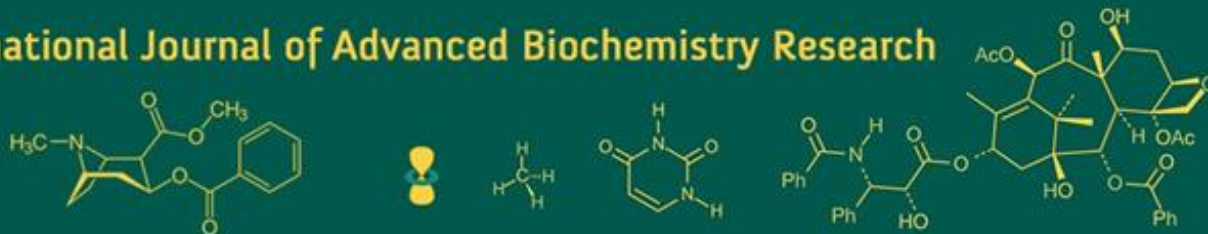


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Heterosis studies for fruit yield and it's component traits through diallel analysis in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract

Heterosis breeding is an effective approach for identifying superior hybrid combinations for the commercial improvement of fruit yield and related traits in okra (*Abelmoschus esculentus* L. Moench). The present investigation was conducted using a 10×10 half-diallel mating design involving ten genetically diverse parental lines to assess the magnitude of heterosis for fruit yield and its component traits. Significant variation in heterotic response was observed among the hybrids. Heterobeltiosis for fruit yield per plant ranged from -38.28% in the cross JOL 20-04 $\times$ GAO 5 to 42.15% in NOL 11-12 $\times$ GP1. Similarly, standard heterosis over the commercial check GJOH 4 ranged from -26.62% to 47.20%, indicating considerable genetic variability for yield improvement. Among the evaluated hybrids, GAO 5 $\times$ GO 6, GP1 $\times$ GAO 8, JOL 20-04 $\times$ GAO 8, JOL 20-04 $\times$ JOL 18-12, GAO 5 $\times$ GAO 8, and JOL 18-07 $\times$ GAO 5 exhibited significant positive heterobeltiosis as well as high standard heterosis for fruit yield per plant, along with desirable performance for several yield-contributing traits. These promising hybrids may serve as potential candidates for commercial hybrid development and can be effectively utilized in future okra breeding programmes aimed at enhancing fruit yield and productivity.

Keywords: Heterosis, half-diallel analysis, heterobeltiosis, standard heterosis, hybrid breeding, fruit yield

Introduction

Okra (*Abelmoschus esculentus* (L.) Moench), popularly known as lady's finger, bhendi, or gumbo, is one of the most important vegetable crops cultivated in tropical and subtropical regions of the world. It belongs to the family *Malvaceae* and is believed to have originated in tropical Africa. The crop is valued for its tender green fruits, which are rich in dietary fiber, vitamins, minerals, antioxidants, and mucilage, making it an important component of human nutrition as well as a valuable source of farm income. India is the largest producer of okra globally, cultivating the crop over approximately 0.531 million hectares, with an annual production of 6.46 million tonnes and an average productivity of 12.17 t ha^{-1} (Anonymous, 2022a) ^[1, 2]. In Gujarat, okra occupies nearly 0.085 million hectares, producing 1.019 million tonnes with an average productivity of 11.97 t ha^{-1} during 2022–23 (Anonymous, 2022b) ^[1, 2]. Despite its economic importance, there remains considerable scope for enhancing fruit yield and productivity through the development of superior hybrids. The exploitation of heterosis has become one of the most successful breeding strategies for improving yield potential, earliness, adaptability, and overall crop performance in cross-pollinated and often crosspollinated vegetable crops. The increasing adoption of F_1 hybrids by farmers has created a growing demand for high-yielding hybrids possessing superior agronomic performance and wider adaptability. Successful hybrid breeding largely depends on the identification of genetically diverse parents capable of producing highly heterotic hybrid combinations.

Heterosis, expressed as the superior performance of F_1 hybrids over their parents or a standard commercial cultivar, provides valuable information for the identification of promising hybrid combinations and the selection of suitable parental lines. Estimation of heterobeltiosis and standard heterosis for fruit yield and its component traits facilitates the development of commercially exploitable hybrids and improves breeding efficiency. Therefore, the present investigation was undertaken to assess the magnitude of heterosis for fruit yield and associated yield-contributing traits in okra using a 10×10 half-diallel mating design, with the objective of identifying superior hybrid combinations for future hybrid breeding programmes.

Materials and Method

The experiment was carried out during kharif (July to October) 2023 at Centre for Vegetable Research, Department of GPB, C. P. college of agriculture, S. D. Agricultural University, Sardarkrushinagar. The basic materials consisted of ten genotypes of okra viz., JOL 20-04, NOL 11-12, JOL 18-07, JOL 18-12, GP2, GP1, GAO 5, GO 6, Pusa Sawani and GAO 8. These varieties were chosen for the current study based on genetic diversity for several agronomic features and maturity parameters. The genotypes are crossed in Half diallel fashion without reciprocals to produce 45 hybrids in summer 2023. These 45 F₁ along with their 10 parents and one standard check (GJOH 4) were evaluated in a randomized complete block design with three replicates during kharif (July to October) 2023. So in this experiment analysis based on fruit yield and its other traits present in okra. Observations were recorded on days to 50% flowering, fruits per plant, fruit length (cm), fruit girth (cm), fruit weight (g), fruit yield per plant (g), plant height (cm) and internodal length (cm). Days to 50% flowering, plant height and internodal length was consider as negative trait in okra so low scoring parent consider as a better parent for estimation of heterobeltiosis. The various observations were recorded on five competitive plants in each plot leaving border ones. Heterosis percentage was worked out as per formula suggested by Fonseca and Patterson (1968) and Meredith and Bridge (1972) [3]. for calculation of heterobeltiosis and standard heterosis, respectively.

The observations were recorded on randomly selected three plants per genotype from each replication and mean values were used for the statistical analysis.

The per cent heterosis was estimated as increase or decrease in the mean value of F₁ hybrid over better parent, i.e., heterobeltiosis (Fonseca and Patterson, 1968) [4] and over standard check (GCU-1), i.e., Standard heterosis (Meredith and Bridge, 1972) [3] for each character.

