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Research Article

Assessment of heterosis and combining ability for fibre yield, its contributing and quality traits in *Bt* BGII upland cotton (*Gossypium hirsutum* L.)

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Abstract
Heterosis breeding is one of the most practical and accomplishing tool for cotton improvement. In this context 32 intra-specific hybrids derived from eight lines and four testers were evaluated on multi-location to assess heterosis and combining ability for seed cotton yield and its contributing traits. Significant heterosis was observed in the crosses NH-2260 BGII x NH-2236 BGII, NH-2202 BGII x NH-2289 BGII and NH-2224 BGII x NH-2289 BGII for seed cotton yield and yield contributing characters over a better parent and best check. Combing ability analysis suggested the preponderance of non-additive gene action for most of studied traits. The line NH-2230 BGII and NH-2260 BGII were observed to be good general combiners for seed cotton yield and its contributing traits and the tester NH-2289 BGII was identified as the best general combiner for seed cotton yield and its contributing characters, ginning outturn, lint index. The hybrid NH-22105 BGII x NH-2236 BGII exhibited a significant positive SCA effect for seed cotton yield per plant.

Keywords: Gene action, *Bt* BG II, Combining ability, Heterosis, Upland cotton

INTRODUCTION

Cotton (*Gossypium spp.*) is one of the most important fiber crops globally, serving as a key raw material for the textile industry and contributing significantly to the economies of many countries. The major cotton-producing countries are India, China, the United States, and Brazil globally. India has emerged as a leading cotton producer, owing to its vast cultivation area and the adoption of advanced technologies like *Bt* (*Bacillus thuringiensis*) cotton varieties, including the BGII (Bollgard II) trait. *Bt* BGII cotton is crucial for its ability to provide dual protection against key pests like bollworms, significantly reducing crop losses and minimizing the need for chemical pesticides. This leads to higher yields and more sustainable cotton production. Hybrid cotton farming plays a significant role in India's cotton production.

The quest for high-yielding cotton varieties is critical in meeting the ever-growing demands of the textile industry and ensuring food security by optimizing land use. Among the various genetic tools available to breeders, heterosis (hybrid vigor) and combining ability stand out as pivotal concepts in developing superior cotton hybrids. Heterosis refers to the phenomenon where hybrid offspring exhibit superior traits, such as higher yield or improved fiber quality, compared to their parental lines. Combining ability, on the other hand, is the capacity of a parent to transmit its desirable traits to its progeny, which is essential in hybrid breeding programs. (Sprague and Tatum, 1942). The interaction between genetic factors and environmental conditions predominantly influences the cotton yield traits. In contrast, genetic factors alone primarily govern the ginning outturn and fiber quality characteristics (Shahzad *et al.*, 2019).

The importance of heterosis and combining ability in cotton breeding cannot be overstated. These genetic principles allow breeders to develop hybrids with enhanced productivity, resistance to pests and diseases, and adaptability to varying environmental conditions. *Bt* BGII cotton hybrids have shown promising results in increasing cotton yields while reducing the need for chemical inputs, thus contributing to sustainable agricultural practices. In this context a study was undertaken to evaluate heterosis and gene action of 32 hybrids along with parental genotypes and commercial check hybrids.

MATERIALS AND METHODS

The experiment commenced during the *Kharif* season of 2022-23. The crossing program was conducted at the Cotton Research Station in Nanded by line x testers fashion to produce cross seeds through manual emasculation followed by pollination Dock (1934) for conventional hybrid seed production. A complete set of 46 entries, consisting of 32 F_1 hybrids, eight lines (NH-2202 BGII, NH-2224 BGII, NH-2230 BGII, NH-2260 BGII, NH-2274 BGII, NH-2292 BGII, NH-22105 BGII, NH-22126 BGII), four testers (NH-2212 BGII, NH-2236 BGII, NH-2247 BGII, NH-2289 BGII) and checks (NHH44 BGII and MRC7347 BGII) were sown in Randomized Block Design with two replications of plot size 2.4 x 6 m^2 , during the *Kharif* season of 2023-24 at three different environments, namely: Cotton Research Station, Nanded (E1), Cotton Research Station at Mahboob Baugh Farm, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (E2), and Agricultural Research Station, Somnathpur (E3).

Observations for all traits *viz*., days to 50% flowering, days to maturity, plant height (cm), number of bolls per plant, number of sympodia per plant, boll weight (g), seed cotton yield per plant (g), lint index(g), seed index(g), ginning outturn (%),upper half mean length (mm), fibre fineness (µg/ inch), fibre strength (g/ tex), uniformity ratio (%) were documented from five randomly chosen competitive plants within each entry, replication, and environment, except for traits such as days to 50 percent flowering and days to maturity, which were recorded based on the entire plot.

The mean data for different characters obtained from the experiments laid out in randomized block design was statistically analyzed for individuals as well as pooled over the environments. The per cent heterosis was calculated as per the procedure suggested by Fonseca and Patterson (1968) and Meredith and Bridge (1972) for individual as well as over the environments. The combining ability analysis pooled over environments for the characters under study was carried out based on the procedure developed by Kempthorne (1957) related to design II of Comstock and Robinson (1963). All the statistical analysis was performed using Windostat version 9.2 for line x tester analysis.

RESULTS AND DISCUSSION

Variance analysis and estimation of gene action: Analysis of variance over pooled environment revealed (**Table 1**) that mean squares due to lines were significant for the characters except for days to 50% flowering and the number of sympodia per plant while, mean squares due to testers were non- significant for days to 50% flowering, days to maturity, boll weight, fiber strength and uniformity ratio. Mean squares due to L vs T were significant for all the characters except days to 50% flowering, number of sympodia per plant, number of bolls per plant, seed index, lint index and fibre fineness. The values of parent’s vs crosses were non-significant for seed index and fibre fineness. Mean sum squares due to crosses were significant for all the characters except days to 50% flowering.

From a statistical standpoint, comparing mean squares is more logical for evaluating the predictability ratio, which assesses the relative importance of GCA and SCA effects for a specific trait to understand its gene action. The significance of the mean squares for line x tester interactions directly indicates the dominance variance, while the significance of the mean squares for lines and testers indicates the additive variance. Similar results were obtained by Ahuja and Dhayal, (2007), Basal *et al.* (2011), Usharani *et al.* (2014), Naik *et al.* (2019) and Hamed *et al.* (2021). Proportional contribution of lines, testers and lines x testers pooled over environment (**Table 2**) revealed that, the per cent contribution of testers towards total variances were greater than lines for all characters except seed cotton yield per plant and UHML. The proportional contribution of lines x testers interaction was found to be greater than lines and testers for days to 50% flowering, days to maturity, plant height, number of sympodia per plant, number of bolls per plant, seed cotton yield per plant, seed index, fibre strength and uniformity ratio. The estimate of variance components revealed that, the magnitude of SCA variance was greater than corresponding GCA variance for traits days to 50% flowering, days to maturity, plant height, number of bolls per plant, seed cotton yield per plant, seed index, fibre strength and uniformity ratio (Khokhare *et al.,* 2018, Rathava *et al.,* 2018). GCA/SCA ratio less than unity indicated non additive gene action for governing these traits and can be exploited through heterosis breeding. If this ratio is around 1, it shows the significance of additive gene action (Mawblei *et al*., 2022). In the traits where non- fixable component is predominant, heterosis breeding and recombination breeding with postponement of selection at later generations would be feasible. Boll weight (Manan *et al*., 2022), UHML and fibre fineness (Fatima *et al*., 2022) and ginning outturn % (Manan *et al*., 2022) were governed by additive gene action. Selecting an optimal female parent is essential in hybridization programs. (Khan *et al.,* 2011) emphasized that maternal effects transmitted *via* the cytoplasm play a significant role in combining ability and that F_1 hybrids exhibiting favorable reciprocal effects should be considered for future breeding. Similarly, Singh *et al.* 2010 advocated for the selection of female parents based on reciprocal analysis. They reported that such combinations might

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Table 1. Pooled analysis of variance for parents and crosses

