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Studies on heterosis for yield, yield contributing and fibre quality traits in Bt (BG II) cotton (*Gossypium hirsutum* L.)

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Abstract
The present investigation, entitled "Studies on heterosis for yield, yield contributing and fibre quality traits in Bt (BG II) cotton (*Gossypium hirsutum* L.)", was carried out during the 2024-2025 kharif season at the Cotton Research Station, Nanded, under Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The objective was to assess heterosis for important agronomic and fibre quality traits using a Line × Tester mating design. The experimental material included five female (line) genotypes and four male (tester) genotypes, resulting in 20 hybrids. Three commercial Bt checks *viz.*, Suraj Bt (variety), NHH 44 BG II, and Jadoo BG II (hybrids) were used for comparison. All 32 entries were evaluated in a Randomized Block Design with two replications. Data were recorded on 14 traits, namely days to 50% flowering, days to maturity, plant height, number of sympodia and bolls per plant, boll weight, seed cotton yield, seed index, lint index, ginning outturn, upper half mean length (UHML), micronaire, fibre strength and uniformity ratio. Analysis of variance revealed significant differences among genotypes for all traits, indicating considerable genetic variability. Hybrids NH 22097 Bt × AC 738 Bt and NH 22057 Bt × AC 738 Bt recorded the highest seed cotton yield. Notably, NH 22097 Bt × AC 738 Bt showed the highest heterosis for seed cotton yield, with 118.86% BPH, 81.08% over NHH 44 BG II, 71.20% over Jadoo BG II, and 93.06% over Suraj Bt. for UHML, NH 22097 Bt × NH 22075 Bt and NH 22057 Bt × NH 22037 Bt were the best performers. These results highlight the potential of specific hybrids for yield and fibre improvement in Bt cotton.

Keywords: Heterosis, heterobeltiosis, cotton, BG II, fibre quality

Introduction

Cotton (*Gossypium* spp.) stands as one of the world's most essential natural fiber crops, forming the backbone of the textile industry by providing critical raw material (Smith & Cothren, 1999) [22]. Beyond its value for fiber, cotton also plays a significant role in the oil and feed sectors as its seeds are utilized as a source of edible oil and protein-rich meal. Among the cultivated species, *Gossypium hirsutum* L. known as upland cotton, dominates global cotton cultivation, contributing to over 90% of total production owing to its superior adaptability and high-yielding nature (Zhang *et al.*, 2008) [27]. The crop holds immense socio-economic importance across both developing and industrialized nations, supporting the livelihoods of millions involved in its farming, post-harvest processing, and commercial distribution. However, cotton productivity is continually threatened by a range of biotic pressures such as pest infestations and diseases, as well as abiotic stresses like water scarcity, extreme temperatures, and saline soils (Reddy *et al.*, 2017) [18]. These challenges, coupled with the limitations of conventional breeding approaches, have led to a plateau in yield gains over recent years.

To overcome barriers in cotton production and enhance yield, researchers are increasingly turning toward advanced breeding strategies such as the exploitation of heterosis (hybrid vigor) (Sprague & Tatum, 1942) [24]. Heterosis refers to the phenomenon where hybrid offspring exhibit superior performance compared to their parents, particularly in key agronomic traits such as yield, fiber quality, and stress tolerance (Sharma *et al.*, 2005) [20]. This phenomenon plays a critical role in hybrid breeding programs by enabling the development of high-performing cultivars that contribute to increased productivity.

A thorough understanding of the genetic basis of yield-related traits and the magnitude of heterosis is therefore essential for identifying superior hybrid combinations. Hence, the present research was undertaken to evaluate the heterotic potential of selected *Gossypium hirsutum* genotypes, with the aim of enhancing cotton productivity through strategic hybrid development.

Materials and methods

The present investigation was carried out to assess heterosis in *Gossypium hirsutum* through the evaluation of twenty F_1 hybrids developed using a Line × Tester mating design. The experimental material consisted of five female lines (NH 22026 Bt, NH 22057 Bt, NH 22097 Bt, NH 22107 Bt, and NH 22141 Bt) and four male testers (NH 22037 Bt, NH 22075 Bt, NH 22065 Bt, and AC 738 Bt), each possessing distinct morphological and agronomic traits. Hybridization was conducted during the summer of 2022 at the Cotton Research Station, Nanded, under the jurisdiction of Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani. Alongside the twenty F_1 hybrids and their nine parents, three commercial check hybrids *viz.*, Suraj Bt, NHH 44 BG II, and Jadoo BG II were included for comparative evaluation. The resulting thirty-two entries (20 hybrids, 5 lines, 4 testers, and 3 checks) were evaluated in a Randomized Block Design (RBD) with two replications during the Kharif season of 2024-25 at the research station. Observations were recorded on a comprehensive set of growth, yield, and fibre quality traits. Growth and yield traits included days to 50% flowering (days), days to maturity (days), plant height (cm), number of sympodia per plant, number of bolls per plant, boll weight (g), seed cotton yield per plant (g), seed index (g), and lint index (g). Fibre quality parameters were assessed using a High Volume Instrument (HVI) at the CIRCOT Regional Station, Nagpur, and included ginning out-turn (%) as well as fibre technological traits such as upper half mean length (UHML, mm), micronaire value (µg/inch), fibre strength (g/tex), and fibre uniformity ratio (%). All recommended agronomic and crop protection measures were followed to maintain a healthy crop stand.

Results

Mean performance

For days to 50% flowering (days), the earliest flowering was observed in line NH 22097 Bt (69.5 days), tester NH 22075 Bt (70.0 days) and hybrid NH 22026 Bt × NH 22065 Bt (66.0 days). For days to maturity (days), earliest maturing genotypes included line NH 22057 Bt (164.5), tester NH 22075 Bt (164.5 days) and hybrid NH 22097 Bt × NH 22075 Bt (157.5 days). Regarding plant height (cm), the tallest were line NH 22141 Bt (135.95 cm), tester AC 738 Bt (142.90 cm) and hybrid NH 22097 Bt × AC 738 Bt (143.80 cm), whereas the shortest plant height was recorded in line NH 22026 Bt (121.81 cm), tester NH 22065 Bt (119.20 cm) and hybrid NH 22057 Bt × NH 22075 Bt (91.60 cm).

