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Genetic Studied of Heterosis and Heterobeltiosis in F_1 Hybrids of Upland Cotton for Yield and Fibre Traits

Ghulam Murtaza Channa[a]* and Sajidah Naz Channa[b]

[a]Agriculture Research Sindh, Tandojam, Sindh, Pakistan

[b]Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Sindh, Pakistan

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Abstract. The mean performance of parents and hybrids is highly significant for all the traits. The hybrids MNH-886 × BT-703 possess maximum numbers of bolls formed 90 days after planting, plant height and the number of sympodial branches/plant, while CRIS-134 × MS-370 produced a maximum number of bolls/plant. Moreover, the high ginning out turn % and seed yield/plant were reported by the cross of BT-703 × MS-370. The cross MNH-886 × IR-1524 gave the highest seed index with the longest staple length. The cross MNH-886 × BT-703 for bolls formed at 90 days after planting, plant height, sympodial branches/plants, number of bolls/plant, seed index and seed cotton yield/plant, while CRIS-134 × IR-1524 high relative heterosis and heterobeltosis boll weight; BT-703 × MS-370 and expressed highest ginning out turn%, MNH-886 × IR-1524 can be utilized for the future breeding program for important yield contributing traits.

Keywords: heterosis, cotton, hybrid

Introduction

Cotton, often referred to as the "king of fibre", holds significant economic and social importance in Pakistan. Belonging to the family Malvaceae and the genus *Gossypium*, cotton is the foremost commercial crop in the country. The cultivated species of cotton in Pakistan encompass various categories, including diploids and tetraploids. However, among these, only four species are primarily cultivated: *Gossypium arboreum* L., *Gossypium herbaceum* L., *Gossypium hirsutum* L. and *Gossypium barbadense* L.

Upland cotton (*Gossypium hirsutum* L.) is renowned for its high production potential, making it a prominent choice for cultivation. On the other hand, Egyptian cotton (*Gossypium barbadense* L.) is valued for its superior fibre quality. Additionally, intraspecific hybrids of *G. hirsutum* L. have been developed with favourable fibre properties and increased yields, as highlighted by (Zhang *et al*., 2014).

These distinctions among cultivated species and hybrids underscore the diverse characteristics and traits that can be selected for and optimized in cotton cultivation, catering to various market demands and agricultural goals.

Cotton holds the distinction of being the world's foremost cash crop, with widespread cultivation across tropical and subtropical regions. This vital crop is primarily grown for its fibre and is cultivated in over 65 countries worldwide. Among the cultivated species of cotton, *Gossypium hirsutum* L. stands out as a domesticated tetraploid species, contributing to over 80% of global cotton production (Shakeel *et al*., 2008).

The dominance of *Gossypium hirsutum* L. in global cotton production underscores its significance in meeting the demand for cotton fiber on a global scale. Its adaptability to various climates and cultivation environments, coupled with its high yield potential, has solidified its position as the preferred choice for cotton cultivation in many regions.

Cotton breeders consistently strive to develop new varieties with increased yield and superior fibre quality, making it a primary objective across cotton breeding programs. Heterosis, also known as hybrid vigour, plays a crucial role in achieving these goals. Heterosis in cotton crop yield is governed by genetic factors such as additive and dominance effects, as reported by (Marani, 1967).

The utilization of heterosis in cotton breeding has been a common practice. However, for a hybrid to be considered valuable, it must demonstrate advantages over the best existing commercial cultivars. This entails not only higher yield potential but also superior fibre quality.

*Author for correspondence; E-mail: gmcchanna@gmail.com

The objective of the present study was to assess heterosis and heterobeltiosis in F_1 hybrids of upland cotton (*Gossypium hirsutum* L.). Heterosis refers to the superiority of F_1 hybrids over their parents, while heterobeltiosis specifically measures the superiority of hybrids over the best parent. By estimating these parameters, breeders gain insights into the potential performance of hybrid varieties and can select those with the most desirable traits for further development and commercialization.

Heterosis, characterized by increased vigour in F_1 hybrids compared to their parents, has been extensively utilized in plant breeding programs to develop new varieties with enhanced traits, particularly in terms of yield. Breaking the yield plateau in cotton productivity requires the identification and development of high-yielding hybrids that exhibit significant economic heterosis.

