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RESEARCH ARTICLE

Diallel Analysis and Heterotic Effects for Yield and Fibre Quality Traits in Upland Cotton

K.Senthil Kumar[1], K.Ashokkumar[1,2*] and R.Ravikesavan[1]

[1]Center of Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore-3, Tamil Nadu, India.

[*2]Department of Plant Biotechnology, Tamil Nadu Agricultural University, Coimbatore-3, Tamil Nadu, India.

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***Address for correspondence**
K.Ashokkumar
Center of Plant Breeding and Genetics,
Tamil Nadu Agricultural University,
Coimbatore-3, Tamil Nadu, India.
Email: biotech.ashok@gmail.com

ABSTRACT

An investigation was carried out to assess the mean performance and heterotic effect for yield and fibre quality traits of 42 hybrids generated from 7 parents in a diallel mating design Results revealed that parent BW 4-1 had the best mean performance for most of the traits. Hybrid TCH 1726 x BW4-1 was found to exhibit positive and significant relative heterosis for lint index, plant height, days to first boll bursting, number of bolls per plant, number of sympodial branches, seed cotton yield, 2.5 per cent span length and seed cotton yield. The hybrid TCH 1705 x Narasimha recorded positive and significant relative heterosis, and heterobeltiosis, for days to first boll bursting, number of bolls per plant, single plant yield. Additionally, hybrid KC 2 x MCU 3 recorded positive and significant relative heterosis, and heterbeltiosis for number of bolls per plant, and seed cotton yield. The heterosis along with *per se* performance of the hybrids gave an idea about the pratical utility of hybrid combinations for heterosis breeding.

Key words: Cotton, heterosis, seed cotton yield, fibre quality traits, diallel analysis

INTRODUCTION

Cotton (*GossypiumhirsutumL.*) is an important fiber, crop and plays a vital role as a cash crop in many countries. It provides fibre for textile industry, cellulose from its lint, oil and protein rich meal from its seed (Ashokkumar and

Ravikesavan, 2011). In any breeding programme, the choice of best parents is an important step. However, cotton is highly amenable for both heterosis and recombination breeding. A considerable amount of heterosis has been reported in this crop (Marani, 1963; Singh, 1982; Ashokkumar and Ravikesavan, 2013; Ashokkumar et al., 2013). To exploit heterosis, the knowledge of selecting appropriate parents with good genetic potential is very essential. The parent should possess good combining ability and wide genetic diversity for various economic traits (Ashokkumar and Ravikesavan, 2011). Heterosis is useful in determining the most appropriate parents for specific traits (Khan et al., 2010). Development of hybrids as commercial varieties is increasingly becoming important. Cotton is highly amenable for both heterosis and recombination breeding. Heterosis has substantially remained as one of the significant developments in cotton breeding programs, (Singh, 1982; Chaudhari et al., 1992; Baloch et al., 2003; Baloch, 2004; Memon et al., 2005; Ganapathy and Nadarajan, 2008; Khan et al., 2010; Ashokkumar and Ravikesavan, 2013). Heterosis has substantially remained as one of the significant developments in cotton breeding programs, (Singh, 1982; Chaudhari et al., 1992; Baloch et al., 2003; Baloch, 2004; Memon et al., 2005; Ganapathy and Nadarajan, 2008; Khan et al., 2010; Ashokkumar and Ravikesavan, 2013).

The development of new cotton varieties with high yield and fibre quality is the primary objective of cotton breeders. The first step in a successful breeding program is the selection of appropriate parents. Diallel analysis provides a systematic approach for detection of appropriate parents and crosses in terms of investigated traits and it has been widely used by plant breeders in the selection of parents and crosses in the early generations (Marani, 1963; Green and Culp, 1990; Islam et al., 2001; Kiani et al., 2007; Karademir and Gencer, 2010; Senthilkumar et al., 2014). Several studies have been reported on yield and yield attributing traits, but little work has been reported on the genetics and heterosis of fibre quality traits in cotton breeding. A few reports in the literature (Rahman et al., 1993; Zhang et al., 2002; Basal and Turgut 2003; Preetha and Raveendran, 2008; Karademir et al., 2009; Karademir and Gencer, 2010; Karademir et al., 2011; Bolek et al., 2011; Ashokkumar and Ravikesavan, 2008; Ashokkumar et al., 2010; Ashokkumar and Ravikesavan, 2011; Ashokkumar et al., 2014) have determined that cotton genotypes differ in fibre quality traits. The estimates of mean performance and heterosis provided useful information with regard to the possibilities and extent of improvement in the yield and fibre characters of breeding material through selection.Therefore, the objective of the present study was to estimate genetic variation of parents and their hybrids and to estimate the effects of heterosis in F_1 cross combinations.

MATERIALS AND METHODS

Genetic material

The field experiment was conducted using seven parents, viz., Narasimha, TCH 1726, TCH 1705, KC2, MCU13, BW4-1 and MCU 3. All the seed materials were obtained from Department of Cotton, Tamil Nadu Agricultural University,Coimbatore, India. The commercial cultivars were cultivated in southern states of India.

Experimental design and field procedures

The cotton cultivars were evaluated in complete randomized block design (RBD) with three replications at Cotton Breeding Station, Tamil Nadu Agricultural University, Coimbatore, and Tamil Nadu in India. The seed of each parental genotype was sown in 20 rows of 6m length in crossing block with a spacing of 90 x 45 cm. Crosses were made between parents in a 7 x 7 full diallel mating design. The conventional hand emasculation and pollination method developed by Doak (1934) was followed. Emasculation of the flower buds was done in the ovule parent on the previous day evening. The entire staminal column with anthers was removed carefully along with corolla and bracts with the help of nail without any damage to ovary. Pollination was done on the next day morning by dusting the pollen grains on the stigma of ovule parent. Crossed bolls were collected separately and ginned to obtain F1 seeds. Seven parents and 42 hybrids were raised along with the standard check with three replications. The diallelanalysis was performed as model 1 and method 1 suggested by Griffing (1956).