Source of variation	df	Days to 50 % flowering	Days to maturity	Plant height	No. of sympodia per plant	No. of boll per plant	Boll weight	Seed cotton yield per plant	Seed Index	Lint Index	Ginning outturn%	UHML (mm)	fibre fineness value (µg/ inch)	Fibre strength (g/ tex)	Uniformity Ratio (%)
Replication	**1**	15.55	5.01	1.95	2.96	29.55	0.07	44.38	0.56	0.02	1.12	1.08	0.80	0.03	**0.28**
Genotype	**43**	27.47**	64.71**	1069.10**	610.27**	190.21**	1.51**	8314.04**	3.90**	3.73**	28.55**	8.61**	0.94**	8.50**	10.92**
Parents	**11**	8.95	13.13**	1426.011**	20.35**	17.23**	0.88**	2059.59**	4.43**	1.83**	10.07**	10.69**	0.65**	3.19*	3.88*
Lines	**7**	8.42	14.00*	1875.33**	6.04	12.51**	109.42**	1.08**	4.11**	1.86**	16.29**	6.93**	0.69**	3.14*	4.54*
Tester	**3**	13.12	0.79	764.90**	59.93**	33.09**	0.27	4709.41**	6.32**	2.31**	10.05**	12.92**	0.74*	2.45	1.34
Line x Tester	**1**	0.08	44.08**	264.06**	1.8	2.72	136.53**	1.33*	0.95	0.26	12.57*	30.34**	0.04	5.76*	6.89*
Parent Vs Crosses	**1**	827.50**	2180.54**	100019.61**	1600.46**	6912.92**	9.77**	222687.90**	3.60	4.47**	17.66*	48.79**	0.23	5.98*	14.63**
Crosses	**31**	8.23	14.77**	653.73**	97.20**	34.73**	1.46**	3618.08*	3.72**	4.38**	33.68**	6.58**	1.07**	10.46**	13.30**
Error	**43**	7.88	4.7	13.65	3.23	3.91	0.29	62.31	1.11	0.57	2.93	2.01	0.23	1.44	1.69

*,**-Significant at 5 per cent and 1 per cent level, respectively

Table 2. Percent contribution of lines, testers and lines x testers pooled over environments

S. No.	Characters	Source of variation			S. No.	Characters	Source of variation		
		Lines	Testers	L x T			Lines	Testers	L x T
1	Days to 50% flowering	37.46	13.18	49.35	8	Seed index	41.76	6.05	52.18
2	Days to maturity	18.54	17.07	64.37	9	Lint index	47.27	24.29	28.42
3	Plant height	43.35	16.33	40.3	10	Ginning outturn %	63.42	23.42	13.15
4	No. of Sympodia per plant	18.6	25.73	55.66	11	UHML (mm)	17.58	43.7	38.71
5	No. of bolls per plant	34.22	6.29	59.48	12	fibre fineness value (µg/ inch)	66.19	7.82	25.98
6	Boll weight	58.77	14.94	26.27	13	Fibre strength (g/ tex)	39.27	4.9	55.82
7	Seed cotton yield per plant	19.59	30.12	50.27	14	Uniformity Ratio (%)	51.25	3.35	45.38

produce desirable transgressive segregants, which could be utilized to develop improved genotypes if additive gene effects are involved. In the present study both GCA and SCA variances were highly significant for most of the characters studied. This suggested that both additive and non-additive variances were important in the expression of these characters.

General Combining ability of lines and testers: The estimates of GCA effects of parents as well as SCA effects of crosses were estimated pooled over environments. The results of GCA effects (**Table 3**) and SCA effects (**Table 4**) for different characters showed that, among lines NH-2274 BGII (-2.53), NH-2202 BGII (-1.90) and NH-2202 BGII (-0.58) possessed significant negative GCA effect for days to 50% flowering (Gopal *et al.,* 2020), days to maturity (Ramdan *et al.,* 2021) and fibre fineness (Naik *et al.,* 2019) respectively. Negative significant values considered to be desirable for these traits. Days to 50% flowering and days to maturity is important morphological trait for earliness of the genotypes. Best general combiners for days 50% flowering and days to maturity will help to develop the early crosses (Basbag *et al.,* 2007).For the trait plant height, lines NH-2224 BGII (4.11) found to have significant positive desirable GCA effects have been considered good combiners for tallness and line NH-2202 BGII (-2.12) shows significant negative desirable GCA effects and have been considered as good combiners for reduced plant height (Hamed *et al.,* 2021). While NH-2260 BGII showed maximum positive GCA effect for the number of sympodia per plant (3.52) (Reddy *et al.,* 2017), number of bolls per plant (2.15) Rajamani *et al.* (2014),boll weight (0.59) Gopal *et al.* (2020), seed index (1.11) Munir *et al.* (2018) and fibre strength (0.98) Gopal *et al.* (2020). NH-22126 BGII (12.30) followed by NH-2260 BGII (12.29) were good combiners for seed cotton yield per plant (Ganasekaran *et al.,* 2020). Line NH-2230 BGII showed the best general combiner for lint index and ginning outturn%. NH-2202 BGII (0.53) Ramdan *et al.* (2021) and NH-2274 BGII (1.55) were found to be good general combiners for UHML and uniformity ratio respectively.

Among testers, NH-2212 BGII showed a significant negative GCA effect for days to 50% flowering (-0.15), plant height (-4.67) and tester NH-2236 BGII (-0.71) for days to maturity while, NH-2236 BGII (-0.05) found to be non-significant negative for fibre fineness. For the number of sympodia per plant tester NH-2236 BGII (2.40) showed a maximum positive significant GCA effect whereas, tester NH-2289 BGII was found to have the best general combiner for the number of bolls per plant (0.61), boll weight (0.27), seed cotton yield per plant (11.22), lint index (-0.64) and ginning outturn % (1.93). Only NH-2212 BGII (0.31) showed positive significant GCA effects for improving seed index (Balcha *et al.,* 2019). Among the testers, NH-2236 BGII (0.95) had good general combining ability for upper half mean length as they possessed positively significant GCA effects (Ramdan *et al.,* 2021). Tester NH-2247 BGII (0.44) was found to have a positive significant good general combiner for fibre strength Gopal *et al.* (2020). Highest positive significant GCA value for fibre uniformity was reported only in NH-2212 BGII (0.45) showed desirable GCA effects for uniformity ratio. Similar results were reported by Reddy *et al.* (2017).

Specific Combining ability: The cross having high SCA negative effects was NH-22126 BGII x NH-2236 BGII (-0.09) for days to 50% flowering, NH-2224 BGII x NH-2212 BGII (-3.65) for days to maturity Ramdan *et al.* (2021). Among 32 cross combinations, nine crosses possessed significant positive SCA effects for plant height *viz.*, NH-2202 BGII x NH-2236 BGII (11.90) and cross NH-2202 BGII x NH-2212 BGII (-4.85) showed significant negative SCA value and have been considered as the best specific combiners for reduce the plant height Hamed *et al.* (2021). NH-2260 BGII x NH-2236 BGII (5.87) for number of sympodia per plant, NH-22105 BGII x NH-2236 BGII (3.75) for number of bolls per plant and seed cotton yield per plant (36.71) Gananasekaran *et al.* (2020), NH-2292 BGII x NH-2289 BGII (0.45) for boll weight were considered as best specific combiners. NH-2274 BGII x NH-2212 BGII (1.44) and NH-22105 BGII x NH-2212 BGII (1.14) had significant positive SCA effects for seed index and lint index respectively (Kumar *et al.,* 2013). The desirable SCA effects for ginning outturn showed by the cross NH-2230 BGII xNH-2289 BGII (1.34) for upper half mean length revealed that, only one cross *viz.*, NH-2224 BGII x NH-2247 BGII (1.70) had significant positive SCA effects. SCA effects for fibre fineness value revealed that cross NH-2224 BGII x NH-2212 BGII (-0.51) was good specific combiner. The top performing cross NH-2224 BGII x NH-2289 BGII (2.23) for fibre strength and NH-2230 BGII x NH-2236 BGII (2.43) cross combinations were considered as best specific combiners for uniformity ratio as evident from significant positive SCA effect (Reddy *et al.,* 2017). Specific combining ability in desirable direction for different characters is shown in the **table 4**. Among the 32 cross combinations, none of the crosses showed the best specific combiner for all the characters studied, results were in accordance with the previous findings of Alkuddsi *et al.* (2013).

