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Expression of heterotic performance in F_1 crosses in Bt-lines and non-Bt tester parents of upland cotton (*Gossypium hirsutum* L.)

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Abstract

The heterotic performance of parents estimated to determine the performance of cotton in line X tester combinations and to determine heterosis for identification of potential genotypes for hybrid crop development in cotton. Two types of heterosis are estimated, the heterotic effect for the F_1 hybrid upon mid parents and better parents relative heterosis and heterobeltiosis. The analysis for x line tester was performed to observe the influence of parents over hybrid with a combination of cotton. Total 7 parents including 4 lines with 3 tester and their 12 replications in Kharif season were grown at Shah Latif experimental areas Sindh Agriculture University, Tandojam in 2011. In this investigation the traits including the height of the plant, sympodial branches per plant, monopodialbranches per plant, bolls number per plant, yield of cotton seed per plant, ginning outturn percentage, sex index and staple length.Regarding heterotic estimates, crosses Bt. NIAB-777 x Sadorigave maximum heterosis for plant height, sympodial branches, seed index, lint index and Bt.CIM-595 x CIM-506 manifested maximum heterosis for G.O.T%, seed index and lint index. Other hybrids, Bt.886 x CIM-506 demonstrated high heterosis for sympodial branches, boll weight and staple length and Bt. NIAB-852 x sadori for monopodial branches, G.O.T% and Staple length. The high heterosis displaying hybrids may be exploited for hybrid vigor for various characters.

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Introduction

Cotton crops are generally known as a cash crop in the World. Cotton thread made from its fiber is utilized for breathable and soft textile, that commonly used in natural fiber thread cloth in recent days (Ramamoorthy *et al.*, 2015; Sarfraz *et al.*, 2020). For the fulfilment of these requirement, major production gained through different cotton upland varieties as well as some required is also fulfilled through American Egyptian sea land cotton commonly grown in the Asia continent. This crop is not only utilized for fiber but also it is 2nd major source of plant protein than soybean as well as 5th maximum oil producing crop after soybean, sunflower, colza and soybean (Texier, 1993). It has been reported that about 7% of the value added in the agriculture, while 1.5% shared in GDP of Pakistan by cotton crop. In previous years 2013 cotton was grown on 2879 thousand hector areas about 1.6% higher as compared to other previous years which 2835 thousand hector area.

In 2013 the 14.5 million targets were mandated by the government of Pakistan which were tried to achieve about 13.0 million bales in the same year, that showed 10.3 reductions in target with reeducation in 4.2% in during next year was 13.6 million number of bales (GOP, 2013). Cotton production has been reported about 4.2% reduced during the year of 2013, it may be due to different pest attack during the early time of crop(GOP, 2013). The world cotton breeders have taken this task, but could not proceed beyond the preliminary stage due to its self-pollinated nature that showed few variation influences for the seed production of hybrid as compared to cross pollinated, while the presence of male sterility source has opened a way for commercial exploitation of hybridization in cotton crop; hence, the importance of the study of the performance of hybrids needs attention of the breeders (Ashokkumar *et al.*, 2014). Heterosis exploitation is one of the effective tools to improve plant yields and different heterosis values have been reported for yield and fiber quality properties by the breeders in their studies. In studies, 26% and 24.5% heterosis and heterobeltiosis in fiber yield have been reported by(Rauf *et al.*, 2005) who also obtained the highest heterosis and heterobeltiosis for lint yield. For fiber quality properties no significant heterotic effects were obtained for miconaire and strength. (Meredith Jr & Brown, 1998) found that significant heterosis for lint yield, lint percentage and fiber length suggest at least one parent should have above average fiber quality. Stagnant cotton yields have been reported in recent years and by exploiting heterosis. Cotton yields can be increased. Significant Heterosis of 1st harvested production, weight of bolls, and percentage of lint and length of 50 percentage life span observed in investigations.

Material and methods

The present experiment was performed at Latif Farm, Sindh Agriculture University, Tandojam, during Kharif 2013, to assess the performance of cotton in line x tester combinations and to determine heterosis for identification of potential genotypes for hybrid crop development in cotton.

The experimental material has consisted of F_1 crosses and their parents belonging to *Gossypiumhirsutum*L. the seeds were sown in a Randomized Complete Block Design (RCBD) with two replications. There were seven parents, out of which 4 were lines/females and 3 were testers/pollinators and their 12 F_1 hybrids.

Thus total 23 genotypes were evaluated for plant height (cm), monopodial branches plant^{-1}, sympodial branches plant^{-1}, boll weight (g), number of bolls plant^{-1}, cotton seed yield plant^{-1} (g), ginning outturn percentage (GOT %), seed index (g), lint index (g) and staple length (mm).

Statistical analysis

Analysis of variance was applied to the data and data Analysis Statistics' 8.1 according to the method suggested by Gomez and Gomez (1984).

Number	Females
1	CIM-595
2	NIAB-852
3	NIAB-777
4	Bt-886

Number	Testers/Pollinators/males
1	CIM-506
2	CIM-554
2	Sadori

Number	Crosses/F_1 hybrids		
1	Bt-CIM-595	×	CIM-506
2	Bt-CIM-595	×	CIM-554
3	Bt-CIM-595	×	Sadori
4	Bt-NIAB-852	×	CIM-506
5	Bt-NIAB-852	×	CIM-554
6	Bt-NIAB-852	×	Sadori
7	Bt-NIAB-777	×	CIM-506
8	Bt-NIAB-777	×	CIM-554
9	Bt-NIAB-777	×	Sadori
10	Bt-886	× CIM-506	
11	Bt-886	×	CIM-554
12	Bt-886	×	Sadori

No	Parents = 07/Lines/Females = 04
1	CIM-595
2	NIAB-852
3	NIAB-777
4	Bt-886

No	Testers/Pollinators/males = 03
1	CIM-506
2	CIM-554
3	Sadori

NO	Crosses/F_1 hybrids = 12		
1	Bt-CIM-595	×	CIM-506
2	Bt-CIM-595	×	CIM-554
3	Bt-CIM-595	×	Sadori
4	Bt-NIAB-852	×	CIM-506
5	Bt-NIAB-852	×	CIM-554
6	Bt-NIAB-852	×	Sadori
7	Bt-NIAB-777	×	CIM-506
8	Bt-NIAB-777	×	CIM-554
9	Bt-NIAB-777	×	Sadori
10	Bt-886	×	CIM-506
11	Bt-886	×	CIM-554
12	Bt-886	×	Sadori

For collecting the data, total of 5 plants were randomly selected from each replication. The distance between plants to plant was kept at 30 cm whereas the distance between rows to row was 75 cm. all the recommended agronomic and cultural practices were carried out properly. At maturity, the data for different characters were recorded as under.