Heterobeltiosis was measured in percentage by using following formula

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

The standard heterosis was measured in percentage by using following formula

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

BP = Mean performance of better parent

SC = Mean performance of standard check i.e., GCU-1, and

F₁ = Mean value of F₁.

The significance of heterosis value was tested using 't' test

$$t = \frac{\overline{F_1} - \overline{BP} \text{ or } \overline{SC}}{\text{S.E. of heterosis over } \overline{BP} \text{ and } \overline{SC}}$$

Calculated 't' value was equated with table 't' values at error degree of freedom for test of significance.

Results and Discussion

The analysis of variance for fourteen characters is presented in Table 1. The mean squares due to genotypes were further partitioned into parents, hybrids, parents vs hybrids and check vs hybrids.

The result revealed that mean square values due to genotypes were found highly significant for all the characters, indicating the presence of sufficient amount of genetic variability in the material under study. The variance due to parents were found significant for the characters like; days to 50% flowering, fruits per plant, fruit length, fruit girth, fruit yield per plant, plant height and internodal length. The mean square due to hybrid indicated significant difference for all the traits under study. The results indicated the existence of sufficient amount of genetic variability among the parents for all the characters except fruit weight and hybrids for all the characters under study. Mean sum of squares due to parents vs hybrids showed significant differences for characters under study viz., fruits per plant, fruit girth, fruit weight, fruit yield per plant, plant height and internodal length which suggested the existence of differences between parents and hybrids leading to manifestation of heterosis. The mean square difference due to check vs hybrid showed significant difference for traits under study viz., fruits per plant, fruit length, fruit girth and fruit yield per plant. The results of mean squares due to check vs hybrids suggesting that hybrids differed statistically from given check for given traits. (Table 1)

Table 1: Analysis of variance (mean sum of squares) for experimental design of fourteen characters in okra

Source of variation	Degree of freedom	Mean sum of square							
		Days to 50% flowering	Fruits per plant	Fruit length	Fruit girth	Fruit weight	Fruit yield per plant	Plant height	Internodal length
Replication	2	1.36	0.15	0.54	0.06	0.02	485.69	54.14	0.16
Genotypes	55	45.25**	27.52**	2.01**	0.45**	7.68**	7319.41**	981.08**	7.19**
Parents (P)	9	9.14**	4.47**	2.70**	0.56**	1.55	1818.80**	353.21**	4.11**
Hybrids (H)	44	54.37**	32.80**	1.87**	0.42**	8.99**	8723.85**	959.54**	6.46**
P vs. H	1	14.15	23.66**	1.32	0.60**	11.86**	2258.80**	8554.35**	74.22**
Check vs. Hybrids	1	0.30	6.22**	2.77**	0.42**	0.92	90.20**	6.36	0.15
Error	110	2.50	1.56	0.20	0.03	0.95	276.47	76.34	0.56

* $p \leq 0.05$, ** $p \leq 0.01$

Heterosis

The hybrid with high value of heterosis in desired direction can be further exploited. The hybrids are normally assessed in terms of per cent increase better parent and over standard check hybrid. The range of heterosis over better parent and standard check found to be different for all traits under study.

1. Days to 50% flowering

For days to 50% flowering earliness, heterotic effect in negative direction is desirable. Heterobeltiosis ranged from -15.49 (JOL 20-04 × GAO 8) to 19.85% (GO 6 × GAO 8). Best crosses were JOL 20-04 × GAO 8 (-15.49%) followed by JOL18-07 × GP2 (-13.50%) and JOL 18-07 × GO 6 (-11.34%). The magnitude of

standard heterosis over GJOH 4 was ranged from -16.09 to 18.17%. Best crosses were JOL 20-04 × GAO 8 (-16.09%) followed by JOL 18-07 × GAO 5 (-16.09%), GAO 5 × GAO 8 (-16.09%) and JOL 18-07 × GO 6 (-12.59%) in desirable direction. The result of days to 50% flowering for

heterobeltiosis and standard heterosis confirmed with the result Budha Ram (2015) [5], Patel *et al.* (2015) [6], Gavint *et al.* (2018) [7], Chavan *et al.* (2021) [8] and Sidapara *et al.* (2021) [9]. (Table 2)

Table 2: Magnitude of heterobeltiosis (HB) and standard heterosis (SH) for days to 50% flowering and fruits per plant

