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RESEARCH ARTICLE

Heterosis studies for fruit yield and its attributing traits in Okra (*Abelmoschus esculentus* L. Moench)

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Abstract

The experiment was aimed to identify superior cross combinations with desirable traits for the commercial use of F_1 hybrids in okra, to achieve higher production and productivity. Eight parental lines and three testers of okra, along with their 24 F_1 hybrids produced by a Line × Tester mating technique, were examined to analyze the magnitude of heterosis for eight quantitative characters. These hybrids and their eleven parents were evaluated during June 2022 using a Randomized Block Design (RBD) with three replicates at Plant Breeding Farm, Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University. Significant and desirable heterosis over the better-parent, mid-parent and standard checks was observed for all the characters examined. The maximum desirable heterosis was recorded in EC 305613 × Varsha Uphar, IC 22237 × Hissar Unnat and IC 22232 × Varsha Uphar over the relative heterosis, standard heterosis and heterobeltiosis for days to first flowering. The hybrids IC 18532 × Hissar Unnat, IC 22232 × Varsha Uphar, IC 22237 × Hissar Unnat, EC 305613 × Hissar Unnat, EC 305613 × Varsha Uphar, EC 305736 × Hissar Unnat and EC 305736 × Arka Abhay exhibited significantly high heterosis and high mean values for yield and most of the traits in desirable directions. Therefore, the cross combinations IC 18532 × Hissar Unnat, IC 22232 × Varsha Uphar and EC 305613 × Varsha Uphar offered excellent opportunities for the exploitation of hybrid vigour in okra. Hence, these crosses could have effectively used to develop high yielding hybrids with desirable traits in okra.

Keywords: hybrid; hybrid vigour; line × tester; okra; standard heterosis

Introduction

Okra (*Abelmoschus esculentus* L. Moench) belongs to the Malvaceae family. Ethiopia was identified as the okra's primary centre of origin by De Candolle and Vavilov (1, 2). Okra is assumed to be originated in the Hindustani region and it was mostly grown in Pakistan, Burma and India (3). It is an economically important vegetable crop cultivated widely in subtropical, tropical and warm temperate regions around the world. It is a versatile crop extensively cultivated for its immature green pods, which are highly valued for its gelatinous texture, taste and nutritional content. It is a polyploidy crop, with a chromosome number of 2n = 72 or 144 and is often cross-pollinated. Outcrossing rates in okra range from 4 % to 30 %, reaching up to 42.2 % due to insect-assisted pollination (4). Okra is rich in vitamins C and A, folate, magnesium and antioxidants, which help lower the risk of chronic diseases such as diabetes, cancer, heart disease and stroke (5). Its leaves were used in traditional medicine to treat diarrhoea and are known to contain a high iodine content, which aids in managing goitre. Additionally, okra seeds are sources of minerals, vitamins and bioactive compounds with potential therapeutic uses (6).

Okra is one of the most traditional and ancient vegetable crops grown in India. It covers an area of 544000 hectares with a production of 6.889 million metric tonnes per hectares and an average productivity of 12.28 metric tonnes ha^{-1} (7). In India, okra accounts for 60 % of total fresh vegetable exports (8). Major producing states includes Orissa, Gujarat, Bihar, Andhra Pradesh, Maharashtra, Telangana, Assam, West Bengal and Uttar Pradesh (9).

India is the world's largest producer and consumer of okra globally, but it struggles with the absence of location-specific varieties that exhibit resistance or tolerance to both abiotic and biotic stresses (11). The primary objectives was to develop varieties or hybrids that efficiently utilize resources and demonstrate resistance to Yellow Vein Mosaic Virus (YVMV). This objective could only be achieved through heterosis breeding, a method known that had proven to be practical and successful in this crop. Utilizing heterosis in okra was essential for increasing productivity and improving other agronomic traits in crop development programs. Although yield was an essential property in okra hybrids and cultivars, significant efforts were made to improve not only yield, productivity and quality attributes. To enhance the performance of existing cross-pollinated okra varieties, the adoption a hybridization-based breeding method was considered necessary (12). The first evidence of hybrid vigour in okra was reported in earlier studies (13).

In okra, hybrid vigour was noticed in different traits, such as yield, plant height, fruit length and early maturity. Understating heterosis in the traits under considered will helped in selecting the most effective breeding methods to enhance genetic composition and productivity (14). Choosing parents solely based on phenotypic performance was an inadequate approach; hence, their ability to combine played a pivotal role in the selection process in making informed breeding decisions. This study employed the line × tester mating design to estimate genetic value. In crop improvement, heterosis played a key role in maintaining genetic diversity, guiding the selection of elite parents and ensuring the success of both hybrid breeding and future gene pool development (15). Therefore, this study was conducted to evaluate the degrees of heterosis for yield and its attributes in okra.

Materials and Methods

The current investigation was taken up in okra involving eight females (IC14909, IC 18532, IC 22232, IC 22237, EC 305613, EC 305675 and EC 306720) and three male parents (Hissar Unnat, Varsha Uphar, and Arka Abhay), which were crossed using a Line × Tester mating technique to produce twenty-four crosses. The parents used for the study were collected from National Bureau of Plant Genetic Resources (NBPGR), New Delhi, Haryana Agriculture University (HAU), Hissar Unnat and Indian Institute of Horticulture Research (IIHR), Bangalore. A total of 24 F_1 hybrids and their eleven parents were evaluated in Randomized Block Design (RBD) with 3 replicates in 3-meter row with a spacing of 45 × 30 cm during June 2022. The study was carried out at Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University, situated at 11.3906° N latitude and 79.7133° E longitude, with an elevation of 4 meter (13 feet) above sea level. Throughout the crop growing period, the recommended cultivation practices for okra were followed. Data were taken on randomly selected plants of each genotype for eight biometric traits *viz.,* days to first flowering (days), plant height (cm), number of branches per plant, number of fruits per plant, fruit length (cm), fruit girth (cm), single fruit weight (g) and fruit yield per plant (g).