Plant height cm

Plant height was measured from the base of tree soil level to top of tree highest pointWhen apical growth of the main stem had ceased, the final height of the plants was measured from the first cotyledonarynode to apical bud in centimetersusing measuring rod. The averages of these measurements were then calculated.

Monopodial branches plant^{-1}

At the time of maturity, monopodial branches were counted manually from all selected plants in each replication. Then average monopodial branches of each genotype were calculated.

Sympodial branches plant^{-1}

Sympodial branches are direct fruit bearing branches. At maturity, number of sympodial branches of all selected plants was counted manually. These are vegetative branches usually present at the base of the plant. These are also called indirect fruit bearing branches.

Boll weight g

Boll weight per plant was recorded through dividing the yield of cotton seed per plant through number of bolls per plant, therefore the average of boll weight per plant was recorded with the following formula.

$$\text{Bill weight g} = \frac{\text{Weight of cotton seed g}}{\text{No. of bolls per plant}}$$

Number of bolls per plant

Complete open bolls were collected and counted as a total number of productive bolls per plant.

Cottonseed yield per plant g

The Cotton seed of each index per plant from all genotypes was collected and weighted separately to record data for cotton seed yield per plant in grams.

Ginning outturn% (GOT)

Cotton seed of all randomly selected plant was cleaned, and gained, while lint was weighted in grams. The outturn of ginning was recorded with the formula of

$$\text{Ginning outturn\% GOT g} = \frac{\text{Weight of lint \%}}{\text{Wight of cotton seed sample}} \times 100$$

Seed Index g

Total of 100 seeds were randomly selected from each plant and weighted in grams.

Lint index g

This is the weight of lint per 100 seeds weighted in grams. The lint index was observed through following formula.

$$\text{Lint index (g)} = \frac{\text{Seed index} \times \text{GOT\%}}{100 - \text{GOT\%}} \times 100$$

Staple length (mm)

The most important fiber quality of cotton is the fiber length. The representative numbers of samples of lint from each plant were measured for staple length with the help of digital fibro graph model 330, developed by spin laboratory. The mean sample staple length was obtained by taking the average of the readings of each sample.

Classification of fiber length

Number	Fiber length (mm)	Group
1	20.5 and below	short fiber
2	21.0 to 25.5	medium finer
3	26.0 to 27.5	medium- long fiber
4	28.5 to 33.5	Long fiber
5	34.0 and above	Extra - long fiber

Classification

No	Fiber length (mm)	Group
1	20.5 and below	short fiber
2	21.0 to 25.5	medium fiber
3	26.0 to 27.5	medium-long fiber
4	28.5 to 33.5	long fiber
5	34.0 and above	extra-long fiber

After recording the all parameters for study traits, the analysis of variance to showed difference between genotypes parents and F_1 performed through the method of Gomez and Gomez, (1984).

The heterosis was recorded in the term of increase percentage (+) or decrease (-) F_1 hybrids against the mid of parents and better parent decrease was recorded as formula suggested by(Memon *et al.*, 2017).

$$\text{Heterosis \%} = \frac{F_1 - MP}{MP} \times 100$$

The heterobeltiosis was estimated in terms of percent increase or decrease of the F_1 hybrid over its better parent according to (Z. Soomro *et al.*, 2006).

$$\text{Heterobeltiosis \%} = \frac{F_1 - BP}{BP} \times 100$$

Data were further subjected for (t) test that it can be determined that F_1 hybrid means are statistically differed from mid parent and better parent values. While the t-test values will be recorded with the below mentioned formula of (Wynne *et al.*, 1970).

$$t = \frac{F_{1ij} - MP_{ij}/BP_{ij}}{\sqrt{\frac{3}{8}(EMS)}}$$

Where

F_1ij = Mean of ijth F_1 cross

MPij = Mid parents value for ijth cross

BPij = Better parents values for ijth cross

EMS Errors mean square.

Results

Analysis of variances

In this experiment analysis of variance for all F_1 hybrid genotypes were observed higher and significant difference ($P \leq 0.01$) about all the traits (Table 1).

Table 1. The mean square of line × tester analysis for different traits of the upland cotton crop.

Source of variation	D.F	Height of plant	Monopodial branches	Sympodial branches	Boll weight	No of bolls plant^{-1}	Cotton seed yield	GOT%	Seed index	Lint index	Staple length
Replication	2	24.596	0.011	0.170	0.009	2.362	64.986	0.689	0.053	0.055	0.155
Genotypes	18	65.35**	1.20**	10.15**	1.88**	18.34**	45.68**	10.56**	5.10**	6.89**	28.38**
Lines (L)	3	58.920**	0.028**	1.989**	0.043**	8.765**	15.765**	0.454**	0.045**	0.050**	0.075**
Testers (T)	2	23.00**	2.30**	1.89**	4.45**	6.78**	9.87**	0.89**	0.67**	0.13**	0.87**
L × T	11	11.78**	5.89**	12.78**	7.90**	5.67**	8.78**	4.70**	3.67**	2.87**	1.30**
Error	36	1.535	0.003	1.989	0.001	1.082	9.844	0.010	0.007	0.002	0.004