Sr. No.	Hybrids	Days to 50% flowering		Fruits Per plant		
		% Heterosis over				
		BP	SC	BP	SC	
1	JOL 20-04 × NOL 11-12	-3.55	-4.91	15.02**	16.96**	
2	JOL 20-04 × JOL 18-07	11.28**	10.49**	-34.67**	-33.58**	
3	JOL 20-04 × JOL 18-12	-7.04*	-7.70**	23.67**	25.74**	
4	JOL 20-04 × GP2	7.06*	6.29*	-18.00**	-16.62**	
5	JOL 20-04 × GP1	10.08**	6.99*	16.68**	18.63**	
6	JOL 20-04 × GAO 5	-2.22	-7.70**	-17.30**	-11.75*	
7	JOL 20-04 × GO 6	-3.55	-4.91	-8.96	-7.27	
8	JOL 20-04 × Pusa Sawani	-0.70	-1.41	-9.74	-8.23	
9	JOL 20-04 × GAO 8	-15.49**	-16.09**	21.73**	27.59**	
10	NOL 11-12 × JOL 18-07	4.26	2.79	-24.39**	-28.37**	
11	NOL 11-12 × JOL 18-12	9.94**	8.39**	-22.13**	-29.10**	
12	NOL 11-12 × GP2	9.94**	8.39**	6.76	-5.43	
13	NOL 11-12 × GP1	8.63**	5.58*	26.13**	16.96**	
14	NOL 11-12 × GAO 5	-3.71	-9.10**	-28.68**	-23.89**	
15	NOL 11-12 × GO 6	-2.13	-3.50	-21.59**	-20.15**	
16	NOL 11-12 × Pusa Sawani	11.34**	9.78**	8.58	1.29	
17	NOL 11-12 × GAO 8	-10.64**	-11.89**	-15.48**	-11.42*	
18	JOL 18-07 × JOL 18-12	9.53**	12.59**	-9.45	-14.21*	
19	JOL 18-07 × GP2	-13.50**	-10.49**	-26.17**	-30.05**	
20	JOL 18-07 × GP1	-9.35**	-11.89**	-10.99	-15.67**	
21	JOL 18-07 × GAO 5	-11.11**	-16.09**	14.32**	21.99**	
22	JOL 18-07 × GO 6	-11.34**	-12.59**	-19.40**	-17.91**	
23	JOL 18-07 × Pusa Sawani	-6.16*	-4.20	-11.81	-16.45**	
24	JOL 18-07 × GAO 8	-4.76	-2.10	-21.14**	-17.35**	
25	JOL 18-12 × GP2	8.16**	11.18**	-12.72*	-20.54**	
26	JOL 18-12 × GP1	12.24**	9.08**	-24.38**	-29.88**	
27	JOL 18-12 × GAO 5	15.56**	9.08**	-18.20**	-12.70*	
28	JOL 18-12 × GO 6	-4.26	-5.60*	9.89	11.92*	
29	JOL 18-12 × Pusa Sawani	-9.60**	-7.70**	-19.44**	-24.85**	
30	JOL 18-12 × GAO 8	2.71	5.58*	-23.81**	-20.15**	
31	GP2 × GP1	-2.87	-5.60*	22.93**	13.99*	
32	GP2 × GAO 5	3.71	-2.10	-24.65**	-19.59**	
33	GP2 × GO 6	7.81**	6.29*	-34.62**	-33.41**	
34	GP2 × Pusa Sawani	2.05	4.20	-13.02*	-18.86**	
35	GP2 × GAO 8	-6.12*	-3.50	-32.03**	-28.76**	
36	GP1 × GAO 5	2.22	-3.50	-17.51**	-11.98*	
37	GP1 × GO 6	10.79**	7.68**	-17.97**	-16.45**	
38	GP1 × Pusa Sawani	-5.03	-7.70**	-2.40	-8.95	
39	GP1 × GAO 8	-8.63**	-11.20**	9.29	14.55*	
40	GAO 5 × GO 6	-6.67*	-11.89**	16.26**	24.06**	
41	GAO 5 × Pusa Sawani	11.84**	5.58*	-19.77**	-14.38*	
42	GAO 5 × GAO 8	-11.11**	-16.09**	20.45**	28.54**	
43	GO 6 × Pusa Sawani	5.68*	4.20	-22.53**	-21.10**	
44	GO 6 × GAO 8	19.85**	18.17**	-30.06**	-26.69**	
45	Pusa Sawani × GAO 8	1.36	3.48	-21.89**	-18.13**	
S.Em. ±		1.29	1.29	1.02	1.02	
Range		Minimum (%)	-15.49	-16.09	-34.67	-33.58
		Maximum (%)	19.85	18.17	26.13	28.54
Positive significant		16	16	9	11	
Negative significant		13	16	26	29	
Total significant		29	32	35	40	

* $p \leq 0.05$, ** $p \leq 0.01$

2. Fruits per plant

The better parent heterosis for fruits per plant was ranged from -34.67 to 26.13 per cent. The crosses NOL 11-12 × GP1 (26.13%) recorded highest heterobeltiosis followed by JOL 20-04 × JOL 18-12 (23.67%) and GP2 × GP1 (22.93%) for this trait. The standard heterosis over check GJOH 4 was ranged from -33.58 to 28.54 per cent for fruits per plant. For fruits per plant, top 3 good crosses were GAO 5 × GAO 8 (28.54%), JOL 20-04 × GAO 8 (27.59%) and JOL 20-04 × GAO 18-12 (25.74%) which were in significant in useful heterosis. Same results were found by [Bhatt et al. \(2015\)](#) ^[10], [Patel and Patel \(2016\)](#) ^[11], [Gavint et al. \(2018\)](#) ^[7], [Chavan et al. \(2021\)](#) ^[8], [Sidapara et al. \(2021\)](#) ^[9] and [Chaudhary et al. \(2023\)](#) ^[12]. (Table

2).

3. Fruit length

The range of heterobeltiosis for this trait was -16.78 to 15.58 per cent. top 3 good crosses were JOL 20-04 × GAO 8 (15.58%), GO 6 × Pusa Sawani (15.21%) and GP1×GAO 8 (8.54%) possessed positive value of heterobeltiosis for this trait. The estimates of standard heterosis over the check GJOH 4 for fruit length were ranged from -2.06 to 28.98 per cent For fruit length, top 3 good crosses were JOL 20-04 × GAO 8 (28.98%), NOL 11-12 × GP2 (26.42%) and GAO 5 × GAO 8 (24.66%). Similar results were reported by [Chavan et al. \(2021\)](#) ^[8]. (Table 3).

Table 3: Magnitude of heterobeltiosis (HB) and standard heterosis (SH) for fruit length and fruit girth

