78.35	180.72*	120.89*	66.90
TCH 1777 × TCB 37	58.20*	34.61	59.47	2.75	2.54	92.36	185.54*	120.67*	65.04
TCH 1777 × TCB 209	51.10	32.60	63.80	2.86	2.76	96.50	117.62	113.45	96.46
TCH 1819 × CCB 36	50.10	35.94*	71.74	3.03	2.68	88.45	158.67*	121.54*	76.60
TCH 1819 × DB 3	53.40	34.37	64.36	3.65*	3.21*	88.07	162.09*	120.23*	74.17
TCH 1819 × SUVIN	33.00	27.68	83.88	2.71	2.56	94.46	119.41	116.78*	97.80
TCH 1819 × TCB 26	55.10*	37.84*	68.68	3.39	2.90	85.55	130.55*	124.49*	95.36
TCH 1819 × TCB 37	52.40	33.89	64.68	3.82*	2.90	76.02	230.74*	128.49*	55.69
TCH 1819 × TCB 209	38.50	35.56	92.36	3.28	3.01*	91.77	126.74	121.39*	95.78
TSH 0250 × CCB 36	36.50	23.67	64.85	3.06	2.87	93.94	121.45	100.78	82.98
TSH 0250 × DB 3	36.00	23.54	65.39	2.28	2.03	89.04	119.03	96.99	81.48
TSH 0250 × SUVIN	36.50	24.90	68.22	2.70	2.40	88.89	129.44	99.39	76.78
TSH 0250 × TCB 26	38.65	26.78	69.29	3.09	2.91	94.33	133.81*	97.26	72.69
TSH 0250 × TCB 37	41.80	29.78	71.24	2.71	2.45	90.57	120.56	96.35	79.92
TSH 0250 × TCB 209	43.50	28.79	66.18	2.96	2.46	83.25	155.51*	100.95	64.92
VS 9-S11-1 × CCB 36	39.40	29.89	75.86	3.07	2.99*	97.55	126.00	115.78	91.89
VS 9-S11-1 × DB 3	56.30*	30.89	54.87	3.57	3.02*	84.59	166.71*	125.87*	75.50
VS 9-S11-1 × SUVIN	36.95	29.67	80.30	2.72	2.20	80.88	140.66*	123.98*	88.14
VS 9-S11-1 × TCB 26	49.50	30.58	61.78	4.10*	3.02*	73.66	171.02*	128.68*	75.24
VS 9-S11-1 × TCB 37	40.10	38.47*	95.94	3.61*	3.05*	84.60	150.80*	139.99*	92.83
VS 9-S11-1 × TCB 209	41.30	37.89*	91.74	2.64	2.25	85.23	125.12	120.82*	96.56
MEAN	45.91	31.30	69.38	3.09	2.67	86.88	111.01	111.01	81.44
DCH 32 (Check)	33.70	29.40	87.24	2.34	1.95	80.25	113.98	100.90	88.54
SEd	7.60	4.20		0.50	0.27		18.51	5.09	
CD (0.05)	15.70	8.40		1.01	0.55		36.99	10.17	
CV %	18.90	15.10		17.20	12.00		15.56	4.35	

** and **: significance at p ≤ 0.05 and p ≤ 0.01 respectively, FC: First crop, RC: Ratoon crop, RA%: Ratooning ability.*

indicating that the highest ratooning ability was due to the superiority of seed cotton yield in ratoon crop, while lowest ratooning ability was due to a high reduction in seed cotton yield in ratoon crop (Table 1). Nine hybrids revealed highest ratooning ability than the check (88.54%) (Table 1). Generally, the changes in ratooning ability and ratoon crop yields are not necessarily to be correlated (Chapman *et al.* 1992; Masri and Amein, 2015). Cotton yield and all of its attributes were significantly affected by crop age. The genotype by crop age interaction was significant for all studied traits, indicating that hybrid performance differed among the crop cycles. Various studies reported that genotype by crop interaction was important for yield and its component traits (Milligan *et al.* 1990; Orgeron *et al.* 2007; EL-Hinnawy and Masri 2009). The evaluated genotypes significantly differed in their ratooning ability for all studied traits and similar phenomenon has been reported for sugarcane ratooning (Milligan *et al.* 1996; Olaoye 2005).