The exploitation of heterosis has played a pivotal role in agriculture, allowing breeders to release advanced cotton hybrids and facilitate large-scale utilization of heterosis in cotton cultivation. Studies focusing on heterosis have led to the development of numerous high-performing cotton hybrids, contributing to increased production and productivity in the cotton industry.

To create potential hybrids in cotton, it is imperative to leverage economic heterosis by capitalizing on the genetic divergence and favourable combining ability of parent plants. By strategically selecting parent varieties with complementary traits and superior combining abilities, breeders can develop hybrids that not only surpass the performance of their parents but also demonstrate higher production and productivity, thus driving advancements in cotton cultivation.

Material and Methods

The seeds of eight F_1 hybrids *viz*., Bt-703 × IR 524, Bt-703 × MS-370, CRIS-134 × MS-370, CRIS-134 × IR-1524, MNH-886 × Bt-703, MNH-886 × IR-1524, MS-370 × MNH-886, MS-370 × IR-1524 was developed by random crossing of five parents *viz*., Bt-703, CRIS-134, MNH-886, MS-370 and IR-1524. Eight intra-hirsutum F_1 hybrids along with five parental varieties were prepared for the present study. For the experimentation, eight F_1 hybrids along with five parents were grown in a randomized complete block design with four replications. The experiment was conducted at the botanical garden, department of plant breeding and genetics, Sindh Agriculture University Tandojam during crop season 2017. Ten index plants were selected at random from each replication per genotype and properly tagged for recording various observations.

The heterobeltiosis, which evaluates heterosis by comparing the performance of F_1 hybrids with that of the best parent. This comparison helps in identifying hybrids that outperform the superior parent in specific traits. The following proposed a formula for estimating heterosis, which is commonly used in breeding studies:

Heterosis (%) = $(F_1 - MP) / MP * 100$

where:

F_1 represents the performance of the F_1 hybrid.

MP (Mid-parent) denotes the average performance of the parents.

By employing this formula, researchers can quantitatively assess the degree of heterosis exhibited by F_1 hybrids in comparison to the average performance of their parents. This allows for the identification of hybrids with superior traits, facilitating the selection of candidates for further breeding and commercialization.

Results and Discussion

The characters are studied from mean squares from analysis of variance presented in Table 1a and 1b showed significant differences among all the genotypes.

Mean performance of genotypes. The mean performance of parent and hybrid is listed in Tables 2a and 2b. It was observed that the performance of hybrid was better than the parents.

Relative and better parent heterosis. The significance of heterosis cannot be overstated in the realm of genetics, particularly in enhancing the yield of both parent and cross-pollinated crops. Heterosis, also known as hybrid vigour, plays a pivotal role in agricultural productivity by leveraging the advantageous combinations of genes from different parental lines. Heterosis can manifest as either positive or negative, contingent upon the magnitude of the hybrid mean value. Positive heterosis occurs when the hybrid exhibits superior traits compared to its parents, resulting in increased vigour and yield. Conversely, negative heterosis, also known as outbreeding depression, occurs when the hybrid demonstrates inferior traits compared to its parents.

Table 1a. Mean squares from analysis of variance for various characters in upland cotton

Source of variation	Degrees of freedom	Mean squares				
		Bolls formed at 90 days after planting	Plant height	Sympodial branches/ plants	Bolls/plant	Boll weight
Replication	3	4.02	19.83	0.11	4.76	0.05
Genotypes	12	30.67**	232.10**	20.97**	100.76**	0.352**
Parents	4	24.66**	86.96**	6.34**	42.11**	0.04**
Hybrids	7	8.73**	333.42**	32.14**	115.79**	0.56**
Error	36	0.80	23.53	1.70	3.39	0.040

** = Significant at 1% probability level

Table 1b. Mean squares from analysis of variance for various traits in upland cotton

Source of variation	Degrees of freedom	Mean squares			
		Ginning outturn	Seed index	Staple length	Seed cotton yield/plant
Replication	3	0.46	20.58	1.681	2.99
Genotypes	12	3.34**	887.40**	5.58**	14.12**
Parents	4	772.12**	2.87**	0.39**	0.97**
Hybrids	7	594.09**	19.43**	8.97**	5.02**
Error	36	0.16	128.41	0.45	1.99