Sampling, traits measurements and methods

For each genotype and its cross combinations, data were recorded on five randomly selected plants per replication for twelve characters namely, days to boll bursting, number of sympodia per plant, plant height at maturity (cm), number of bolls per plant, boll weight (g), lint index, seed index, ginning percent, single plant yield (g), 2.5% span length (mm), elongation percent and fiber fineness. Quality parameters were analyzed by High Volume Instrument (HVI). The expression of heterosiswas worked out for all the characters over mid parent, and better parent was estimated in theentire cross combinations under this study.The significance of heterosis was estimated by't' test using the formulae (Wynne et al., 1970).

't' value of relative heterosis (d_i) = $$\frac{\left(\overline{\mathrm{Fij}}\right)-\left(\overline{\mathrm{MPij}}\right)}{\sqrt{(3-2)\left(\sigma^2 e / r\right)}}$$

't' value of heterobeltiosis (d_{ii}) = $$\frac{\left(\overline{\mathrm{Fij}}\right)-\left(\overline{\mathrm{BPij}}\right)}{\sqrt{2\sigma^2 e / r}}$$

Where,

$\overline{\mathrm{Fij}}$ = Mean of the ijthF$_1$ cross

$\overline{\mathrm{MPij}}$ = Mean of mid parent value for ijth hybrid

$\overline{\mathrm{BPij}}$ = Mean of better parent value for ijth hybrid

σ_e^2 = error variance

r = Number of replication

Statistical analysis was carried out by using the mean values over five sample plants (Indostat Statistical Software Package; Indostat Pvt. Ltd., Hyderabad, India).

RESULTS AND DISCUSSION

Analysis of variance showed highly significant differences among genotypes for all the traits, indicating the presence of sufficient variability among the genotypes assessed (Table 1). Significant differences in parents versus hybrids interaction provided adequacy for comparing the heterotic expression for all the characters except boll weight and micronaire. However, parents and hybrids showed significant differences between all the characters studied except single plant yield and bundle strength. Ashokkumar and Ravikesavan (2013) reported that all the characters were significant with parents and hybrids in upland cotton, and this is in agreement with our results.

Mean performance

The mean performance of seven parents and their 42 hybrids are presented (Table 2-5). Among the parents, plant height was ranged from 87.0 cm to 127.0 cm. The differences observed for mean plant height among cotton cultivars can be attributed tovariation in genetic makeup of crop plants. These results are supported by the findings of Anwaret al. (2002), Copur (2006) Ashokkumar et al. (2010) and Ashokkumar and Ravikesavan, (2011)who also noted significant differences among cultivars for plant height. Of the hybrids, the meanvalues ranged from 81.0. cm in BW4-1 x Narasimha to 136.0 cm in TCH 1726 x TCH 1705. For parents, highest number of sympodia per plant and lowest number of sympodia per plantwere produced by KC 2 (13) and TCH 1726 (17), respectively (Table 2). In hybrids, the weakest value of 13 and the greatest value of 19 were recorded with a mean value of 16. There was significant difference between the parents for the number of bolls per plant. The meanvalues for number of bolls per plants ranged from 21 in TCH 1726 to 27 in BW4-1. The hybridsdisplayed a variation from 21 bolls in MCU 13 x KC 2 to 34 bolls in KC 2 x TCH 1726 for the number of bolls per plant with a mean value of 25.4 bolls. The result indicates the importance of hybrid KC 2 x TCH 1726 offering the scope of selection and can be utilized for the improvement of number of bolls per plant which will directly influence the seed cotton yield. In addition, the present results have been further supported by Soomro (2000), Baloch (2002),Chandio et al. (2002), Basbag and Gencer (2004), Soomro et al. (2008), and Ashokkumar andRavikesavan, (2011 and 2013).Boll weight is directly related to the seed cotton yield of cotton. An evaluation of data indicated that greatest boll weight was recorded in cultivar BW4-1(4.7 g), and the lowest boll weight was recorded Narasimha (4.1 g). Significant differences among parents for average boll weight also were reported (Hofs et al. 2006; Ashokkumar and Ravikesavan, 2011 and 2013). Mean boll weight among the hybrids ranged from 3.91g in Narasimha x Bw4-1 to 4.95 in MCU 13 x KC2. Boll weight was positively associated with seed cotton yield as reported (Rauf et al., 2005; Giteet al., 2006; Preetha and Raveendran, 2007; Ashokkumar and Ravikesavan, 2013). The ginning per cent ranged from 34.9 to 40.5% and 36.6 to 41.0% in the parents and hybrids respectively, these results were supported by those of Ehsan et al. (2008). There were significant differences in all the hybrids in the case of lint index (g) and seed index (g) (Table 3). All the parents and hybrids had wide variation for seed cotton yield per plant. The mean value of seed cotton yield was ranged from 75.2 g to 119.4 g and 73.8 to 139.8 in parents and hybrids. Among hybrids, Narasimha x KC2 recorded lowest value of 8.89 and the highest value of 11.74 was observed in KC2 x TCH1726. Similar findings for seed cotton yield have also been reported (Baloch, 2004; Soomro et al., 2008).