The analysis of variance (ANOVA) for the randomized block design was performed using the method described in previous studies (16). The efficiency of the F-1 hybrids was assessed based on heterosis over the standard check, better parent and mid-parent, following the approach suggested by previous study (17). The degrees of heterosis involved exhibiting the percentage decrease or increase relative to standard check (SC), better parent (BP) and mid-parent (MP), using the formulas proposed in a earlier study (18). The significance of standard heterosis, heterobeltiosis and relative heterosis was statistically evaluated using a t-test (19).

$$\text{Relative heterosis (RH \%)} = \frac{\text{F1 - MP}}{\text{MP}} \times 100$$

$$\text{Heterobeltiosis (HB \%)} = \frac{\text{F1 - BP}}{\text{BP}} \times 100$$

$$\text{Standard heterosis (SH \%)} = \frac{\text{F1 - BP}}{\text{BP}} \times 100$$

Where, MP = Mean of mid-parent, BP = Mean of better parent and SC = Mean of standard check.

Results and Discussion

The mean performance of genotypes and their hybrids for eight traits in okra was presented in Table 1. Among the lines, EC 305613 showed significantly earlier days to first flowering (36.47 days), while the tester Hissar Unnat also recorded significantly earlier days to first flowering (40.30 days). Among the crosses, EC 305613 × Varsha Uphar exhibited substantially earlier (33.67 days) results compared to the other crosses. A reduced number of days required for first flowering was directly proportional to the crop's earliness. As a result, earlier flowering led to an increased early yield (20, 21). The line EC 305613 (74.45 cm) and the tester Varsha Uphar (74.39 cm) recorded significant plant height. Among the cross combinations, IC22232 × Varsha Uphar exhibited significant dwarfism (64.18 cm). Okra bears capsules at most of the nodes on the main stem and primary branches; that's why plant height was an important trait to increase yields (20).

Among the lines, EC 305613 recorded the maximum significant number of branches per plant (5.76), while the tester Varsha Uphar also displayed a significant maximum for this trait (5.29). The cross EC 305613 × Varsha Uphar showed the significantly highest for this trait, with a mean of 7.55. The trait number of branches per plant played an important role in influencing the yield. Based on mean values of F1 crosses and their parents, the hybrid was found to be either higher or lower than that of their respective parents. This deviation was largely due to heterosis (21, 22). The maximum number of fruits per plant was recorded in the line EC 305613 (22.17) and the tester Varsha Uphar (21.23). Among the crosses, EC305613 × Varsha Uphar exhibited a significantly higher number of fruits per plant (32.67). The trait was known to be dependent on other yield-contributing parameters and superior performance was noted in this study, which reflected a positive heterotic effect (22).

The line EC 305613 recorded the maximum fruit length (16.55 cm), while the tester Varsha Uphar exhibited a significantly higher fruit length (16.90 cm). Among the hybrids, EC 305613 × Varsha Uphar produced the longest fruits (20.45 cm). Fruit length was a key trait that positively influenced yield and heterosis; enhancing this trait was crucial for better productivity. Similar conclusions were also drawn in previous study (22). The line EC 305613 showed the maximum fruit girth (6.81 cm), while Varsha Uphar recorded 6.35 cm. The hybrid EC 305613 × Varsha Uphar produced a significantly higher fruit girth (6.58 cm). Fruit girth played an essential role in fruit quality and market acceptance, highlighting its importance in selection (20).

The line EC 305613 reported the maximum single fruit weight (17.44 g), while the tester Varsha Uphar showed 16.89 g, which was significantly high. Among the hybrids, EC 305613 × Varsha Uphar recorded the highest single fruit weight (19.58 g). The fruit weight was directly proportional to total yield; it is an important trait for selection (20, 22). Among the lines, EC 305613 produced the maximum fruit yield per plant (341.84 g), whereas Varsha Uphar displayed a significantly higher yield (326.25 g) among testers. The hybrid EC 305613 × Varsha Uphar achieved the maximum yield per plant (421.89 g). Since yield was the primary target in okra breeding, this trait held significant

Table 1. Mean performance of parents and their hybrids for eight characters in okra