** = Significant at 1% probability level.

Table 2a. Mean performance of genotypes for various plant traits in upland cotton

Varieties	Bolls formed at 90 days after planting	Plant height (cm)	Sympodial branches/plants	Bolls/plant	Boll weight (g)
Parents (05)					
BT-703	11.00	131.10	28.47	41.80	3.19
CRIS-134	19.00	139.67	29.67	46.33	3.13
MNH-886	14.33	133.67	27.40	44.87	3.41
MS-370	15.00	129.84	26.80	50.67	3.43
IR-1524	14.00	125.00	25.93	41.53	3.28
Total	73.33	659.28	138.27	225.2	16.44
Average	14.66	131.85	27.65	45.04	3.28
Hybrids (10)					
BT-703 × MS-370	20.00	139.33	31.00	48.33	3.77
BT-703 × IR-1524	20.33	143.03	28.10	47.67	3.27
CRIS-134 × MS-370	19.00	126.77	26.00	60.93	3.03
CRIS-134 × IR-1524	20.00	137.47	30.00	44.00	4.23
MNH-886 × BT-703	21.00	152.40	33.00	42.00	3.14
MNH-886 × IR-1524	16.00	125.37	25.00	52.33	3.14
MS-370 × MNH-886	21.00	137.13	28.00	56.00	3.10
MS-370 × IR-1524	18.00	120.13	23.10	49.00	3.00
Total	155.33	1081.63	224.2	400.26	26.68
Average	19.41	135.20	28.02	50.03	3.33
LSD (5%)	1.51	8.17	2.19	3.10	0.33

Table 2b. Mean performance of genotypes for various plant traits in upland cotton

Varieties	Ginning outturn% (GOT%)	Seed index (100-seed wt.g)	Staple length (mm)	Seed cotton yield/plant (g)
Parents (05)				
BT-703	38.33	6.16	27.67	133.48
CRIS-134	37.45	6.92	28.35	145.33
MNH-886	37.82	6.04	28.25	152.92
MS-370	39.91	6.46	28.67	173.53
IR-1524	39.00	7.42	28.15	136.33
Total	192.51	33	141.09	741.59
Average	38.50	6.60	28.21	148.31
Hybrids (08)				
BT-703 × MS-370	43.56	5.18	29.67	182.30
BT-703 × IR-1524	40.70	5.22	28.00	155.43
CRIS-134 × MS-370	37.05	5.18	28.22	184.99
CRIS-134 × IR-1524	37.67	5.04	25.29	155.53
MNH-886 × BT-703	41.46	7.67	26.13	177.63
MNH-886 × IR-1524	41.34	8.33	30.33	163.57
MS-370 × MNH-886	41.86	6.33	26.49	173.57
MS-370 × IR-1524	36.73	7.00	27.40	147.07
Total	320.37	49.95	221.53	1340.09
Average	40.04	6.24	27.69	167.51
LSD (5%)	0.68	19.09	1.13	2.37

The exploitation of heterosis has become a cornerstone in modern plant breeding programs, as it enables breeders to develop hybrids with enhanced performance and productivity. By strategically crossing genetically diverse parental lines, breeders can capitalize on the beneficial interactions between alleles as indicated in Table 3a, 3b and 3c).

Bolls formed at 90 days after planting. The analysis of variance expressed highly significant differences among parents, hybrids and the genotypes for all the traits which predicted that variability among the crosses for all the traits denotes significant variability in the experimental materials (Table 1a) such results were reported by Baloch *et al*. (2015); Srinivas and D. Bhadru (2015).

As far as mean performance is concerned the maximum number of bolls formed by parent CRIS-134 (19.00) followed by MS-370 (15.00), while in hybrid the maximum number of bolls were recorded by the MNH-886 × BT-703 (21.00), MS-370 × NH-886 (21.00) followed by BT-703 × IR-1524 (20.33) as shown in Table 2a. Thus, results suggested that both parents and hybrids possess the maximum number of bolls formed at 90 days are suitable for the further breeding program.