Mean performance and ratooning ability for fibre quality traits

Cotton fibre length, strength and quality properties have a great influence in the textile industry. The development of high fibre length and fibre strength in cultivars or hybrids are essential to modern advanced spinning mills. The data presented in Table 2 revealed that the presence of significant differences among evaluated hybrids for fibre quality traits such as 2.5% span length, fibre bundle strength and elongation percentage. Mean performance of first crop, for fibre length (or) 2.5% span length has a minimum expression of 29.90 mm (MCU 13 × TCB 209) to 37.80 mm (TSH 0250 ×

Table 2: Mean performance and ratooning ability of thirty cotton hybrids for fibre quality traits

Hybrid	2.5% Span Length (mm)			Fibre Bundle Strength (g/ tex)			Elongation Percentage (%)		
	FC	RC	RA%	FC	RC	RA%	FC	RC	RA%
MCU 13 × CCB 36	35.90	29.34	81.73	24.00	20.46	85.25	6.90*	5.40	78.26
MCU 13 × DB 3	34.70	29.16	84.03	24.10	20.00	82.99	6.70	5.60	83.58
MCU 13 × SUVIN	36.10	29.10	80.61	25.60	21.56	84.22	7.30*	5.70	78.08
MCU 13 × TCB 26	36.90	28.14	76.26	27.10	21.67	79.96	6.30	5.70	90.48
MCU 13 × TCB 37	33.80	29.12	86.15	26.30	19.99	76.01	6.30	5.30	84.13
MCU 13 × TCB 209	29.90	29.45	98.49	26.90	20.45	76.02	6.90*	5.40	78.26
TCH 1777 × CCB 36	37.40	30.83	82.43	25.60	22.23	86.84	5.50	5.10	92.73
TCH 1777 × DB 3	37.60	28.89	76.84	23.30	21.56	92.53	5.50	5.20	94.55
TCH 1777 × SUVIN	37.20	28.56	76.77	22.40	21.00	93.75	5.40	5.10	94.44
TCH 1777 × TCB 26	36.50	31.26*	85.64	26.90	22.24	82.68	6.20	5.94*	95.81
TCH 1777 × TCB 37	36.10	29.26	81.05	23.80	20.28	85.21	6.20	5.78*	93.23
TCH 1777 × TCB 209	35.90	29.13	81.14	24.60	21.59	87.76	6.00	5.60	93.33
TCH 1819 × CCB 36	35.70	29.18	81.74	27.10	20.35	75.09	5.80	5.20	89.66
TCH 1819 × DB 3	36.10	29.99	83.07	27.60	22.57	81.78	7.80*	5.40	69.23
TCH 1819 × SUVIN	37.70	28.33	75.15	27.90	23.45	84.05	5.60	5.30	94.64
TCH 1819 × TCB 26	34.80	30.26	86.95	28.00	22.58	80.64	6.30	6.00*	95.24
TCH 1819 × TCB 37	35.50	30.01	84.54	28.50	23.46	82.32	6.90*	6.00*	86.96
TCH 1819 × TCB 209	30.90	30.49	98.67	24.70	23.10	93.52	8.60*	6.20*	72.09
TSH 0250 × CCB 36	36.60	28.73	78.50	26.00	19.92	76.62	5.50	4.90	89.09
TSH 0250 × DB 3	36.30	26.33	72.53	25.00	19.83	79.32	6.30	5.50	87.30
TSH 0250 × SUVIN	37.80	27.34	72.33	26.90	20.00	74.35	4.90	4.40	89.79
TSH 0250 × TCB 26	38.20	28.01	73.32	26.80	20.56	76.72	4.90	4.50	91.84
TSH 0250 × TCB 37	30.70	28.01	91.24	27.70	21.23	76.64	5.20	4.60	88.46
TSH 0250 × TCB 209	36.50	27.98	76.66	26.20	21.34	81.45	5.40	4.50	83.33
VS 9-S11-1 × CCB 36	36.30	30.32	83.53	26.30	24.56*	93.38	6.40	6.00*	93.75
VS 9-S11-1 × DB 3	36.80	31.65*	86.01	24.60	23.89*	97.11	5.90	5.70	96.61
VS 9-S11-1 × SUVIN	37.70	30.61	81.19	29.30	24.01*	81.95	6.20	6.00*	96.77
VS 9-S11-1 × TCB 26	36.30	30.78	84.79	27.00	25.89*	95.89	5.90	5.70	96.61
VS 9-S11-1 × TCB 37	37.10	32.89*	88.65	28.30	27.35*	96.64	6.40	6.20*	96.88
VS 9-S11-1 × TCB 209	35.80	30.99	86.56	27.20	26.67*	98.05	6.40	6.20*	96.88
MEAN	35.83	29.47	82.55	26.19	22.13	84.62	6.19	5.47	89.01
DCH 32 (Check)	33.30	29.00	87.06	26.20	22.90	87.51	6.20	4.90	78.87
SEd	3.90	1.53		3.90	1.37		0.70	0.25	
CD (0.05)	7.30	3.06		7.80	2.57		1.60	0.46	
CV %	11.80	5.34		14.90	5.79		10.60	3.35	