Sr. No.	Hybrids	Fruit length		Fruit girth	
		% Heterosis over			
		BP	SC	BP	SC
1	JOL 20-04 × NOL 11-12	-9.85**	6.09	-5.83*	5.82*
2	JOL 20-04 × JOL 18-07	-6.53*	5.40	-2.53	4.91
3	JOL 20-04 × JOL 18-12	2.62	7.86*	5.46*	12.36**
4	JOL 20-04 × GP2	-12.18**	5.50	-7.70**	4.55
5	JOL 20-04 × GP1	1.71	5.30	-0.69	5.27
6	JOL 20-04 × GAO 5	7.34*	23.58**	-3.11	7.45**
7	JOL 20-04 × GO 6	-2.09	1.38	-4.29	1.45
8	JOL 20-04 × Pusa Sawani	-1.52	1.96	-3.95	1.82
9	JOL 20-04 × GAO 8	15.58**	28.98**	14.92**	21.82**
10	NOL 11-12 × JOL 18-07	-6.76*	9.72**	-3.72	8.18**
11	NOL 11-12 × JOL 18-12	-8.68**	7.47*	-5.34*	6.36*
12	NOL 11-12 × GP2	5.23	26.42**	-9.31**	2.73
13	NOL 11-12 × GP1	-11.52**	4.13	-7.12**	4.36
14	NOL 11-12 × GAO 5	-8.93**	7.17*	-5.83*	5.82*
15	NOL 11-12 × GO 6	-9.02**	7.07*	-5.99*	5.64*
16	NOL 11-12 × Pusa Sawani	-16.78**	-2.06	-16.67**	-6.36*
17	NOL 11-12 × GAO 8	-10.60**	5.21	-16.99**	-6.73*
18	JOL 18-07 × JOL 18-12	-4.44	7.76*	-0.68	6.91*
19	JOL 18-07 × GP2	-0.25	19.84**	11.56**	26.36**
20	JOL 18-07 × GP1	-4.79	7.37*	0.84	8.55**
21	JOL 18-07 × GAO 5	-11.35**	2.06	-8.03**	2.00
22	JOL 18-07 × GO 6	-5.75	6.29	-0.84	6.73*
23	JOL 18-07 × Pusa Sawani	-3.14	9.23*	1.86	9.64**
24	JOL 18-07 × GAO 8	-3.57	8.74*	1.35	9.09**
25	JOL 18-12 × GP2	3.03	23.77**	3.53	17.27**
26	JOL 18-12 × GP1	6.54	11.98**	0.51	7.09**
27	JOL 18-12 × GAO 5	-3.41	11.20**	-1.64	9.09**
28	JOL 18-12 × GO 6	-1.78	3.24	-2.56	3.82
29	JOL 18-12 × Pusa Sawani	-0.37	4.72	-1.37	5.09
30	JOL 18-12 × GAO 8	-0.44	11.10**	3.58	10.36**
31	GP2 × GP1	2.21	22.79**	-5.46*	7.09**
32	GP2 × GAO 5	-10.71**	7.27*	-6.42**	6.00*
33	GP2 × GO 6	-9.65**	8.55*	-7.06**	5.27
34	GP2 × Pusa Sawani	1.96	22.50**	12.68**	27.64**
35	GP2 × GAO 8	-11.20**	6.68	-6.74**	5.64*
36	GP1 × GAO 5	-8.70**	5.11	-5.08*	5.27
37	GP1 × GO 6	8.27*	2.85	11.64**	2.91
38	GP1 × Pusa Sawani	3.71	7.17*	-0.18	2.36
39	GP1 × GAO 8	8.54**	21.12**	14.91**	19.09**
40	GAO 5 × GO 6	-7.76*	6.19	-9.34**	0.55
41	GAO 5 × Pusa Sawani	-8.36**	5.50	-4.92*	5.45*
42	GAO 5 × GAO 8	8.28**	24.66**	6.56**	18.18**
43	GO 6 × Pusa Sawani	15.21**	19.06**	5.50*	8.18**
44	GO 6 × GAO 8	-4.93	6.09	1.93	5.64*
45	Pusa Sawani × GAO 8	-6.25	4.62	1.23	4.91
S.Em. ±		0.36	0.36	0.15	0.15
Range	Minimum (%)	-16.78	-2.06	-16.99	-6.73
	Maximum (%)	15.58	28.98	14.92	27.64
Positive significant		06	25	08	29
Negative significant		17	00	17	02
Total significant		23	25	25	31

* $p \leq 0.05$, ** $p \leq 0.01$

4. Fruit girth

The extent of heterosis over better parent for fruit girth was varied from -16.99 to 14.92 per cent. For fruit girth, top 3 good crosses were positive value of heterobeltiosis in which JOL 20-04 × GAO 8 (14.92%) had highest positive value followed by GP1 × GAO 8 (14.91%) and GP2 × Pusa Sawani (12.68%). The standard heterosis for this trait was ranged from -6.67 to 27.58 per cent. Top good crosses GP2 × Pusa Sawani (27.64%), JOL 18 – 07×GP2 (26.36%) and JOL 20-04 × GAO 8 (21.82%) recorded positive value of standard heterosis for fruit girth. Same results were found by Chavan *et al.* (2021) [8] and Sidapara *et al.* (2021) [9]. Value of standard heterosis for fruit girth. (Table 3)

5. Fruit weight

The magnitudes of heterobeltiosis ranged from -19.81 (GP1 × Pusa Sawani) to 30.14 (GP2×GAO8) per cent for this trait. The top three crosses for better parent heterosis were GP2 × GAO 8 (30.14%), GAO 5 × GO 6 (25.87%), GP1 × GO 6 (23.44%). Similar results were reported by Budha Ram (2015) [5]. The range of standard heterosis was varied from -15.98 (GP2 × GAO 5) to 35.98 (GP2 × GAO 8) per cent. Among seventeen, top three crosses viz., GP2 × GAO 8 (35.98%), GP1 × GAO 8 (24.41%) and JOL 18-12 × GP1 (23.39%). Similar result were found by Patel and Patel (2016) [11], Gavint *et al.* (2018) [7] and Chaudhary *et al.* (2023) [12]. (Table 4)

Table 4: Magnitude of heterobeltiosis (HB) and standard heterosis (SH) for fruit weight and fruit yield per plant

