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Exploitation of Heterosis for Growth, Earliness and Yield Attributes in Okra (*Abelmoschus esculentus* (L.) Moench)

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ABSTRACT

Heterotic studies of 45 single crosses derived from crossing 10 horticulturally superior, optimally diverse and nearly homozygous lines of okra (*Abelmoschus esculentus* (L.) Moench), namely P_1(IC282248), P_2(IC27826-A), P_3(IC29119-B), P_4(IC31398-A), P_5(IC45732), P_6(IC89819), P_7(IC89976), P_8(IC90107), P_9(IC99716) and P_{10}(IC111443) in a half diallel fashion over three seasons (early, mid and late *kharif*, 2009) revealed an appreciable amount of average heterosis and heterobeltiosis in a desirable direction in a good number of crosses for the majority of growth, earliness and yield attributes. Cross $C_4(P_1\times P_5)$, displaying high negative heterosis over the standard check for days to 50% flowering (-4.24%) and first flowering and fruiting node (-13.22 %) is important to exploit heterosis for earliness in okra. The crosses with non-significant standard heterosis in any direction for total yield per plant $C_{42}(P_7\times P_{10})$, $C_{31}(P_5\times P_6)$, $C_{35}(P_5\times P_{10})$, $C_{25}(P_4\times P_5)$ and $C_{17}(P_2\times P_{10})$ and marketable yield per plant $C_{42}(P_7\times P_{10})$, $C_{31}(P_5\times P_6)$, were statistically on par with the standard check in their mean performance and were as promising as that of the standard check under comparison (Mahyco Hybrid No. 10). Of the two comparable hybrids identified for both total yield and marketable yield/plant (C_{42} and C_{31}), the F_1 hybrid $C_{42}(P_7\times P_{10})$ also had good fruit quality, which can be exploited after further testing at different locations for commercial cultivation for the entire *kharif* season.

Keywords: heterosis, okra, productivity, quality
Abbreviations: FSB, fruit and shoot borer; **IC**, indigenous collection; **YVMV**, *Yellow vein mosaic virus*

INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench) is an important vegetable crop throughout the tropics and subtropics (Kochhar 1986). It has a prominent position among fruit vegetables in India. Being a warm season crop, it is grown in summer and rainy seasons in India, in general and in Andhra Pradesh, in particular. The area, production and productivity of okra in India and Andhra Pradesh are 0.409 and 0.020 million ha, 4.193 and 0.409 million t and 10.30 and 15.00 t ha^{-1}, respectively (NHB 2010). Okra occupies 5.50% of total vegetable area and contributes 3.60% to total vegetable production of India; Andhra Pradesh is one of the leading okra-producing states of India with 4.96 and 10.84% of total area and production, respectively (NHB 2010). Although Andhra Pradesh has relatively little acreage in okra, it is an important cash crop for small and marginal farmers, with a potential to boost food, nutritional and health security, foster rural development and support sustainable land care (Reddy 2010). To turn okra into a perfect candidate for sustainable agriculture, the crop should be attractive to both producers and consumers in terms of yield and quality, respectively.

In okra, so far, the major breeding objective has been yield. Being an often cross-pollinated crop, a good amount of variability exists for various growth, earliness and yield attributes (Manivannan *et al*. 2007; Yadav *et al*. 2007). The variability available has been exploited in various line breeding programmes resulting in the development and release of a good number of varieties. In spite of the availability of a good number of varieties, okra is being neglected because of low-yielding potential of current varieties, suboptimal fruit quality and reduction in yield due to frequent attacks of pests and diseases, especially the fruit and shoot borer (FSB) and *Yellow vein mosaic virus* (YVMV). Hence, it is not only the yield and its contributing characters that should be taken care of but there may be many quality traits, which are not related with yield directly. At present, improving yield and quality and ensuring its sustainability under adverse conditions through the development of F_1 hybrids is the major objective. Incorporation of acceptable pod quality traits and resistance or tolerance to either fruit and shoot borer or YVMV or both in the F_1 hybrids is possible and will help to realize sustainable yield, even under problematic environments.

Heterosis breeding is a quick and convenient way of combining economic and desirable horticultural traits in vegetable crops. In India, several organizations are now undertaking breeding programmes to improve productivity, pod quality and to incorporate YVMV resistance through the development of F_1 hybrids in okra. Many researchers have advocated heterosis breeding as a tool for genetic improvement of yield and yield components in okra (Venkataramani 1952; Joshi *et al*. 1958; Partap and Dhankar 1980; Elangovan *et al*. 1981; Partap *et al*. 1981; Mehta *et al*. 2007; Weerasekara *et al*. 2007; Jindal *et al*. 2009). In okra, commercial exploitation of heterosis is profitable proposition owing to the phenomenon of protogyny and its floral biology, which enables easy emasculation and pollination besides being able to produce large number of seeds in single pollination (Reddy 2010). The wide range of heterosis observed by various workers may not be of much practical value unless it is manifested as an increase or a decrease over the standard commercial hybrids.