Genotypes / Traits	DFF	PH	NBPP	NFPP	FL	FG	SFW	FYPP
Lines								
IC 14909	38.18	78.03**	3.90	17.56	14.09	6.10	14.23	242.56
IC 18532	37.23*	76.02**	4.87*	20.46**	15.79*	6.15*	16.25	335.60**
IC 22232	36.67*	83.64	5.01**	21.23**	15.82*	6.18*	16.48*	338.21**
IC 22237	38.75	85.45	4.25	19.56	15.44	5.36	15.89	263.45
EC 305613	36.47**	74.45**	5.76**	22.17**	16.55**	6.81**	17.44**	341.84**
EC 305675	41.34	91.31	4.53	15.99	14.87	5.70	15.45	232.66
EC 305736	39.54	83.00	4.65	19.52	15.47	5.25	15.21	264.58
EC 306720	41.25	82.97	4.65	17.20	15.24	5.68	15.47	265.10
Mean of Lines	38.67	81.85	4.67	19.27	15.07	5.90	15.79	285.50
Testers								
Hissar Unnat	40.30*	77.23	4.92*	20.56*	16.85*	6.31*	16.83*	322.89*
Varsha Uphar	40.73*	74.39*	5.29**	21.23**	16.90*	6.35*	16.89*	326.25**
Arka Abhay	45.60	78.52	3.98	16.99	15.43	5.84	15.68	301.25
Mean of Testers	42.33	77.37	4.72	19.59	16.15	6.06	16.15	306.18
Hybrids								
IC 14909 × Hissar Unnat	43.25	81.34	5.98	25.55	17.76	5.36	19.32**	335.69
IC 14909 × Varsha Uphar	40.21	80.19	5.43	25.67	16.76	5.31	17.35	363.67*
IC 14909 × Arka Abhay	43.34	83.20	4.80	23.78	18.44*	5.24	18.34	300.21
IC 18532 × Hissar Unnat	36.21**	66.32**	6.98**	28.80**	19.74**	6.33*	19.44**	380.87**
IC 18532 × Varsha Uphar	40.78	69.49**	4.54	26.56*	18.12	5.47	16.34	333.56
IC 18532 × Arka Abhay	44.78	74.51	6.45**	25.56	17.77	6.10*	17.54	286.56
IC 22232 × Hissar Unnat	38.48	89.67	6.12*	26.78*	17.55	5.70	15.87	345.56
IC 22232 × Varsha Uphar	35.21**	64.18**	7.14**	29.67**	19.65**	6.48*	19.51**	392.67**
IC 22232 × Arka Abhay	39.89	83.91	5.87	24.78	18.66**	5.41	16.56	319.34
IC 22237 × Hissar Unnat	35.76**	66.32**	6.58**	27.99**	14.50	6.29*	19.43**	369.67**
IC 22237 × Varsha Uphar	39.78	71.24**	6.79**	28.78**	15.47	6.21*	17.87	380.62**
IC 22237 × Arka Abhay	39.89	70.46**	6.89**	27.68**	16.50	6.02*	16.78	368.23**
EC 305613 × Hissar Unnat	36.56**	68.46**	5.98	27.67**	18.98**	5.47	18.76*	370.87**
EC 305613 × Varsha Uphar	33.67**	64.25**	7.55**	32.67**	20.45**	6.58*	19.58**	421.89**
EC 305613 × Arka Abhay	40.78	76.87	4.76	24.67	17.56	5.48	17.98	347.78
EC 305675 × Hissar Unnat	40.56	77.56	6.34**	20.45	16.54	5.60	18.54	293.87
EC 305675 × Varsha Uphar	40.76	74.39	5.44	21.52	17.59	5.70	17.87	320.65
EC 305675 × Arka Abhay	43.87	80.71	5.12	21.67	18.76**	5.81	16.89	340.54
EC 305736 × Hissar Unnat	38.12*	78.16	5.68	26.54*	18.65*	5.45	18.74*	368.20**
EC 305736 × Varsha Uphar	39.78	79.16	5.47	27.45**	18.25	5.64	18.45	369.25**
EC 305736 × Arka Abhay	38.60	89.57	5.62	25.64	17.56	5.48	17.68	370.25**
EC 306720 × Hissar Unnat	41.21	74.20	5.47	24.15	16.54	5.62	17.95	298.25
EC 306720 × Varsha Uphar	40.76	73.67	5.44	24.30	17.00	5.61	17.87	300.21
EC 306720 × Arka Abhay	42.12	74.89	5.12	23.56	17.65	5.74	17.48	301.2
Mean of Hybrids	39.77	75.73	5.90	25.91	17.77	5.75	18.01	344.97
CD @ 5 %	1.58	2.36	0.19	0.93	0.67	0.23	0.67	16.63
CD @ 1 %	2.10	3.14	0.26	1.24	0.90	0.31	0.88	19.44

* Significant at 5 percent level, ** Significant at 1 percent level

DFF- Days to first flowering, PH- Plant height (cm), NBPP- Number of branches per plant, NFPP- Number of fruits per plant, FL- Fruit length (cm), FG- Fruit girth (cm), SFW- Single fruit weight (g), FYPP- Fruit yield per plant (g)

importance. Based on mean performance, the line EC 305613, the tester Varsha Uphar and the hybrid EC 305613 × Varsha Uphar recorded maximum significant means for most of the yield traits (20, 22).

The hybrid vigour could exploited based on the degree and nature of heterosis, as well as the type of gene action. Understanding the relationship between inbreeding depression and heterosis could aid in identifying and eliminating problematic crosses early on. The percentage of heterosis for yield parameters was calculated relative to mid-parent (MP), better parent (BP) and standard check (SC). The desirable heterosis was considered for the traits such as yield per plant, days to first flowering, fruit length, single fruit weight, fruit girth, plant height, number of fruits per plant and number of branches per plant (23, 24). The findings were presented in Table 2 and discussed below. Top five crosses based on standard heterosis for yield and its attributing traits in okra were displayed in Fig. 1. Earliness was a crucial trait in vegetable crops like okra. Hybrids with early flowering produced early yields, which could attract higher prices in the market. It also extended the fruiting period of okra plants. As a result, this character preferred negative heterosis. In the current study, the highest significant and negative relative heterosis was recorded in the hybrids EC 305613 × Varsha Uphar, IC 22237 × Hissar Unnat and IC 22232 × Varsha Uphar. Significant and negative relative heterosis was exhibited in eight hybrids. The maximum significant negative heterobeltiosis was reported in EC305613 × Varsha Uphar, followed by EC 305736 × Arka Abhay and IC 22232 × Varsha Uphar. In addition, 14 crosses exhibited negatively significant heterobeltiosis. The maximum negative and significant standard heterosis was registered in EC 305613 × Varsha Uphar, IC22232 × Varsha Uphar and IC 22237 × Hissar Unnat. In this study, EC 305613 Varsha Uphar and IC 22232 Varsha Uphar displayed maximum negative heterosis over standard check, better parent and mid-parent individually, suggesting their potential to exploit heterosis for early flowering in okra (25).