**= significant at 1% probability level.

Mean performance

The recorded data about mean performance of F_1 12 hybrids with 7 parents' lines were interpreted to find out major quantitative characteristics in crop of cotton. The results have been described in Tabel 2 the F_1 hybrid produced a maximum amount as compare to its parent lines for all under investigation traits. While SadoriX F_1Bt- CIM- 95 showed highest height of plant 131.35 and contains 35.25 numbers of bolls per plant and produced highest cotton seed yield per plant. (115.42), and Bt-NIAB-852 x CIM-554 gave minimum monopodial branches plant^{-1} (1.25), was next ranker in boll weight (3.56g) and seed index (7.37) among the twelve hybrids. While Bt-NIAB-852 x Sadori gave highest seed index (7.56) and lint index (4.38), gave next maximum sympodial branches plant^{-1} (22.42) and GOT% (36.67), among the hybrids. The F_1 hybrid Bt-NIAB-777 x CIM-506 gave lowest plant height (119.39), lowest seed cotton yield (100.87), ginned lowest (35.32) lint and lowest seed index (6.88), minimum lint index (3.76). While Bt-NIAB-777 x Sadori gave maximum sympodial branches plant^{-1}(22.59), and was next ranker in number of bolls plant^{-1} (34.54), gave smaller bolls (3.28g); however, Bt-886 x CIM-506 gave maximum monopodial branches plant^{-1} (1.59) and was next ranker in seed cotton yield plant^{-1} (113.75), and fiber length (28.10), Bt-886 x Sadori gave highest GOT% (37.10), and fiber length (28.20), was next ranker in lint index (4.25), and plant height (130.79) among the hybrids. Among the parents, line NIAB-852 gave maximum performance for sympodial branches plant^{-1} (21.2), seed index (7.80), and lint index (4.43). Among the testers, Sadori gave maximum production regarding length of fiber 28.18 and bolls number per plant 30.5 while in 2nd position ginning outturn% cotton seed yield and sympodial branches per plant.

Table 2. Mean performance of 12 hybrids and their 7 parents of different quantitative traits of upland cotton.

F1 Hybrids	Height of plant cm	Monopodial branches per plant	Sympodial branches per plant	Boll Wight g	No. of bolls per plant	Cotton seed yield per plant (g)	Got%	Seed index (g)	Lint index (g)	Staple length (mm)
Bt.CIM-595 x CIM-506	122.25	1.52	21.50	3.42	34.33	113.32	35.70	7.22	4.01	27.50
Bt.CIM-595 x CIM-554	128.13	1.43	20.78	3.60	32.54	112.91	35.66	7.31	4.05	27.45
Bt.CIM-595 x Sadori	131.35	1.31	22.34	3.39	35.25	115.42	36.27	7.30	4.15	27.75
Bt.NIAB-852 x CIM-506	119.43	1.46	21.87	3.34	32.29	103.88	35.98	7.23	4.06	27.72
Bt.NIAB-852 x CIM-554	121.52	1.25	21.26	3.56	29.72	101.38	36.17	7.37	4.18	27.66
Bt.NIAB-852 x Sadori	124.36	1.34	22.42	3.31	34.45	109.89	36.67	7.56	4.38	28.00
Bt. NIAB-777 x CIM-506	119.39	1.46	21.96	3.35	31.29	100.87	35.32	6.88	3.76	27.52
Bt. NIAB-777 x CIM-554	123.56	1.43	21.48	3.49	30.85	103.28	35.48	7.10	3.90	27.62
Bt. NIAB-777 x Sadori	127.38	1.27	22.59	3.28	34.54	109.34	35.91	7.23	4.05	27.73
Bt-886 x CIM-506	122.46	1.59	21.67	3.50	33.78	113.75	36.57	7.12	4.11	28.10
Bt-886 x CIM-554	129.52	1.42	20.55	3.55	32.45	111.21	36.35	7.27	4.15	27.92
Bt-886 x Sadori	130.79	1.47	22.36	3.42	33.16	109.15	37.10	7.18	4.25	28.20
PARENTS										
Female line										
CIM-595	121.4	1.1	20.4	3.39	28.6	92.98	35.47	7.27	4.00	27.10
NIAB-852	111.5	0.9	21.2	3.25	27.5	85.98	36.24	7.80	4.43	27.55
NIAB-777	112.4	1.0	20.5	3.20	28.2	86.37	34.84	7.05	3.77	27.41
Bt-886	118.7	1.5	19.5	3.47	28.0	93.11	37.09	7.20	4.24	28.02
Tester										
CIM-506	108.4	1.6	18.9	3.30	30.0	95.00	35.50	6.41	3.53	27.77
CIM-554	117.7	1.3	18.1	3.67	25.4	90.03	35.67	6.58	3.65	27.64
Sadori	120.1	1.2	20.7	3.26	30.5	94.70	36.45	6.71	3.85	28.18

Plant height

Among twelve-line X tester crosses, results in (Table3) showed that ten F_1 hybrids exceeded in plant height over their respective mid parents as well as better parents. The relative heterosis of this character ranged from 6.03% to 9.57% and 0.70% to 8.90% was heterobeltiosis whereas only two F_1 hybrids gave negative heterosis over their only better parents. The highest heterosis (9.57%) was manifested by Bt-866 x CIM-554 and Bt- NIAB-777 x sadori over their mid parents followed by the cross Bt-CIM-595 x sadorithat showed the 8.77% of heterosis upon the mid parents, while maximum heterosisof 8.90% over better parent.

Table 3. The F_1hybrids heterotic influence upon the mid parents and their heterobeltiosis better parent's forplant height cm.