Estimation of heterosis over better parent: The wide range of heterosis for yield and yield contributing characters indicated the vast diversity present among the parents shown in **Table 5**. Heterosis was highly influenced by the environment. There was a strong association between mean performance and heterosis for seed cotton yield along with many other characteristics. Increased mean over high-yielding environments considerably decreased heterobeltiosis for seed cotton yield and vice versa for low yielding environment. The highest negative heterobeltiosis was observed in NH-22105 BGII x NH-2289 BGII (-4.00 %) for days to 50% flowering while for days to maturity in NH-2274 BGII x NH-2212 BGII (-5.34%) Arbad *et al.*(2017). Heterosis over better parent for plant height varied between -6.63 (NH-2202 BGII x NH-2236 BGII) to

Table 3. Pooled estimates of GCA effects of parents studied over three environments

S. No.	Genotypes	Days to 50% flowering	Days to maturity	Plant height	No. of sympodia per plant	No. of bolls per plant	Boll weight	Seed cotton yield per plant	Seed index	Lint index	Ginning outturn%	UHML (mm)	fibre fineness value (µg/ inch)	Fibre strength (g/ tex)	Uniformity Ratio (%)
GCA of Line															
1	NH-2202 BGII	-1.03	-1.90*	-2.12 **	1.19 **	-1.26**	-0.21	0.36	-0.38	-0.56**	-1.49 **	0.53	-0.58 **	0.42	-1.64**
2	NH-2224 BGII	-0.03	0.59	4.11 **	0.51	0.37	0.01	-0.24	0.38	0.04	-1.06 **	-0.4	0.45**	-1.55 **	-1.33**
3	NH-2230 BGII	-0.03	1.46	4.88 **	0.51	0.33	0.53 **	4.93 **	-0.23	0.60**	2.67 **	0.55	0.36**	0.34	-0.46
4	NH-2260 BGII	0.46	-1.40	-6.09 **	3.52 **	2.15**	0.59 **	12.29 **	1.11 **	0.33 *	-2.33 **	0.25	-0.30**	0.98 **	0.33
5	NH-2274 BGII	-2.53 *	0.71	7.94 **	-1.42 **	-1.35**	0.03	-2.88	-0.39	0.09	2.08 **	-0.12	0.17	0.49*	1.55**
6	NH-2292 BGII	1.71	0.96	-1.41 *	-1.66 **	-0.39	-0.39 **	-2.84	-0.26	-0.66 **	-1.15 **	0.25	0.06	0.07	0.73**
7	NH-22105 BGII	1.09	0.46	-13.45 **	-1.89 **	-1.77**	-0.54 **	-23.95 **	-0.39	-0.76 **	-0.95 **	-0.65 *	0.05	-1.11 **	0.05
8	NH-22126 BGII	0.34	-0.90	6.13 **	-0.76	1.93**	-0.03	12.30 **	0.16	0.91 **	2.25 **	-0.41	-0.23*	0.34	0.75**
			GCA of Tester												
1	NH-2212 BGII	-0.15	1.78**	-4.67**	-1.75 **	-0.97**	-0.07	-22.63 **	0.31*	-0.33**	-0.70**	0.17	0.03	-0.04	0.45*
2	NH-2236 BGII	-0.65	-0.71	4.03**	2.40 **	0.25	0.03	5.08 **	-0.13	0.08	-0.83**	0.95**	-0.05	-0.03	-0.16
3	NH-2247 BGII	-0.40	-1.09	-3.59**	-2.20 **	0.1	-0.23**	6.31 **	-0.17	-0.39**	-0.4	-0.19	-0.18**	0.44*	-0.27
4	NH-2289 BGII	1.21	0.03	4.23**	1.56 **	0.61*	0.27**	11.22 **	0	0.64**	1.93**	-0.93**	0.21**	-0.36*	-0.01
	GCA Line	**0.99**	**0.76**	**0.75**	**0.36**	**0.41**	**0.11**	**1.61**	**0.21**	**0.15**	**0.34**	**0.28**	**0.09**	**0.24**	**0.26**
	GCA Tester	**0.7**	**0.54**	**0.53**	**0.25**	**0.29**	**0.07**	**1.13**	**0.15**	**0.1**	**0.24**	**0.2**	**0.07**	**0.17**	**0.18**
	Gi-Gj Line	**1.4**	**1.08**	**1.06**	**0.51**	**0.59**	**0.15**	**2.27**	**0.3**	**0.21**	**0.49**	**0.4**	**0.14**	**0.34**	**0.37**
	Gi-Gj Tester	**0.99**	**0.76**	**0.75**	**0.36**	**0.41**	**0.11**	**1.61**	**0.21**	**0.15**	**0.34**	**0.28**	**0.28**	**0.24**	**0.26**

Table 4. Pooled estimates of SCA effects of crosses studied over three environments

S. No.	Genotypes (Crosses)	Days to 50 % flowering	Days to maturity	Plant height	No. of sympodia per plant	No. of bolls per plant	Boll weight	Seed cotton yield per plant
1	NH-2202 BGII x NH-2212 BGII	0.28	2.34	-4.85**	-2.23**	-0.15	0.05	-3.31
2	NH-2202 BGII x NH-2236 BGII	0.78	-0.15	11.90**	-2.51**	0.83	0.41	7.28
3	NH-2202 BGII x NH-2247 BGII	-2.96	-1.78	-9.71**	-1.00	-2.55**	-0.41	-31.36**
4	NH-2202 BGII x NH-2289 BGII	1.90	-0.40	2.66	5.76**	1.87*	-0.06	27.39**
5	NH-2224 BGII x NH-2212 BGII	1.28	-3.65*	-9.65**	-0.35	1.07	0.15	-13.49**
6	NH-2224 BGII x NH-2236 BGII	-0.71	-1.65	-0.94	-3.88**	-0.77	-0.63**	0.78
7	NH-2224 BGII x NH-2247 BGII	2.03	3.71*	1.01	-1.14	-0.98	0.14	-5.81
8	NH-2224 BGII x NH-2289 BGII	-2.59	1.59	9.58**	5.38**	0.68	0.33	18.53**
9	NH-2230 BGII x NH-2212 BGII	-0.21	-0.03	0.36	0.24	-1.38	0.19	9.05*
10	NH-2230 BGII x NH-2236 BGII	1.78	1.46	1.66	4.20**	-0.18	0.09	15.71**
11	NH-2230 BGII x NH-2247 BGII	-0.46	-2.15	-3.58*	-1.45	-0.60	-0.02	-18.29**
12	NH-2230 BGII x NH-2289 BGII	-1.09	0.71	1.55	-2.99**	2.16*	-0.25	-6.48
13	NH-2260 BGII x NH-2212 BGII	1.28	2.84	7.18**	-3.77**	2.25**	0.06	-12.76**
14	NH-2260 BGII x NH-2236 BGII	-1.71	-3.15*	0.71	5.87**	-0.03	0.24	23.55**
15	NH-2260 BGII x NH-2247 BGII	0.03	0.21	1.97	-2.71**	-0.23	-0.16	-9.39**
16	NH-2260 BGII x NH-2289 BGII	0.40	0.09	-9.86**	0.61	-1.99*	-0.15	-1.39
17	NH-2274 BGII x NH-2212 BGII	-0.21	1.21	9.05**	1.57*	-1.81*	-0.09	-6.84
18	NH-2274 BGII x NH-2236 BGII	0.78	2.71	-20.48**	-2.76**	-3.56**	0.10	-18.62**
19	NH-2274 BGII x NH-2247 BGII	-0.96	-3.40*	6.99**	2.41**	2.49**	0.15	14.84**
20	NH-2274 BGII x NH-2289 BGII	0.40	-0.53	4.42**	-1.22	2.88**	-0.16	10.63**
21	NH-2292 BGII x NH-2212 BGII	-0.96	-0.03	-0.37	0.97	0.74	-0.33	-7.42*
22	NH-2292 BGII x NH-2236 BGII	1.53	-0.46	1.75	-2.81**	-1.07	-0.40	-11.92**
23	NH-2292 BGII x NH-2247 BGII	-0.21	1.34	2.19	2.70**	0.52	2.88	14.14**
24	NH-2292 BGII x NH-2289 BGII	-0.34	-1.78	-3.57*	-0.86	-0.19	0.45*	5.20
25	NH-22105 BGII x NH-2212BGII	1.56	0.46	2.93*	3.95**	-2.67**	0.19	21.80**
26	NH-22105 BGII x NH-2236BGII	-2.34	-4.03*	3.40*	-2.32**	3.75**	0.10	-27.92**
27	NH-22105 BGII x NH-2247BGII	-0.09	2.84	2.39	2.30**	1.77*	-0.16	36.71**
28	NH-22105 BGII x NH-2289BGII	1.28	0.71	-8.73**	-3.93**	-2.85**	-0.13	-30.59**
29	NH-22126 BGII x NH-2212BGII	-2.59	-3.15*	-4.64**	-0.39	1.94*	-0.23	12.98**
30	NH-22126 BGII x NH-2236BGII	-0.09	4.34*	1.98	4.23**	1.03	0.07	11.14**
31	NH-22126 BGII x NH-2247BGII	2.65	-0.78	-1.28	-1.09	-0.42	0.18	-0.83
32	NH-22126 BGII x NH-2289BGII	0.031	-0.40	3.94**	-2.74**	-2.56**	-0.01	-23.29**
	Sij – Skl	**2.80**	**2.17**	**1.99**	**1.11**	**1.18**	**0.31**	**4.55**
	Sij – Sik	**4.21**	**3.25**	**2.99**	**1.67**	**1.77**	**0.46**	**6.83**

Table 4. cont..