For number of sympodia per plant, line NH 22057 Bt (24.21), tester AC 738 Bt (23.81) and hybrid NH 22097 Bt × AC 738 Bt (32.81) recorded the highest values. The maximum number of bolls per plant was seen in line NH 22107 Bt (23.15), tester NH 22075 Bt (26.10), and hybrid NH 22107 Bt × AC 738 Bt (33.25). For boll weight (g), line NH 22026 Bt (4.75 g), tester NH 22037 Bt (3.80 g) and hybrid NH 22097 Bt × AC 738 Bt (5.93 g) were superior. In seed cotton yield per plant (g), the highest values were found in line NH 22057 Bt (97.10 g), tester NH 22075 Bt (122.85 g) and hybrid NH 22097 Bt × AC 738 Bt (207.15 g).

For seed index (g), the highest was in line NH 22026 Bt (9.25 g), tester AC 738 Bt (9.50 g) and hybrid NH 22107 Bt × AC 738 Bt (10.00 g). In lint index (g), line NH 22026 Bt (4.25 g), tester NH 22037 Bt (4.12 g) and hybrid NH 22026 Bt × NH 22037 Bt (6.50 g) ranked top. For ginning out-turn (%), highest values were noted in line NH 22026 Bt (35.35%), tester AC 738 Bt (33.55%) and hybrid NH 22026 Bt × AC 738 Bt (36.40%). In fibre length (mm), line NH 22107 Bt (32.09 mm), tester NH 22075 Bt (33.98 mm) and hybrid NH 22097 Bt × NH 22075 Bt (30.17 mm) were best. For micronaire (µg/inch), the highest values were found in line NH 22107 Bt (5.03 µg/inch), tester AC 738 Bt (4.93 µg/inch) and hybrid NH 22026 Bt × AC 738 Bt (5.58 µg/inch). In fibre strength (g/tex), the best values were recorded in line NH 22141 Bt (26.80 g/tex), tester NH 22037 Bt (27.65 g/tex) and hybrid NH 22097 Bt × AC 738 Bt (27.00 g/tex). Lastly, for fibre uniformity ratio (%), the top genotypes were line NH 22141 Bt (84.98%), tester NH 22075 Bt (86.06%) and hybrid NH 22097 Bt × NH 22075 Bt (85.82).

Heterosis

In the present investigation, heterosis was assessed in terms of better parent heterosis (BPH) and heterosis over three standard check varieties: Suraj Bt, Jadoo BG II and NHH 44 BG II, for a range of yield-contributing and fibre quality traits in cotton. For days to 50% flowering, the cross NH 22026 Bt × NH 22065 Bt exhibited the highest earliness, recording negative heterosis values of -13.16% over the better parent, -9.59% over Suraj Bt, -10.20% over Jadoo BG II, and -9.59% over NHH 44 BG II, indicating a significant reduction in flowering duration. The same hybrid also recorded the earliest maturity with heterosis values of -5.11% (BPH), -1.56% over Suraj Bt, -4.24% over Jadoo BG II and -3.95% over NHH 44 BG II, highlighting its potential suitability for early-maturing cotton cultivation. In terms of plant height, the hybrid NH 22097 Bt × AC 738 Bt showed maximum positive heterosis with values of 0.63% over the better parent, 8.12% over Suraj Bt, 35.66% over Jadoo BG II and 18.84% over NHH 44 BG II, suggesting enhanced vegetative growth. For plant compactness, the cross NH 22057 Bt × NH 22075 Bt displayed the greatest reduction, with heterosis of - 34.80% (BPH), -31.12% over Suraj Bt, -13.58% over Jadoo BG II and -24.29% over NHH 44 BG II indicating its promise for high-density planting due to its compact growth habit.

The number of sympodia per plant was highest in the hybrid NH 22097 Bt × AC 738 Bt, with heterosis values of 37.81% (BPH), 25.64% over Suraj Bt, 59.17% over Jadoo BG II and 62.32% over NHH 44 BG II, suggesting a robust reproductive structure. The cross NH 22107 Bt × AC 738 Bt exhibited the maximum number of bolls per plant, recording heterosis of 35.71% over the better parent, 46.79% over Suraj Bt, 60.62% over Jadoo BG II and 44.25% over NHH 44 BG II. In terms of boll weight, NH 22097 Bt × AC 738 Bt was superior, showing 55.92% (BPH), 63.44% over Suraj Bt, 94.26% over Jadoo BG II, and 36.20% over NHH 44 BG II, reflecting improved boll development. For seed cotton yield per plant, the hybrid NH 22097 Bt × AC 738 Bt again demonstrated superiority, with exceptionally high heterosis values of 118.86% over the better parent, 81.08% over Suraj Bt, 93.06% over Jadoo BG II and 71.20% over NHH 44 BG II, clearly identifying it as a high-yielding genotype. Regarding seed index, the cross NH 22107 Bt × AC 738 Bt recorded the highest improvement over Suraj Bt (29.03%), with heterosis of 5.26% over the better parent, 8.10% over Jadoo BG II and -2.43% over NHH 44 BG II, suggesting enhanced seed size and weight.