** and **: significance at $p \leq 0.05$ and $p \leq 0.01$ respectively, FC: First crop, RC: Ratoon crop, RA%: Ratooning ability.*

SUVIN) (Table 2). The mean fibre length of hybrids was found to be 37.80 mm in these interspecific cotton hybrids. *Niagum* and *Khadi* (2001) observed that the mean fibre length for *Gossypium barbadense* crosses was 35.9 mm and this is the lower value compared to our results and is in confirmation with *G. barbadense* × *G. hirsutum* crosses which are higher in fibre length than *G. hirsutum* × *G. hirsutum* crosses. In case of ratoon crop, the hybrids TSH 0250 × TCB 26 and TSH 0250 × TCB 37 expressed minimum fibre length (28.01 mm) and the hybrid VS 9-S11-1 × TCB 37 showed maximum fibre length (32.89 mm). Three hybrids were significantly better than the overall mean in ratoon crop. The cross combinations TSH 0250 × SUVIN and TCH 1819 × TCB 209 expressed lowest (72.33%) and highest (98.67%) ratooning ability. The four hybrids revealed highest ratooning ability than the check (87.06%) (Table 2).

Fibre strength is the most important characteristic feature of the fibre quality of cotton and is extremely useful for the textile industry (Patel *et al.* 2014). In first crop, fibre strength ranged from 22.40 g/tex (TCH 1777 × SUVIN) to 29.30 g/tex (VS 9-S11-1 × SUVIN), whereas in ratoon crop, it varied from 19.83 g/tex (TSH 0250 × DB 3) to 27.35 g/tex (VS 9-S11-1 × TCB 37) (Table 2). These results were supported by earlier studies by Khan, (2002), and Karademir *et al.* (2011) in which it has been found that the average bundle strength of hybrids in first crop was 25.4 g/tex. Ashok kumar *et al.* (2013) observed that the mean fibre length for *G. hirsutum* crosses was 21.9 g/tex and it was the lower value compared to our results. In case of ratoon crop, six hybrids were significant than overall mean value. Ratooning ability ranged from 74.35% (TSH 0250 × SUVIN) to 98.05% (VS 9-S11-1 × TCB 209). Nine hybrids expressed highest ratooning ability than the check (87.51%) (Table 2).

Fibre elongation percentage in first crop ranged from 4.90% in TSH 0250 × SUVIN TSH 0250 × TCB 26 to 8.60% in TCH 1819 × TCB 209 (Table 2). In ratoon crop, it varied from 4.40% (TSH 0250 × SUVIN) to 6.20% (TCH 1819 × TCB 209, VS 9-S11-1 × TCB 37 and VS 9-S11-1 × TCB 209). Six hybrids in first crop and nine hybrids in ratoon crop showed significant values than overall mean for this trait. The lowest ratooning ability was recorded in TCH 1819 × DB 3 (69.23%) and highest in VS 9-S11-1 × TCB 37 and VS 9-S11-1 × TCB 209 (96.88%) (Table 2).