Sr. No.	Hybrids	Fruit weight		Fruit yield per plant	
		% Heterosis over			
		BP	SC	BP	SC
1	JOL 20-04 × NOL 11-12	14.30*	12.68*	8.48	22.00**
2	JOL 20-04 × JOL 18-07	9.70	15.75**	-21.85**	-12.11*
3	JOL 20-04 × JOL 18-12	16.88**	22.68**	24.48**	40.00**
4	JOL 20-04 × GP2	-0.30	4.17	-26.95**	-17.85**
5	JOL 20-04 × GP1	11.84*	7.09	8.30	21.80**
6	JOL 20-04 × GAO 5	-11.35*	-15.12**	-38.28**	-24.18**
7	JOL 20-04 × GO 6	-3.78	-7.87	-17.91**	-7.67
8	JOL 20-04 × Pusa Sawani	-4.54	0.94	-24.26**	-14.82*
9	JOL 20-04 × GAO 8	15.53**	20.08**	18.57**	41.76**
10	NOL 11-12 × JOL 18-07	0.90	6.46	-28.23**	-21.97**
11	NOL 11-12 × JOL 18-12	-1.95	2.91	-11.01*	-5.33
12	NOL 11-12 × GP2	-18.61**	-14.96**	14.64*	18.54**
13	NOL 11-12 × GP1	17.41**	15.75**	42.15**	31.18**
14	NOL 11-12 × GAO 5	-6.55	-7.87	-36.44**	-21.92**
15	NOL 11-12 × GO 6	10.62	9.06	10.15	7.84
16	NOL 11-12 × Pusa Sawani	-3.72	1.81	-9.06	-4.80
17	NOL 11-12 × GAO 8	2.27	6.30	-9.78	7.87
18	JOL 18-07 × JOL 18-12	-14.55**	-9.84	-25.80**	-19.33**
19	JOL 18-07 × GP2	3.96	9.69	-29.27**	-23.09**
20	JOL 18-07 × GP1	-17.54**	-12.99*	-28.22**	-21.95**
21	JOL 18-07 × GAO 5	6.49	12.36*	11.23*	36.63**
22	JOL 18-07 × GO 6	-0.37	5.12	-9.87	-2.01
23	JOL 18-07 × Pusa Sawani	4.77	10.79*	-19.79**	-12.79*
24	JOL 18-07 × GAO 8	4.63	10.39	-14.07**	2.75
25	JOL 18-12 × GP2	-11.33*	-6.93	-27.50**	-22.87**
26	JOL 18-12 × GP1	17.55**	23.39**	-7.44	-1.53
27	JOL 18-12 × GAO 5	-12.83*	-8.50	-35.94**	-21.31**
28	JOL 18-12 × GO 6	11.40*	16.93**	26.97**	35.07**
29	JOL 18-12 × Pusa Sawani	-15.64**	-10.79*	-26.80**	-22.13**
30	JOL 18-12 × GAO 8	0.83	5.83	-20.90**	-5.42
31	GP2 × GP1	16.80**	22.05**	31.14**	35.61**
32	GP2 × GAO 5	-19.59**	-15.98**	-35.91**	-21.28**
33	GP2 × GO 6	1.21	5.75	11.22	15.01*
34	GP2 × Pusa Sawani	-17.72**	-12.99*	-26.02**	-22.55**
35	GP2 × GAO 8	30.14**	35.98**	5.78	26.47**
36	GP1 × GAO 5	-6.53	-10.94*	-32.59**	-17.20**
37	GP1 × GO 6	23.44**	16.93**	13.59*	11.20
38	GP1 × Pusa Sawani	-19.81**	-15.20**	-28.49**	-25.14**
39	GP1 × GAO 8	19.70**	24.41**	18.69**	41.91**
40	GAO 5 × GO 6	25.87**	19.92**	19.83**	47.20**
41	GAO 5 × Pusa Sawani	-9.68	-4.49	-31.51**	-15.87**
42	GAO 5 × GAO 8	16.44**	21.02**	12.56*	38.27**
43	GO 6 × Pusa Sawani	-13.63**	-8.66	-29.91**	-26.62**

44	GO 6 × GAO 8	18.56**	23.23**	-11.15*	6.23
45	Pusa Sawani × GAO 8	10.57*	16.93**	-17.51**	-1.37
S.Em. ±		0.68	0.68	13.58	13.58
Range	Minimum (%)	-19.81	-15.98	-38.28	-26.62
	Maximum (%)	30.14	35.98	42.15	47.20
Positive significant		15	17	11	14
Negative significant		11	08	25	19
Total significant		26	25	36	33

$p \leq 0.05, p \leq 0.01$

6. Fruit yield per plant

Fruit yield per plant is very important attribute for okra which the breeder attempt to improve by evolving high yielding hybrids. The perusal of results revealed that heterobeltiosis varied from -38.28 to 42.15 per cent. The cross NOL 11-12 × GP1 (42.15%) was reported highest significant and positive heterobeltiosis followed by GP2 × GP1 (31.14%) and JOL 18-12 × GO 6 (26.97%). The estimate of standard heterosis for this trait was ranged from -26.62 to 47.20 per cent. Top four crosses depicted standard heterosis in desired direction for this trait are GAO 5 × GO 6 (47.20%), GP1 × GAO 8 (41.91%) and JOL 20-04 × GAO 8 (41.76%) as well JOL 20-04 × JOL 18-12 (40.00%) were found to be best hybrids for fruit yield per plant based on the positive standard heterosis. These results Confirmed with findings of Patel and Patel (2016)^[11], Gavint *et al.* (2018)^[7], Chavan *et al.* (2021)^[8] Sidapara *et al.* (2021)^[9] and Chaudhary *et al.* (2023)^[12]. (Table 4 and Figure 4 & 5)

7. Plant height

For plant height, heterotic effect in negative direction was considered as desirable. The magnitude of heterobeltiosis range from -7.43% (JOL 18-12 × GP2) to 49.43% (GP1 × GAO 8) for this character. The range of standard heterosis over check GJOH4 was -22.22% (NOL 11-12 × GO 6) to 20.97% (GAO 5 × GAO 8). Out of forty five crosses, Seven crosses manifested significant negative heterosis. The cross NOL 11-12 × GO 6 (-22.22%) had highest significant and negative standard heterosis followed by JOL 20-04 × JOL 18-07 (-17.93%) and NOL 11-12 × JOL 18-12 (-16.16%) for this trait. Similar results were reported by Kumar and Sreeparvathy (2010)^[13], Raghuvanshi *et al.* (2011), Khatik *et al.* (2012)^[14], Paul (2013)^[15], Kishor *et al.* (2013)^[16], Kumar *et al.* (2013)^[17], Nagesh *et al.* (2014)^[18], Badiger *et al.* (2014)^[19] and Tiwari *et al.* (2015)^[20]. (Table 5)

Table 5: Magnitude of heterobeltiosis (HB) and standard heterosis (SH) for plant height and internodal length