S. No	Genotypes (Crosses)	Seed index	Lint index	Ginning outturn %	UHML (mm)	fibre fineness value(µg/ inch)	Fibre strength (g/ tex)	Uniformity index
1	NH-2202 BGII x NH-2212 BGII	-0.21	-0.32	-0.28	0.86	0.24	0.49	-1.53**
2	NH-2202 BGII x NH-2236 BGII	-0.52	0.16	0.06	-0.85	-0.22	0.61	0.37
3	NH-2202 BGII x NH-2247 BGII	0.30	-0.03	1.03	0.86	0.00	1.38**	1.31*
4	NH-2202 BGII x NH-2289 BGII	0.44	0.19	-0.82	-0.86	-0.02	-2.4**	-0.16
5	NH-2224 BGII x NH-2212 BGII	-0.37	0.05	1.05	-0.86	-0.51*	-1.84**	0.10
6	NH-2224 BGII x NH-2236 BGII	0.06	-0.14	0.18	-0.25	0.03	-0.92	-0.70
7	NH-2224 BGII x NH-2247 BGII	-0.14	-0.08	-1.46*	-0.59	0.02	0.53	0.34
8	NH-2224 BGII x NH-2289 BGII	0.45	0.17	0.23	1.70**	0.44*	2.23**	0.25
9	NH-2230 BGII x NH-2212 BGII	-1.09*	-0.65*	-0.45	0.37	0.06	-0.48	-1.45**
10	NH-2230 BGII x NH-2236 BGII	0.69	0.31	0.42	-0.40	-0.10	0.75	2.43**
11	NH-2230 BGII x NH-2247 BGII	0.54	0.11	-1.31	-0.88	0.18	-1.12*	-1.07**
12	NH-2230 BGII x NH-2289 BGII	-0.14	0.22	1.34	0.91	-0.14	0.85	0.08
13	NH-2260 BGII x NH-2212 BGII	-0.51	-0.64*	1.09	0.07	-0.26	0.46	0.70
14	NH-2260 BGII x NH-2236 BGII	-0.46	0.47	-0.30	-0.27	0.12	-0.23	-0.57
15	NH-2260 BGII x NH-2247 BGII	0.53	0.47	-0.21	-0.17	0.15	-0.26	0.28
16	NH-2260 BGII x NH-2289 BGII	0.44	-0.30	-0.57	0.37	-0.01	0.04	-0.41
17	NH-2274 BGII x NH-2212 BGII	1.44**	-0.80**	1.20	0.09	-0.07	-0.32	0.08
18	NH-2274 BGII x NH-2236 BGII	-0.08	0.29	-0.98	1.02	-0.21	-0.14	0.78
19	NH-2274 BGII x NH-2247 BGII	-0.53	-0.33	0.24	-0.11	0.04	1.33*	0.24
20	NH-2274 BGII x NH-2289 BGII	-0.82	0.84**	-0.45	-1.01	0.23	-0.86	-1.11*
21	NH-2292 BGII x NH-2212 BGII	1.08*	0.56	-1.49*	-0.43	0.23	0.78	-0.06
22	NH-2292 BGII x NH-2236 BGII	0.17	-0.39	-1.06	0.05	0.24	-0.16	-1.66**
23	NH-2292 BGII x NH-2247 BGII	-0.62	-0.07	1.23	0.34	-0.14	-0.52	0.39
24	NH-2292 BGII x NH-2289 BGII	-0.62	-0.09	1.32	0.04	-0.33	-0.09	1.33**
25	NH-22105 BGII x NH-2212BGII	0.42	1.14**	-0.67	0.27	0.07	1.59**	1.01
26	NH-22105 BGII x NH-2236BGII	-0.08	-0.37	0.95	0.09	-0.03	-0.38	1.11*
27	NH-22105 BGII x NH-2247BGII	-0.22	-0.08	0.22	0.34	0.14	-1.31*	-0.92
28	NH-22105 BGII x NH-2289BGII	-0.11	-0.67*	-0.50	-0.71	-0.18	0.10	-1.20*
29	NH-22126 BGII x NH-2212BGII	-0.74	0.66*	-0.44	-0.39	0.22	-0.68	1.16*
30	NH-22126 BGII x NH-2236BGII	0.23	-0.33	0.72	0.62	0.17	0.49	-1.72**
31	NH-22126 BGII x NH-2247BGII	0.155	0.02	0.25	0.21	-0.41*	-0.02	-0.59
32	NH-22126 BGII x NH-2289BGII	0.36	-0.36	-0.54	-0.45	0.01	0.21	1.21*
	Sij – Skl	**0.60**	**0.43**	**0.98**	**0.81**	**0.28**	**0.69**	**0.75**
	Sij – Sik	**0.91**	**0.65**	**1.48**	**1.22**	**0.42**	**1.04**	**1.12**

-34.62 percent (NH-2274 BGII x NH-2236 BGII). Among 32 crosses, none of the crosses exhibited significant positive heterobeltiosis (Malathi *et al.,* 2019).The highest significant positive heterobeltiosis obtained in the cross NH-2260 BGII x NH-2236 BGII to the extent of 162.57 percent for number of sympodia per plant (Islam *et al.,* 2021). The heterosis value over better parent for number of bolls per plant has been ranging from NH-22105 BGII x NH-2247 BGII (31.22%) to NH-2274 BGII x NH-2236 BGII (150.04%). All 32 crosses showed significant positive heterosis over better parent Patil *et al.* (2019). The cross NH-2292 BGII x NH-2289 BGII (29.77%) possessed highest better parent heterosis for boll weight and cross NH-2274 BGII x NH-2247 BGII (278.66%) recorded highest significant positive heterobeltiosis for seed cotton yield per plant Naik *et al.* (2019). Plotting the heterobeltiosis of the top five high-yielding cotton crosses against the environmental mean reveals a decrease in heterosis for yield as the environmental mean increases. This trend may be due to the physiological responses of the crosses, influenced by individual buffering in varying environmental conditions. Cole *et al*. (2009) also observed a similar pattern of heterosis. Heterobeltiosis for highest seed index and lint index was observed in cross NH-2292 BGII x NH-2212 BGII (18.00%), NH-2230 BGII x NH-2289 BGII (41.82%) respectively. Whereas, cross NH-2230 BGII x NH-2289 BGII (14.86%) for ginning outturn % , NH-2230 BGII x NH-2289 BGII (9.39%) for UHML, NH-22126 BGII x NH-2212 BGII (-0.76) for fibre fineness, NH-2274 BGII x NH-2247 BGII (8.07%) for fibre strength and cross NH-2230 BGII x NH-2236 BGII (3.62%) for uniformity ratio showed to have maximum heterosis over better parent for respective traits. Similar findings were also reported by Sirisha *et al.* (2019) and Bilwal *et al.* (2018).