Analysis of variance for combining ability

The analysis of variance for combining ability for the all characters was presented in Table 3. The variance due to lines was highly significant for all characters studied except for boll weight and elongation percentage both in first crop and ratoon crop. The testers showed highly significant values for all traits except boll weight, fibre bundle strength and elongation percentage in first crop, whereas in ratoon crop the testers did not show significant variation for boll weight and fibre quality traits. The analysis of variance suggested that the presence of considerable genetic variation with respect to various yield contributing and fibre quality traits. Estimation of variances due to the general and specific combining ability for all studied traits were presented in Table 3. The variances for general combining ability for female parents were highly significant for the characters except for boll weight and elongation percentage, which revealed that the occurrence of the possible role of additive type gene effects. In the assemblage of the general combining ability for males, the all traits were significant except boll weight and fibre quality traits, which were non-significant at both $p \leq 0.05$ and $p \leq 0.01$ level of significance and it disclosed the presence of possible role of non-additive type gene effects which might be dominant or epistatic.

Gene action

The gene action involved for the concerned traits and the nature of gene effects controlling the traits determine the success in the breeding programme. If the additive variance is greater, the chance of fixing superior genotype will be greater. If dominance and epistatic interactions are predominant, heterosis breeding and recombination breeding with the postponement of selection to later generation will be ideal for obtaining useful genotypes (Panse 1942).

Additive gene action provides fixable effects and non-additive gene action includes dominance, epistasis and other interactions which are non-fixable. The gene action involved in the expression of such traits depends on the predominance of additive and dominance variances. The predominance of additive variance corresponds to additive gene action (additive/dominance value is more than 1) and the predominance of dominance variance

Table 3: Analysis of variance for combining ability of yield components and fibre quality traits in first crop and ratoon crop. The values in parentheses indicate ratoon crop

Source of variation	Mean squares						
	df	**NBPP**	**BW**	**SCYPP**	**2.5% SL**	**Str**	**EP**
Replication	1	63.65 (6.68)	2.40 (0.02)	80.34 (22.17)	20.53 (0.80)	13.63 (4.97)	0.00 (0.00)
Crosses	29	65.71** (51.55**)	0.29 (0.09)	991.44** (135.83**)	24.24** (3.30**)	12.85** (7.70**)	1.09 (0.26)
Lines	4	114.63** (147.92**)	0.66 (0.15)	811.87** (305.68**)	25.06** (7.29*)	14.94** (20.46**)	3.21 (0.34)
Testers	5	64.43** (22.12**)	0.68 (0.14)	933.50** (14.51**)	23.47** (3.29)	3.65 (0.43)	0.65 (0.00)
L × T	20	56.24** (39.64**)	0.12 (0.07)	1041.84** (132.19**)	24.26** (2.50*)	14.73** (6.96**)	0.77 (0.32)
Error	29	72.72** (22.13**)	0.31 (0.07)	450.73** (23.50**)	20.16** (1.68)	18.13** (1.60)	0.42 (0.02)
σ^2 GCA		0.31 (0.39)	0.00 (0.00)	-1.65 (0.11)	0.00 (0.02)	-0.06 (0.02)	0.01 (0.00)
σ^2 SCA		-8.24 (8.75)	-0.09 (0.00)	295.55 (54.34)	2.05 (0.41)	-1.69 (2.68)	0.17 (0.15)
σ^2 GCA/ σ^2 SCA		-0.038 (0.045)	0.00 (0.00)	-0.006 (0.002)	0.00 (0.049)	0.036 (0.007)	0.059 (0.00)
σ^2 A		0.62 (0.78)	0.01 (0.00)	-3.31 (0.23)	0.00 (0.05)	-0.12 (0.04)	0.02 (0.00)
σ^2 D		-8.24 (8.75)	-0.09 (0.00)	295.55 (54.34)	2.05 (0.41)	-1.69 (2.68)	0.17 (0.15)
σ^2 A/ σ^2 D		-0.075 (0.089)	-0.111 (0.00)	-0.011 (0.004)	0.00 (0.122)	0.071 (0.015)	0.118 (0.00)

** and **: significance at $p \leq 0.05$ and $p \leq 0.01$ respectively, df: Degrees of freedom, NBPP: Number of bolls per plant, BW: Boll weight, SCYPP: Seed cotton yield per plant, 2.5% SL: 2.5% Span length, Str: Fibre bundle strength, EP: Elongation percentage, L × T: lines × testers, σ2 GCA: General combining ability variance, σ2 SCA: Specific combining ability variance, σ^2 A: Additive genetic variance, σ2 D: Dominance genetic variance.*

corresponds to dominance gene action (additive/ dominance value is less than 1).