Sr. No.	Hybrids	Plant height		Internodal length	
		%Heterosis over			
		BP	SC	BP	SC
1	JOL 20-04 × NOL 11-12	37.89**	14.29**	70.43**	11.04
2	JOL 20-04 × JOL 18-07	-3.92	-17.93**	-3.87	-35.95**
3	JOL 20-04 × JOL 18-12	34.79**	15.14**	81.95**	21.23**
4	JOL 20-04 × GP2	19.32**	1.92	56.54**	4.29
5	JOL 20-04 × GP1	19.89**	-5.29	59.78**	-8.83
6	JOL 20-04 × GAO 5	17.24**	0.15	50.64**	0.37
7	JOL 20-04 × GO 6	20.25**	2.72	58.93**	5.89
8	JOL 20-04 × Pusa Sawani	12.18*	-4.18	42.73**	-4.91
9	JOL 20-04 × GAO 8	38.70**	18.47**	98.90**	32.52**
10	NOL 11-12 × JOL 18-07	15.85**	-3.97	32.77**	-13.50
11	NOL 11-12 × JOL 18-12	1.14	-16.16**	8.66	-29.20**
12	NOL 11-12 × GP2	23.16**	2.09	63.84**	6.75
13	NOL 11-12 × GP1	12.75*	-10.93*	47.31**	-15.95*
14	NOL 11-12 × GAO 5	25.24**	3.81	67.42**	9.08
15	NOL 11-12 × GO 6	-6.16	-22.22**	-11.86	-42.58**
16	NOL 11-12 × Pusa Sawani	14.95**	-4.72	43.88**	-6.26
17	NOL 11-12 × GAO 8	40.46**	16.42**	88.7**	22.94**
18	JOL 18-07 × JOL 18-12	18.04**	1.53	45.23**	6.38
19	JOL 18-07 × GP2	7.26	-7.74	16.58	-14.60
20	JOL 18-07 × GP1	18.06**	-6.73	51.61**	-13.50
21	JOL 18-07 × GAO 5	12.07*	-3.61	14.57	-16.07*
22	JOL 18-07 × GO 6	18.09**	1.57	45.06**	6.26
23	JOL 18-07 × Pusa Sawani	19.71**	2.96	50.25**	10.06
24	JOL 18-07 × GAO 8	15.59**	-0.58	42.88**	4.66
25	JOL 18-12 × GP2	-7.43	-11.84**	-12.62	-20.98**
26	JOL 18-12 × GP1	29.38**	2.21	85.81**	6.01
27	JOL 18-12 × GAO 5	14.67**	1.72	38.46**	3.80
28	JOL 18-12 × GO 6	31.64**	19.37**	53.21**	28.96**
29	JOL 18-12 × Pusa Sawani	4.34	-0.63	12.62	1.84
30	JOL 18-12 × GAO 8	24.25**	16.23**	35.82**	22.82**
31	GP2 × GP1	25.15**	-1.14	76.34**	0.61
32	GP2 × GAO 5	27.08**	12.73**	56.96**	17.67*
33	GP2 × GO 6	6.42	-3.50	13.12	-4.79

34	GP2 × Pusa Sawani	3.64	0.73	10.98	4.17
35	GP2 × GAO 8	-0.51	-6.93	-1.34	-9.33
36	GP1 × GAO 5	29.95**	2.66	86.45**	6.38
37	GP1 × GO 6	25.43**	-0.91	72.69**	-1.47
38	GP1 × Pusa Sawani	22.36**	-3.34	66.24**	-5.15
39	GP1 × GAO 8	49.34**	17.97**	122.15**	26.75**
40	GAO 5 × GO 6	35.16**	19.90**	69.72**	27.24**
41	GAO 5 × Pusa Sawani	-1.41	-12.55**	1.64	-23.80**
42	GAO 5 × GAO 8	36.38**	20.97**	75.29**	31.41**
43	GO 6 × Pusa Sawani	3.91	-5.77	6.71	-10.18
44	GO 6 × GAO 8	-0.48	-9.75*	-5.69	-20.61**
45	Pusa Sawani × GAO 8	25.65**	17.55**	37.12**	26.01**
S.Em. ±		7.13	7.13	0.61	0.61
Range	Minimum (%)	-7.43	-22.22	-12.62	-42.58
	Maximum (%)	49.34	20.97	122.15	32.52
Positive significant		33	11	32	10
Negative significant		00	07	00	08
Total significant		21	18	32	18

* $p \leq 0.05$, ** $p \leq 0.01$

8. Internodal length

For internodal length, heterotic effect in negative direction is desirable. The magnitude of heterosis over better parent was varies between -12.62(JOL 18-12 × GP2) to 122.15 (GP1 × GAO 8) per cent. The magnitude of standard heterosis over GJOH was ranged from -42.58 to 32.52 per cent. Best three crosses were NOL 11-12 × GO 6 (-42.58%) followed by JOL 20-04 × JOL 18-07 (-35.95%) and NOL 11-12 × JOL 18-12 (-29.20%). Similar results were reported by Kumar and

Sreeparvathy (2010) [13], Khatik *et al.* (2012) [14], Paul (2013) [15], Kumar *et al.* (2013) [17], Nagesh *et al.* (2014) [18], Badiger *et al.* (2014) [19] and Tiwari *et al.* (2015) [20]. (Table 5)

Based on overall performance of Standard heterosis and heterobeltiosis, the top heterotic combinations were viz., GAO 5 × GO 6, GP 1 × GAO 8, JOL 20-04 × GAO 8, JOL 20-04 × JOL 18-12, GAO 5 × GAO 8 and JOL 18-07 × GAO for fruit yield per plant. (Table 6)

Table 6: Manifestation of Heterobeltiosis (BP) and Standard Heterosis (SH) for other characters in six top ranking crosses for fruit yield per plant

Sr. No.	Hybrids	Mean	%Heterosis over		Desired and significant standard heterosis/ heterobeltiliosis for attributes
			Better parent	Standard check	
Fruit yield per plant with attributes					
1	GAO 5 × GO 6	338.08	19.83**	47.20**	DF, FPP, FW
2	GP1 × GAO 8	325.92	18.69**	41.91**	DF, FPP, FL, FG, FW
3	JOL 20-04 × GAO 8	325.58	18.57**	41.76**	DF, FPP, FL, FG, FW
4	JOL 20-04 × JOL 18-12	321.54	24.48**	40.00**	DF, FPP, FL, FG, FW
5	GAO 5 × GAO 8	317.56	12.56*	38.27**	DF, FPP, FL, FG, FW
6	JOL 18-07 × GAO 5	313.80	11.23*	36.63**	DF, FPP, FW, IL

* $p \leq 0.05$; ** $p \leq 0.01$

DF = Days to 50% flowering, FPP = Fruits per plant, FL = Fruit length, FG = Fruit girth, FW = Fruit weight, IL = Internodal length

The highest yielding cross GAO 5 × GO recorded 47.20% higher fruit yield per plant than standard check variety GJOH 4 and also significant for other trait viz., days to 50% flowering, fruits per plant and fruit weight. This cross had founded 19.83% higher value than its better parent and also significant for other traits as same as standard heterosis in desire direction. (Table 6) The next superior hybrid GP 1 × GAO 8 had standard heterosis for fruit yield per plant (41.91%) with yield attributing characters viz., days to 50% flowering, fruits per plant, fruit length, fruit girth and fruit weight. This cross also exhibited 18.69% heterobeltiosis and also significant for other traits as same as standard heterosis except fruit per plant in desire direction. (Table 6)