For mean performance of parents, 2.5% span length had a minimum expression of 27.2 mm in TCH 1705 to 30.6 mm in Narasimha. Previous studies indicated that fiber length could vary widely with plant variety and growing conditions. Ehsan et al. (2008), Copur (2006) and Khan et al. (1989) reported similar results for fiber length. The hybrids TCH 1726 x TCH 1705 and MCU 13 x TCH1726 registered minimum (25.8 mm) and maximum (31.9 mm) length. The mean fibre length of hybrids was 29.7 mm. Niagun and Khadi (2001) observed that mean fibre length for Gossypiumbarbadense crosses was 35. 9 mm and this is the greater value compare to our results, and is in conformation with G. barbadanse which is higher in fibre length than G. hirsutum. Fibre fineness or micronaire and fibre strength are very important characteristic of the fiber quality of cotton and are extremely useful for textile industry. In parents, bundle strength was ranged from 20.6 to 22.4 (g/tex). Maximum and minimum valuesrecorded in hybrids were 23.40 g/tex in BW4-1 x MCU 3and 17.40 g/tex in Narasimha x KC 2.These results were supported by earlier studies (Khan, 2002; Karademir et al., 2011). The parentBW 4-1 recorded the greatest micronaire value of 4.7 µg/inch and lowest of 3.9 µg/inch in MCU3. Differences between the cultivars with respect to fiber fineness were also found significant byCopur (2006), Ehsan et al. (2008) and Ashokkumar et al. (2013). Of the 42 hybrids, BW 4-1 xMCU 13 recorded the lowest value of 3.85 µg/inch. The highest value (4.90 µg/inch) was recorded by TCH 1726 × MCU 3. The average value of micronaire value in hybrids was 4.30µg/inch (Table 3). Niagun and Khadi (2001) observed mean micronaire for G. hirsutum and G.barbadense crosses was 2.95 µg/inch, and this showed that the present study significantlyexploited the hybrids than earlier studies.

Estimation of heterosis for yield attributing traits

Estimation of heterotic effects is necessary to identify the new cross combinations that are suitable for direct exploitation. Therefore, the heterotic expression of 42 cross combinations over mid parental and better parental heterosis was examined and results arepresented (Table 3-5). Hybrid Narasimha x KC 2 recorded highest significant positive relative heterosis (28.30%) and heterobeltiosis (26.96%) for plant height. Among fourty two hybrids, 13 crosses recorded significant positive relative heterosis and six crosses showed positivesignificant heterobeltiosis. These results were supported from those of Sayal et al. (1999), Hassan et al. (1999) Rauf et al., (2005) and Ashokkumar and Ravikesavan, (2013) who observed considerable amount of heterosis for plant height. For number of sympodia, the hybrid KC2 xTCH 1726 recorded highest positive significant relative heterosis (45.0%), and heterobeltiosis (45.00%) followed by TCH 1726 x KC 2 with relative heterosis of 35.0%, and heterobeltiosis of 35.0%. This is similar with earlier finding of Koodalingam et al. (1991), Ganapathy and Nadarajan (2008) and Ashokkumar and Ravikesavan, (2013). Among 42 hybrids, 19 hybrids showed positive significant relative heterosis and 16 hybrids showed positive and significant heterobeltiosis for number of bolls per plant. Three hybrids showed positive significant relative heterosis and two hybrids recorded positive significant heterobeltiosis for boll weight. Of the fourty two hybrids, none of the hybrids recorded positive significant relative heterosis and heterobeltiosis for ginning percentage (Table. 4). For seed index, the cross MCU3 x KC2 recorded a maximum significant positive relative heterosis (29.41%) followed by MCU 13 x KC 2 (26.88%). The cross MCU3 x KC2 exhibited highest and significant heterobeltiosis (26.19 %.). However, seventeen hybrids showed positive significant relative heterosis, 6 hybrids showed positive and significant heterobeltiosis over better parent for seed index (Table 4). Significant positive heterosis as well as heterobeltiosis for seed index also reported in previous studies (Khan, 1986; Rahman et al., 1993; Ashokkumar and Ravikesavan, 2013).

Expression of heterosis for seed cotton yield

Sixteen hybrids exhibited positive and significant relative heterosis, and 11 hybrids showed positive significant heterobetiosis. Ganapathy and Nadarajan (2008) also reported positive heterobeltiotic effect over better parent 20 hybrids for seed cotton yield. Additionally, similar results were already reported (Chaudhari et al.,1992; Ashokkumar and Ravikesavan, 2013) forseed cotton yield. The hybrid KC 2 x TCH 1726 recorded maximum positive significant relative heterosis (81.40%), and heterobeltiosis (77.11%) followed by TCH 1726 x KC 2 with positive significant values of relative heterosis (62.24%), heterobeltiosis (58.40%) for seed cotton yield.

Expression of heterosis for fibre quality traits

For fibre length or 2.5% span length, eighteen hybrids recorded positive and significant relative heterosis over mid parental value (Table 5). The hybrid BW4-1 x MCU 13 recorded maximum positive significant relative heterosis (21.98%) and heterobeltiosis (13.01%). Eight hybrids showed significant and positive heterosis over mid and better parent. The results of heterosis are in conformity with the reports of Tuteja et al. (2005), Iraddi and Kajjidoni (2009), Karademir and Gencer (2010), Karademir et al. (2011) and Ashokkumar et al. (2013). For bundle or fibre strength, one hybrids displayed significant positive relative heterosis over mid parental value and heterobeltiosis for better parental value. Hybrid vigour was also observed by Hassan et al. (1999), Soomro (2000), Rauf et al. (2005) Karademir et al. (2011) and Ashokkumar et al. (2013). The hybrid BW4-1 x TCH 1705 recorded maximum positive and significant relative heterosis (12.77%) and heterobeltiosis (11.961%) for bundle strength. For micronaire, The hybrid TCH 1726 x KC2 recorded maximum positive and significant relative heterosis (16.21%), heterobeltiosis(10.53%) followed by KC 2 x TCH 1726 with significant and positive relative heterosis (13.83%), and heterobeltiosis (8.27%). Two hybrids showed significant and positive heterosis over mid parent, and better parent. Six hybrids showed positive significant relative heterosis, and four hybrids showed positive significant heterobeltiosis for micronaire.