F_1 hybrids	Parent seed	Parent pollen	F_1 hybrids	Mid parents	Percentage + increase or decrease - over	
					Mid parent	Better parent
Bt.CIM-595 x CIM-506	121.4	108.4	122.25	114.90	6.39	0.69
Bt.CIM-595 x CIM-554	121.4	117.7	128.13	119.55	7.17	5.54
Bt.CIM-595 x Sadori	121.4	120.1	131.35	120.75	8.77	8.19
Bt.NIAB-852 x CIM-506	111.5	108.4	119.43	109.95	8.62	7.11
Bt.NIAB-852 x CIM-554	111.5	117.7	121.52	114.60	6.03	3.24
Bt.NIAB-852 x Sadori	111.5	120.1	124.36	115.80	7.39	3.54
Bt. NIAB-777 x CIM-506	112.4	108.4	119.39	110.40	8.14	6.21
Bt. NIAB-777 x CIM-554	112.4	117.7	123.56	115.05	7.39	4.97
Bt. NIAB-777 x Sadori	112.4	120.1	127.38	116.25	9.57	6.06
Bt-886 x CIM-506	118.7	108.4	122.46	113.55	7.84	3.16
Bt-886 x CIM-554	118.7	117.7	129.52	118.20	9.57	9.11
Bt-886 x Sadori	118.7	120.1	130.79	119.40	9.53	8.90

Monopodial branch per plant

The results from heterosis (Table-4) showed that the cross Bt.NIAB-852 x Sadori gave maximum (27.61%) relative heterosis whereas Bt.NIAB-777 x CIM-506 recorded highest (30.00%) heterobeltiosis while the cross Bt-886 x CIM-554 ranked minimum heterosis over both mid parent and better parent. Our findings conform with those of (Aslam, 2004; Muhammad *et al.*, 2014) who also reported significant values for character monopodial branches. Present results, however, suggested that hybrids Bt. NIAB-852 x Sadori and Bt. NIAB-777 x CIM-506 may be utilized for hybrid crop development to improve yield.

Table 4. The heterotic influence on hybrids upon the mid parents with better parent's heterobeltiosis for monopodial branch per plant trait.

F_1 hybrids	Parent seed	Parent pollen	F_1	Mid parent	Percentage + increase and decrease – over F_1 hybrids	
					Mid parents	Better parents
Bt.CIM-595X CIM-506	1.1	1.6	1.52	1.35	12.59	-5.00
Bt.CIM-595X CIM-554	1.1	1.3	1.43	1.20	19.16	10.00
Bt.CIM-595X Sadori	1.1	1.2	1.31	1.15	13.91	9.16
Bt.NIAB-852X CIM-506	0.9	1.6	1.46	1.25	16.8	-8.75
Bt.NIAB-852X CIM-554	0.9	1.3	1.25	1.10	13.63	-3.84
Bt.NIAB-852X Sadori	0.9	1.2	1.34	1.05	27.61	11.66
Bt. NIAB-777X CIM-506	1.0	1.6	1.46	1.30	12.30	-8.75
Bt. NIAB-777X CIM-554	1.0	1.3	1.43	1.15	24.34	10
Bt. NIAB-777X Sadori	1.0	1.2	1.27	1.10	15.45	5.83
Bt-886X CIM-506	1.5	1.6	1.59	1.55	2.58	-0.625
Bt-886X CIM-554	1.5	1.3	1.42	1.40	1.42	-5.33
Bt-886X Sadori	1.5	1.2	1.47	1.35	8.88	-2

Sympodial branches per plant

Regarding heterosis (Table-5), cross Bt-886 x CIM-506 gave maximum (12.86%) relative heterosis, however, cross Bt. NIAB-777 x Sadori gave maximum heterobeltiosis. Other hybrids also show the fair amount of heterosis for sympodial branches. Other researchers like (Abro *et al.*, 2009; Aslam, 2004; Muhammad *et al.*, 2014), described a sufficient amount of heterosis for the sympodial branch. The findings of heterotic suggested hybrids, Bt-886 x CIM-506 and Bt. NIAB-777 x Sadori is the best crosses for exploiting hybrid vigor in cotton crop.

Table 5. The heterotic influence of F_1 hybrids upon mid parent and better parent's heterobeltiosis for sympodial branches per plant trait.

F_1 hybrids	Parent seed	Parent pollen	F_1 hybrids	Mid parent	Percentage + increase or decrease – over F_1 hybrids	
					Mid parents	Better parents
Bt.CIM-595X CIM-506	20.4	18.9	21.5	19.65	9.42	5.39
Bt.CIM-595X CIM-554	20.4	18.1	20.78	19.25	7.948	1.86
Bt.CIM-595X Sadori	20.4	20.7	22.34	20.55	8.71	7.92
Bt.NIAB-852X CIM-506	21.2	18.9	21.87	20.05	9.07	3.16
Bt.NIAB-852X CIM-554	21.2	18.1	21.26	19.65	8.19	0.28
Bt.NIAB-852X Sadori	21.2	20.7	22.42	20.95	-7.01	5.75
Bt. NIAB-777X CIM-506	20.5	18.9	21.96	19.70	11.47	7.12
Bt. NIAB-777X CIM-554	20.5	18.1	21.48	19.30	11.29	4.78
Bt. NIAB-777X Sadori	20.5	20.7	22.59	20.60	9.66	9.13
Bt-886X CIM-506	19.5	18.9	21.67	19.20	12.86	11.12
Bt-886X CIM-554	19.5	18.1	20.55	18.80	9.30	5.38
Bt-886X Sadori	19.5	20.7	22.36	20.10	11.24	8.019

Boll weight

The results for heterotic and heterobeltiotic influenced for boll weight (Table 6) showed 11 F_1 hybrids showed positive heterosis, mid parent, that change 1.46 to 3.24% with 7 positive crosses showed better parents heterosis 0.00 to 1.535 between 12 hybrids. The highest (3.24%) relative heterosis was produced by Bt-886 x CIM-506. While hybrid Bt-NIAB-852 x Sadori which displayed maximum (1.53%) heterobeltiosis for the character of boll weight.

Table 6. The heterotic influence of F_1 hybrids upon mid parents and better parent's (heterobeltiosis) for the character boll weight (g).