The third cross, JOL 20-04 × GAO 8 had standard heterosis for fruit yield per plant (41.76%) over standard check variety GJOH 4 for fruit yield per plant also exhibited in desirable direction significant for the characters viz., days to 50% flowering, fruits

per plant, fruit length, fruit girth and fruit weight. This cross showed 18.57% heterobeltiosis and also significant for other traits as same as standard heterosis. (Table 6)

The cross JOL 20-04 × JOL 18-12 observed significant 40.00% higher than standard check GJOH 4 and also significant for other trait viz., days to 50% flowering, fruits per plant, fruit length, fruit girth and fruit weight. This cross showed 24.48% higher value than its better parent and also significant for related to other traits as same as standard heterosis expect fruit length in desire direction. (Table 6)

The cross GAO 5 × GAO 8 observed significant 38.27% higher than standard check GJOH 4 and also significant for other trait viz., days to 50% flowering, fruits per plant, fruit length, fruit girth and fruit weight. This cross had founded 12.56% higher value than its better parent and also significant for other traits as same as standard heterosis in desire direction. (Table 6)



Fig 1: Fruit view of top six performing hybrids basis on heterosis

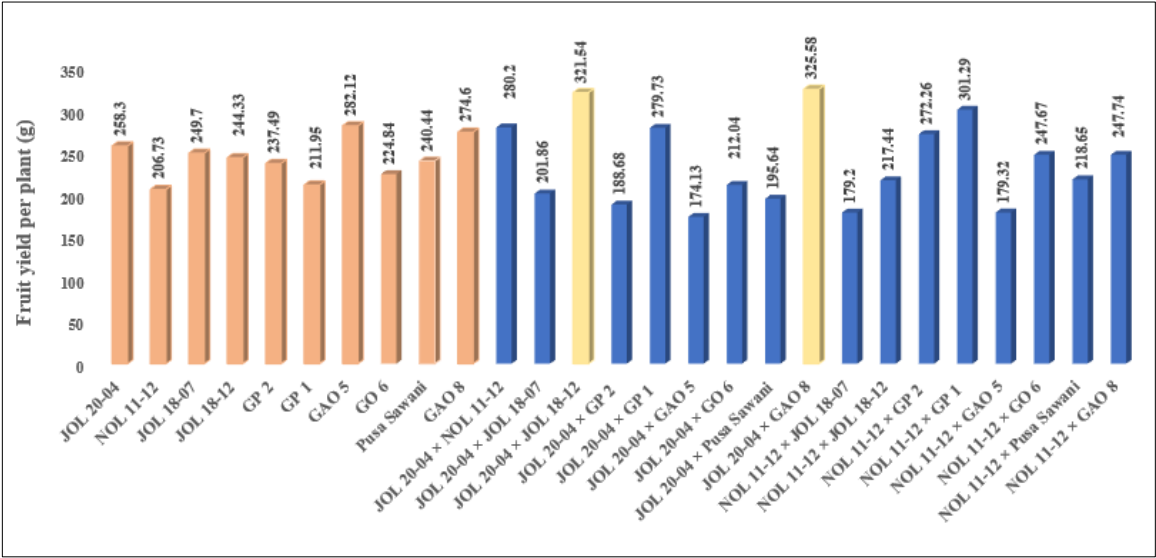


Fig 2: Graphical representation of mean performance parents and hybrids in okra for fruit yield per plant

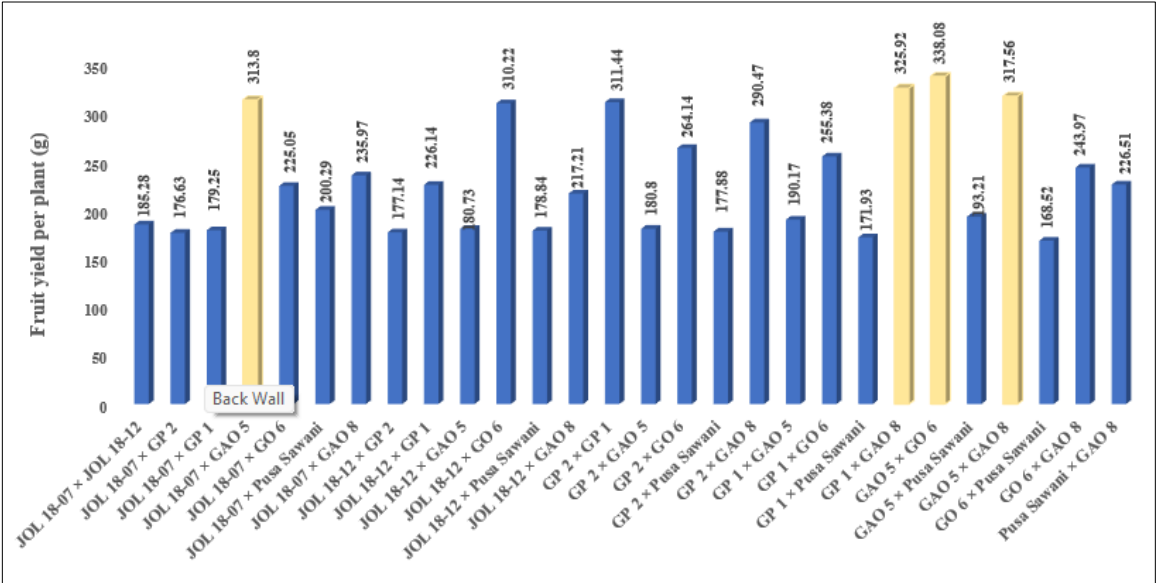
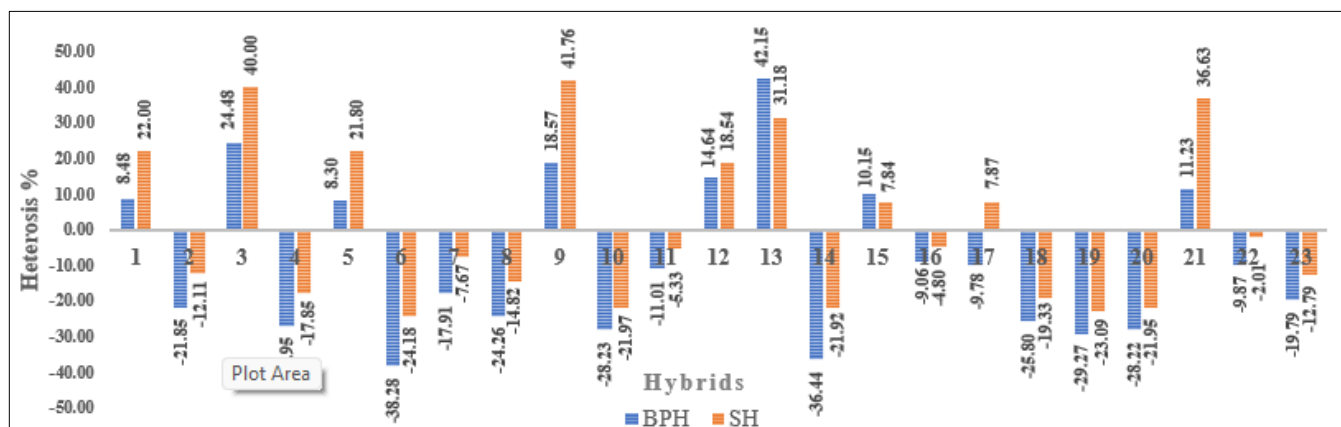
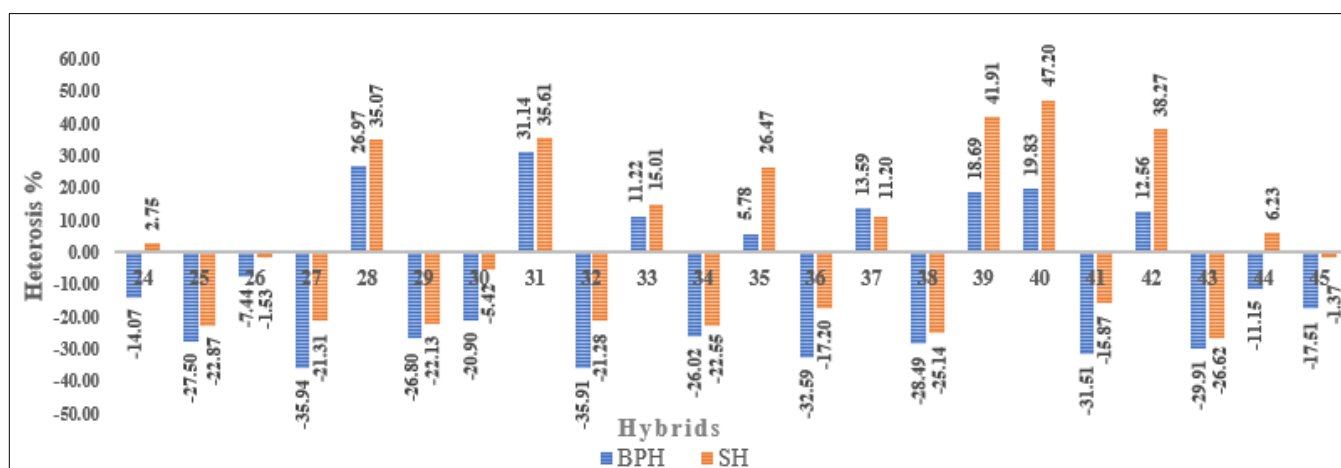