CONCLUSION

Cottonfibre quality traits have a vital influence on the yarn strength. High fibre length and the tensile strength of the fibres becomes the controlling factor of yarn strength. The developing high yields with fibre quality cultivars or hybrids are essential to current modernized spinning mills. Therefore, the present study was carried out for improving yield and fibre quality traits from upland cotton by diallel mating design. The results showed that hybrids are superior to the parents for all the yield and fibre quality traits. A hybrid KC 2 x MCU 3 recorded positive and significant relative heterosis, and heterbeltiosis for number of bolls per plant, and seed cotton yield. Hybrid TCH 1726 X BW4-1 found to be exhibit positive and significant relative heterosisfor most of the yield and firbe quality traits is found to be utilized for direction choice.Further more, increasing the fibre quality traits are a valuable addition to cotton cultivars orhybrids, and it will be useful for textile industries.

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Table 1.Analysis of variance for means square of yield and fibre quality traits

Source	d.f	Days to first boll bursting	Number of sympodial branches	Plant height (cm)	Number of bolls per plant	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning (%)	Single plant yield (g)	2.5.per cent span length (mm)	Bundle strength (g/tex)	Micronaire
Replications	2	0.659	4.27	14.88	1.55	0.143	0.235	0.157	4.96	493.3	4.62	3.076	0.046
Genotypes	48	6.31**	9.98**	727.6**	39.3**	0.136**	0.758**	1.906**	6.20**	1072.9**	7.367**	3.010**	0.203**
Parents	6	6.09**	5.52*	618.4**	11.93*	0.143**	1.348**	1.719**	14.28**	628.3	16.32**	2.088	0.287**
Hybrids	41	6.24**	10.63**	752.0**	40.1**	0.138**	0.568**	1.538**	5.014**	1141.2**	5.066**	3.054**	0.196**
Parents V_s Hybrids	1	10.44**	10.01**	385.3**	181.4**	0.0006	5.000**	18.13**	6.63**	943.7**	47.92**	6.774*	0.003
F_1's	20	6.73**	10.98**	625.4**	50.86**	0.177**	0.443**	1.319**	5.87**	1207.1**	5.660**	3.552**	0.197**
Reciprocals	20	5.71**	10.77**	906.6**	27.40**	0.102	0.714**	1.436**	4.049**	1124.8**	4.553**	2.703**	0.195**
$F_{1\ Vs}$ reciprocals	1	7.14**	0.79	188.9*	79.36*	0.079	0.147**	7.940**	7.081**	149.4	3.433	0.108	0.186*
Error	96	1.020	1.48	23.35	5.30	0.048	0.221	0.581	0.935	146.3	1.266	1.215	0.039
Total	146	2.757	4.31	254.7	16.50	0.078	0.398	1.011	2.724	455.7	3.317	1.831	0.093

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

Table 2.Mean performance of parents for yield and fibre quality traits

Genotypes	Days to boll first boll bursting	Number of sympodia per plant	Plant height (cm)	Number of bolls per plant	Boll weight (g)	Lint index (g)	Seed index (g)	Ginning percent (%)	Single plant yield (g)	2.5 % span length (mm)	Bundle strength (g/tex)	Micro naire
Narasimha	102	15	100.0	22	4.10	5.76	8.86	39.2	95.8	30.6	20.7	4.1
KC 2	101	13	102.1	22	4.28	5.89	8.22	38.0	75.2	27.2	22.1	4.4
MCU 3	102	15	127.0	22	4.31	5.59	8.65	39.2	95.7	30.2	22.0	3.9
TCH 1705	102	15	114.7	24	4.50	6.53	9.54	40.5	93.8	27.2	20.9	4.6
BW4-1	105	17	122.3	27	4.70	6.76	10.27	39.7	119.4	28.6	20.6	4.7
MCU 13	103	15	87.0	22	4.58	6.73	10.12	39.9	98.9	27.6	22.3	4.5
TCH 1726	101	13	119.3	21	4.61	4.96	9.23	34.9	78.9	28.7	22.4	4.0
Grand mean	102	15	110.3	23	4.44	6.03	9.27	39.3	93.9	27.8	21.6	4.3

Table 3. Mean performance and expression of heterosis in hybrids (%) for yield attributing traits.