The highest lint index was observed in NH 22026 Bt × NH 22037 Bt, which showed considerable heterosis of 52.94% (BPH), 73.33% over Suraj Bt, 52.94% over Jadoo BG II and 23.80% over NHH 44 BG II, indicating improved lint yield. In ginning outturn, the cross NH 22026 Bt × NH 22075 Bt showed positive heterosis over Suraj Bt (13.23%) and NHH 44 BG II (7.06%), though slightly negative over the better parent (-0.23%) and Jadoo BG II (-0.75%). For upper half mean length (UHML), the hybrid NH 22097 Bt × NH 22075 Bt displayed moderate fibre length with heterosis of -11.21% (BPH), -0.98% over Suraj Bt, -5.05% over Jadoo BG II and -1.98% over NHH 44 BG II. The most desirable micronaire value was recorded in NH22097 Bt × NH 22065 Bt, which showed negative heterosis of -5.70% (BPH), -22.82% over Suraj Bt, -17.01% over Jadoo BG II and -23.29% over NHH 44 BG II, indicating finer and more desirable fibre fineness. In terms of fibre strength, NH 22026 Bt × NH 22075 Bt was the best performing hybrid, with heterosis values of 4.38% (BPH), 7.03% over Suraj Bt, 12.99% over Jadoo BG II and 2.24% over NHH 44 BG II. Finally, for uniformity ratio, the cross NH 22097 Bt × NH 22075 Bt exhibited the highest improvement with heterosis values of -0.28% over the better parent, 2.08% over Suraj Bt, 1.06% over Jadoo BG II and 0.92% over NHH 44 BG II, indicating superior fibre uniformity.

Discussion: Based on the results obtained, several insights can be drawn regarding the genetic behavior of key agronomic and fibre quality traits in upland cotton. Earliness, a desirable trait in cotton, was associated with significant and negative heterosis for days to 50% flowering and days to maturity, indicating early flowering and maturing crosses such as NH 22026 Bt × NH 22065 Bt and NH22097 Bt × NH22075 Bt. These findings align with earlier reports by Ganapathy *et al.* (2008), Patel *et al.* (2014) and Arbad *et al.* (2017) [1, 5]. A compact plant structure, indicated by significant and negative heterosis for plant height, is also advantageous as it facilitates easy intercultural operations; similar observations were made by Dawod *et al.* (2010) [4], Guvercin *et al.* (2011) [7] and Kumar *et al.* (2013) [10]. Positive and significant heterosis for yield-contributing traits such as number of sympodia per plant, number of bolls per plant, boll weight, and seed cotton yield per plant was observed in several hybrids, including NH22097 Bt × AC 738 Bt and NH 22107 Bt × AC 738 Bt, corroborating findings by Tuteja *et al.* (2011) [25], Balu *et al.* (2012) [2], Monicashree *et al.* (2017) [12], Patil *et al.* (2019) [16], Solongi *et al.* (2019) [23] and Naik *et al.* (2020) [13]. Traits like seed index and lint index also exhibited significant and positive heterosis, consistent with earlier studies by Kumar *et al.* (2017) [9], Gohil *et al.* (2017) [6] and Mangi *et al.* (2019) [11]. Fibre quality parameters such as ginning outturn, UHML (fibre length), micronaire (fibre fineness), fibre strength and uniformity ratio are crucial to textile industries. Significant and positive heterosis for ginning outturn and fibre strength was recorded in crosses such as NH 22057 Bt × NH 22075 Bt and NH 22026 Bt × NH 22075 Bt, aligning with findings by Ranganatha *et al.* (2013) [17], Patel *et al.* (2015), Kannan *et al.* (2016) and Sirisha *et al.* (2019) [8, 21]. On the other hand, significant negative heterosis for micronaire, which indicates finer fibre, was observed in crosses like NH 22097 Bt × NH 22065 Bt, similar to results by Usharani *et al.* (2015), Shakel *et al.* (2016) and Bilwal *et al.* (2018) [3, 19, 26].

Table 1 contd..: Mean performance of Parents, crosses and checks for all characters in *Gossypium hirsutum* L.

Sr.No.	Treatment	DTF	DTM	PH(cm)	NS/P	NB/P	BW (g)	SCY (g)
		Mean	Mean	Mean	Mean	Mean	Mean	Mean
	Lines							
1	NH 22026 Bt	76.00	166.50	121.81	20.21	20.40	4.75	71.55
2	NH 22057 Bt	75.00	164.50	135.50	24.21	22.50	3.36	97.10
3	NH 22097 Bt	69.50	165.50	129.90	22.61	22.10	3.80	94.65
4	NH 22107 Bt	73.50	165.00	127.10	22.61	23.15	3.53	94.55
5	NH 22141 Bt	75.50	167.50	135.95	22.31	22.80	3.45	81.40
	Mean	73.90	165.80	130.05	22.39	22.19	3.77	87.85
	Range	69.5-76	164.5-167.5	121.81-135.95	20.21-24.21	20.40-23.15	3.36-4.75	71.55-97.1
	Testers							
6	NH 22065 Bt	73.00	161.50	119.20	19.91	19.00	3.03	61.85
7	NH 22037 Bt	74.00	166.00	139.75	21.01	19.55	3.80	75.20
8	NH 22075 Bt	70.00	164.50	140.50	23.71	26.10	3.83	122.85
9	AC 738 Bt	73.00	165.00	142.90	23.81	24.50	3.20	83.65
	Mean	72.50	164.25	135.58	22.11	22.28	3.46	85.88
	Range	70-74	161.5-166	119.20-142.90	19.91-23.81	19.00-26.10	3.03-3.83	61.85-122.85
	Crosses							
10	NH22026 Bt X NH22065 Bt	66.00	158.00	139.00	25.01	29.60	4.05	149.55
11	NH22026 Bt X NH22037 Bt	71.50	162.50	121.40	24.51	28.75	4.38	117.80
12	NH22026 Bt X NH22075 Bt	72.00	159.50	136.50	26.61	31.20	3.66	163.35
13	NH22026 Bt X AC 738 Bt	67.50	161.00	136.30	28.61	28.90	5.05	139.95
14	NH22057 Bt X NH22065 Bt	75.00	165.00	110.00	24.21	29.95	3.63	138.90
15	NH22057 Bt X NH22037 Bt	70.00	158.50	123.00	27.10	27.00	4.70	129.90