Plant height significantly influenced crop yield. Among the 24 crosses, fifteen hybrids showed significant and negative relative heterosis and the most negatively significant heterosis was noticed in the crosses, namely, IC 22237 × Arka Abhay, EC 305623 × Varsha Uphar and IC 22237 × Hissar Unnat. The hybrids, IC 22237 × Hissar Unnat, IC 22232 × Varsha Uphar and EC 305675 × Varsha Uphar exhibited the highest significant and negative heterobeltiosis and seventeen hybrids

Table 2. Magnitude of heterosis for yield and its attributing traits in okra

Hybrids	Days to first flowering			Plant height			No. of branches per plant			No. of fruits per plant		
Heterosis	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**
IC 14909 × Hissar Unnat	10.22**	7.32**	5.23**	4.78**	4.24**	6.48**	35.91**	22.04**	13.04**	34.06**	24.27**	20.36**
IC 14909 × Varsha Uphar	1.44	-2.17	-2.17	3.86**	2.77	4.97**	18.17**	2.65	2.65	32.35**	20.91**	20.91**
IC 14909 × Arka Abhay	3.45*	-4.97**	5.44**	6.29**	5.96**	8.91**	21.83**	20.60**	-9.26**	37.64**	35.42**	12.01**
IC 18532 × Hissar Unnat	-6.60**	-10.16**	-11.91**	-13.44**	-14.12**	-13.18**	45.72**	42.45**	31.95**	40.41**	40.06**	35.66**
IC 18532 × Varsha Uphar	4.12*	-0.78	-0.78	-8.81**	-9.04**	-9.04**	-8.86**	-14.11**	-14.11**	27.42**	25.11**	25.11**
IC 18532 × Arka Abhay	8.11**	-1.81	8.95**	-3.57**	-5.10**	-2.46	49.04**	37.89**	21.99**	36.49**	24.93**	20.40**
IC 22232 × Hissar Unnat	-0.01	-4.52*	-6.37**	11.48**	7.21**	17.38**	23.51**	22.16**	15.69**	28.15**	26.14**	26.14**
IC 22232 × Varsha Uphar	-9.45**	-14.33**	-14.33**	-19.8**	-23.27**	-15.99**	38.64**	34.97**	34.97**	39.76**	39.76**	39.76**
IC 22232 × Arka Abhay	-3.02	-12.52**	-2.94	3.49**	0.32	9.85**	30.59**	17.17**	10.96**	29.66**	16.72**	16.72**
IC 22237 × Hissar Unnat	-9.52**	-11.26**	-12.98**	-18.47**	-22.39**	-13.18**	43.83**	34.29**	24.39**	39.52**	36.12**	31.84**
IC 22237 × Varsha Uphar	-0.35	-3.20	-3.20	-11.96**	-16.63**	-6.74**	42.35**	28.36**	28.36**	41.11**	35.56**	35.56**
IC 22237 × Arka Abhay	-5.41**	-12.52**	-2.94	-14.06**	-17.55**	-7.76**	67.44**	62.12**	30.25**	51.45**	41.51**	30.38**
EC 305613 × Hissar Unnat	-4.75**	-9.28**	-11.05**	-9.73**	-11.35**	-10.38**	12.23**	3.88*	13.04**	29.50**	24.81**	30.33**
EC 305613 × Varsha Uphar	-13.19**	-18.08**	-18.08**	-14.81**	-15.89**	-15.89**	36.69**	31.15**	42.72**	50.54**	47.35**	53.87**
EC 305613 × Arka Abhay	-0.63	-10.58**	-0.78	0.51	-2.10	0.63	-2.23	-17.31**	-10.02**	25.99**	11.28**	16.20**
EC 305675 × Hissar Unnat	-0.64	-1.89	-1.31	-7.96**	-15.06**	1.53	34.46**	29.39**	19.85**	11.89**	-0.55	-3.67
EC 305675 × Varsha Uphar	-1.12	-1.40	-0.83	-11.28**	-18.53**	-2.62	10.79**	2.84	2.84	15.64**	1.37	1.37
EC 305675 × Arka Abhay	0.91	-3.81*	6.73**	-4.95**	-11.61**	5.66**	20.33**	13.02**	-3.21	31.42**	27.54**	2.09
EC 305736 × Hissar Unnat	-4.51*	-5.41**	-7.25**	-2.44	-5.83**	2.32	18.95**	15.92**	7.37**	32.42**	29.06**	25.01**
EC 305736 × Varsha Uphar	-1.34	-3.21	-3.21	-0.67	-4.63**	3.63*	10.06**	3.40	3.40	34.72**	29.30**	29.30**
EC 305736 × Arka Abhay	-9.33**	-15.36**	-6.08**	10.91**	7.92**	17.26**	30.24**	20.86**	6.24**	40.44**	31.35**	20.77**
EC 306720 × Hissar Unnat	1.06	-0.11	0.27	-7.36**	-10.57**	-2.87	14.55**	11.63**	3.40	27.90**	17.44**	13.75**
EC 306720 × Varsha Uphar	-1.01	-1.20	-0.83	-7.55**	-11.21**	-3.57*	9.46**	2.84	2.84	26.48**	14.48**	14.48**
EC 306720 × Arka Abhay	-3.02	-7.65**	2.47	-7.25**	-9.74**	-1.96	18.66**	10.11**	-3.21	37.80**	36.98**	10.98**