F_1 hybrids	Seed parent	Pollen parent	F_1 hybrid	Mid parent	Percentage increase + or decrease – over F_1 hybrids	
					Mid parent	Better parent
Bt.CIM-595X CIM-506	3.39	3.30	3.42	3.35	2.089	0.88
Bt.CIM-595X CIM-554	3.39	3.67	3.60	3.53	1.98	1.907
Bt.CIM-595X Sadori	3.39	3.26	3.39	3.33	1.80	0.00
Bt. NIAB-852X CIM-506	3.25	3.30	3.34	3.28	1.09	1.21
Bt.NIAB-852X CIM-554	3.25	3.67	3.56	3.46	2.89	-2.997
Bt. NIAB-852X Sadori	3.25	3.26	3.31	3.26	1.53	1.53
Bt. NIAB-777X CIM-506	3.2	3.30	3.35	3.25	3.016	1.52
Bt. NIAB-777X CIM-554	3.20	3.67	3.49	3.44	1.45	-4.90
Bt. NIAB-777X Sadori	3.20	3.26	3.28	3.23	1.547	0.61
Bt-886X CIM-506	3.47	3.30	3.50	3.39	3.24	0.86
Bt-886X CIM-554	3.47	3.67	3.55	3.57	0.56	-3.269
Bt-886X Sadori	3.47	3.26	3.42	3.37	1.48	-1.44

Number of bolls plant^{-1}

Among the twelve-line x tester crosses, results (Tabel 7) showed 11 F_1 hybrids positive heterosis as well as heterobeltiosis of numbers of bolls per plant trait over their respective mid parents as well as better parents. Whereas, only one F_1 hybrids gave negative heterosis over its better parent. Relative heterosis ranging from 12.31 to 21.54% and heterobeltiosis varied from 1.15 to 15.57%. Bt-866 x CIM-554 showed highest heterosis (21.54%) over its mid parent and the highest heterobeltiosis 15.57% was manifested by CIM-595 x Sadori.

Table 7. The heterotic influence of F_1 upon mid parent as well as better parent heterobeltiosis of number of bolls per plant trait.

F_1 hybrids	Parent seed	Parent pollen	F_1 hybrid	Mid parents	Percentage increase + or decrease – F_1 hybrids	
					Mid parent	Better parent
Bt.CIM-595X CIM-506	28.6	30.0	34.33	29.30	17.17	14.43
Bt.CIM-595X CIM-554	28.6	25.4	32.54	27.00	20.52	13.78
Bt.CIM-595X Sadori	28.6	30.5	35.25	29.55	19.29	15.57
Bt. NIAB-852X CIM-506	27.5	30.0	32.29	28.75	12.31	7.63
Bt.NIAB-852X CIM-554	27.5	25.4	29.72	26.45	12.36	0.07
Bt. NIAB-852X Sadori	27.5	30.5	34.45	29.00	18.79	12.95
Bt. NIAB-777X CIM-506	28.2	30.0	31.29	29.10	7.53	4.3
Bt. NIAB-777X CIM-554	28.2	25.4	30.85	26.80	15.11	9.39
Bt. NIAB-777X Sadori	28.2	30.5	34.54	29.35	17.68	13.24
Bt-886X CIM-506	28.0	30.0	33.78	29.00	16.48	12.6
Bt-886X CIM-554	28.0	25.4	32.45	26.70	21.54	15.89
Bt-886X Sadori	28.0	30.5	33.16	29.25	13.37	8.72

Cotton seed yield plant^{-1}

Between 12 F_1 hybrids, total hybrids were found positive results for heterosis and heterobeltiosis of cotton seed yield trait (Tabel 8). The heterosis values are between 11.23 to 23.39% and heterobeltiosis varied from 12.61% to 21.88% in which Bt-CIM-595 x CIM-554 showed highest heterosis (23.39%) over its mid parent and the highest heterosis (21.88%) over its better parents was manifested by CIM-595 x Sadori.

Table 8. Heterotic effect of F_1 over mid-parents (relative heterosis) and better parents (heterobeltiosis) for the character cotton seed yield plant^{-1}.

F_1 hybrids	Parent seed	Parent pollen	F_1 hybrids	Mid parent	Percentage increase + decrease – upon F_1 hybrids	
					Mid parent	Better parent
Bt.CIM-595X CIM-506	92.98	95.00	113.32	93.99	20.56	19.28
Bt.CIM-595X CIM-554	92.98	90.03	112.91	91.51	23.38	21.43
Bt.CIM-595X Sadori	92.98	94.70	115.42	93.84	22.9	21.88
Bt.NIAB-852X CIM-506	85.98	95.00	103.88	90.49	14.79	9.34
Bt.NIAB-852X CIM-554	85.98	90.03	101.38	88.01	15.19	12.60
Bt.NIAB-852X Sadori	85.98	94.70	109.89	90.34	21.64	16.04
Bt. NIAB-777X CIM-506	86.37	95.00	100.87	90.69	11.225	6.17
Bt. NIAB-777X CIM-554	86.37	90.03	103.28	88.20	17.09	14.7
Bt. NIAB-777X Sadori	86.37	94.70	109.34	90.54	20.76	15.45
Bt-886X CIM-506	93.11	95.00	113.75	94.06	20.93	19.73
Bt-886X CIM-554	93.11	90.03	111.21	91.57	21.45	19.43
Bt-886X Sadori	93.11	94.70	109.15	93.91	16.23	15.26

GOT%

The results for heterosis and heterobeltiosis for GOT%(Table 9) revealed that eleven crosses showed positive mid parent heterosis varied from 0.25 to 0.89% and only one cross revealed negative better parent heterosis and only three hybrids showed positive better parent heterosis ranging from 0.02 to 0.56%, whereas all the rest hybrids showed negative the heterosis better parents. The maximum 0.89% of heterosis showed Bt-886 x Sadori while hybrid Bt-CIM-595 x CIM-506 which displayed maximum (0.56%) heterobeltiosis for the character of GOT% respectively.

Seed index

The results for hybrids mid parent and better parent heterosis and heterobeltiosis trait for seed index (Table 10) showed mid parent heterosis varied from 1.68 to 5.55% and only five hybrids showed positive better parent heterosis ranging from 0.41 to 2.55%, whereas all the rest hybrids showed negative for heterosis of better parent.

While maximum 5.555 related heterosis showed Bt-CIM-595 x CIM-506 while hybrid Bt-NIAB-777 x Sadori which displayed maximum (2.55%) heterobeltiosis for the character of seed index.

Table 9. The heterotic influence of F_1 hybrid upon mid parent and better parent's heterosis as well as heterobeltiosis for GOT% trait.