Useful Heterosis: The range of heterosis over standard check *i.e*. useful heterosis has been given in **Table 5**. For days to 50% flowering significant negative heterosis over the best check (MRC 7347 BGII), it varies from -4.64 (NH-22105 BGII x NH-2289 BGII) to -15.23 percent (NH-2202 BGII x NH-2247 BGII) Bilwal *et al.* (2018). Standard heterosis was in the range of -3.16 (NH-2274 BGII x NH-2212 BGII) to -8.33 percent (NH-2260 BGII x NH-2236 BGII) over check MRC 7347 BGII and for check NHH 44 BGII it was in range of -3.99 (NH-2274 BGII x NH-2212 BGII) to -9.12 (NH-2260 BGII x NH-2236 BGII) for the trait days to maturity. The days for 50 % flowering and days to maturity is indication of earliness and negative heterosis has been considered as desirable for both the traits Arbad *et al.* (2017). The heterosis over standard check NHH 44 BGII was in the range of -1.39 (NH-2224 BGII x NH-2247 BGII) to 12.99 percent (NH-2224 BGII x NH-2289 BGII) for the trait plant height. Plant height in cotton is a vital morphological characteristic because it forms the foundation for nodes and internodes, which ultimately shape the plant's structure and significantly impact cotton yield. The results are similar to the finding of Muthu *et al.* (2005). Standard heterosis over the check NHH 44 BGII range varied from -0.11 (NH-2260 BGII x NH-2289 BGII) to 26.52 percent (NH-2260 BGII x NH-2236 BGII). Among 32 only NH-2260 BGII x NH-2236 BGII (26.52%) cross combination recorded significant positive heterosis for number of sympodia per plant. While range of standard heterosis over check MRC 7347 BGII was -3.38 (NH-2224 BGII x NH-2289 BGII) to 13.63 percent (NH-2260 BGII x NH-2236 BGII). The number of sympodia in cotton is significant because it directly influences the plant's branching pattern, flower production, and boll development, which are critical factors for overall cotton yield and quality. High heterosis for sympodial branches was also revealed by Islam *et al.* (2021). The highest significant positive standard heterosis was observed in the cross NH-2260 BGII x NH-2236 BGII (44.47% and 46.04 %) over checks NHH 44 BHII and MRC 7347 BGII respectively. Range of -0.27 (NH-2292 BGII x NH-2236 BGII) to 43.33 percent (NH-2260 BGII x NH-2236 BGII) over check NHH 44 BGII whereas, over check MRAC 7347 BGII range of standard heterosis varied from -0.65 (NH-22105 BGII x NH-2289 BGII) to 30.34 percent (NH-2260 BGII x NH-2236 BGII). Farmers prefer cotton with larger boll sizes as they are easier to pick. Boll weight is a crucial trait that significantly contributes to yield and directly impacts the seed cotton yield. High heterosis for boll weight is also recorded by Patil *et al.* (2019). The percent economic heterosis varied in between -2.93(NH-2230 BGII x NH-2247 BGII) to 36.12 percent (NH-2260 BGII x NH-2236 BGII). Sixteen crosses exhibited significant positive heterosis over NHH 44 BGII for this trait. While, percent economic heterosis for seed cotton yield per plant varied in between -1.31 (NH-22126 BGII x NH-2247 BGII) to 27.98 percent (NH-2260 BGII x NH-2236 BGII) over a check MRC 7347 BGII. Twelve crosses recorded significant positive heterosis over check MRC 7347 BGII. A wide range of heterosis was observed for seed cotton yield, likely due to the high variability in yield-contributing traits such as the number of sympodia per plant and the number of bolls per plant. This variability in heterosis for yield highlights the complexity of yield traits and demonstrates the potential for commercial exploitation of heterosis and hybrid vigor Naik *et al.* (2019). The cross NH-2260 BGII x NH-2289 BGII (22.87%) and cross NH-2260 BGII x NH-2289 BGII (10.95%) exhibited maximum economic heterosis over check NHH 44 BGII and MRC 7347 BGII respectively for seed index. The seed index is significant as it represents the weight of seeds, which is a critical factor in determining the overall seed quality and yield. A higher seed index typically correlates with better seed health and potential for higher cotton production. The results confirmed the findings of Mangi *et al.* (2019). The cross NH2274 BGII xNH-2289 BGII recorded the top ranking in pooled analysis over both checks for the lint index. The heterosis for ginning outturn ranged between -1.11 (NH-2224 BGII x NH-2236 BGII) to 20.88 (NH-2230 BGII x NH-2289 BGII) over check NHH 44 BGII on a pooled basis. While, over check MRC 7347

Table 5. Heterosis over better parent and standard check for traits under study

S. No.	Treatments	Days to 50% flowering			Days to maturity			Plant height		
		BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII
1	NH-2202 BGII x NH-2212 BGII	-10.00 *	-10.00 *	-10.60 **	-6.18 **	-4.84 **	-4.02 **	-18.46**	-12.95**	-14.90**
2	NH-2202 BGII x NH-2236 BGII	-13.46 **	-10.00 *	-10.60 **	-8.99 **	-7.69 **	-6.90 **	-6.63**	9.38**	6.93**
3	NH-2202 BGII x NH-2247 BGII	-16.34 **	-14.67 **	-15.23 **	-10.36 **	-8.83 **	-8.05 **	-16.80**	-16.27**	-18.15**
4	NH-2202 BGII x NH-2289 BGII	-6.00	-6.00	-6.62	-8.71 **	-7.41 **	-6.61 **	-17.21**	1.46	-0.81
5	NH-2224 BGII x NH-2212 BGII	-4.14	-7.33	-7.95 *	-8.15 **	-6.84 **	-6.03 **	-18.32**	-11.69**	-13.67**
6	NH-2224 BGII x NH-2236 BGII	-14.10 **	-10.67 **	-11.26 **	-7.91 **	-7.12 **	-6.32 **	-11.58**	3.58**	1.26
7	NH-2224 BGII x NH-2247 BGII	-8.50 *	-6.67	-7.28	-5.88 **	-4.27 **	-3.45 **	-8.90**	-1.39	-3.60*
8	NH-2224 BGII x NH-2289 BGII	-10.67 **	-10.67 **	-11.26 **	-6.18 **	-4.84 **	-4.02 **	-7.80**	12.99**	10.46**
9	NH-2230 BGII x NH-2212 BGII	-7.48	-9.33 *	-9.93 *	-5.88 **	-4.27 **	-3.45 **	-9.41**	-2.22	-4.41*
10	NH-2230 BGII x NH-2236 BGII	-10.90 **	-7.33	-7.95 *	-6.44 **	-4.84 **	-4.02 **	-9.05**	6.55**	4.16*
11	NH-2230 BGII x NH-2247 BGII	-11.76 **	-10.00 *	-10.60 **	-8.68 **	-7.12 **	-6.32 **	-11.75**	-4.75**	-6.89**
12	NH-2230 BGII x NH-2289 BGII	-8.67 *	-8.67 *	-9.27 *	-6.44 **	-4.84 **	-4.02 **	-12.99**	6.64**	4.24**
13	NH-2260 BGII x NH-2212 BGII	-6.67	-6.67	-7.28	-5.62 **	-4.27 **	-3.45 **	-11.83**	-5.88**	-7.99**
14	NH-2260 BGII x NH-2236 BGII	-14.74 **	-11.33 **	-11.92 **	-9.89 **	-9.12 **	-8.33 **	-17.98**	-3.92*	-6.07**
15	NH-2260 BGII x NH-2247 BGII	-10.46 **	-8.67 *	-9.27 *	-8.96 **	-7.41 **	-6.61 **	-10.08**	-9.50**	-11.32**
16	NH-2260 BGII x NH-2289 BGII	-6.00	-6.00	-6.62	-8.15 **	-6.84 **	-6.03 **	-29.02**	-13.01**	-14.96**
17	NH-2274 BGII x NH-2212 BGII	-16.56 **	-12.67 **	-13.25 **	-5.34 **	-3.99 **	-3.16 *	-21.32**	8.08**	5.66**
18	NH-2274 BGII x NH-2236 BGII	-15.92 **	-12.00 **	-12.58 **	-5.37 **	-4.56 **	-3.74 **	-34.62**	-10.19**	-12.20**
19	NH-2274 BGII x NH-2247 BGII	-17.83 **	-14.00 **	-14.57 **	-9.80 **	-8.26 **	-7.47 **	-21.95**	7.22**	4.81**
20	NH-2274 BGII x NH-2289 BGII	-14.01 **	-10.00 *	-10.60 **	-7.30 **	-5.98 **	-5.17 **	-18.59**	11.84**	9.33**
21	NH-2292 BGII x NH-2212 BGII	-7.38	-8.00 *	-8.61 *	-5.90 **	-4.56 **	-3.74 **	-24.49**	-8.40**	-10.46**
22	NH-2292 BGII x NH-2236 BGII	-8.97 *	-5.33	-5.96	-6.50 **	-5.70 **	-4.89 **	-16.66**	1.10	-1.17
23	NH-2292 BGII x NH-2247 BGII	-9.15 *	-7.33	-7.95 *	-7.00 **	-5.41 **	-4.60 **	-21.86**	-5.20**	-7.33**
24	NH-2292 BGII x NH-2289 BGII	-5.33	-5.33	-5.96	-7.87 **	-6.55 **	-5.75 **	-21.17**	-3.39	-5.56**
25	NH-22105 BGII x NH-2212BGII	-6.00	-6.00	-6.62	-5.90 **	-4.56 **	-3.74 **	-21.36**	-16.05**	-17.93**
26	NH-22105 BGII x NH-2236BGII	-14.74 **	-11.33 **	-11.92 **	-9.32 **	-8.55 **	-7.76 **	-21.47**	-8.01**	-10.07**
27	NH-22105 BGII x NH-2247BGII	-9.80 *	-8.00 *	-8.61 *	-6.44 **	-4.84 **	-4.02 **	-16.12**	-15.58**	-17.47**
28	NH-22105 BGII x NH-2289BGII	-4.00	-4.00	-4.64	-6.74 **	-5.41 **	-4.60 **	-33.48**	-18.47**	-20.30**
29	NH-22126 BGII x NH-2212BGII	-15.38 **	-12.00 **	-12.58 **	-8.71 **	-7.41 **	-6.61 **	-13.44**	-5.52**	-7.64**
30	NH-22126 BGII x NH-2236BGII	-12.82 **	-9.33 *	-9.93 *	-5.37 **	-4.56 **	-3.74 **	-7.87**	7.92**	5.50**
31	NH-22126 BGII x NH-2247BGII	-8.97 *	-5.33	-5.96	-9.24 **	-7.69 **	-6.90 **	-9.88**	-1.64	-3.84*
32	NH-22126 BGII x NH-2289BGII	-10.26 **	-6.67	-7.28	-8.15 **	-6.84 **	-6.03 **	-10.39**	9.82**	7.36**
	SE±		**2.80**			**2.17**			**2.13**	

Table 5. Continued.