The results from the line × tester analysis in first crop indicated that predominance of GCA variance and additive variance (or) additive gene action for the traits namely, number of bolls per plant, boll weight and fibre bundle strength. Samreen *et al.* (2008) reported that the additive gene action for number of bolls per plant and boll weight and the predominance of SCA variance and dominance variance (or) dominance gene action for the seed cotton yield per plant, 2.5% span length and elongation percentage. Similar findings have been reported for seed cotton yield per plant (Simon *et al.* 2013; Kannan and Saravanan, 2015; Sawarkar *et al.* 2015), 2.5% span length (Lukonge *et al.* 2008; Ahuja and Dhayal, 2007; Preetha and Raveendran, 2008; Ranganatha *et al.* 2013), elongation percentage (Simon *et al.* 2013, Sawarkar *et al.* 2015).

In the case of ratoon crop, the SCA variances and dominance genetic variance (or) dominance gene action were higher than the GCA variances and additive genetic variance for the all studied traits (Table 3). The ratio of σ^2 GCA/ σ^2 SCA and σ^2 A / σ^2 D were significantly less than unity for all the traits both in first crop and ratoon crop indicating the preponderance of dominant gene action, which plays an important role in the exploitation of heterosis through hybrid breeding. Similar findings have been reported for number of bolls per plant (Deshpande *et al.* 2008; Ahuja and Dhayal, 2007; Simon *et al.* 2013), boll weight (Ahuja and Dhayal, 2007; Simon *et al.* 2013; Sawarkar *et al.* 2015; Kannan and Saravanan, 2015), seed cotton yield per plant (Simon *et al.* 2013; Sawarkar *et al.* 2015; Kannan and Saravanan, 2015), 2.5% span length (Lukonge *et al.* 2008; Ahuja and Dhayal, 2007; Preetha and Raveendran, 2008; Ranganatha *et al.* 2013), fibre bundle strength (Srinivas *et al.* 2014; Ahuja and Dhayal, 2007; Preetha and Raveendran, 2008; Ranganatha *et al.* 2013) and elongation percentage (Simon *et al.* 2013; Sawarkar *et al.* 2015).

For additive gene action, simple selection procedure like pedigree breeding method is sufficient. However, the presence of dominance gene action in most of the characters indicates that the postponement of selection to later generations after effecting crosses. Heterosis breeding procedures are effective in harnessing dominance gene action to the full extent.

Proportional contributions of lines, testers and line × tester interactions to total variance

The proportional combinations of the lines (females), testes (males) and their interactions to the total

Table 4: Proportional contribution of lines, testers and their interactions to total variance for the investigated traits in first and ratoon crop. The values in parentheses indicate ratoon crop

Source of variation	NBPP	BW	SCYPP	2.5% SL	Str	EP
Lines	24.06 (39.57)	30.88 (22.07)	11.29 (31.04)	14.26 (30.49)	16.03 (36.65)	40.70 (17.42)
Testers	16.91 (7.40)	39.80 (25.39)	16.23 (1.84)	16.69 (17.20)	4.90 (0.96)	10.41 (0.27)
L × T	59.03 (53.03)	29.31 (52.54)	72.47 (67.12)	69.04 (52.31)	79.07 (62.38)	48.89 (82.31)

NBPP: Number of bolls per plant, BW: Boll weight, SCYPP: Seed cotton yield per plant, 2.5% SL: 2.5% Span length, Str: Fibre bundle strength, EP: Elongation percentage, L × T: lines × testers.

variance in first crop for the investigated characters are presented in Table 4. These results revealed that the contribution to the total variance of all traits was made by both female and male parents. The female parents contributed to number of bolls per plant, fibre bundle strength and elongation percentage. The male parents contributed to boll weight, SCYPP and 2.5% span length. Furthermore, the contribution of the line × tester interactions was higher than that of both females and males for all the investigated characters except for boll weight. In case of ratoon crop, the results revealed that the maximum contribution to the total variance of all traits was made by female parents except for boll weight. Moreover, the contribution of the line × tester interactions was higher than both female and male parents for all the studied traits.