Hybrids	Fruit length			Fruit girth			Single fruit weight			Fruit yield per plant		
Heterosis	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**	**RH**	**HB**	**SH**
IC 14909 × Hissar Unnat	16.31**	7.96**	7.18**	-12.32**	-12.56**	-13.73**	26.94**	19.19**	16.57**	22.58**	10.01**	7.54**
IC 14909 × Varsha Uphar	9.33**	1.15	1.15	-13.73**	-14.54**	-14.54**	12.65**	4.69*	4.69*	31.12**	16.50**	16.50**
IC 14909 × Arka Abhay	24.93**	19.51**	11.29**	-12.15**	-14.00**	-15.61**	22.63**	16.97**	10.64**	10.41**	-0.35	-3.83
IC 18532 × Hissar Unnat	26.95**	20.00**	19.13**	3.09	2.93	1.88	19.78**	19.63**	17.30**	18.69**	13.31**	21.82**
IC 18532 × Varsha Uphar	16.08**	9.35**	9.35**	-11.51**	-11.96**	-11.96**	-0.44	-1.41	-1.41	2.99	-0.61	6.86**
IC 18532 × Arka Abhay	18.15**	15.17**	7.24**	1.81	-0.76	-1.77	9.88**	7.94**	5.83**	-10.01**	-14.61**	-8.20**
IC 22232 × Hissar Unnat	14.07**	6.69**	5.91**	-7.39**	-7.77**	-8.26**	-2.71	-3.33	-4.22*	7.43**	2.18	10.70**
IC 22232 × Varsha Uphar	27.23**	18.59**	18.59**	4.57**	4.29*	4.29*	18.27**	17.72**	17.72**	20.76**	16.10**	25.80**
IC 22232 × Arka Abhay	25.45**	20.93**	12.61**	-9.98**	-12.46**	-12.93**	3.19	0.85	-0.08	-0.12	-5.58	2.30
IC 22237 × Hissar Unnat	-9.06**	-11.85**	-12.49**	9.49**	2.61	1.23	21.08**	19.88**	17.26**	30.03**	21.15**	18.43**
IC 22237 × Varsha Uphar	-3.34	-6.64**	-6.64**	7.26**	-0.11	-0.11	10.09**	7.82**	7.82**	32.34**	22.02**	22.02**
IC 22237 × Arka Abhay	6.90**	6.87**	-0.42	7.50**	3.08	-3.11	6.31**	5.60**	1.25	30.41**	22.23**	17.96**
EC 305613 × Hissar Unnat	15.02**	14.66**	14.54**	-15.46**	-19.68**	-11.96**	11.51**	7.59**	13.19**	14.65**	8.49**	18.81**
EC 305613 × Varsha Uphar	23.48**	23.42**	23.42**	1.05	-3.38	5.90**	15.14**	12.29**	18.14**	29.02**	23.42**	35.16**
EC 305613 × Arka Abhay	9.81**	6.08**	5.97**	-13.36**	-19.53**	-11.80**	8.60**	3.12	8.49**	8.16**	1.74	11.42**
EC 305675 × Hissar Unnat	5.62**	0.55	-0.18	-5.33**	-8.65**	-9.87**	17.14**	14.39**	11.89**	9.29**	-3.69	-5.86*
EC 305675 × Varsha Uphar	11.90**	6.16**	6.16**	-4.31*	-8.26**	-8.26**	11.61**	7.82**	7.82**	17.71**	2.72	2.72
EC 305675 × Arka Abhay	23.83**	21.58**	13.22**	0.69	-0.51	-6.49**	8.52**	7.74**	1.91	27.56**	13.04**	9.09**
EC 305736 × Hissar Unnat	16.85**	13.37**	12.55**	-4.22*	-11.09**	-12.29**	19.29**	15.61**	13.07**	29.26**	20.66**	17.96**
EC 305736 × Varsha Uphar	13.92**	10.14**	10.14**	-1.54	-9.17**	-9.17**	16.08**	11.30**	11.30**	28.05**	18.29**	18.29**
EC 305736 × Arka Abhay	13.68**	13.53**	5.99**	-1.17	-6.16**	-11.80**	14.48**	12.78**	6.68**	30.87**	22.90**	18.61**
EC 306720 × Hissar Unnat	4.39*	0.55	-0.18	-4.85**	-8.32**	-9.55**	13.34**	10.75**	8.33**	4.61*	-2.26	-4.45
EC 306720 × Varsha Uphar	6.88**	2.60	2.60	-5.69**	-9.71**	-9.71**	11.52**	7.80**	7.80**	4.01	-3.83	-3.83
EC 306720 × Arka Abhay	15.10**	14.39**	6.52**	-0.38	-1.71	-7.62**	12.24**	11.50**	5.47**	6.37**	-0.02	-3.51

* Significant at 5 percent level, ** Significant at 1 percent level RH- Relative Heterosis HB- Heterobeltiosis SH- Standard Heterosis