S. No.	Treatments	No. of sympodia per plant			No. of bolls per plant			Boll weight		
		BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII
1	NH-2202 BGII x NH-2212 BGII	28.87 **	-37.18 **	-43.58 **	42.79 **	4.62	5.75	10.65	13.70	3.40
2	NH-2202 BGII x NH-2236 BGII	63.51 **	-20.30 **	-28.42 **	57.77 **	15.59 **	16.85 **	21.23 **	26.25 **	14.81
3	NH-2202 BGII x NH-2247 BGII	35.76 **	-33.82 **	-40.56 **	33.90 **	-1.90	-0.83	-11.79	-2.85	-11.65
4	NH-2202 BGII x NH-2289 BGII	55.26 **	12.19 **	0.76	67.23**	22.52**	23.85**	16.96 *	19.97 *	9.10
5	NH-2224 BGII x NH-2212 BGII	38.48 **	-31.95 **	-38.89 **	128.79 **	18.81 **	20.10 **	12.7	22.38 **	11.29
6	NH-2224 BGII x NH-2236 BGII	43.96 **	-29.26 **	-36.47 **	85.09 **	15.76 **	17.01 **	-3.81	4.45	-5.02
7	NH-2224 BGII x NH-2247 BGII	27.36 **	-37.42 **	-43.79 **	119.57 **	14.03 *	15.26 *	7.19	18.06 *	7.36
8	NH-2224 BGII x NH-2289 BGII	48.87 **	7.57	-3.38	71.70**	24.75**	26.11**	25.97 **	36.79 **	24.39 **
9	NH-2230 BGII x NH-2212 BGII	18.54 *	-29.36 **	-36.55 **	81.77 **	6.44	7.59	9.61	37.50 **	25.04 **
10	NH-2230 BGII x NH-2236 BGII	77.99 **	6.07	-4.74	89.45 **	18.48 **	19.77 **	9.75	37.68 **	25.20 **
11	NH-2230 BGII x NH-2247 BGII	2.82	-38.73 **	-44.97 **	97.55 **	15.68 **	16.93 **	1.6	27.45 **	15.90 *
12	NH-2230 BGII x NH-2289 BGII	-1.73	-28.99 **	-36.23 **	81.47 **	31.85 **	33.28 **	7.45	34.79 **	22.57 **
13	NH-2260 BGII x NH-2212 BGII	37.58 **	-33.76 **	-40.51 **	98.59 **	16.09 **	17.35 **	11.98	35.59 **	23.30 **
14	NH-2260 BGII x NH-2236 BGII	162.57 **	26.52 **	13.63 **	98.84**	44.47**	46.04**	18.37 **	43.33 **	30.34 **
15	NH-2260 BGII x NH-2247 BGII	43.09 **	-31.10 **	-38.12 **	86.73 **	9.16	10.34	3.45	25.27 **	13.92
16	NH-2260 BGII x NH-2289 BGII	38.24 **	-0.11	-10.28 *	41.72 **	2.97	4.09	14.84 *	39.06 **	26.46 **
17	NH-2274 BGII x NH-2212 BGII	27.11 **	-31.98 **	-38.90 **	102.30 **	13.28 *	14.51 *	13.38	16.50	5.95
18	NH-2274 BGII x NH-2236 BGII	25.58 **	-32.79 **	-39.64 **	77.04 **	10.73	11.93 *	19.86 *	24.82 **	13.51
19	NH-2274 BGII x NH-2247 BGII	30.23 **	-30.30 **	-37.40 **	67.23 **	22.52 **	23.85 **	8.00	18.95 *	8.17
20	NH-2274 BGII x NH-2289 BGII	-2.75	-29.73 **	-36.89 **	77.31 **	10.89	12.09 *	28.67 **	23.98 **	12.74
21	NH-2292 BGII x NH-2212 BGII	27.61 **	-35.68 **	-42.23 **	86.00 **	13.37 *	14.60 *	-4.07	-1.42	-10.36
22	NH-2292 BGII x NH-2236 BGII	30.74 **	-34.10 **	-40.81 **	76.65 **	10.48	11.68	-4.23	-0.27	-9.30
23	NH-2292 BGII x NH-2247 BGII	38.61 **	-30.13 **	-37.25 **	93.04 **	17.66 **	18.93 **	0.89	11.12	1.05
24	NH-2292 BGII x NH-2289 BGII	-2.05	-29.23 **	-36.43 **	60.46 **	16.58 **	17.85 **	29.77 **	28.96 **	17.27 *
25	NH-22105 BGII x NH-2212BGII	58.60 **	-23.64 **	-31.42 **	31.22 **	-10.40	-9.42	-3.62	8.81	-1.05
26	NH-22105 BGII x NH-2236BGII	39.15 **	-32.95 **	-39.78 **	86.81 **	27.56 **	28.94 **	-3.31	9.16	-0.73
27	NH-22105 BGII x NH-2247BGII	39.50 **	-32.83 **	-39.68 **	71.34 **	17.00 **	18.27 **	-15.80 *	-4.94	-13.55
28	NH-22105 BGII x NH-2289BGII	-21.98 **	-43.62 **	-49.37 **	32.98 **	-3.38	-2.34	-3.23	9.25	-0.65
29	NH-22126 BGII x NH-2212BGII	37.37 **	-37.74 **	-44.08 **	138.86 **	30.86 **	32.28 **	-9.82	10.72	0.69
30	NH-22126 BGII x NH-2236BGII	108.82 **	0.62	-9.63 *	71.70 **	24.75 **	26.11 **	-0.76	21.84 *	10.80
31	NH-22126 BGII x NH-2247BGII	26.26 *	-42.77 **	-48.60 **	127.26 **	24.50 **	25.85 **	-4.06	17.79 *	7.12
32	NH-22126 BGII x NH-2289BGII	-7.98	-33.51 **	-40.28 **	60.23 **	16.42 **	17.68 **	2.64	26.02 **	14.60
	SE±	**1.03**			**1.18**				**0.31**	

Table 5. Continued.