SL. No.	Cross	Days to first boll bursting			Plant height (cm)			Number of Sympodia per plant			Number of Bolls per plant		
		Mean	d_i	d_{ii}	Mean	d_i	d_{ii}	Mean	d_i	d_{ii}	Mean	d_i	d_{ii}
1.	Narasimha x KC 2	107	4.92**	4.58**	129.6	28.30**	26.96**	15	3.53	-2.22	28	23.88**	23.88**
2.	Narasimha x MCU 3	105	2.94**	2.94**	103.4	-8.84**	-18.53**	14	-6.67	-6.67	27	23.31**	22.39**
3.	Narasimha x TCH1705	103	0.98	0.98	116.0	8.10*	1.16	17	15.56**	15.56*	32	38.13**	33.33**
4.	Narasimha x BW4-1	102	-1.93**	-3.48**	131.5	18.34**	7.55*	16	-1.03	-7.69	29	18.92**	8.64
5.	Narasimha x MCU 13	103	0.32	-0.32	94.3	0.86	-5.67	18	18.68**	17.39**	32	44.36**	43.28**
6.	Narasimha x TCH 1726	101	-0.33	-0.65	130.3	18.86**	9.25**	18	29.41**	22.22**	33	50.77**	46.27**
7.	KC2 x Narasimha	103	1.31	0.98	123.6	22.36**	21.08**	16	15.29*	8.89	30	37.31**	37.31**
8.	KC2 x MCU 3	103	1.31	0.98	103.0	-10.10**	-18.90**	17	20.00**	13.33*	33	47.37**	46.27**
9.	KC2 x TCH 1705	104	2.30**	1.96*	98.3	-9.31**	-14.29**	14	20.00**	13.33*	28	22.30**	18.06*
10.	KC2 x BW 4-1	104	0.97	-0.95	92.0	-18.02**	-24.78**	15	-10.87	-21.15**	22	-12.16	-19.75**
11.	KC2 x MCU13	101	-1.63*	-2.58**	96.2	1.70	-5.81	15	4.65	-2.17	26	17.29*	16.42
12.	KC2 x TCH 1726	102	0.66	0.66	103.6	-6.37*	-13.10**	19	45.00**	45.00**	34	58.46**	53.73**
13.	MCU 3 x Narasimha	102	0.00	0.00	88.2	-22.29**	-30.55**	14	-4.44	-4.44	24	6.77	5.97
14.	MCU3 x KC 2	104	2.30**	1.96*	84.8	-25.98**	-33.23**	14	-1.18	-6.67	23	3.76	2.99
15.	MCU3 x TCH 1705	105	2.94**	2.94**	87.2	-27.85**	-31.34**	14	-6.67	-6.67	23	0.00	-4.17
16.	MCU 3 x BW4-1	102	-1.61*	-3.16**	92.6	-25.66**	-27.03**	14	-11.34*	-17.31**	22	-8.84	-17.28*
17.	MCU 3 x MCU 13	103	0.32	-0.32	93.6	-12.48**	-26.25**	14	-5.49	-6.52	24	10.61	10.61
18.	MCU 3 x TCH 1726	102	-0.00	-0.33	91.4	-25.78**	-28.03**	16	10.59	4.44	28	28.68**	25.76**
19.	TCH1705 x Narasimha	105	2.94**	2.94**	109.6	2.14	-4.42	18	22.22**	22.22**	32	38.13**	33.33**
20.	TCH1705 x KC2	103	1.31	0.98	128.2	18.23**	11.74**	14	1.18	-4.44	25	7.91	4.17
21.	TCH1705 x MCU 3	101	-0.65	-0.65	116.0	-4.03	-8.66**	19	26.67**	26.67**	29	27.54**	22.22**
22.	TCH1705 x BW4-1	102	-1.29	-2.85**	111.3	-6.06*	-8.97**	13	-17.53**	-23.08**	22	-15.03*	-19.75**
23.	TCH1705 x MCU 13	103	0.32	-0.32	108.0	7.05*	-5.87	18	18.68**	17.39**	25	8.70	4.17
24.	TCH 1705 x TCH 1726	102	0.33	0.00	122.6	4.83	2.82	15	8.24	2.22	26	14.07	6.94
25.	BW4-1 x Narasimha	105	1.29	-0.32	81.0	-27.13**	-33.77**	15	-5.15	-11.54*	27	8.11	-1.23
26.	BW4-1 x KC2	103	-0.32	-2.22**	92.6	-17.42**	-24.23**	14	-6.52	-17.31**	24	-2.70	-11.11
27.	BW4-1 x MCU 3	105	1.29	-0.32	95.1	-23.68**	-25.09**	15	-7.22	-13.46*	22	-10.20	-18.52**
28.	BW4-1 x TCH 1705	103	-0.64	-2.22**	86.6	-26.87**	-29.14**	15	-7.22	-13.46*	25	-0.65	-6.17
29.	BW4-1 x MCU 13	102	-2.24**	-3.16**	110.6	5.72	-9.51**	13	-20.41**	-25.00**	22	-11.56	-19.75**
30.	BW4-1 x TCH 1726	105	1.61*	-0.32	86.7	-28.20**	-29.08**	18	17.39**	3.85	28	-16.67*	3.70
31.	MCU 13 x Narasimha	103	0.32	-0.32	90.0	-3.77	-10.00*	13	-12.09*	-13.04*	22	-0.75	-1.49
32.	MCU 13 x KC 2	104	1.95**	0.97	95.3	0.78	-6.66	14	-2.33	-8.70	21	-5.26	-5.97
33.	MCU13 x MCU 3	102	-0.65	-1.29	117.3	9.63**	-7.61*	15	-1.10	-2.17	26	18.18*	18.18*
34.	MCU13 x TCH 1705	103	0.32	-0.32	113.8	12.86**	-0.76	13	-14.29*	-15.22*	22	-4.35	-8.33
35.	MCU13 x BW4-1	104	0.00	-0.95	92.0	-12.11**	-24.78**	15	-8.16	-13.46*	25	0.68	-8.64
36.	MCU13 x TCH 1726	102	0.00	-0.97	91.7	-11.09**	-23.11**	14	-2.33	-8.70	22	2.33	0.00
37.	TCH 1726 x Narasimha	102	0.66	0.33	110.1	0.41	-7.71*	16	15.29*	8.89	28	29.23**	25.37**
38.	TCH 1726 x KC 2	103	1.64*	1.64*	105.6	-4.56	-11.43**	18	35.00**	35.00**	26	21.54**	17.91*
39.	TCH 1726 x MCU 3	102	0.33	0.00	134.3	9.08**	5.77	19	31.76**	24.44**	27	25.58**	22.73**
40.	TCH 1726 x TCH 1705	105	3.28**	2.94**	136.0	16.22**	14.00**	14	-3.53	-8.89	23	0.74	-5.56
41.	TCH 1726 x BW4-1	107	3.55**	1.58*	127.6	5.68*	4.39	19	21.74**	7.69	28	15.28*	2.47
42.	TCH 1726 x MCU 13	103	0.33	-0.65	117.8	14.17**	-1.26	15	6.98	0.00	23	6.98	4.55