General combining ability effects for yield components and fibre quality traits

Combining ability of parents gives useful information on the choice of parents in terms of expected performance of their hybrids and progenies (Dhillon 1975). Simmonds, (1979) reported that GCA effect is controlled by additive gene effects which are fixable. Singh and Hari singh, (1985) suggested that parents with high GCA would produce transgressive segregates in F_2 (or) later generations. Therefore, the selection of parents based on favorable GCA would have an impact on the breeding programme.

In the present study of first crop, the lines TCH 1777 and TCH 1819 exhibited negatively significant and TSH 0250 had positively significant GCA effects for elongation percentage. Among the testers, TCB 26 expressed positively significant GCA effects for boll weight (Table 5). From the above discussions, it can be inferred that none of the parents was found to be a good general combiner for all the traits. Similar finding was reported by Ahuja and Dhayal, (2007). In case of ratoon crop, the lines MCU 13 and TCH 1819 possessed positively significant and TCH 1777 negatively significant GCA effects for number of bolls per plant. TCH 1819 and TSH 0250 expressed positively and negatively significant GCA effects, respectively. For 2.5% span length, the line TCH 1777 showed negatively significant and TCH 1819 expressed positively significant GCA effects (Table 5). For fibre bundle strength, the lines MCU 13 and TCH 1819 exhibited positively significant and remaining three lines expressed negatively significant GCA effects. For elongation percentage, the lines MCU 13 and VS 9-S11-1 showed positively and negatively significant GCA effects. However, among the testers, none of them was expressed the significant GCA effects for any of the investigated traits (Table 5). These results were indicating that both the parents retain more additive genes, thus could be utilized in hybridization programs for the improving the respective traits.

Specific combining ability effects for yield components and fibre quality traits

The specific combining ability effect designates the deviation from the predicted performance on the basis of general combining ability (Allard, 1960). According to Sprague and Tatum, (1942) the specific combining ability is controlled by non-additive gene action. The SCA effect is an important criterion for the evaluation of hybrids next to mean performance. The SCA effects not only are genetically controlled by dominance and epistasis effects, but also are subjected to considerable amount of genotype and environmental (G × E) interaction (Allard, 1960). In the present investigation of first crop, none of the hybrids expressed significant SCA effects for number of bolls per plant, boll weight and fibre bundle strength (Table 6). Two hybrids TCH 1777 × TCB 26 and VS 9-S11-1 × SUVIN expressed

Table 5: General combining ability effects for yield components and fibre quality traits in first and ratoon crop. The values in parentheses indicate ratoon crop