The result presented in Table 3a revealed that all the hybrids showed positively significant results for relative heterosis and better parents. The maximum relative heterosis and better parent heterosis were recorded by MNH-886 × BT-703 (39.69 and 31.76% respectively) followed by BT-703 × IR-1524 (38.51 and 31.14% respectively) indicating their priority to be used for the exploitation in hybrid crop development.

Plant height (cm). The analysis of variance by plant height revealed highly significant differences among the genotypes (Table 1a). Such types of result indicated that there is sufficient variability exist among the genotypes. Regarding mean performance presented in Table 2a. The highest plant height was recorded by CRIS-134 (139.67%) and MNH-886 (133.67%), while in hybrid maximum plant height was recorded by MNH-886 × BT-703 (152.40%), followed by BT-703 × IR-1524 (143.03%). These results suggest that parents and hybrids with high mean value can be utilized for the development of tall cotton varieties. For plant height, both positive and negative heterosis were reported in Table 3a. The results showed that the maximum positive and negative relative heterosis was observed by crosses MNH-886 × BT-703 (13.13%)

followed by BT-703 × IR-1524 (10.48%) and CRIS-134 × MS-370 (-6.30%) and MNH-886 × IR-1524 (-0.317%), while the maximum better parent heterosis was recorded by cross MNH-886 × BT-703 (12.29%) followed by BT-703 × IR-1524 (8.34%) and maximum negative better parent heterosis was recorded by hybrid CRIS-134 × MS-370 (-10.18%) followed by MS-370 × IR-1524 (-8.08%). The results suggested that positive heterosis can be used for the exploitation in hybrid crop development. Such results were predicted by Murthy *et al*. (2017), Tigga *et al*. (2017) and Baloch *et al*. (2015a).

Table 3a. Estimation relative heterosis (RH) and better parent (BP) heterosis for various traits in upland cotton

Genotypes	Bolls formed at 90 days after planting		Plant height		Sympodial branches/plants	
	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)
BT-703 × MS-370	35.00	25.00	6.36	5.91	-33.18	-37.20
BT-703 × IR-1524	38.51	31.14	10.48	8.34	-39.93	-45.88
CRIS-134 × MS-370	10.53	1.15	-6.30	-10.18	-50.59	-58.24
CRIS-134 × IR-1524	17.50	5.00	3.73	-1.60	-36.34	-33.35
MNH-886 × BT-703	39.69	31.76	13.13	12.29	-0.67	-2.59
MNH-886 × IR-1524	11.47	10.44	-3.17	-6.62	-11.24	-18.10
MS-370 × MNH-886	30.17	28.57	3.92	2.53	-30.60	-32.05
MS-370 × IR-1524	19.44	16.67	-6.07	-8.08	-27.03	-36.26

Table 3b. Estimation relative heterosis (RH) and better parent (BP) heterosis for various traits in upland cotton

Genotypes	Bolls/plant		Boll weight		Ginning outturn% (G.O.T %)	
	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)
BT-703 × MS-370	66.82	63.63	12.12	8.94	10.19	8.38
BT-703 × IR-1524	68.49	66.21	0.97	-0.41	5.00	4.18
CRIS-134 × MS-370	61.74	60.03	-8.13	-13.08	-4.40	-7.72
CRIS-134 × IR-1524	65.57	64.84	24.29	22.52	-1.46	-3.52
MNH-886 × BT-703	71.56	70.56	-5.10	-8.60	8.16	7.54
MNH-886 × IR-1524	62.83	61.45	-6.53	-8.60	7.08	5.65
MS-370 × MNH-886	65.17	63.05	-10.32	-10.65	7.15	4.65
MS-370 × IR-1524	58.80	57.82	-11.83	-14.33	-7.42	-8.66

Table 3c. Estimation relative heterosis (RH) and better parent (BP) heterosis for various traits in upland cotton