*significant at 5 per cent level, ** significant at 1 per cent level, di, relative heterosis; dii, heterobeltiosis

Table 4. Mean performance and expression of heterosis in hybrids (%) for boll weight and seed quality traits.

SL. No.	Cross	Boll weight (g)			Lint index (g)			Seed index (g)			Ginning per cent (%)		
		Mean	d_i	d_{ii}	Mean	d_i	d_{ii}	Mean	d_i	d_{ii}	Mean	d_i	d_{ii}
1.	Narasimha x KC 2	4.32	3.10	0.93	6.15	5.52	4.36	8.89	4.02	0.26	40.7	0.70	-2.24
2.	Narasimha x MCU 3	3.96	-5.91	-8.20	6.47	13.95*	12.27	9.59	9.53	8.24	40.1	2.21	2.12
3.	Narasimha x	4.26	-1.01	-5.47	6.36	3.55	-2.55	10.05	9.26	5.38	38.7	-2.96	-4.52
4.	Narasimha x BW4-1	3.91	-11.31**	-17.06**	6.05	-3.30	-10.45	9.43	-1.46	-8.21	39.0	-1.06	-1.60
5.	Narasimha x MCU	4.26	-1.80	-6.98	6.72	7.66	-0.10	9.16	-3.49	-9.49	39.7	6.73	5.84
6.	Narasimha x TCH	4.54	4.24	-1.59	6.43	19.93**	11.63	9.30	2.84	0.79	40.7	9.84	3.74
7.	KC2 x Narasimha	4.09	-2.47	-4.52	6.21	6.55	5.38	10.09	18.10**	13.84	38.0	-6.13	-8.87
8.	KC2 x MCU 3	4.10	-4.62	-4.95	5.68	-1.10	-3.62	9.03	6.97	4.31	38.6	-4.57	-7.43
9.	KC2 x TCH 1705	4.44	1.14	-1.41	6.18	-0.43	-5.31	9.37	5.54	-1.75	39.6	-3.73	-5.04
10.	KC2 x BW 4-1	4.66	3.67	-1.06	6.80	7.46	0.54	10.08	9.01	-1.85	40.2	-1.15	-3.52
11.	KC2 x MCU13	4.50	1.54	-1.82	6.42	1.80	-4.56	10.71	16.74**	5.80	37.4	-8.21	-10.15
12.	KC2 x TCH 1726	4.36	-2.06	-5.63	6.58	21.25**	11.71	9.85	12.91*	6.75	39.9	4.26	-4.24
13.	MCU 3 x Narasimha	4.52	7.57*	4.95	6.68	17.65**	15.91*	11.08	26.55**	25.05**	37.5	-4.42	-4.50
14.	MCU3 x KC 2	4.59	6.95	6.57	6.35	10.57	7.75	10.92	29.41**	26.19**	36.7	-9.19	-11.91
15.	MCU3 x TCH 1705	4.47	1.32	-0.89	6.53	7.76	0.00	11.14	22.50**	16.81*	36.8	-7.73	-9.29
16.	MCU 3 x BW4-1	4.77	5.84	1.34	6.82	10.45	0.89	10.25	8.30	-0.23	39.9	1.14	0.50
17.	MCU 3 x MCU 13	4.37	-1.65	-4.58	6.28	1.95	-6.69	10.35	10.26	2.27	37.7	-4.72	-5.59
18.	MCU 3 x TCH 1726	4.59	2.84	-0.58	6.39	21.16**	14.37*	10.11	13.07*	9.53	38.7	4.63	-1.11
19.	TCH1705 x	4.38	1.86	-2.74	6.75	9.90	3.42	10.50	14.15*	10.10	39.1	-2.05	-3.62
20.	TCH1705 x KC2	4.33	-1.52	-3.99	6.11	-1.61	-6.43	9.50	7.00	-0.38	39.0	-5.19	-6.47
21.	TCH1705 x MCU 3	4.31	-2.23	-4.36	6.31	4.07	-3.42	9.92	9.09	4.02	38.8	-2.72	-4.35
22.	TCH1705 x BW4-1	4.36	-5.39	-7.43	6.87	3.39	1.63	9.99	0.82	-2.76	40.7	1.58	0.49
23.	TCH1705 x MCU 13	4.81	5.76	4.87	6.39	-3.57	-5.00	10.93	11.16*	7.97	36.9	-8.32	-9.04
24.	TCH 1705 x TCH	4.57	0.26	-0.94	6.95	20.94**	6.43	10.61	13.02*	11.18	39.5	4.86	-2.47
25.	BW4-1 x Narasimha	4.38	-0.64	-7.08	7.20	15.07**	6.56	10.71	11.99*	4.32	40.1	1.65	1.09
26.	BW4-1 x KC2	4.40	-2.04	-6.51	6.75	6.72	-0.15	9.94	7.45	-3.25	40.0	-1.56	-3.92
27.	BW4-1 x MCU 3	4.56	1.03	-3.26	7.04	14.01*	4.14	10.98	16.08**	6.95	38.9	-1.23	-1.85
28.	BW4-1 x TCH 1705	4.42	-4.09	-6.16	7.18	8.10	6.26	11.74	18.53**	14.31*	37.9	-5.48	-6.49
29.	BW4-1 x MCU 13	4.60	-1.08	-2.41	6.53	-3.14	-3.35	10.10	-0.93	-1.66	39.2	-1.47	-1.75
30.	BW4-1 x TCH 1726	4.35	-6.72*	-7.64*	7.51	28.12**	11.09	10.65	9.23	3.70	41.0	9.92	3.27
31.	MCU 13 x	4.58	5.57	0.00	7.35	17.64**	9.16	10.91	14.94**	7.81	40.3	1.77	0.92
32.	MCU 13 x KC 2	4.95	11.70**	8.00*	7.26	15.11**	7.92	11.64	26.88**	14.99*	38.3	-6.00	-7.99
33.	MCU13 x MCU 3	4.43	-0.45	-3.42	6.85	11.20*	1.78	11.58	23.40**	14.46*	37.1	-6.15	-7.01
34.	MCU13 x TCH 1705	4.30	-5.46	-6.25	6.06	-8.55	-9.91	10.46	6.41	3.36	36.6	-8.90	-9.61
35.	MCU13 x BW4-1	4.57	-1.65	-2.97	6.57	-2.64	-2.86	11.23	10.15	9.35	36.8	-7.49	-7.76
36.	MCU13 x TCH 1726	4.72	2.54	2.17	6.90	17.96**	2.48	10.92	12.90*	7.94	38.8	3.70	-2.84
37.	TCH 1726 x	4.35	-0.11	-5.70	6.48	20.86**	12.50	9.84	8.81	6.65	39.6	6.97	1.02
38.	TCH 1726 x KC 2	4.77	7.23*	3.32	5.93	9.21	0.62	9.78	12.03	5.92	37.8	-1.22	-9.27
39.	TCH 1726 x MCU 3	4.41	-1.27	-4.55	5.96	13.01*	6.68	9.81	9.71	6.28	37.8	2.11	-3.49
40.	TCH 1726 x TCH	4.43	-2.96	-4.12	5.66	-1.51	-13.32*	9.69	3.25	1.57	36.8	-2.47	-9.29
41.	TCH 1726 x BW4-1	4.68	0.43	-0.57	6.93	18.28**	2.56	10.63	9.03	3.51	39.4	5.72	-0.67
42.	TCH 1726 x MCU	4.52	-1.67	-2.02	6.83	16.76**	1.44	10.08	4.22	-0.36	40.4	8.15	1.34