Parent	NBPP	BW	SCYPP	2.5% SL	Str	EP
Line						
MCU 13	2.83 (4.18**)	-0.08 (-0.04)	-10.94 (2.48)	-1.66 (0.73)	-1.14 (1.35**)	0.38 (0.24**)
TCH 1777	0.39 (-3.78**)	-0.06 (-0.07)	-5.44 (-2.37)	-0.05 (-1.01*)	-0.91 (-0.99*)	-0.62** (0.01)
TCH 1819	-2.16 (3.23*)	-0.32 (0.15)	1.03 (6.87**)	2.10 (0.82*)	-0.04 (1.51**)	-0.46* (0.04)
TSH 0250	2.99 (-1.30)	0.19 (-0.12)	8.81 (-6.54**)	0.55 (-0.09)	1.63 (-0.96*)	0.56** (-0.06)
VS 9-S11-1	-4.06 (-2.33)	0.27 (0.09)	6.54 (-0.44)	-0.93 (-0.45)	0.46 (-0.91*)	0.14 (-0.23**)
SE	2.46 (1.35)	0.16 (0.08)	6.12 (1.39)	1.29 (0.37)	1.22 (0.36)	0.18 (0.04)
Tester						
CCB 36	2.83 (1.21)	-0.28 (0.15)	-8.71 (-0.51)	0.28 (0.66)	-0.42 (0.11)	-0.05 (-0.01)
DB 3	-0.31 (-1.90)	-0.03 (-0.12)	0.23 (1.53)	0.99 (-0.04)	0.08 (0.16)	0.39 (0.03)
SUVIN	-2.57 (0.69)	0.07 (-0.03)	13.04 (-1.02)	-2.29 (-0.62)	-0.68 (-0.27)	-0.21 (-0.01)
TCB 26	3.43 (1.21)	0.47* (0.15)	10.01 (-0.51)	-1.48 (0.66)	0.36 (0.11)	0.23 (-0.01)
TCB 37	-1.81 (-1.90)	-0.18 (-0.12)	-9.99 (1.53)	1.04 (-0.04)	0.98 (0.16)	-0.27 (0.03)
TCB 209	-1.57 (0.69)	-0.05 (-0.03)	-4.58 (-1.02)	1.47 (-0.62)	-0.30 (-0.27)	-0.07 (-0.01)
SE	2.69 (1.48)	0.17 (0.08)	6.71 (1.53)	1.41 (0.41)	1.34 (0.40)	0.20 (0.04)

** and **: significance at p ≤ 0.05 and p ≤ 0.01 respectively, NBPP: Number of bolls per plant, BW: Boll weight, SCYPP: Seed cotton yield per plant, 2.5% SL: 2.5% Span length, Str: Fibre bundle strength, EP: Elongation percentage, SE: Standard error.*

Table 6: Specific combining ability effects for yield components and fibre quality traits in first and ratoon crop. The values in parentheses indicate ratoon crop

Hybrid	NBPP	BW	SCYPP	2.5% SL	Str	EP
MCU 13 × CCB 36	-3.65 (0.04)	-0.05 (0.09)	6.05 (14.83**)	-4.14 (0.49)	1.94 (1.95*)	0.10 (0.40**)
MCU 13 × DB 3	5.39 (5.80)	0.17 (0.01)	-0.76 (10.15**)	-1.08 (-0.44)	4.14 (2.15*)	0.76 (0.30**)
MCU 13 × SUVIN	-2.65 (3.36)	0.02 (0.22)	-27.58 (9.45*)	-1.22 (1.00)	-3.50 (3.08**)	0.76 (0.32**)
MCU 13 × TCB 26	2.05 (-3.28)	-0.22 (-0.39)	-11.21 (-16.09**)	-0.58 (-0.14)	-0.54 (-1.80)	-0.58 (-0.33**)
MCU 13 × TCB 37	5.09 (-2.87)	-0.23 (-0.05)	3.45 (-10.58**)	6.30 (-0.15)	1.24 (-2.46*)	-0.68 (-0.37**)
MCU 13 × TCB 209	-6.25 (-3.05)	0.31 (0.12)	30.06 (-7.75*)	1.42 (-0.76)	-3.28 (-2.91**)	-0.38 (-0.33**)
TCH 1777 × TCB 26	2.29 (-1.82)	-0.06 (0.05)	39.45* (-0.67)	2.66 (-0.82)	-1.57 (-0.51)	0.22 (0.07)
TCH 1819 × CCB 36	2.34 (-3.65)	-0.03 (0.24)	12.41 (-3.80)	-0.25 (-0.06)	-1.46 (-1.92*)	-0.06 (-0.78**)
TCH 1819 × DB 3	4.38 (-8.34*)	0.08 (0.14)	10.53 (-6.74)	-1.01 (0.02)	-0.96 (-1.89*)	-0.50 (-0.42**)
TCH 1819 × SUVIN	2.14 (-0.36)	-0.19 (-0.14)	-2.84 (-10.72**)	2.32 (-0.75)	4.40 (-2.88**)	0.10 (-0.42**)
TCH 1819 × TCB 2	-4.56 (0.99)	-0.10 (-0.10)	-20.58 (10.44**)	0.31 (0.40)	1.66 (1.78)	0.16 (0.60**)
TCH 1819 × TCB 37	-8.32 (6.75)	0.10 (-0.18)	3.83 (5.76)	-0.51 (-0.53)	-3.76 (1.98*)	-0.24 (0.50**)
TCH 1819 × TCB 209	4.04 (4.31)	0.14 (0.03)	-3.34 (5.06)	-0.84 (0.92)	0.12 (2.92**)	0.56 (0.52**)
TSH 0250 × CCB 36	0.59 (4.20)	-0.25 (-0.30)	-8.57 (-7.07*)	1.30 (0.68)	0.37 (0.50)	-0.68 (-0.03)
TSH 0250 × TCB 37	-1.67 (-2.75)	-0.16 (-0.02)	4.92 (1.39)	-8.95** (0.82)	-0.93 (0.27)	1.14* (-0.10)
VS 9-S11-1 × CCB 36	-1.66 (-3.28)	0.18 (-0.11)	0.85 (-2.61)	2.58 (-1.38)	-0.26 (-0.58)	0.34 (0.31**)
VS 9-S11-1 × DB 3	-0.22 (0.21)	0.14 (-0.11)	-9.04 (-0.06)	-0.08 (-2.00*)	-2.76 (-0.41)	0.30 (0.36**)
VS 9-S11-1 × SUVIN	5.14 (-1.54)	0.33 (-0.20)	60.69** (2.01)	-3.15 (0.36)	0.50 (0.41)	-1.00* (0.14)
VS 9-S11-1 × TCB 26	-1.26 (1.90)	-0.04 (0.30)	-30.41 (3.51)	-2.57 (1.21)	0.86 (0.50)	-0.04 (-0.52**)
SE	6.03 (3.32)	0.39 (0.19)	15.01 (3.42)	3.17 (0.91)	3.01 (0.89)	0.45 (0.10)