16	NH22057 Bt X NH22075 Bt	74.00	164.50	91.60	22.50	22.05	3.15	107.30
17	NH22057 Bt X AC 738 Bt	71.00	161.50	124.50	28.41	29.20	4.30	168.50
18	NH22097 Bt X NH22065 Bt	72.50	165.50	119.70	26.01	28.20	4.23	165.30
19	NH22097 Bt X NH22037 Bt	76.50	167.50	126.50	27.01	29.70	3.98	135.45
20	NH22097 Bt X NH22075 Bt	68.50	157.50	121.80	27.91	29.35	4.48	91.20
21	NH22097 Bt X AC 738 Bt	68.00	159.50	143.80	32.81	33.00	5.93	207.15
22	NH22107 Bt X NH22065 Bt	73.50	162.50	130.00	25.01	28.30	4.12	118.95
23	NH22107 Bt X NH22037 Bt	73.50	168.50	137.60	25.51	31.90	4.18	163.73
24	NH22107 Bt X NH22075 Bt	73.50	166.00	120.60	29.21	30.20	4.00	153.00
25	NH22107 Bt X AC 738 Bt	75.00	161.50	130.30	26.72	33.25	3.93	165.20
26	NH22141 Bt X NH22065 Bt	76.50	167.50	124.50	25.61	30.00	3.45	132.80
27	NH22141 Bt X NH22037 Bt	69.00	162.50	130.30	27.91	29.35	4.45	155.35
28	NH22141 Bt X NH22075 Bt	75.00	163.00	133.50	24.61	28.20	3.83	135.30
29	NH22141 Bt X AC 738 Bt	73.50	165.50	131.15	24.31	23.20	4.23	147.00
	Mean	72.10	162.80	126.60	26.48	29.07	4.10	143.76
	Range	66-76.5	157.5-168.5	91.60-143.80	22.50-32.81	22.05-33.25	3.15-5.93	91.20-207.15
	checks							
30	NHH44 BG II (Ch)	73.00	160.50	133.00	26.11	22.65	3.63	114.40
31	Jadoo BG II (Ch)	73.00	164.50	121.10	20.21	23.05	4.35	121.00
32	Suraj Bt (Ch)	73.50	165.00	106.00	20.61	20.70	3.05	107.30
	SE±	0.87	0.54	8.23	1.31	1.72	0.13	11.37
	CD at 95%	2.53	1.56	23.75	3.80	4.97	0.39	32.82

Table 1: contd..: Mean performance of Parents, crosses and checks for all characters in *Gossypium hirsutum* L.

Sr.No.	Treatment	SI (g)	LI (g)	GOT (%)	UHML (mm)	MIC (µg/inch)	FS (g/tex)	UR (%)
		Mean	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
	Lines							
1	NH 22026 Bt	9.25	4.25	35.35	31.13	4.93	24.5	83.11
2	NH 22057 Bt	9.00	4.24	34.09	31.47	4.60	26.5	83.95
3	NH 22097 Bt	7.75	4.00	31.88	31.74	4.03	27.15	84.86
4	NH 22107 Bt	7.25	3.75	33.50	32.09	5.03	23.8	82.14
5	NH 22141 Bt	7.75	4.00	30.88	30.74	4.20	26.8	84.98
	Mean	8.20	4.04	33.14	31.43	4.55	25.75	83.80
	Range	7.25-9.25	3.75-4.25	30.88-35.35	30.74-32.09	4.03-5.03	23.8-27.15	82.14-84.98
	Testers							
6	NH 22065 Bt	7.50	3.00	30.40	33.03	3.91	21.65	81.89
7	NH 22037 Bt	8.25	4.12	32.83	32.96	3.78	27.65	84.83
8	NH 22075 Bt	7.75	4.01	32.89	33.98	4.74	26.25	86.06
9	AC 738 Bt	9.50	4.25	33.55	33.33	4.93	22.79	83.95
	Mean	8.25	3.84	32.41	33.32	4.34	24.58	84.18
	Range	7.50-9.50	3.00-4.25	30.40-33.55	32.96-33.98	3.91-4.93	21.65-27.65	81.89-86.06
	Crosses							
10	NH22026 Bt X NH22065 Bt	8.75	4.25	33.51	23.98	4.84	26.85	84.05
11	NH22026 Bt X NH22037 Bt	9.25	6.50	35.22	26.01	5.19	24.80	84.02
12	NH22026 Bt X NH22075 Bt	8.00	4.22	35.27	28.90	4.86	27.40	85.05
13	NH22026 Bt X AC 738 Bt	8.50	4.75	36.40	29.51	5.58	24.30	84.85
14	NH22057 Bt X NH22065 Bt	7.50	3.75	33.14	27.90	4.32	25.80	84.87
15	NH22057 Bt X NH22037 Bt	9.50	6.25	34.86	29.85	4.86	25.70	84.94
16	NH22057 Bt X NH22075 Bt	7.25	4.00	36.31	26.31	4.80	25.70	85.09
17	NH22057 Bt X AC 738 Bt	7.75	4.25	33.81	24.32	5.49	25.60	84.88
18	NH22097 Bt X NH22065 Bt	8.75	3.75	31.01	26.60	3.80	25.85	84.03
19	NH22097 Bt X NH22037 Bt	9.75	4.50	33.14	24.65	4.57	25.90	85.14
20	NH22097 Bt X NH22075 Bt	9.75	4.23	33.60	30.17	4.94	26.90	85.82
21	NH22097 Bt X AC 738 Bt	8.75	3.50	32.81	28.26	5.07	27.00	84.74
22	NH22107 Bt X NH22065 Bt	7.25	4.00	32.36	29.21	4.66	25.20	83.93
23	NH22107 Bt X NH22037 Bt	9.50	4.75	36.21	27.25	4.42	26.80	83.94
24	NH22107 Bt X NH22075 Bt	8.25	4.75	35.52	27.58	5.07	25.50	84.92
25	NH22107 Bt X AC 738 Bt	10.00	4.52	33.05	25.70	5.31	26.05	83.78
26	NH22141 Bt X NH22065 Bt	8.75	4.05	33.21	25.30	4.15	26.00	83.00
27	NH22141 Bt X NH22037 Bt	9.50	4.70	33.98	28.56	4.46	26.40	84.78
28	NH22141 Bt X NH22075 Bt	8.25	4.50	32.19	24.98	4.84	27.30	85.03
29	NH22141 Bt X AC 738 Bt	9.75	4.75	32.90	26.93	4.74	26.20	84.07
	Mean	8.75	4.36	33.48	27.20	4.80	25.97	84.84
	Range	7.25-10.00	3.50-4.75	31.01-36.21	24.32-30.17	3.80-5.49	25.2-27.3	83-85.82
	Checks							
30	NHH44 BG II (Ch)	7.75	3.75	31.15	30.47	4.93	25.6	84.07