*significant at 5 per cent level, ** significant at 1 per cent level, di, relative heterosis; dii, heterobeltiosis

Table 5. Mean performance and expression of heterosis in hybrids (%) for yield and fibre quality traits

SL.No	Cross	Seed cotton yield per plant(g)			2.5per cent span length (mm)			Bundle strength (g/tex)			Micronaire		
		Mean	**d_i**	**d_{ii}**	**Mean**	**d_i**	**d_{ii}**	**Mean**	**d_i**	**d_{ii}**	**Mean**	**d_i**	**d_{ii}**
1.	Narasimha x KC 2	90.2	5.55	-5.81	27.9	-3.23	-8.61**	17.4	-18.51**	-21.20**	4.15	-3.30	-6.39
2.	Narasimha x MCU 3	86.2	-10.02	-10.05	28.4	-6.36*	-6.97*	21.3	-0.08	-3.17	4.40	9.32**	6.02
3.	Narasimha x TCH1705	120.0	26.57**	25.25*	27.3	-5.65*	-10.78**	19.3	-6.89	-7.34	4.53	3.62	-1.45
4.	Narasimha x BW4-1	102.5	-4.72	-14.13	28.2	4.06	-7.84*	20.5	-0.40	-0.64	4.00	-9.60**	-14.89**
5.	Narasimha x MCU 13	121.9	25.15**	23.17*	29.9	2.63	-2.29	19.9	-7.59*	-11.03**	4.50	4.05	0.00
6.	Narasimha x TCH 1726	130.0	48.77**	35.65**	29.6	-0.17	-3.27	20.5	-4.71	-8.46*	4.50	10.43**	8.43*
7.	KC2 x Narasimha	107.5	25.70*	12.17	28.3	-1.85	-7.30*	21.8	2.02	-1.35	4.50	4.85	1.50
8.	KC2 x MCU 3	118.8	39.05**	24.12*	28.9	0.93	-4.08	21.4	-3.24	-3.46	4.40	5.60	-0.75
9.	KC2 x TCH 1705	115.4	36.62**	23.06*	29.6	8.69**	8.56*	21.5	0.15	-2.71	4.35	-3.69	-5.43
10.	KC2 x BW 4-1	81.3	-16.38	-31.85**	28.7	12.99**	5.51	21.2	-0.86	-4.36	4.15	-9.12**	-11.70**
11.	KC2 x MCU13	95.5	9.74	-3.44	28.7	4.62	3.73	20.6	-7.49*	-7.90	4.65	4.10	3.33
12.	KC2 x TCH 1726	139.8	81.40**	77.11**	28.1	0.54	-2.09	21.6	-3.21	-3.86	4.80	13.83**	8.27*
13.	MCU 3 x Narasimha	84.6	-11.69	-11.72	31.5	3.84	3.16	21.4	0.08	-3.02	4.10	1.86	-1.20
14.	MCU3 x KC 2	83.2	-2.63	-13.09	29.5	2.79	-2.32	21.9	-0.98	-1.20	4.07	4.80	-1.50
15.	MCU3 x TCH 1705	82.5	-12.90	-13.78	31.5	9.63**	4.30	22.3	3.80	1.06	4.35	-5.88	-13.04**
16.	MCU 3 x BW4-1	86.4	-19.69*	-27.64**	30.7	14.37**	1.88	22.2	4.06	0.60	4.10	-4.65	-12.77**
17.	MCU 3 x MCU 13	86.6	-10.99	-12.43	31.1	7.49**	2.98	21.2	-4.28	-4.92	4.07	-3.17	-9.63**
18.	MCU 3 x TCH 1726	105.9	21.31*	10.65	31.0	5.49*	2.87	21.5	-3.14	-4.01	4.35	10.13**	8.75*
19.	TCH1705 x Narasimha	130.2	37.36**	35.93**	28.7	-0.81	-6.21*	21.1	1.44	0.96	4.10	-6.29	-10.87**
20.	TCH1705 x KC2	88.3	4.55	-5.83	28.8	5.75	5.62	21.0	-2.17	-4.96	4.30	-7.01*	-8.70*