F_1 hybrid	Seed index	Parent pollen	F_1 hybrids	Mid parent	Percentage increase + decrease – upon	
					Mid parent	Better parent
Bt.CIM-595X CIM-506	35.47	35.50	35.70	35.49	0.59	0.56
Bt.CIM-595X CIM-554	35.47	35.67	35.66	35.57	0.25	-0.02
Bt.CIM-595X Sadori	35.47	36.45	36.27	35.96	0.86	-0.49
Bt. NIAB-852X CIM-506	36.24	35.50	35.98	35.87	0.30	0.71
Bt.NIAB-852X CIM-554	36.24	35.67	36.17	35.96	0.58	-0.19
Bt. NIAB-852X Sadori	36.24	36.45	36.67	36.35	0.87	0.60
Bt. NIAB-777X CIM-506	34.84	35.50	35.32	35.17	0.42	-0.53
Bt. NIAB-777X CIM-554	34.84	35.67	35.48	35.26	0.62	-2.66
Bt. NIAB-777X Sadori	34.84	36.45	35.91	35.65	0.72	-1.48
Bt-886X CIM-506	37.09	35.50	36.57	36.30	0.74	-1.40
Bt-886X CIM-554	37.09	35.67	36.35	36.38	-0.08	-1.99
Bt-886X Sadori	37.09	36.45	37.10	36.77	0.89	0.02

Lint index

The information about heterotic effect for the character lint index (Table 11) which exhibited that all the F_1 hybrids gave positive relative the hybrid heterosis and showed positively and heterobeltiosis were negative. The relativity of mid parent heterosis, varied from 2.01 to 6.50% whereas positive heterobeltiosis ranged from 0.00% to 5.19%. The highest (6.50%) relative heterosis was calculated from cross Bt-CIM-595 x CIM-506. While hybrid Bt-NIAB-777 x Sadori which exhibited highest (5.19%) heterobeltiosis.

Staple length

The results for heterosis and heterobeltiosis for the character staple length are shown in (Table 12), that showed heterosis of mid parent changed from -0.25 to 0.725 and single hybrid showed positive better parent whereas all the rest hybrids showed negative better parent heterosis respectively among the twelve hybrids. The highest (0.72%) relative heterosis was depicted by Bt-886 x CIM-506 while hybrid Bt-886 x Sadori which displayed maximum (0.07%) heterobeltiosis respectively.

Discussion

Plant height

Height trait in cotton crop reduced with the number of branches increased. Thus, there is not too much close but positive association between plant height and cotton yield. The analysis of variance (Table-1) showed significant differences among the genotypes.

On an average, the maximum plant height (131.35 cm) was attained by the cross Bt.CIM-595 x sadori followed by Bt-886 x sadori (130.79 cm) as per hybrid performance. Among the parental lines, CIM-595 set highest plant height (121.4 cm), whereas, in testers, sadori gave maximum plant height (120.1 cm). Minimum plant height (119.43) however obtained by F_1 hybrid Bt.NIAB-852 x CIM-506. The heterotic performance (Table-3) showed that Bt.NIAB-777 x sadori manifested maximum (9.57%) relative heterosis whereas cross Bt-886 x sadori displayed highest (8.90%) heterobeltiosis. Our findings conform with (Panni *et al.*, 2012) who also reported 0.66 to 23.99% positive heterosis for plant height. (Abro *et al.*, 2009; Aleksoski, 2010; Z. A. Soomro, 2010) also noted fairs amount of relative heterosis and heterobeltiosis for plant height. These hybrids thus expressed more hybrid vigor for plant height, hence may be exploited for hybrid crop development.

Table 10. Heterotic effect of F_1 over mid-parents (relative heterosis) and better parents (heterobeltiosis) for the character seed index (g).

F_1 hybrids	Seed parent	Pollen parent	F_1 hybrids	Mid parent	Percentage increase + decreases - upon	
					Mid-parent	Better parent
Bt.CIM-595X CIM-506	7.27	6.41	7.22	6.84	5.55	-0.69
Bt.CIM-595X CIM-554	7.27	6.58	7.31	6.93	5.48	0.55
Bt.CIM-595X Sadori	7.27	6.71	7.30	6.99	4.43	0.41
Bt.NIAB-852X CIM-506	7.80	6.41	7.23	7.11	1.68	-7.30
Bt.NIAB-852X CIM-554	7.80	6.58	7.37	7.19	2.50	-5.51
Bt.NIAB-852X Sadori	7.80	6.71	7.56	7.26	4.13	-3.08
Bt. NIAB-777X CIM-506	7.05	6.41	6.88	6.73	2.22	-2.41
Bt. NIAB-777X CIM-554	7.05	6.58	7.10	6.82	4.10	0.71
Bt. NIAB-777X Sadori	7.05	6.71	7.23	6.88	5.08	2.55
Bt-886X CIM-506	7.20	6.41	7.12	6.81	4.55	-1.11
Bt-886X CIM-554	7.20	6.58	7.27	6.89	5.51	0.97
Bt-886X Sadori	7.20	6.71	7.18	6.96	3.16	-0.27

Monopodial branches plant^{-1}

It is assumed that as monopodial branches increase the yield correspondingly increases. The analysis of variance revealed that genotypes differed significantly for the character monopodial branches (Table-1). Regarding average performance, tester CIM-506 gave maximum (1.6) number of monopodial branches whereas in the female lines Bt-886 gave maximum (1.5) monopodial branches. Among the F_1 hybrids *per se,* Bt-886 x CIM-506 gave maximum (1.59) monopodial branches while Bt.CIM-595 x CIM-506 gave the next maximum (1.52) monopodial branches (Table-2). The results from heterosis (Table-4) showed that the cross Bt.NIAB-852 x Sadori gave maximum (27.61%) relative heterosis whereas Bt.NIAB-777 x CIM-506 recorded highest (30.00%) heterobeltiosis while the cross Bt-886 x CIM-554 ranked minimum heterosis over both mid parent and better parent. Our findings conform with those of (Aslam, 2004; Muhammad *et al.*, 2014) who also reported significant values for character monopodial branches. Present results, however, suggested that hybrids Bt.NIAB-852 x Sadori and Bt.NIAB-777 x CIM-506 may be utilized for hybrid crop development to improve yield.