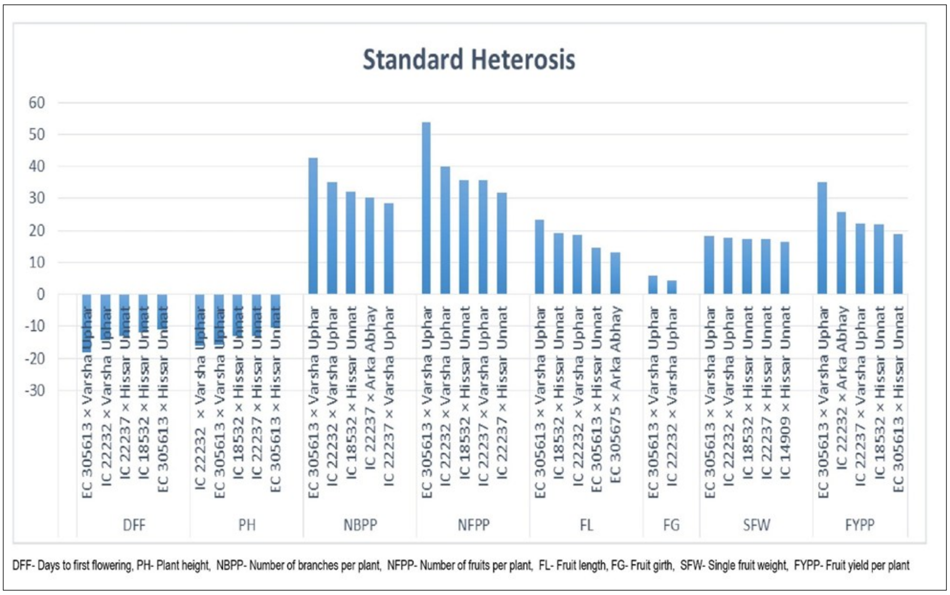

Fig. 1. Top five okra crosses based on standard heterosis for yield and its yield contributing traits.

registered negative heterobeltiosis. The highest significant and negative standard heterosis was observed in IC 22232 × Varsha Uphar, IC 18532 × Hissar Unnat, EC 305613 × Varsha Uphar and IC 22237 × Hissar Unnat. Among 24 hybrids, only nine hybrids showed negative and significant standard heterosis. The hybrid IC 22232 × Hissar Unnat exhibited the highest percentage of negative heterosis over standard check, better parent and mid-parent (26, 27).

Vegetative growth significantly contributed to yield enhancement, as the number of branches per plant was directly associated with the number of fruits. Therefore, positive heterosis was desirable for this trait. The highest positive and significant relative heterosis was observed in the hybrids IC 22237 × Arka Abhay, IC 18532 × Arka Abhay and IC 18532 × Hissar Unnat. Among all hybrids evaluated, except IC 18532 × Varsha Uphar and EC 305613 × Arka Abhay, all others displayed significant and positive heterosis for this trait. Moreover, eighteen hybrids showed desirable heterobeltiosis, with IC 22237 × Arka Abhay recording the highest significant and positive heterobeltiosis, followed by IC 18532 × Arka Abhay and IC 18532 × Hissar Unnat. Among the hybrids, fourteen hybrids exhibited significant and positive standard heterosis. The hybrids, IC 18532 × Hissar Unnat, EC 305613 × Varsha Uphar and IC 22232 × Varsha Uphar, recorded the maximum standard heterosis. Notably, the cross IC 18532 × Hissar Unnat demonstrated the maximum positive heterosis over standard check, better parent and mid-parent, indicating its superior performance for this character (28).

For the number of fruits per plant, the highest significant and positive standard heterosis, heterobeltiosis and relative heterosis were recorded in IC 18532 × Hissar Unnat, EC 305613 × Varsha Uphar, IC 22237 × Arka Abhay, IC 22237 × Varsha Uphar, IC 18532 × Hissar Unnat and IC 22232 × Varsha Uphar. Among twenty four hybrids, all the hybrids exhibited significant relative heterosis, twenty one showed standard heterosis and twenty two crosses exhibited heterobeltiosis. The number of fruits per plant was a key factor increasing yield per plant. Therefore, positive heterosis was ideal for this character. The reports indicated that the positive heterosis for this trait was due to favourable genes in the parental lines (27, 29).

Fruit length was a significant factor in consumer preference. In all crosses except IC 22237 × Hissar Unnat and IC 22237 × Varsha Uphar, significantly positive relative heterosis was recorded for fruit length. Better parent heterosis was positive significant in all the hybrids except IC 14909 × Varsha Uphar, IC 22237 × Varsha Uphar, IC 22237 × Hissar Unnat, EC 305675 × Hissar Unnat, EC 306720 × Hissar Unnat and EC 306720 × Varsha Uphar. Among all the crosses, EC 305613 × Varsha Uphar showed the maximum significant positive value, followed by IC 18532 × Hissar Unnat and IC 22232 × Varsha Uphar. Standard heterosis was found to be significantly positive in 17 crosses. The highest significant positive heterosis was observed in the hybrids EC 305613 × Varsha Uphar, IC 18532 × Hissar Unnat and IC 22232 × Varsha Uphar for fruit length over standard check, better parent and mid-parent (29).