Genotypes	Seed index (100-seed wt. g)		Staple length		Seed cotton yield/plant	
	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)	Relative heterosis (RH)	Better parents (B.P)
BT-703 × MS-370	-21.92	-24.82	5.04	3.36	15.80	4.81
BT-703 × IR-1524	-30.01	-42.07	0.32	-0.54	13.21	12.29
CRIS-134 × MS-370	-29.03	-33.47	-1.04	-1.61	13.82	6.19
CRIS-134 × IR-1524	-42.17	-47.12	-11.69	-12.08	9.45	6.56
MNH-886 × BT-703	20.43	19.65	-6.99	-8.10	19.38	13.91
MNH-886 × IR-1524	19.24	10.96	7.03	6.87	11.58	6.51
MS-370 × MNH-886	1.32	-2.00	-7.42	-8.22	5.96	0.02
MS-370 × IR-1524	0.86	-6.00	-3.67	-4.62	-5.35	-17.99

Sympodial branches/plant. For analysis of variance, the mean value for 13 genotypes including 5 parents and 8 F_1 hybrids revealed a highly significant difference as clearly shown in Table 1a. Considering mean performance, the parent variety CRIS-134 set maximum number of sympodial branches/plant, while in cross MNH-886 × BT-703 produced 33.00% the maximum number of sympodial branches/plant indicating that the higher the number of sympodial branches higher the chance of producing more fruits as indicated in Table 2a. For heterosis, the negative values were observed in all cross combinations as shown in Table 3a. The maximum negative relative heterosis was observed by CRIS-134 × MS-70 (-50.59%) followed by BT-703 × IR-1524 (-39.93%), while maximum negative better parent heterosis was recorded by CRIS-134 × MS-370 (-58.24%) followed by BT-703 × IR-1524 (-45.88%). Similar findings were by Bilwal *et al*. (2018), Chhavikant *et al*. (2017) and Baloch *et al*. (2015b).

Boll/plant. The result was predicted in Table 1a showed that highly significant differences among all genotypes. The result depicted in Table 2a revealed that among the parents, the maximum number of bolls/plant were produced by MS-370 (50.67) followed by CRIS-134 (46.33), while in hybrids CRIS-134 × MS-370 (60.93) followed by MS-370 × MNH-886 (56.00) indicated that these genotypes tend to have good potential for hybridization and future selection programs. The results predicted in Table 3a, showed positive heterosis in the entire cross combination. The maximum positive relative heterosis was recorded by MNH-886 × IR-1524 (71.56) followed by BT-703 × IR-1524 (68.49%), while maximum better parent heterosis was observed by MNH-886 × IR-1524 (70.56%) followed by BT-703 × IR-1524 (66.21%). The present findings conform with those already been reported by Murthy *et al*. (2017), Tigga *et al*. (2017), Srinivas and Bhadru (2015) and Baloch *et al*. (2015). The result suggested that the more the number of bolls/plant, the higher the chances of more yields.

Boll weight (g). The result for boll weight showed a significant variance among all the genotypes as depicted in Table 1a. The importance of heterotic effects was evident from the significant mean performance revealed that performance of F_1 hybrids is better than parents due to heterotic effects as shown in Table 2a. The average boll weight (3.288 g) was recorded among the parents, while variety MS-370 showed a maximum (3.43 g) boll weight among the parents. However, in hybrid the average boll weight (3.33 g) was recorded, while CRIS-134 × IR-1424 attained maximum boll weight (4.23 g) among the crosses. Both positive and negative values for relative heterosis and better parent heterosis were recorded for boll weight in Table 3b. The maximum positive relative heterosis and maximum better parent heterosis was shown by CRIS-134 × IR-1524 (24.29 and 22.52% respectively), followed by BT-703 × MS-370 (12.12 and 8.94% respectively), while maximum negative relative heterosis and maximum negative better parent heterosis was observed by MS-370 × IR-1524 (-11.83 and 14.33% respectively) followed by and MS-370 × MNH-886 (-10.32 and -10.65% respectively). Such results have been suggested by Chhavikant *et al*. (2017), Tigga *et al.* (2017), Baloch *et al*. (2015a) and Basal *et al*. (2011) that boll weight absolutely favoured the exploitation of heterosis breeding.