Sympodial branches plant^{-1}

Sympodial branches in cotton are generally referred to those branches which bears the flowers and the fruiting bodies and the bolls of cotton, so that as these branches increases, it may increase yield. The analysis of variance including the wheat genotypes showed significantly difference in (Tabel-1) mention traits sympodial branches. Regarding mean performance *per se,* hybrid Bt.NIAB-777 x Sadori gave maximum (22.59) sympodial branches whereas cross Bt.NIAB-852 x Sadori gave next maximum (22.42) sympodial branches among the twelve hybrids, while among the parents, female line NIAB-852 (21.2) and from testers Sadori (20.7) gave maximum number of sympodial branches (Table-2). Regarding heterosis (Table-5), cross Bt-886 x CIM-506 gave maximum (12.86%) relative heterosis, however, cross Bt.NIAB-777 x Sadori gave maximum heterobeltiosis. Other hybrids also show the fair amount of heterosis for sympodial branches. Other researchers like (Abro *et al.*, 2009; Aslam, 2004; Muhammad *et al.*, 2014), described a sufficient amount of heterosis for the sympodial branch. The findings of heterotic suggested hybrids, Bt-886 x CIM-506 and Bt.NIAB-777 x Sadori is the best crosses for exploiting hybrid vigor in cotton crop.

Tabel 11. The heterotic influence of F_1 hybrid upon mid parent and better parent heterosis and heterobeltiosis for lint index trait g.

F_1 hybrids	Parent seed	Parent pollen	F_1 hybrid	Mid parent	Percentage increase + decrease - upon	
					Mid parent	Better parent
Bt.CIM-595 X CIM-506	4.00	3.53	4.01	3.76	6.50	0.25
Bt.CIM-595 X CIM-554	4.00	3.65	4.05	3.82	6.02	1.25
Bt.CIM-595 X Sadori	4.00	3.85	4.15	3.92	5.86	3.75
Bt.NIAB-852 X CIM-506	4.43	3.53	4.06	3.98	2.01	-8.35
Bt.NIAB-852 X CIM-554	4.43	3.65	4.18	4.04	3.46	-5.46
Bt.NIAB-852 X Sadori	4.43	3.85	4.38	4.14	5.79	-1.13
Bt. NIAB-777 X CIM-506	3.77	3.53	3.76	3.65	3.01	-0.26
Bt. NIAB-777 X CIM-554	3.77	3.65	3.90	3.71	5.12	3.45
Bt. NIAB-777X Sadori	3.77	3.85	4.05	3.81	6.29	5.19
Bt-886 X CIM-506	4.24	3.53	4.11	3.88	5.92	-3.07
Bt-886 X CIM-554	4.24	3.65	4.15	3.94	5.32	-2.12
Bt-886 X Sadori	4.24	3.85	4.25	4.04	5.19	0.23

Boll weight

It is assumed that as boll weight increases, the yield correspondingly increases if number of bolls is kept constant. The analysis of variance revealed that genotypes differed significantly for the character boll weight (Table-1). Regarding average performance among the F_1 hybrids *per se,* Bt-CIM-595 x CIM-554 gave maximum (3.60g) boll weight, while Bt.-886 x CIM-506 gave next maximum (3.50g) boll weight. Tester CIM-554 gave maximum (3.67g) boll weight whereas in the female lines Bt-886 gave maximum (3.47) boll weight, (Table-2). The result from heterosis (Table-6) showed that the cross Bt-886 x CIM-506 gave maximum (3.24%) relative heterosis, whereas Bt.NIAB-852 x Sadori recorded highest (1.53%) heterobeltiosis while the cross Bt-886 x CIM-554 ranked minimum heterosis over both mid parent and a better parent. The findings of our investigation agreed by (Khan *et al.*, 2009; Mangi *et al.*, 2019; Panni *et al.*, 2012). Present results, however, suggested that hybrids Bt.NIAB-852 x Sadori and Bt.NIAB-777 x CIM-506 may be utilized for hybrid crop development to improve yield.

Number of bolls plant^{-1}

Cotton crop has bolls per plant, showed higher production, so it has been observed strong positive relation among cotton seed production and bolls. While the analysis of variance is given in (Tabel-1) observed highly significant between genotypes. On the average maximum numbers of bolls plant^{-1} (35.25) were set by cross BT.CIM-595 followed by Bt.NIAB-777 x Sadori (34.54) as per hybrid performance. The heterotic performance (Table-7) showed that the cross Bt.886 x CIM-554 manifested maximum (21.54%) relative heterosis, whereas cross Bt.CIM-595 x Sadori displayed highest (15.57%) heterobeltiosis. Findings of the current investigation are in accordance with findings of (Ahmad *et al.*, 2002; Esmail, 2007; Mangi *et al.*, 2019; Pole *et al.*, 2008), they had reported nought magnitude of heterobeltiosis and heterosis of per plant number of bolls. These hybrids thus expressed more hybrid vigor for number of bolls plant^{-1}; hence may be exploited for hybrid crop development.

Seed cotton yield plant^{-1} (g)

The cotton seed production per plant is considered major traits between various other traits of plant, due to its major role in the improvement of farmer economy as well as country. Based on the analysis of variance, genotypes displayed significant differences (Table-1) for seed cotton yield plant^{-1}. Regarding mean performance hybrid Bt.CIM-595 x Sadori gave highest (115.42g), whereas cross Bt-886 x CIM-506 produced next maximum (113.75g) seed cotton yield plant^{-1} among the twelve F_1 hybrids (Table-2). Among the parents, female line Bt-886 (93.11g) and from testers CIM-506 (95.00g) gave maximum seed cotton yield. Regarding heterosis (Table-8), the cross Bt.CIM-595 x CIM-554 gave maximum (23.39%) relative heterosis while cross Bt.CIM-595 x sadori scored (21.88%) for heterobeltiosis. Other hybrids also showed fair amount of heterosis of cotton seed production. The results of our experiment are in agreement with findings of Aslam *et al.* (2004) which are 34.56% of heterosis of seed cotton yield plant^{-1} and other researchers like (Ahmad *et al.*, 2002; Desalegn *et al.*, 2004; Kaynak *et al.*, 2000; Mangi *et al.*, 2019) who also noted fair amount of heterosis for seed cotton yield plant^{-1}. Heterotic results suggested that hybrids, Bt.CIM-595 x CIM-554 and Bt.CIM-595 x Sadori is best crosses for exploiting hybrid vigor in cotton crop.