31	Jadoo BG II (Ch)	10.25	5.25	32.95	30.78	4.96	26.8	85.03
32	Suraj Bt (Ch)	9.25	4.25	35.54	31.78	4.58	24.25	84.92
	SE±	0.59	0.10	0.73	0.41	0.04	0.63	0.14
	CD at 95%	1.72	0.30	2.12	0.23	0.11	1.82	0.41

Table 2: Heterobeltiosis, useful and standard heterosis for different characters in *Gossypium hirsutum* L.

Sr. no.	crosses	Days to 50% flowering				Days to maturity				Plant height			
		BPH	SH	JH	UH	BPH	SH	JH	UH	BPH	SH	JH	UH
1	NH22026 Bt X NH22065 Bt	-13.16**	-9.59**	-9.59**	-10.20**	-5.11**	-1.56**	-3.95**	-4.24**	14.11	4.51	14.87	31.13**
2	NH22026 Bt X NH22037 Bt	-5.92**	-2.05	-2.05	-2.72	-2.40**	1.25*	-1.22*	-1.52**	-13.13	-8.72	0.33	14.52
3	NH22026 Bt X NH22075 Bt	-5.26**	-1.37	-1.37	-2.04	-4.20**	-0.62	-3.04**	-3.33**	-2.85	2.63	12.80	28.77*
4	NH22026 Bt X AC 738 Bt	-11.18**	-7.53**	-7.53**	-8.16**	-3.30**	0.31	-2.13**	-2.42**	-4.62	2.48	12.64	28.58*
5	NH22057 Bt X NH22065 Bt	0.00	2.74	2.74	2.04	0.30	2.80**	0.30	0.00	-18.82*	-17.29	-9.09	3.77
6	NH22057 Bt X NH22037 Bt	-6.67**	-4.11*	-4.11*	-4.76**	-4.52**	-1.25*	-3.65**	-3.94**	-11.99	-7.51	1.65	16.03
7	NH22057 Bt X NH22075 Bt	-1.33	1.37	1.37	0.68	0.00	2.49**	0.00	-0.30	-34.80**	-31.12**	-24.29*	-13.58
8	NH22057 Bt X AC 738 Bt	-5.33**	-2.74	-2.74	-3.40	-2.12**	0.62	-1.82**	-2.12**	-12.88	-6.39	2.89	17.45
9	NH22097 Bt X NH22065 Bt	-0.68	-0.68	-0.68	-1.36	0.00	3.12**	0.61	0.30	-7.85	-10	-1.07	12.92
10	NH22097 Bt X NH22037 Bt	3.38	4.79**	4.79**	4.08*	0.90	4.36**	1.82**	1.52**	-9.48	-4.88	4.54	19.33
11	NH22097 Bt X NH22075 Bt	-2.14	-6.16**	-6.16**	-6.80**	-4.83**	-1.87**	-4.26**	-4.55**	-13.31	-8.42	0.66	14.90
12	NH22097 Bt X AC 738 Bt	-6.85**	-6.85**	-6.85**	-7.48**	-3.63**	-0.62	-3.04**	-3.33**	0.63	8.12	18.84	35.66**
13	NH22107 Bt X NH22065 Bt	0.00	0.68	0.68	0.00	-1.52**	1.25*	-1.22**	-1.52**	2.28	-2.25	7.43	22.64*
14	NH22107 Bt X NH22037 Bt	-0.68	0.68	0.68	0.00	1.51 **	4.98**	2.43**	2.12**	-1.54	3.45	13.71	29.81*
15	NH22107 Bt X NH22075 Bt	0.00	0.68	0.68	0.00	0.61	3.43**	0.91	0.61	-14.16	-9.32	-0.33	13.77
16	NH22107 Bt X AC 738 Bt	2.04	2.74	2.74	2.04	-2.12**	0.62	-1.82**	-2.12**	-8.82	-2.03	7.68	22.92*
17	NH22141 Bt X NH22065 Bt	1.32	4.79**	4.79**	4.08*	0.00	4.36**	1.82**	1.52**	-8.42	-6.39	2.89	17.45
18	NH22141 Bt X NH22037 Bt	-8.61**	-5.48**	-5.48**	-6.12**	-2.99**	1.25*	-1.22*	-1.52**	-6.76	-2.03	7.68	22.92*
19	NH22141 Bt X NH22075 Bt	-0.66	2.74	2.74	2.04	-2.69**	1.56**	-0.91	-1.21**	-4.98	0.37	10.33	25.94*
20	NH22141 Bt X AC 738 Bt	-2.65	0.68	0.68	0.00	-1.19 *	3.12**	0.61	0.30	-8.22	-1.39	8.38	23.72*
	SE±	1.21				0.79				11.59			
	CD at 95%	2.54				1.66				24.27			
	CD at 99%	3.48				2.27				33.18			

Note:- BPH- Btter parent heterosis, SH- Heterosis over check hybrid NHH 44 BG II, JH- Heterosis over check hybrid jadoo BG II, UH- Heterosis over check Suraj Bt

Table 2: contd… Heterobeltiosis, useful and standard heterosis for different characters in *Gossypium hirsutum* L