Fig 3: Graphical representation of mean performance hybrids in okra for fruit yield per plant



1	JOL 20-04 × NOL 11-12	7	JOL 20-04 × GO 6	13	NOL 11-12 × GP 1	19	JOL 18-07 × GP 2
2	JOL 20-04 × JOL 18-07	8	JOL 20-04 × Pusa Sawani	14	NOL 11-12 × GAO 5	20	JOL 18-07 × GP 1
3	JOL 20-04 × JOL 18-12	9	JOL 20-04 × GAO 8	15	NOL 11-12 × GO 6	21	JOL 18-07 × GAO 5
4	JOL 20-04 × GP 2	10	NOL 11-12 × JOL 18-07	16	NOL 11-12 × Pusa Sawani	22	JOL 18-07 × GO 6
5	JOL 20-04 × GP 1	11	NOL 11-12 × JOL 18-12	17	NOL 11-12 × GAO 8	23	JOL 18-07 × Pusa Sawani
6	JOL 20-04 × GAO 5	12	NOL 11-12 × GP 2	18	JOL 18-07 × JOL 18-12		

Fig 4: Graphical representation of heterobeltiosis (BPH) and standard heterosis (SH) of hybrids in okra for fruit yield per plant



24	JOL 18-07 × GAO 8	30	JOL 18-12 × GAO 8	36	GP 1 × GAO 5	42	GAO 5 × GAO 8
25	JOL 18-12 × GP 2	31	GP 2 × GP 1	37	GP 1 × GO 6	43	GO 6 × Pusa Sawani
26	JOL 18-12 × GP 1	32	GP 2 × GAO 5	38	GP 1 × Pusa Sawani	44	GO 6 × GAO 8
27	JOL 18-12 × GAO 5	33	GP 2 × GO 6	39	GP 1 × GAO 8	45	Pusa Sawani × GAO 8
28	JOL 18-12 × GO 6	34	GP 2 × Pusa Sawani	40	GAO 5 × GO 6		
29	JOL 18-12 × Pusa Sawani	35	GP 2 × GAO 8	41	GAO 5 × Pusa Sawani		

Fig 5: Graphical representation of heterobeltiosis (BPH) and standard heterosis (SH) of hybrids in okra for fruit yield per plant

Conclusion

The present investigation demonstrated the considerable potential of heterosis breeding for improving fruit yield and associated agronomic and quality traits in okra. Among the evaluated hybrids, GAO 5 × GO emerged as the most promising cross, exhibiting 47.20% standard heterosis over the commercial check GJOH 4 and 19.83% heterobeltiosis for fruit yield per plant. In addition to superior yield performance, this hybrid showed significant improvement in several important traits, including days to 50% flowering, number of fruits per plant, average fruit weight, plant height, total soluble sugars, protein content, total chlorophyll content, and fruit moisture. Based on the combined assessment of standard heterosis and heterobeltiosis, the hybrids GAO 5 × GO 6, GP1 × GAO 8, JOL 20-04 × GAO 8, JOL 20-04 × JOL 18-12, GAO 5 × GAO 8, and JOL 18-07 × GAO 5 were identified as the most promising combinations for enhancing fruit yield and desirable quality

attributes. These hybrids possess substantial potential for commercial hybrid development and warrant further evaluation across diverse environments to assess their yield stability and adaptability. Furthermore, they may serve as valuable breeding material for exploiting hybrid vigour and for generating superior segregating populations aimed at developing high-yielding, quality-rich okra cultivars.

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