S. No.	Treatments	Seed cotton yield per plant			Seed index			Lint Index		
		BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII
1	NH-2202 BGII x NH-2212 BGII	106.14 **	-18.01 **	-22.92 **	-2.45	0.20	-9.52	-20.72**	-13.31	-26.36**
2	NH-2202 BGII x NH-2236 BGII	75.53 **	13.17 **	6.4	-19.96 **	-9.01	-17.83 **	-11.87	3.51	-12.07
3	NH-2202 BGII x NH-2247 BGII	107.98 **	-17.28 **	-22.23 **	-13.83 *	0.61	-9.15	-16.95*	-9.19	-22.86**
4	NH-2202 BGII x NH-2289 BGII	78.48 **	34.54 **	26.49 **	1.77	4.53	-5.61	4.77	14.56	-2.69
5	NH-2224 BGII x NH-2212 BGII	62.14 **	-26.80 **	-31.18 **	-11.73	7.74	-2.71	0.27	5.15	-10.68
6	NH-2224 BGII x NH-2236 BGII	66.55 **	7.38 *	0.96	-11.75	7.72	-2.73	-7.08	9.12	-7.30
7	NH-2224 BGII x NH-2247 BGII	128.19 **	3.01	-3.15	-14.34 *	4.55	-5.59	11.62	1.37	-13.89*
8	NH-2224 BGII x NH-2289 BGII	68.24 **	26.82 **	19.23 **	-6.51	14.11	3.04	29.96**	25.48**	6.59
9	NH-2230 BGII x NH-2212 BGII	79.33 **	-4.23	-9.96 **	-15.59 *	-8.76	-17.61 **	-2.31	2.45	-12.97
10	NH-2230 BGII x NH-2236 BGII	91.94 **	23.75 **	16.35 **	-5.25	7.72	-2.73	9.06	28.09**	8.81
11	NH-2230 BGII x NH-2247 BGII	81.77 **	-2.93	-8.74 *	-9.79	5.33	-4.89	27.20**	15.52	-1.87
12	NH-2230 BGII x NH-2289 BGII	46.82 **	10.68 **	4.06	-8.29	-0.88	-10.49	41.82**	36.93**	16.32*
13	NH-2260 BGII x NH-2212 BGII	54.63 **	-15.99 **	-21.02 **	-1.75	14.91 *	3.76	-7.04	-2.51	-17.19*
14	NH-2260 BGII x NH-2236 BGII	111.13 **	36.12 **	27.98 **	-5.78	10.19	-0.50	7.40	26.13**	7.14
15	NH-2260 BGII x NH-2247 BGII	103.05 **	10.31 **	3.71	4.21	21.87 **	10.05	28.95**	17.10*	-0.53
16	NH-2260 BGII x NH-2289 BGII	60.27 **	20.81 **	13.58 **	5.06	22.87 **	10.95	26.29**	21.94**	3.59
17	NH-2274 BGII x NH-2212 BGII	144.23 **	-23.53 **	-28.11 **	2.15	20.44 **	8.76	-14.18	-9.99	-23.54**
18	NH-2274 BGII x NH-2236 BGII	38.71 **	-10.57 **	-15.92 **	-18.39 **	-3.78	-13.11	0.74	18.31*	0.50
19	NH-2274 BGII x NH-2247 BGII	278.66 **	17.67 **	10.64 **	-23.54 **	-9.84	-18.59 **	7.42	-2.45	-17.14*
20	NH-2274 BGII x NH-2289 BGII	56.87 **	18.24 **	11.17 **	-24.70 **	-11.21	-19.82 **	43.88**	38.92**	18.01**
21	NH-2292 BGII x NH-2212 BGII	12.03 *	-23.97 **	-28.52 **	18.00 *	17.64 *	6.23	-3.28	1.43	-13.84*
22	NH-2292 BGII x NH-2236 BGII	39.87 **	-5.08	-10.75 **	-11.12	1.04	-8.76	-22.30**	-8.75	-22.49**
23	NH-2292 BGII x NH-2247 BGII	72.62 **	17.15 **	10.14 **	-22.35 **	-9.33	-18.13 **	-12.53	-11.82	-25.10**
24	NH-2292 BGII x NH-2289 BGII	51.05 **	13.86 **	7.05 *	-6.88	-7.11	-16.12 *	6.37	7.23	-8.91
25	NH-22105 BGII x NH-2212BGII	63.58 **	-17.34 **	-22.29 **	16.24 *	8.00	-2.47	-5.52	10.40	-6.22
26	NH-22105 BGII x NH-2236BGII	0.43	-35.25 **	-39.12 **	-15.27 *	-3.68	-13.02	-23.49**	-10.15	-23.68**
27	NH-22105 BGII x NH-2247BGII	134.23 **	18.35 **	11.27 **	-19.50 **	-6.00	-15.12 *	-4.96	-13.69	-26.68**
28	NH-22105 BGII x NH-2289BGII	-10.37 *	-32.43 **	-36.47 **	-2.25	-2.49	-11.95	-1.96	-5.34	-19.59**
29	NH-22126 BGII x NH-2212BGII	92.61 **	4.96	-1.31	-2.96	0.37	-9.37	26.64**	32.81**	12.81
30	NH-22126 BGII x NH-2236BGII	95.48 **	26.03 **	18.49 **	-5.87	7.00	-3.37	3.86	21.97**	3.61
31	NH-22126 BGII x NH-2247BGII	115.21**	17.28 **	10.27 **	-9.69	5.45	-4.78	31.75**	19.65*	1.63
32	NH-22126 BGII x NH-2289BGII	36.64 **	3.00	-3.16	6.48	10.13	-0.55	36.48**	31.78**	11.94
	SE±		**4.55**			**0.60**			**0.43**	

Table 5. Continued..

Sr. No.	Treatments	Ginning outturn %			UHML(mm)			Fibre fineness (µg/ inch)		
		BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII
1	NH-2202 BGII x NH-2212 BGII	-5.88 *	-3.31	-10.76 **	2.20	14.15 **	-4.03	-1.63	-6.20	-5.47
2	NH-2202 BGII x NH-2236 BGII	-3.27	-2.68	-10.18 **	-0.88	10.70 **	-6.93 **	-14.05 *	-19.38 **	-18.75 **
3	NH-2202 BGII x NH-2247 BGII	0.72	1.34	-6.47 *	0.99	12.79 **	-5.17 *	-22.46 **	-17.05 *	-16.41 *
4	NH-2202 BGII x NH-2289 BGII	-2.4	2.72	-5.20	-7.16 **	3.69	-12.82 **	-16.90 **	-8.53	-7.81
5	NH-2224 BGII x NH-2212 BGII	-0.96	1.75	-6.09 *	-2.75	4.31	-12.31 **	-10.69	0.39	1.17
6	NH-2224 BGII x NH-2236 BGII	-2.11	-1.11	-8.73 **	2.06	9.47 **	-7.96 **	-1.38	10.85	11.72
7	NH-2224 BGII x NH-2247 BGII	-5.58	-4.62	-11.96 **	-3.1	3.94	-12.62 **	-4.14	7.75	8.59
8	NH-2224 BGII x NH-2289 BGII	1.64	6.97 *	-1.27	2.29	9.72 **	-7.76 **	12.76 *	26.74 **	27.73 **
9	NH-2230 BGII x NH-2212 BGII	5.25	8.13 **	-0.20	7.28 *	12.42 **	-5.48 *	-2.70	11.63	12.50
10	NH-2230 BGII x NH-2236 BGII	11.16 **	10.29 **	1.79	5.3	12.42 **	-5.48 *	-8.11	5.43	6.25
11	NH-2230 BGII x NH-2247 BGII	7.39 *	6.54 *	-1.66	5.49	6.40 *	-10.55 **	-4.73	9.30	10.16
12	NH-2230 BGII x NH-2289 BGII	14.86 **	20.88 **	11.57 **	9.39 **	10.33 **	-7.24 **	-3.38	10.85	11.72
13	NH-2260 BGII x NH-2212 BGII	-4.39	-1.77	-9.34 **	2.52	10.21 **	-7.34 **	-8.80	-11.63	-10.94
14	NH-2260 BGII x NH-2236 BGII	-3.08	-6.17 *	-13.39 **	4.00	11.81 **	-6.00 *	-1.60	-4.65	-3.91
15	NH-2260 BGII x NH-2247 BGII	-1.67	-4.68	-12.02 **	0.40	7.93 **	-9.26 **	-13.04 *	-6.98	-6.25
16	NH-2260 BGII x NH-2289 BGII	-4.04	0.99	-6.79 *	-0.23	7.26 *	-9.82 **	-10.56	-1.55	-0.78
17	NH-2274 BGII x NH-2212 BGII	5.3	11.21 **	2.64	1.78	8.92 **	-8.43 **	1.90	3.88	4.69
18	NH-2274 BGII x NH-2236 BGII	-1.01	4.54	-3.51	7.70 **	15.25 **	-3.1	-3.42	-1.55	-0.78
19	NH-2274 BGII x NH-2247 BGII	3.51	9.31 **	0.89	-0.23	6.77 *	-10.24 **	-5.07	1.55	2.34
20	NH-2274 BGII x NH-2289 BGII	7.96 **	14.02 **	5.24	-5.86 *	0.74	-15.31 **	4.58	15.12 *	16.02 *
21	NH-2292 BGII x NH-2212 BGII	-10.59 **	-5.84 *	-13.09 **	-2.11	8.36 **	-8.89 **	5.26	8.53	9.38
22	NH-2292 BGII x NH-2236 BGII	-9.76 **	-4.96	-12.28 **	2.11	13.04 **	-4.96 *	3.38	6.59	7.42
23	NH-2292 BGII x NH-2247 BGII	-2.33	2.87	-5.06	-0.78	9.84 **	-7.65 **	-11.59	-5.43	-4.69
24	NH-2292 BGII x NH-2289 BGII	4.30	9.84 **	1.38	-4.22	6.03 *	-10.86 **	-9.86	-0.78	0.00
25	NH-22105 BGII x NH-2212BGII	-11.84 **	-2.91	-10.39 **	2.70	7.63 *	-9.51 **	3.85	4.65	5.47
26	NH-22105 BGII x NH-2236BGII	-7.91 **	1.41	-6.40 *	2.88	9.84 **	-7.65 **	-0.77	0.00	0.78
27	NH-22105 BGII x NH-2247BGII	-8.69 **	0.56	-7.19 **	5.61	6.52 *	-10.44 **	-5.43	1.16	1.95
28	NH-22105 BGII x NH-2289BGII	-4.51	5.16	-2.94	-0.98	-0.12	-16.03 **	-6.69	2.71	3.52
29	NH-22126 BGII x NH-2212BGII	0.44	6.98 *	-1.26	-0.06	6.03 *	-10.86 **	-0.76	1.55	2.34
30	NH-22126 BGII x NH-2236BGII	3.24	9.96 **	1.49	5.53 *	12.67 **	-5.27 *	-4.17	-1.94	-1.17
31	NH-22126 BGII x NH-2247BGII	3.13	9.85 **	1.39	0.75	6.89 *	-10.13 **	-23.91 **	-18.60 **	-17.97 **
32	NH-22126BGII x NH-2289BGII	7.28 **	14.26 **	5.46 *	-4.12	1.72	-14.48 **	-8.45	0.78	1.56
	SE±		**0.98**			**0.81**			**0.28**	

Table 5. Continued.