** and **: significance at p ≤ 0.05 and p ≤ 0.01 respectively, NBPP: Number of bolls per plant, BW: Boll weight, SCYPP: Seed cotton yield per plant, 2.5% SL: 2.5% Span length, Str: Fibre bundle strength, EP: Elongation percentage, SE: Standard error.*

positively significant SCA effects for seed cotton yield per plant. The hybrid TSH 0250 × TCB 37 expressed negatively significant SCA effects for 2.5% span length and positively significant SCA effects for elongation percentage. Whereas, the hybrid VS 9-S11-1 × SUVIN expressed negatively significant SCA effects for elongation percentage (Table 6).

In case of the ratoon crop, only one hybrid TCH 1819 × DB 3 exhibited negatively significant SCA effects for number bolls per plant. Among the thirty hybrids, four hybrids showed positively significant SCA effects and another four hybrids showed negatively significant SCA effects for seed cotton yield per plant (Table 6). Only one hybrid VS 9-S11-1 × DB 3 exhibited negatively significant SCA effects for 2.5% span length. For fibre bundle strength, five hybrids showed positively significant and another five hybrids showed negatively significant SCA effects. For elongation percentage, eight hybrids showed positively significant and seven hybrids showed negatively significant SCA effects (Table 6). Similar findings of significant SCA effects were reported by Karademir and Gencer, (2010), Hinze *et al.* (2011) and Shaukat *et al.* (2013) for number of bolls per plant, seed cotton yield per plant and fibre quality traits.

CONCLUSION

The study demonstrated that the parent TCH 1819 was a good combiner for all the investigated traits except boll weight and the parent TCB 26 was found to be a good combiner for only boll weight. The SCA effects revealed the best specific combinations, (i) the hybrid TCH 1819 × DB 3 for number bolls per plant; (ii) TCH 1777 × TCB 26 and VS 9-S11-1 × SUVIN for seed cotton yield per plant; (iii) TSH 0250 × TCB 37 and VS 9-S11-1 × DB 3 for 2.5% span length; (iv) MCU 13 × SUVIN and TCH 1819 × TCB 209 for fibre bundle strength; (v) TSH 0250 × TCB 37 and VS 9-S11-1 × SUVIN for elongation percentage.

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