Sr. no.	crosses	Number of sympodia/plant				Number of bolls per plant				Boll weight			
		BPH	SH	JH	UH	BPH	SH	JH	UH	BPH	SH	JH	UH
1	NH22026 Bt X NH22065 Bt	23.76 *	-4.23	23.72*	21.32*	45.10**	30.68**	28.41*	42.99**	-14.74**	11.72*	-6.89	32.78**
2	NH22026 Bt X NH22037 Bt	16.66	-6.14	21.25*	18.89*	40.93**	26.93*	24.72*	38.88**	-7.89	20.68**	0.57	43.44**
3	NH22026 Bt X NH22075 Bt	12.23	1.89	31.64**	29.08**	19.54	37.74**	35.35**	50.72**	-23.05**	0.82	-15.97**	19.83**
4	NH22026 Bt X AC 738 Bt	20.16 *	9.55	41.53**	38.79**	17.96	27.59*	25.37*	39.61**	6.32	39.31**	16.09**	65.57**
5	NH22057 Bt X NH22065 Bt	0.00	-7.29	19.76*	17.44	33.11**	32.22**	29.93**	44.68**	7.89	0	-16.66**	18.85**
6	NH22057 Bt X NH22037 Bt	11.96	3.79	34.09**	31.48**	20.00	19.20	17.13	30.43*	23.68**	29.65**	8.04	54.09**
7	NH22057 Bt X NH22075 Bt	-7.04	-13.83	11.33	9.17	-15.52	-2.64	-4.33	6.52	-17.65**	-13.10*	-27.58**	3.27
8	NH22057 Bt X AC 738 Bt	17.35 *	8.78	40.54**	37.82**	19.18	28.91*	26.68*	41.06**	27.98**	18.62**	-1.14	40.98**
9	NH22097 Bt X NH22065 Bt	15.04	-0.40	28.67**	26.17**	27.60 *	24.50*	22.34*	36.23**	11.18 *	16.55**	-2.87	38.52**
10	NH22097 Bt X NH22037 Bt	19.46 *	3.42	33.62**	31.02**	34.39	31.12**	28.85*	43.47**	4.61	9.65	-8.62	30.32**

						**							
11	NH22097 Bt X NH22075 Bt	17.72 *	6.87	38.07**	35.39**	12.43	29.55*	27.31*	41.76**	16.99 **	23.44**	2.87	46.72**
12	NH22097 Bt X AC 738 Bt	37.81 **	25.64**	62.32**	59.17**	34.69 **	45.69**	43.16**	59.42**	55.92 **	63.44**	36.20**	94.26**
13	NH22107 Bt X NH22065 Bt	10.62	-4.23	23.72*	21.32*	22.25 *	24.94*	22.77*	36.71**	16.74 **	13.51*	-5.40	34.91**
14	NH22107 Bt X NH22037 Bt	12.83	-2.31	26.19**	23.75*	37.80 **	40.83**	38.39**	54.10**	9.87	15.17**	-4.02	36.88**
15	NH22107 Bt X NH22075 Bt	23.20 **	11.85	44.50**	41.70**	15.71	33.33**	31.01**	45.89**	4.58	10.34	-8.04	31.14**
16	NH22107 Bt X AC 738 Bt	12.25	2.33	32.21**	29.64**	35.71 **	46.79**	44.25**	60.62**	11.35	8.27	-9.77*	28.68**
17	NH22141 Bt X NH22065 Bt	14.79	-1.91	26.71**	24.26*	31.58 **	32.45**	30.15**	44.92**	0.00	-4.82	-20.68**	13.11*
18	NH22141 Bt X NH22037 Bt	25.11 **	6.87	38.07**	35.39**	28.73 *	29.58*	27.33*	41.78**	17.11 **	22.75**	2.29	45.90**
19	NH22141 Bt X NH22075 Bt	3.80	-5.76	21.74*	19.38*	8.05	24.50*	22.34*	36.23**	0.00	5.51	-12.06*	25.40**
20	NH22141 Bt X AC 738 Bt	2.10	-6.91	20.26*	17.92	-5.31	2.42	0.65	12.07	22.46 **	16.55**	-2.87	38.52**
	SE±	1.87				2.44				0.19			
	CD at 95%	3.93				5.11				0.40			
	CD at 99%	5.37				6.98				0.55			

Note:- BPH- Btter parent heterosis, SH- Heterosis over check hybrid NHH 44 BG II, JH- Heterosis over check hybrid jadoo BG II, UH- Heterosis over check Suraj Bt

Table 2: contd… Heterobeltiosis, useful and standard heterosis for different characters in *Gossypium hirsutum* L