Tabel 12. The heterotic influence of F_1 hybrid upon mid and better parent's heterosis and heterobeltiosis for length of staple trait mm.

F_1 hybrid	Parent seed	Parent pollen	F_1 hybrid	Mid parent	Percentage increase + decrease - upon	
					Mid parent	Better parent
Bt.CIM-595X CIM-506	27.10	27.77	27.50	27.44	0.22	-0.97
Bt.CIM-595X CIM-554	27.10	27.64	27.45	27.37	0.29	-0.69
Bt.CIM-595X Sadori	27.10	28.18	27.75	27.64	0.39	-1.52
Bt.NIAB-852X CIM-506	27.55	27.77	27.72	27.66	0.21	-0.18
Bt.NIAB-852X CIM-554	27.55	27.64	27.66	27.60	0.22	0.07
Bt.NIAB-852X Sadori	27.55	28.18	28.00	27.87	0.46	-0.63
Bt. NIAB-777X CIM-506	27.41	27.77	27.52	27.59	-0.25	-2.90
Bt. NIAB-777X CIM-554	27.41	27.64	27.62	27.53	0.33	-0.07
Bt. NIAB-777X Sadori	27.41	28.18	27.73	27.80	-0.25	-1.60
Bt-886X CIM-506	28.02	27.77	28.10	27.90	0.72	0.28
Bt-886X CIM-554	28.02	27.64	27.92	27.83	0.32	-0.35
Bt-886X Sadori	28.02	28.18	28.20	28.10	0.36	0.07

Ginning outturn percentage

The heterosis results (Table9) showed that a high percentage (0.88%) of heterosis was given the F_1 hybrid Bt.NIAB-852 x Sadori over mid parent and the cross Bt.CIM-595 x CIM-506 gave maximum (1.97%) lint percent over better parent. Our findings are in agreement with those of (Khan *et al.*, 2009) who also reported 0.27 to 3.88% heterosis for G.O.T% and (Baloch *et al.*, 2014; Mangi *et al.*, 2019) also reported fair amount of heterosis for lint percentage. Above results proposed that crosses Bt. NIAB-852 x Sadori and Bt.CIM-595 x CIM-506 may be the potential hybrids for hybrid crop development.

Seed index

Regarding heterosis (Table 10), the cross Bt.CIM-595 x CIM-506 showed maximum (5.55%) relative heterosis and the cross Bt. NIAB-777 x Sadori gave maximum (2.55%) heterobeltiosis among the twelve F_1 hybrids. Our results are in agreement with other researchers like (Deosarkar *et al*., 2008; Pole *et al*., 2008) and who also reported positive heterosis for seed index. These results suggested that Bt.CIM-595 x CIM-506 and Bt. NIAB-777 x Sadori could serve as best breeding material for hybrid crop development to improve seed index.

Lint index

The results of heterotic effects (Table 11) revealed that all the crosses exhibited positive relative heterosis for lint index, which were moderate to high in magnitude. The top two ranker nevertheless were; Bt.CIM-595 x CIM-506, Bt. NIAB-777 x Sadori expressing 6.50% and 6.29% relative heterosis and Bt. NIAB-777 x Sadori also gave maximum (5.19%) heterobeltiosis. The results of our study are in accordance with results of (Desalegn *et al*., 2004). Based on heterotic results, crosses Bt.CIM-595 x CIM-506 and Bt.NIAB-777 x Sadori could be used to exploit hybrid vigor for the character lint index.

Staple length

Among the fiber properties such as staple length is one of the most important properties from economic point of view. However, fiber length is more useful in yarn manufacturing. The analysis of variance showed significant differences ($P \leq 0.01$) for all the genotypes regarding fiber length (Table-1). Mean performance (Table-2) for staple length indicated that among the F_1 hybrids, Bt-886 x Sadori measured longer fiber length (28.20mm) whereas Bt-886 x CIM-506 measured next maximum longer fiber length of (28.10mm). Among the parents, line Bt-886 and tester Sadori produced maximum (28.02mm) and (28.18mm) fiber length. The information regarding heterosis (Table-12) Suggested large number of crosses were observed negative association of heterosis on mid as well as better parent for length of staple. While maximum hybrid percentage was recorded CIM- 506 x Bt- 886 showed 0.72% association of heterosis cross of Sadori x Bt- 886 with maximum 0.07% heterobeltiosis.

The results of (Ahmad *et al*., 2002; Baloch *et al*., 2014; Khan *et al*., 2009; Mangi *et al*., 2019). Showed significant results for length of staple. The above results suggested that from F_1 hybrids, Bt-886 x CIM-506 and Bt.886 x Sadori could reliably be used for hybrid crop development.

Conclusion

It is concluded from present research that. The parents and the hybrids differed significantly for their mean performance regarding all the traits studied. Regarding heterosis, hybrid Bt.NIAB-777 x sadori gave maximum heterosis for plant height, sympodial branches, seed index, lint index and Bt.CIM-595 x CIM-506 manifested maximum heterosis for G.O.T%, seed index and lint index. Thus, these hybrids could be exploited for hybrid vigor, consequently for hybrid cotton development for these characters.

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Competing interests

The authors declare that they have no competing interests.

Authors' contributions

NM, FS conceived and designed the experiments. SK and AL collected the data. SAS and ZJ analyzed the data. NM and MB performed the experiment. NM, XW, and QM wrote the paper. FS critically revised of the manuscript for intellectual content. All authors read and approved the final manuscript.

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