Fruit girth was another factor that impacted yield. The highest significant relative heterosis for fruit girth was observed in the positive direction for four hybrids, namely, IC 22237 × Hissar Unnat, IC22237 × Arka Abhay, IC 22237 × Varsha Uphar and IC 22232 × Varsha Uphar. Heterobeltiosis was significantly positive in only one hybrid, IC 22232 × Varsha Uphar. The maximum positive and significant standard heterosis was recorded in 2 crosses, namely, EC 305613 × Varsha Uphar and IC 22232 × Varsha Uphar for fruit girth. The hybrid IC 22232 × Varsha Uphar showed the maximum and positively significant heterosis over the standard check, better parent and mid-parent. The maximum significant and positive heterobeltiosis and relative were noticed in the crosses IC 14909 × Hissar Unnat, IC 14909 × Arka Abhay and IC 22237 × Hissar Unnat for single fruit weight. The crosses EC 305613 × Varsha Uphar, IC 18532 × Hissar Unnat and IC 22232 × Varsha Uphar recorded the maximum standard heterosis. Out of twenty four hybrids, twenty one displayed significant and positive relative heterosis, twenty for heterobeltiosis and nineteen for standard heterosis (29, 30). Fruit girth, fruit length and single fruit weight were important traits that were directly associated with overall yield. Therefore, positive and significant heterosis for these characters was highly desirable to increase productivity.

The most significant trait in this study was fruit yield. The maximum significant positive relative heterosis was observed in the hybrid IC 22237 × Varsha Uphar, IC 14909 × Varsha Uphar, EC 305736 × Arka Abhay, IC 18532 × Hissar Unnat and IC 22232 × Varsha Uphar. Significant positive heterobeltiosis was observed in the crosses EC 305613 × Varsha Uphar EC 305736 × Arka Abhay, IC 22237 × Arka Abhay, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat. The maximum significant positive standard heterosis was noted in EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar, IC 18532 × Hissar Unnat and IC 22237 × Varsha Uphar. Out of the twenty-four hybrids studied, twenty documented significant positive relative heterosis, thirteen proved heterobeltiosis and sixteen exhibited standard heterosis in terms of fruit yield per plant. Fruit yield depended on the combined effects of many traits and enhancing them through heterosis played a significant role in increasing okra production and profitability. The maximum significant and positive heterosis was observed in the crosses EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat over the mid-parent, better parent and standard check, due to the presence of dominant genes in the parents (28, 29).

Conclusion

Heterosis was a significant tool for increasing fruit yields. Negative heterosis was found particularly beneficial for promoting earliness in terms of days to first flowering and reducing plant height. These traits were highly advantageous from a farmer's perspective, as they led to earlier maturity and quicker harvesting. All other traits exhibited significant positive heterosis, contributing to overall yield improvement. The present study identified three high-performing okra hybrids: IC 18532 × Hissar Unnat, IC 22232 × Varsha Uphar and EC 305613 × Varsha Uphar. These hybrids displayed the highest mean values for yield and documented significant heterosis for most yield attributing traits in desirable directions. Their superior performance recommended strong potential for utilizing hybrid vigour in okra breeding programs. Therefore, these cross combinations could be effectively used to develop high-yielding okra hybrid with desirable traits. Their adoption in cultivation practices could have led to improved productivity and better economic returns for farmers.

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Authors' contributions

MV planned the study, provided guidance for manuscript preparation, supervised the work and reviewed the manuscript. RP collected samples, conducted experiments, recorded data and performed statistical analysis. MSAR provided guidance in data analysis and manuscript writing. All authors read and approved the manuscript.

Compliance with ethical standards

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

Ethical issues: None

References

1. De Candolle A. Origine des Plantes Cultivees. Germer bailliere. Paris. 1883; p. 123.
2. Vavilov NI. The origin, variation, immunity and breeding of cultivated plants. Cronica Botanica. 1951;13(1/6):36-37. https://doi.org/10.1097/00010694-195112000-00018
3. Zeven AC, Zhukovsky PM. Dictionary of cultivated plants and their centres of diversity. Centre for Agricultural Publishing and Documentation, Wageningen. The Netherlands. 1975;p.219.
4. Sakriya SG, Vaja SJ, Patel S, Mahesha KV. Exploitation of heterosis for yield and yield attributes in okra [*Abelmoschus esculentus* (L.) Moench]. J. Pharm. Innov., 2023; 12(8):4008-4013
5. Elkhalifa AEO, Alshammari E, Adnan M, Alcantara JC, Awadelkareem AM, Eltoum NE, et al. Okra (*Abelmoschus esculentus*) as a potential dietary medicine with nutraceutical importance for sustainable health applications. *Molecules*, 2021; 26(3): p.696. https://doi.org/10.3390/molecules26030696
6. Gupta P, Patra S. Okra Plant: A Multi-purpose Underutilized Vegetable Crop: A Review. Bhartiya Krishi Anusandhan Patrika. 2021; 36(3):208-11. https://doi.org/10.18805/BKAP261
7. Statista. Worldwide okra production. Accessed August 01 2023. https://www.statista.com/outlook/20030000/100 worldokraproduction/worldwide
8. National Horticulture Board. Ministry of Agriculture and Farmers Welfare, Government of India 2021.
9. Vennila S, Elangaimannan R, Lubna AS, Sudhasha S. Study on genetic divergence, association between morphological traits and path analysis among different okra (*Abelmoschus esculentus* L. Moench) genotypes. Vegetos. 2024;1-9. https://doi.org/10.1007/s42535-024-01067-z
10. Anonymous. Area and Production of Horticulture Crops: All India NHB database, Gurgaon, India. NHB, 2021b. http://www.nhb.gov.in
11. Yadav KA, Dhankhar SK, Singh DA, Singh UD. Exploitation of combining ability and heterosis potential for improvement in okra (*Abelmoschus esculentus*) genotypes. Indian J. Agric. Sci. 2023;93 (2):127-32. https://doi.org/10.56093/ijas.v93i2.132161
12. Kumar R, Pandey MK, Pitha CC, Mehandi S, Chaudhary PL. Analysis of heterotic potential for yield and its attributing traits in okra (*Abelmoschus esculentus* L. Moench). Electron. J. Plant Breed. 2023;14(4);1515-26. https://doi.org/10.37992/2023.1404.176
13. Vijayaraghavan C, Warrier VA. Evolution of high yielding hybrid bhindi (*Hibiscus esculentus* L). Proceeding of the 33rd Indian Science Congress, Bangalore, India 1946;163.
14. Sapavadiya SB, Kachhadia VH, Savaliya JJ, Sapovadiya MH, Singh SV. Heterosis studies in okra [*Abelmoschus esculentus* (L.) Moench]. *J. Pharm. Innov.* 2019;8(6): 408-11.
15. Chaudhary PL, Kumar B, Kumar R. Analysis of heterosis and heterobeltiosis for earliness, yield and its contributing traits in okra (*Abelmoschus esculentus* L. Moench). Int. J. Plant Sci., 2023;35(11), 84-98. https://doi.org/10.9734/IJPSS/2023/v35i112949
16. Panse VG, Sukhatme PV. Statistical methods for agricultural research. ICAR, New Delhi, 1985;8:308-18.
17. Fonseca S, Patterson F. Hybrid vigour in a seven parent diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Sci., 1968;8(1):85-88. https://doi.org/10.2135/cropsci1968.0011183X000800010025x
18. Singh RK, Chaudhary BD. Biometrical methods in quantitative genetic analysis, 3rd edn. Kalyani Publishers, Ludhiana 1977.
19. Wynne JC, Emery DA, Rice PM. Combining ability estimates in *Arachis hypogeae* L. II. Field performance of F1 hybrids. Crop Sci. 1970;10:713-15. https://doi.org/10.2135/