In view of the above, the present investigation was carried out to generate information on the heterotic effects for developing suitable F_1 hybrids with high yield potential coupled with good quality, resistance to pests and diseases

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Table 1 Pooled analysis of variance for heterosis in okra.

Character	Source of variation			
	Parents (9)	Hybrids (44)	Parents x Hybrids (1)	Error (108)
Plant height (cm)	701.65871**	822.84995**	3.38082	172.74224
Number of branches/plant	2.55511**	1.91384**	0.26075	0.12987
Internode length (cm)	4.93488**	2.90483**	0.71596	0.53247
Days to 50% flowering	3.28519**	4.18799**	9.24456**	0.72675
First flowering node	1.25853**	1.12527**	3.67282**	0.01368
First fruiting node	1.25853**	1.12527**	3.67282**	0.01368
Fruit length (cm)	15.14408**	7.52488**	20.74714**	0.04146
Fruit width (cm)	0.10638**	0.03662**	0.00203**	0.00018
Fruit weight (g)	22.33036**	9.77477**	13.38880**	0.10736
Total number of fruits/plant	14.00550**	23.94705**	34.42759**	2.17616
Number of marketable fruits/plant	9.29793**	17.67353**	20.06473**	1.64996
Total yield/plant (g)	9806.27249**	8720.79948**	23468.33658**	530.74740
Marketable yield/plant (g)	6000.49381**	5887.74249**	15163.87982**	400.09720
FSB infestation on fruits (%)	0.35272**	0.18101**	0.13172*	0.03125
FSB infestation on shoots (%)	0.34486**	0.24817**	0.29668**	0.02679
YVMV infestation on fruits (%)	0.55413**	0.69443**	0.62755**	0.06895
YVMV infestation on plants (%)	157.35191**	234.33924**	144.48259*	24.10104

*, ** Significant at 5 and 1% levels, respectively
Values in parentheses denote degrees of freedom

and high performance under a wide range of environmental conditions for commercial exploitation.

MATERIALS AND METHODS

Ten nearly homozygous, horticulturally superior and optimally divergent genotypes namely P_1(IC282248), P_2(IC27826-A), P_3(IC29119-B), P_4(IC31398-A), P_5(IC45732), P_6(IC89819), P_7(IC89976), P_8(IC90107), P_9(IC99716) and P_{10}(IC111443) selected from the germplasm were crossed in all possible combinations excluding reciprocals to generate 45 single crosses during summer, 2009. Fifty six genotypes involving 45 single cross F_1 hybrids along with their 10 parents and one standard check (Mahyco Hybrid No.10) were evaluated in a randomized block design with three replications under three diverse environments tailored at a single location by changing the date of sowing *viz*., 1st June (early *kharif*), 1st July (mid *kharif*) and 1st August (late *kharif*), 2009. Okra flowers 40-45 days after sowing. The pods become ready for harvest 5 days after anthesis. Flowering and fruiting spreads over a period of 11 weeks. The *kharif* (rainy) season (June-September) is one of the important growing seasons in India. The experiment was conducted at the Vegetable Research Station, Rajendranagar, Hyderabd, Andhra Pradesh, India. In each replication, each genotype was grown in a double row plot of 3 m in length at a spacing of 60 × 30 cm, accommodating 10 plants/row and 20 plants/plot and genotype. Recommended package of practices was followed to raise a successful crop. Regular plant protection measures were carried out to safeguard the crop from pests and diseases. Biometric observations were recorded on five randomly selected competitive plants in each genotype in each replication for plant height (cm), number of branches/plant, internode length (cm), first flowering node, first fruiting node, fruit length (cm), fruit width (cm) and fruit weight (g) and on whole plot basis for days to 50% flowering, total number of fruits/plant, number of marketable fruits/plant, total yield/plant (g), marketable yield/plant (g), fruit and shoot borer (FSB) infestation on fruits and shoots (%) and YVMV infestation on fruits and plants (%). The mean replicated values of FSB infestation on fruits and shoots and YVMV infestation on fruits were subjected to square root transformation, while the mean replicated values of YVMV infestation on plants were subjected to arc sin transformation to restore the distribution to normality. Heterosis over three bases *viz*., mid parent, better parent and standard check were calculated as per standard formulae (Singh 1973).

RESULTS AND DISCUSSION

Analysis of variance

The pooled analysis of variance (**Table 1**) indicated highly significant differences among parents and crosses indicating wide range of variability in the genotypes. The mean squares due to parents × crosses, which is a measure of the importance of average heterosis was significant for majority of the characters except plant height, number of branches/plant and internode length.