Ginning outturn% (GOT%). In Table 1b the result showed that there were highly significant differences among the genotypes. The mean squares from the analysis of variance showed significant differences among the parents and F_1 hybrids as listed in Table 2b. The average maximum ginning outturn percentage (40.04%) was obtained in hybrids as compared to parents (38.502%), while the maximum GOT% was recorded in cross BT-703 × MS-370 (43.56%), whereas the highest GOT% was recorded in variety MS-370 (39.91%). The result in Table 3b revealed that the maximum positive relative heterosis and better parent heterosis was observed by BT-703 × MS-370 (10.19 and 8.38% respectively) followed by MS-370 × IR-1524 and (8.16 and 7.54% respectively), while negative maximum heterosis and better parent heterosis was observed by MS-370 × IR-1524 (7.42 and -8.66% respectively) followed by CRIS-134 × MS-370 (-4.40 and -7.72% respectively). Chhavikant *et al*. (2017), Lingaraja *et al*. (2017), Murthy *et al*. (2017) and Baloch *et al*. (2015b) also revealed that similar kinds of results regarding heterosis for GOT% in cotton hybrids. Thus, the result suggested that lower the magnitude of heterosis for GOT% leads to the additive gene was responsible for the expression of these traits.

Seed index (100 seed wt. g). The result was delineated highly significant differences among the genotypes as shown in Table 1b. The present findings are by Chhavikant *et al*. (2017), Lingaraja *et al.* (2017) and Baloch *et al*. (2015a; 2015b) who also noted the importance of heterotic effect controlling seed index in cotton. In Table 2b among the parents, the maximum mean performance (6.92 g) was recorded in CRIS-134 followed by MS-370 (6.46 g), while in F_1 hybrids the maximum seed index was recorded by crosses MNH-886 × IR-1524 (8.33 g) and MNH-886 × BT-703 (7.67 g). These results thus suggested that desirable segregates could be obtained for selection to improve seed index in cotton, while maximum positive relative heterosis and better parent heterosis were reported by MNH-886 × BT-703 (20.43 and 19.65% respectively). Similar findings with those of Baloch *et al*. (2015) who had also estimated for seed index.

Staple length (mm). In Table 1b, the results indicated the importance of heterotic effects was evident from the significant mean squares of genotypes. For mean performance itself as listed in Table 2b the average longest staple length (27.691 mm) was measured by the hybrid which is less than the average of hybrids (27.69 mm). The variety MS-370 showed the longest staple length (28.67 mm) as compared to cross MNH-886 × IR-1524 (30.33 mm) longest staple length among the genotypes. In Table 1b, the results showed that the maximum relative heterosis and better parents for stable length were recorded for hybrids MNH-886 × IR-1524 (7.03 and 6.87%) followed by BT-703 × MS-370 (5.04 and 3.36%). These results, therefore, demonstrated that this hybrid could be proved potential material for hybrid cotton exploitation was also reported by Baloch *et al*. (2015).

Seed cotton yield/plant (g). The results were shown in Table 1b indicated that there is much inconsistency exists among parents, hybrids and the genotypes. The average maximum seed cotton yield was produced by hybrids (167.511 g) as compared to parents (148.318 g), while maximum seed cotton yield (184.99 g) was obtained by hybrid CRIS-134 × MS-370 whereas, among the parents, the highest yield (173.53 g) was reported in Table 2b. While in Table 3c, the hybrid MNH-886 × BT-703 showed maximum relative heterosis and better parent heterosis (19.38 and 13.91%) followed by BT-703 × MS-370 (18.80%) and BT-703 × IR-1524 (12.29%), while negative relative heterosis and better parent heterosis was observed only in MS-370 × IR-1524 (-5.35 and -17.99%). Similar findings were observed by Monicashree *et al*. (2017), Murthy *et al*. (2017), Baloch *et al*. (2015) and Khan *et al*. (2015). Thus these results could be used in the future breeding program for obtaining good segregants for important yield contributing traits and commercial exploitation of heterosis.