Sr. no.	crosses	Seed cotton yield/plant(g)				Seed Index(g)				Lint Index(g)			
		BPH	SH	JH	UH	BPH	SH	JH	UH	BPH	SH	JH	UH
1	NH22026 Bt X NH22065 Bt	109.01 **	30.73*	23.60	39.38*	-5.41	12.90	-14.63	-5.40	0.00	13.33**	-19.04**	0
2	NH22026 Bt X NH22037 Bt	56.65 *	2.97	-2.64	9.79	0.00	19.35	-9.75	0	52.94 **	73.33**	23.80**	52.94**
3	NH22026 Bt X NH22075 Bt	32.97 *	42.79**	35.00*	52.24**	-13.51	3.22	-21.95*	-13.51	-0.71	12.53**	-19.61**	-0.70
4	NH22026 Bt X AC 738 Bt	67.30 **	22.33	15.66	30.43	-10.53	9.67	-17.07*	-8.10	11.76 **	26.66**	-9.52**	11.76**
5	NH22057 Bt X NH22065 Bt	43.05 *	21.42	14.79	29.45	-16.67	-3.22	-26.82**	-18.91*	-11.45 **	0	-28.57**	-11.76**
6	NH22057 Bt X NH22037 Bt	33.78	13.55	7.36	21.06	5.56	22.58*	-7.31	2.70	47.58 **	66.66**	19.04**	47.05**
7	NH22057 Bt X NH22075 Bt	-12.66	-6.21	-11.32	0.00	-19.44	-6.45	-29.26**	-21.62*	-5.55	6.66	-23.80**	-5.88
8	NH22057 Bt X AC 738 Bt	73.53 **	47.29**	39.26**	57.04**	-18.42	0	-24.39**	-16.21	0.00	13.33**	-19.04**	0
9	NH22097 Bt X NH22065 Bt	74.64 **	44.49**	36.61**	54.05**	12.90	12.90	-14.63	-5.40	-6.25	0	-28.57**	-11.76**
10	NH22097 Bt X NH22037 Bt	43.11 *	18.40	11.94	26.23	18.18	25.80*	-4.87	5.40	9.36 *	20**	-14.28**	5.88
11	NH22097 Bt X NH22075 Bt	-25.76	-20.28	-24.63	-15.00	25.81 *	25.80*	-4.87	5.40	5.62	12.8**	-19.42**	-0.47
12	NH22097 Bt X AC 738 Bt	118.86 **	81.08**	71.20**	93.06**	-7.89	12.90	-14.63	-5.40	-17.65 **	-6.66	-33.33**	-17.64**
13	NH22107 Bt X NH22065 Bt	25.81	3.98	-1.69	10.86	-3.33	-6.45	-29.26**	-21.62*	6.67	6.66	-23.80**	-5.88
14	NH22107 Bt X NH22037 Bt	73.17 **	43.13**	35.32**	52.60**	15.15	22.58*	-7.31	2.70	15.43 **	26.66**	-9.52**	11.76**
15	NH22107 Bt X NH22075 Bt	24.54	33.74*	26.45	42.59**	6.45	6.45	-19.51*	-10.81	18.60 **	26.66**	-9.52**	11.76**
16	NH22107 Bt X AC 738 Bt	74.72 **	44.41**	36.53*	53.96**	5.26	29.03*	-2.43	8.10	6.35	20.53**	-13.90**	6.35
17	NH22141 Bt X NH22065 Bt	63.14 **	16.08	9.75	23.77	12.90	12.90	-14.63	-5.40	1.25	8	-22.85**	-4.70
18	NH22141 Bt X NH22037 Bt	90.85 **	35.80*	28.39*	44.78**	15.15	22.58*	-7.31	2.70	14.22 **	25.33**	-10.47**	10.58**
19	NH22141 Bt X NH22075 Bt	10.13	18.27	11.82	26.10	6.45	6.45	-19.51*	-10.81	12.36 **	20**	-14.28**	5.88
20	NH22141 Bt X AC 738 Bt	75.73 **	28.50	21.49	37.00**	2.63	25.80*	-4.87	5.40	11.76 **	26.66**	-9.52**	11.76**

	SE±	16.02	0.88	0.15
	CD at 95%	33.53	1.84	0.31
	CD at 99%	45.83	2.52	0.43

Note:- BPH- Btter parent heterosis, SH- Heterosis over check hybrid NHH 44 BG II, JH- Heterosis over check hybrid jadoo BG II, UH- Heterosis over check Suraj Bt

Sr. no.	crosses	Ginning percentage (%)				Upper half mean length (mm)				Micronaire value (µg/inch)			
		BPH	SH	JH	UH	BPH	SH	JH	UH	BPH	SH	JH	UH
1	NH22026 Bt X NH22065 Bt	-5.23	7.56*	1.69	-5.72	-27.40 **	-21.30**	-22.09**	-24.53**	-1.83	-1.83	-2.42*	5.56**
2	NH22026 Bt X NH22037 Bt	-0.39	13.04**	6.88*	-0.91	-21.07 **	-14.63**	-15.49**	-18.14**	5.38 **	5.38**	4.74**	13.30**
3	NH22026 Bt X NH22075 Bt	-0.23	13.23**	7.06*	-0.75	-14.95 **	-5.15**	-6.11**	-9.05**	-1.32	-1.32	-1.92	6.11**
4	NH22026 Bt X AC 738 Bt	2.95	16.83**	10.46**	2.41	-11.46 **	-3.17*	-4.14**	-7.14**	13.17 **	13.29**	12.60**	21.81**
5	NH22057 Bt X NH22065 Bt	-2.79	6.38	0.58	-6.75*	-15.54 **	-8.45**	-9.37**	-12.21**	-6.08 **	-12.27**	-12.80**	-5.67**
6	NH22057 Bt X NH22037 Bt	2.25	11.89**	5.79	-1.92	-9.42 **	-2.03	-3.02*	-6.06**	5.65 **	-1.32	-1.92	6.11**
7	NH22057 Bt X NH22075 Bt	6.50 *	16.54**	10.19**	2.16	-22.58 **	-13.67**	-14.54**	-17.21**	1.26	-2.54*	-3.13**	4.80**
8	NH22057 Bt X AC 738 Bt	-0.82	8.53*	2.62	-4.86	-27.02 **	-20.18**	-20.98**	-23.46**	11.25 **	11.36**	10.69**	19.74**
9	NH22097 Bt X NH22065 Bt	-2.72	-0.46	-5.89	-12.75**	-19.46 **	-12.70**	-13.58**	-16.28**	-5.70 **	-22.82**	-23.29**	-17.01**
10	NH22097 Bt X NH22037 Bt	0.95	6.39	0.59	-6.74*	-25.20 **	-19.10**	-19.91**	-22.42**	13.26 **	-7.30**	-7.86**	-0.33
11	NH22097 Bt X NH22075 Bt	2.19	7.87*	1.99	-5.44	-11.21 **	-0.98	-1.98	-5.05**	4.11 **	0.20	-0.40	7.74**
12	NH22097 Bt X AC 738 Bt	-2.22	5.32	-0.43	-7.68*	-15.21 **	-7.27**	-8.20**	-11.08**	2.84 *	2.94*	2.32*	10.69**
13	NH22107 Bt X NH22065 Bt	-3.40	3.89	-1.78	-8.93**	-11.56 **	-4.13**	-5.10**	-8.07**	-7.36 **	-5.48**	-6.05**	1.64
14	NH22107 Bt X NH22037 Bt	8.08 *	16.23**	9.90**	1.89	-17.32 **	-10.58**	-11.48**	-14.25**	-12.03 **	-10.24**	-10.79**	-3.49**
15	NH22107 Bt X NH22075 Bt	6.01	14.01**	7.79*	-0.06	-18.85 **	-9.50**	-10.41**	-13.22**	0.80	2.84*	2.22	10.58**
16	NH22107 Bt X AC 738 Bt	-1.51	6.08	0.30	-7.01*	-22.88 **	-15.65**	-16.50**	-19.12**	5.57 **	7.71**	7.06**	15.81**
17	NH22141 Bt X NH22065 Bt	7.55 *	6.61	0.79	-6.55*	-23.43 **	-16.98**	-17.82**	-20.39**	-1.43	-15.82**	-16.33**	-9.49**
18	NH22141 Bt X NH22037 Bt	3.50	9.08*	3.13	-4.38	-13.35 **	-6.28**	-7.23**	-10.13**	6.18 **	-9.43**	-9.98**	-2.62*
19	NH22141 Bt X NH22075 Bt	-2.12	3.33	-2.31	-9.43**	-26.50 **	-18.03**	-18.86**	-21.40**	2.00	-1.83	-2.42*	5.56**
20	NH22141 Bt X AC 738 Bt	-1.96	5.60	-0.16	-7.43*	-19.19 **	-11.62**	-12.51**	-15.25**	-3.95 **	-3.85**	-4.44**	3.38**
	SE±	1.05				0.41				0.05			0.05
	CD at 95%	2.20				0.86				0.11			0.11
	CD at 99%	3.01				1.18				0.16			0.16