S. No.	Treatments	Fibre strength (g/ tex)			Uniformity ratio (%)		
		BPH	NHH44 BGII	MRC7347 BGII	BPH	NHH44 BGII	MRC7347 BGII
1	NH-2202 BGII x NH-2212 BGII	0.00	15.83 **	-8.08 **	-2.96 **	-1.70	-0.61
2	NH-2202 BGII x NH-2236 BGII	0.48	16.38 **	-7.65 **	-0.32	-0.14	0.96
3	NH-2202 BGII x NH-2247 BGII	4.93	21.54 **	-3.55	0.71	0.87	1.99 *
4	NH-2202 BGII x NH-2289 BGII	-11.76 **	2.20	-18.90 **	-0.71	-0.61	0.49
5	NH-2224 BGII x NH-2212 BGII	-13.75 **	-2.00	-22.23 **	-1.07	0.67	1.78
6	NH-2224 BGII x NH-2236 BGII	-10.36 **	1.86	-19.17 **	-2.78 **	-1.07	0.02
7	NH-2224 BGII x NH-2247 BGII	-3.33	9.84 **	-12.83 **	-1.65	0.08	1.19
8	NH-2224 BGII x NH-2289 BGII	-0.06	13.56 **	-9.89 **	-1.45	0.28	1.39
9	NH-2230 BGII x NH-2212 BGII	1.57	11.49 **	-11.52 **	-1.44	-0.16	0.94
10	NH-2230 BGII x NH-2236 BGII	6.27 *	16.66 **	-7.43 **	3.62 **	3.81 **	4.95 **
11	NH-2230 BGII x NH-2247 BGII	-0.80	10.87 **	-12.02 **	-0.75	-0.59	0.51
12	NH-2230 BGII x NH-2289 BGII	7.69 **	15.69 **	-8.19 **	1.03	1.13	2.25 *
13	NH-2260 BGII x NH-2212 BGII	4.13	18.03 **	-6.34 **	0.41	3.42 **	4.56 **
14	NH-2260 BGII x NH-2236 BGII	1.64	15.21 **	-8.57 **	-1.83 *	1.11	2.23 *
15	NH-2260 BGII x NH-2247 BGII	3.28	17.07 **	-7.10 **	-0.94	2.02 *	3.15 **
16	NH-2260 BGII x NH-2289 BGII	1.46	15.00 **	-8.74 **	-1.45	1.5	2.62 **
17	NH-2274 BGII x NH-2212 BGII	0.18	12.73 **	-10.54 **	2.82 **	4.15 **	5.30 **
18	NH-2274 BGII x NH-2236 BGII	0.92	13.56 **	-9.89 **	3.48 **	4.25 **	5.40 **
19	NH-2274 BGII x NH-2247 BGII	8.07 **	21.61 **	-3.50	2.69 **	3.46 **	4.60 **
20	NH-2274 BGII x NH-2289 BGII	-2.94	9.22 **	-13.33 **	1.37	2.13 *	3.25 **
21	NH-2292 BGII x NH-2212 BGII	2.25	15.62 **	-8.25 **	1.66	2.98 **	4.11 **
22	NH-2292 BGII x NH-2236 BGII	-1.16	11.77 **	-11.31 **	-0.98	0.28	1.39
23	NH-2292 BGII x NH-2247 BGII	-0.73	12.25 **	-10.92 **	1.36	2.65 **	3.79 **
24	NH-2292 BGII x NH-2289 BGII	-2.13	10.67 **	-12.18 **	2.80 **	4.11 **	5.26 **
25	NH-22105 BGII x NH-2212BGII	3.89	14.04 **	-9.50 **	1.45	3.46 **	4.60 **
26	NH-22105 BGII x NH-2236BGII	-3.51	5.92	-15.95 **	0.83	2.83 **	3.97 **
27	NH-22105 BGII x NH-2247BGII	-6.90 *	4.06	-17.42 **	-1.73	0.22	1.33
28	NH-22105 BGII x NH-2289BGII	-2.82	6.61 *	-15.40 **	-1.75	0.20	1.31
29	NH-22126 BGII x NH-2212BGII	0.82	10.67 **	-12.18 **	3.14 **	4.49 **	5.65 **
30	NH-22126 BGII x NH-2236BGII	5.33	15.62 **	-8.25 **	-1.14	0.16	1.27
31	NH-22126 BGII x NH-2247BGII	3.26	15.42 **	-8.41 **	0.16	1.48	2.60 **
32	NH-22126BGII x NH-2289BGII	4.78	13.08 **	-10.27 **	2.64 **	3.99 **	5.14 **
	SE±		**0.69**			**0.75**	

BGII standard heterosis ranged from -0.20 (NH-2230 BGII x NH-2212 BGII) to 11.57 (NH-2230 BGII x NH-2289 BGII). Genotypes with higher ginning percentages are thus preferred due to the premium attached to improved ginning efficiency in cotton processing. Among the economic traits ginning percentage primarily depends upon seed weight and lint weight reported by Patel *et al.* (2012). The range of standard heterosis for UHML over checks NHH 44 BGII -0.12 (NH-22105 BGII x NH-2212 BGII) to 15.25 percent (NH-2274 BGII x NH-2236 BGII). The range of standard heterosis over check MRC 7347 BGII varied from -3.10 (NH-2274 BGII x NH-2236 BGII) to -16.03 percent (NH-22105 BGII x NH-2212 BGII). Fiber is the primary economic product of cotton, so in addition to seed cotton yield, lint quality is crucial. High fiber length and strength are desirable traits. Heterosis values for fiber quality traits were typically lower than those for yield components, consistent with findings by Basal *et al.* (2011).-0.78 (NH-2292 BGII x NH-2289 BGII) to 26.74 percent (NH-2224 BGII x NH-2289 BGII) and -0.78 (NH-2274 BGII x NH-2236 BGII) to 27.73 percent (NH-2224 BGII x NH-2289 BGII) over check NHH 44 BGII and MRC 7347 BGII respectively for fibre fineness. Negative heterosis is often preferred for achieving lower fibre fineness values. This reduction in fibre fineness may result from a decrease in fiber diameter, insufficient cellulose deposition in the fiber wall, or a combination of factors affecting diameter and wall thickness (Bilwal *et al.,* 2018). The maximum 21.61 percent (NH-2274 BGII x NH-2247 BGII) over check NHH 44 BGII and -22.23 (NH-2224 BGII x NH-2212 BGII) over check MRC 7347 BGII for fibre strength. Heterosis ranged from -0.14 (NH-2202 BGII x NH-2236 BGII) to 4.49% (NH-22126 BGII x NH-2212 BGII) over check NHH 44 BGII. While for check MRC 7347 BGII standard heterosis ranged from -0.61 (NH-2202 BGII x NH-2212 BGII) to 5.65 % (NH-22126 BGII x NH-2212 BGII) for uniformity ratio. The heterosis for fibre properties was less influenced by environment for this crosses and parents, similar finding were reported by Udaya *et al.* (2023).

The study highlights several promising avenues for future research and breeding programs. Specifically, lines NH-2230 BGII, NH-2292 BGII, and NH-2202 BGII demonstrated exceptional potential in various desirable traits such as sympodia per plant, boll weight, seed cotton yield, and fiber properties. Testers like NH-2289 BGII and NH-2260 BGII showed significant mean performance in traits like plant height, number of bolls per plant, ginning outturn, and fiber quality. The results indicated that heterosis could be effectively exploited for commercial purposes, particularly in crosses like NH-2260 BGII x NH-2236 BGII and NH-2202 BGII x NH-2289 BGII, which displayed high heterosis for seed yield and yield-contributing traits. Additionally, the study underscored the importance of additive gene action in traits such as boll weight, lint index, and fiber fineness, suggesting the potential for selection in segregating generations and traits such as days to 50% flowering, days to maturity, plant height, number of bolls per plant, seed cotton yield per plant, seed index, fibre strength and uniformity ratio indicated non additive gene action for governing these traits and can be exploited through heterosis breeding. Overall, the findings provide a robust foundation for future breeding efforts aimed at enhancing both yield and fiber quality in cotton.

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