The present studies were conducted to estimate the magnitude of heterosis for yield and yield contributing characters. The heterosis was used that involved 13 genotypes of cotton of which five were considered as parents (BT-703, CRIS-134, MNH-886, MS-370 and IR-1524) and eight (08) as F_1 hybrids (BT-703 × MS-370, BT-703 × IR-1524, CRIS-134 × MS-370, CRIS-134 × IR-1524, MNH-886 × BT-703, MNH-886 × IR-1524, MS-370 × MNH-886 and MS-370 × IR-1524). The characters studied were bolls formed at 90 days after planting, plant height (cm), sympodial branches/plants, bolls/plant, boll weight (g), ginning outturn% (GOT%), seed index (100-seed wt.g), staple length (mm) and seed cotton yield/plant (g). The mean squares from the analysis of variance were significant differences among all the characters. The mean performance for parents and hybrid revealed that genotypes are highly significant in all the traits. The parent CRIS-134 (19) produced maximum bolls at 90 days, with the highest plant height (139.67 cm) and maximum sympodial branches/plant (29.67). MS-370 produced the maximum number of bolls/plant (50.67), maximum boll weight (3.43 g) with highest ginning outturn% (39.91%), staple length (28.67 mm) and seed cotton yield/plant (g) (173.53 g). While the maximum seed index (100-seed weight in g) was recorded by IR-1524 (7.42 g). In respect to per performance of hybrids, MNH-886 × BT-703 and MS-370 × MNH-886 formed maximum numbers of bolls at 90 days after the planting (21.00) each, while MNH-886 × BT-703 had maximum plant height with the maximum number of sympodial branches/plant with 152.40 cm and 33.00, respectively. However, this hybrid MNH-886 × BT-703 may be utilized for the improvement of maximum numbers of bolls at 90 days after the planting, plant height and the number of sympodial branches/plant, while CRIS-134 × MS-370 produced the maximum number of bolls/plant, the maximum boll weight was obtained by hybrid CRIS-134 × IR-1524 (4.23 g). Moreover, the maximum ginning outturn % and seed cotton yield/plant (43.56 and 182.30 g) were reported by hybrid BT-703 × MS-370, while the hybrid MNH-886 × IR-1524 showed the highest seed index (8.33 g) with the longest staple length (30.33 mm). Thus, the result suggested that these hybrids may be evolved to improve various traits in the breeding programmes.

In heterosis the maximum relative heterosis and better parent heterosis showed by MNH-886 × BT-703 for bolls formed at 90 days after planting (39.69 and

31.76%), plant height (13.13 and 12.29%), sympodial branches/plant (-0.67 and -2.59%), number of bolls/plant (71.56 and 70.56%), seed index (20.43 and 19.65%) and seed cotton yield/plant (19.38 and 13.91%), while for other traits the maximum heterosis for boll weight were recorded by CRIS-134 × IR-1524 (24.29 and 22.52% respectively), ginning outturn % by BT-703 × MS-370 (10.19 and 8.38% respectively) and long staple length were recorded by the hybrid MNH-886 × IR-1524 (7.03 and 6.87% respectively). Thus, the majority of traits for heterosis suggested that to improve various traits, different hybrids may be considered.

Conclusion

The analysis of variance revealed significant differences among crosses for all the traits studied. The mean performance of different hybrids highlighted specific strengths in various traits.

Hybrid MNH-886 × BT-703 exhibited the highest number of bolls at 90 days after planting, a greater number of sympodial branches per plant and higher seed cotton yield per plant. Hybrid MNH-886 × IR-1524 produced the maximum number of bolls per plant, highest seed index and longest staple length. CRIS-134 × IR-1524 recorded the highest boll weight and maximum yield per plant. Hybrid BT-703 × MS-370 had the highest ginning outturn percentage. These results suggest that these hybrids possess valuable traits that could contribute to improving different aspects of cotton breeding programs. Regarding heterosis, both positive and negative heterosis were observed. The hybrid MNH-886 × BT-703 exhibited the maximum relative heterosis for several traits, including bolls formed at 90 days after planting, plant height, sympodial branches per plant, number of bolls per plant, seed index and seed cotton yield per plant. Other notable instances of heterosis include CRIS-134 × IR-1524 for boll weight, BT-703 × MS-370 for ginning outturn percentage and MNH-886 × IR-1524 for staple length. These findings suggest that these hybrids have the potential to generate transgressive segregants with desirable traits, which can be utilized in future breeding programs to enhance important yield-contributing traits and leverage heterosis for commercial cotton production.

Conflict of Interest. The authors declare that they have no conflict of interest.

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