Note:- BPH- Btter parent heterosis, SH- Heterosis over check hybrid NHH 44 BG II, JH- Heterosis over check hybrid jadoo BG II, UH- Heterosis over check Suraj Bt

Table 2: contd… Heterobeltiosis, useful and standard heterosis for different characters in *Gossypium hirsutum* L

Sr. no.	crosses	Fibre strength (g/tex)				Uniformity ratio (%)			
		BPH	SH	JH	UH	BPH	SH	JH	UH
1	NH22026 Bt X NH22065 Bt	9.59 *	4.88**	0.19	10.72**	1.13 **	-0.03	-1.16**	-1.02**
2	NH22026 Bt X NH22037 Bt	-10.31 **	-3.13**	-7.46**	2.27	-0.95 **	-0.06	-1.19**	-1.05**
3	NH22026 Bt X NH22075 Bt	4.38	7.03**	2.24*	12.99**	-1.18 **	1.16**	0.02	0.15
4	NH22026 Bt X AC 738 Bt	-0.82	-5.08**	-9.33**	0.21	1.08 **	0.93**	-0.21	-0.08
5	NH22057 Bt X NH22065 Bt	-2.64	0.78	-3.73**	6.39**	1.10 **	0.95**	-0.19	-0.05
6	NH22057 Bt X NH22037 Bt	-7.05 *	0.39	-4.10**	5.98**	0.13	1.03**	-0.11	0.02
7	NH22057 Bt X NH22075 Bt	-3.02	0.39	-4.10**	5.98**	-1.13 **	1.21**	0.07	0.21
8	NH22057 Bt X AC 738 Bt	-3.40	0.00	-4.48**	5.57**	1.10 **	0.96**	-0.18	-0.05
9	NH22097 Bt X NH22065 Bt	-4.79	0.98	-3.54**	6.60**	-0.98 **	-0.05	-1.18**	-1.05**
10	NH22097 Bt X NH22037 Bt	-6.33	1.17	-3.36**	6.80**	0.34	1.27**	0.13	0.26
11	NH22097 Bt X NH22075 Bt	-0.92	5.08**	0.37	10.93**	-0.28	2.08**	0.92**	1.06**

12	NH22097 Bt X AC 738 Bt	-0.55	5.47**	0.75	11.34**	-0.14	0.79**	-0.35	-0.21
13	NH22107 Bt X NH22065 Bt	5.88	-1.56	-5.97**	3.92**	2.19 **	-0.17	-1.29**	-1.16**
14	NH22107 Bt X NH22037 Bt	-3.07	4.69**	0.00	10.52**	-1.04 **	-0.15	-1.28**	-1.15**
15	NH22107 Bt X NH22075 Bt	-2.86	-0.39	-4.85**	5.15**	-1.32 **	1.01**	-0.13	0.01
16	NH22107 Bt X AC 738 Bt	9.45 *	1.76	-2.80*	7.42**	-0.20	-0.35	-1.48**	-1.34**
17	NH22141 Bt X NH22065 Bt	-2.99	1.56	-2.99**	7.22**	-2.34 **	-1.28**	-2.39**	-2.26**
18	NH22141 Bt X NH22037 Bt	-4.52	3.12**	-1.49	8.87**	-0.23	0.84**	-0.29	-0.16
19	NH22141 Bt X NH22075 Bt	1.87	6.64**	1.87	12.58**	-1.20 **	1.14**	-0.01	0.13
20	NH22141 Bt X AC 738 Bt	-2.24	2.34*	-2.24**	8.04**	-1.07 **	-0.01	-1.13**	-1.00**
	SE±	0.90				0.19			
	CD at 95%	1.88				0.41			
	CD at 99%	2.57				0.56			

Note:- BPH- Btter parent heterosis, SH- Heterosis over check hybrid NHH 44 BG II, JH- Heterosis over check hybrid jadoo BG II, UH-Heterosis over check Suraj Bt

Conclusion

The present investigation revealed significant heterotic effects for key agronomic and fibre quality traits in cotton, underscoring the potential of specific hybrids for commercial exploitation. Among the crosses evaluated, NH 22097 Bt × AC 738 Bt emerged as the most promising hybrid, exhibiting superior performance for seed cotton yield per plant, boll weight and number of sympodia, along with favourable heterosis across all standard checks. The hybrid NH22026 Bt × NH22065 Bt was notably early in flowering and maturity, making it suitable for early cropping systems. For fibre quality traits such as micronaire value and uniformity ratio, NH 22097 Bt × NH 22075 Bt and NH 22097 Bt × NH 22065 Bt demonstrated desirable values, indicating their suitability for improving fibre characteristics. Overall, the expression of positive heterosis over better parent and standard check hybrids highlights the scope for developing high-yielding, early-maturing and quality fibre genotypes through hybrid breeding in cotton.

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