cropsci1970.0011183X001000060036x

20. Kerure P, Pitchaimuthu M. Evaluation for heterosis in okra (*Abelmoschus esculentus* L. Moench). *Electron. J. Plant Breed*., 2019:10(1):248-55. https://doi.org/10.5958/0975-928X.2019.00029.2

21. Devi AP, Bhattacharjee T, Banerjee S, Maurya PK, Chatterjee S, Chattopadhyay A. Heterotic expression of okra hybrids for tolerance to enation leaf curl virus. Int. *J. Veg. Sci.,* 2020;26(2):163-89. https://doi.org/10.1080/19315260.2019.1624670

22. Bharathkumar MV, Kumar SD, Singh MD. Correlation, Path Analysis, Heterosis and Inbreeding Depression for Yield and Quality Traits of Okra Lines and their Hybrids. *Indian J. Pure Appl. Biosci.,* 2021;9(2):180 -87. https://doi.org/10.18782/2582-2845.8639

23. Rani M, Kumar S, Kumar M. Estimation of heterosis for yield and its contributing traits in brinjal. J Environ Biol. 2018;39(5):710-18. http://doi.org/10.22438/jeb/39/5/MRN-609

24. Kumar P, Singh H, Lal C, Choudhary R. Heterosis analysis for yield and its component traits in bread wheat (*Triticum aestivum* L.) over different environments. J Environ Biol. 2021;42:438-45. http://doi.org/10.22438/jeb/42/2(SI)/SI-251

25. Ranga AD, Vikram A, Kumar R, Dogra RK, Sharma R Sharma HR. Exploitation of heterosis and combining ability potential for improvement in okra (*Abelmoschus esculentus* L.). Scientific Reports. 2024;14(1):24539. https://doi.org/10.1038/s41598-024-75764-9

26. Pathania R, Mehta DK, Bhardwaj RK, Dogra RK, Singh K, Kaplex A, et al. Exploitation of heterosis, combining ability and gene action potential for improvement in okra (*Abelmoschus esculentus*). The Indian Journal of Agricultural Sciences. 2024;4(12):1340-48. https://doi.org/10.56093/ijas.v94i12.152294

27. Kavya VN, Kerure P, Srinivasa V, Pitchaimuthu M, Kantharaj Y, Harish BBN. Genetic variability studies in F2 segregating populations for yield and its component traits in Okra [*Abelmoschus esculentus* (L.) Moench]. International Journal of Current Microbiology and Applied Sciences. 2019;8(04):855-64. https://doi.org/10.20546/ijcmas.2019.804.096

28. Valluru MV, Singh BK, Singh AK, Raju SVS, Jaiswal DK, Sharma KR. Exploitation of Heterosis for Plant and Yield Characteristics in Okra (*Abelmoschus esculentus* (L.) Moench). Environment and Ecology. 2024;42(3):968-78. https://doi.org/10.60151/envec/DKAU4078

29. Makdoomi MI, Wani KP, Dar ZA, Hussain K, Nabi A, Mushtaq F, et al. Heterosis studies in okra (*Abelmoschus esculentus* L. Moench). International Journal of Current Microbiology and Applied Sciences 2018;7(2):3297-3304. https://doi.org/10.20546/ijcmas.2018.702.396

30. Mulge SA, Khot R. Exploitation of hybrid vigour for yield and quality parameters in Okra [*Abelmoschus esculentus* (L.) Moench] through half diallel analysis. Int. J. Chem. Stud. 2018;6(6):1269-1273.

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