21.	TCH1705 x MCU 3	134.8	42.23**	40.79**	28.9	0.81	-4.08	21.9	1.94	-0.76	4.05	1.18	-6.52
22.	TCH1705 x BW4-1	73.8	-30.77**	-38.18**	30.7	20.71**	12.59**	21.7	4.90	4.15	3.90	-12.90**	-13.83**
23.	TCH1705 x MCU 13	123.9	28.60**	25.26*	28.4	3.40	2.65	20.8	-3.85	-7.00	4.20	-14.29**	-15.22**
24.	TCH 1705 x TCH 1726	99.6	15.38	6.22	30.6	9.35**	6.62*	21.4	-1.31	-4.75	4.65	-3.49	-9.78**
25.	BW4-1 x Narasimha	98.6	-8.38	-17.42*	28.8	6.27*	-5.88	19.6	-5.08	-5.31	4.60	5.08	-1.06
26.	BW4-1 x KC2	87.9	-9.59	-26.33**	28.5	12.20**	4.78	20.1	-6.00	-9.32*	4.65	0.73	-2.13
27.	BW4-1 x MCU 3	93.2	-13.31	-21.89**	29.8	10.78**	-1.32	23.4	-3.91	-7.10	4.60	3.49	-5.32
28.	BW4-1 x TCH 1705	94.3	-11.49	-20.97*	29.9	17.82**	9.90**	22.1	12.77**	11.96**	4.35	-6.45*	-7.45*
29.	BW4-1 x MCU 13	74.4	-31.83**	-37.66**	31.2	21.98**	13.01**	21.2	3.18	-0.89	3.85	-16.30**	-18.09**
30.	BW4-1 x TCH 1726	127.1	28.17**	6.45	30.5	16.89**	6.50*	21.2	-1.24	-5.34	4.10	1.15	-6.38
31.	MCU 13 x Narasimha	76.7	-21.25*	-22.50*	28.9	-0.57	-5.34	21.3	-1.08	-4.77	4.40	9.83**	5.56
32.	MCU 13 x KC 2	84.5	-2.89	-14.55	30.8	12.27**	11.33**	21.0	-5.39	-5.81	4.75	6.34*	5.56
33.	MCU13 x MCU 3	94.2	-3.22	-4.78	31.5	9.10	4.53	21.5	-2.93	-3.58	4.75	-1.19	-7.78*
34.	MCU13 x TCH 1705	74.6	-22.54*	-24.55*	30.3	10.32	9.52**	21.7	0.31	-2.98	4.15	-7.69*	-8.70*
35.	MCU13 x BW4-1	95.4	-12.62	-20.10*	29.2	13.91	5.54	20.9	-2.72	-6.56	4.20	-4.35	-6.38
36.	MCU13 x TCH 1726	86.1	-3.13	-12.93	31.9	13.42**	11.38**	21.2	-5.43	-5.64	4.40	4.71	-1.11
37.	TCH 1726 x Narasimha	110.8	26.80**	15.62	29.6	0.06	-3.05	19.5	-9.65**	-13.20**	4.45	3.07	1.20
38.	TCH 1726 x KC 2	125.0	62.24**	58.40**	29.9	6.98*	4.18	20.0	-10.08**	-10.68**	4.20	16.21**	10.53**
39.	TCH 1726 x MCU 3	131.7	50.16**	36.96**	28.7	-2.32	-4.75	19.8	-10.78**	-11.57**	4.90	3.80	2.50
40.	TCH 1726 x TCH 1705	81.6	-5.54	-13.04	25.8	-7.80**	-10.10**	20.6	-4.69	-8.01*	4.10	-3.49	-9.78**
41.	TCH 1726 x BW4-1	129.8	30.92**	8.74	29.8	13.96**	3.83	20.9	-2.63	-6.68	4.15	-6.90*	-13.83**
42.	TCH 1726 x MCU 13	96.0	7.93	-3.00	28.7	2.07	0.23	19.8	-11.38**	-11.57**	4.05	-3.53	-8.89*

*significant at 5 per cent level, ** significant at 1 per cent level, di, relative heterosis; dii, heterobeltiosis