Mean performance

From the mean performance of the genotypes, it is evident that, in general, the mean values of hybrids were desirably higher than those of the parents (**Table 2**) for plant height and number of branches/plant, fruit length and weight, total number of fruits and number of marketable fruits/plant, total and marketable yield/plant, while the mean values of hybrids were desirably lower than those of the parents for internode length, fruit width and FSB infestation on fruits and plants. From the grand mean values of crosses and their parents, it is evident that the crosses, in general, had desirably higher or lower mean values than their parents indicating the presence of hybrid vigour for some of the growth, earliness and yield attributes in the single cross F_1 hybrids.

In general, the range of mean values of parents (**Table 2**) was highest for total yield/plant (209.56 to 303.82 g) followed by marketable yield/plant (170.92 to 252.21 g) and plant height (129.52 to 158.78 cm). Similarly, the range of mean values of crosses was highest for total yield/plant (202.46 to 345.28 g) followed by marketable yield/plant (171.28 to 272.46 g) and plant height (125.58 to 166.46 cm).

Plant height among the parents and crosses varied from 129.52 to 158.78 cm and 125.58 to 166.14 cm, respectively (**Table 2**). Number of branches per plant varied from 1.47 to 3.00 and 1.18 to 3.47 among the parents and crosses, respectively. Internode length among the parents and crosses varied from 4.86 to 7.19 cm and 4.91 to 7.32 cm, respectively. The number of days taken to 50% flowering among the parents and crosses varied from 37.33 to 39.44 and 37.33 to 39.89, respectively. The first flowering and fruiting node varied from 4.01 to 5.13 among parents and 3.87 to 5.33 among hybrids. Fruit length among the parents and crosses varied from 11.41 to 15.54 cm and 12.16 to 16.22 cm, respectively. Fruit width varied from 1.69 to 2.07 cm among parents and 1.70 to 2.01 cm among hybrids. Fruit weight varied from 12.67 to 17.21 g among parents and 13.70 to 17.70 g among hybrids. Total number of fruits/plant among the parents and crosses varied from 15.13 to 18.64 and 13.18 to 21.00, respectively. Number of marketable fruits/plant varied from 12.66 to 15.74 and 11.20 to 17.92 among the parents and crosses, respectively. Total yield/plant among the parents and crosses varied from 209.56 to 303.82 g and 202.46 to 345.28 g, respectively.

Table 2 Range and average performance of parents, crosses and check and average and standard heterosis in okra.

	Parents		Crosses		Check	Heterosis (%)	
Range		Mean	Range	Mean	Mean	AH	SH
Plant height (cm)	129.52-158.78	146.90	125.58-166.14	147.12	165.51	0.15	-11.11
Number of branches/plant	1.47-3.00	2.01	1.18-3.47	2.07	2.18	2.99	-5.05
Internode length (cm)	4.86-7.19	6.29	4.91-7.32	6.19	6.53	-1.59	-5.21
Days to 50% flowering	37.33-39.44	38.30	37.33-39.89	38.65	39.33	0.91	-1.73
First flowering node	4.01-5.13	4.50	3.87-5.33	4.73	4.61	5.11	2.60
First fruiting node	4.01-5.13	4.50	3.87-5.33	4.73	4.61	5.11	2.60
Fruit length (cm)	11.41-15.54	13.78	12.16-16.22	14.31	13.84	3.85	3.40
Fruit width (cm)	1.69-2.07	1.90	1.70-2.01	1.89	1.85	-0.53	2.16
Fruit weight (g)	12.67-17.21	14.80	13.70-17.70	15.22	16.35	2.84	-6.91
Total number of fruits/plant	15.13-18.64	17.17	13.18-21.00	17.85	19.66	3.96	-9.21
Number of marketable fruits/plant	12.66-15.74	14.51	11.20-17.92	15.03	18.00	3.58	-16.50
Total yield/plant (g)	209.56-303.82	249.72	202.46-345.28	267.57	317.40	7.15	-15.70
Marketable yield/plant (g)	170.92-252.21	210.11	171.28-272.46	224.46	290.28	6.83	-22.67
FSB infestation on fruits (%)	2.41-3.09	2.80	2.37-3.06	2.75	2.51	-1.79	9.56
FSB infestation on shoots (%)	1.99-2.65	2.30	1.98-2.62	2.24	1.97	-2.61	13.71
YVMV infestation on fruits (%)	2.38-3.18	2.73	2.21-3.40	2.83	1.46	3.66	93.84
YVMV infestation on plants (%)	37.19-50.83	42.87	33.65-59.80	44.27	29.42	3.27	50.48

AH = Average heterosis; SH = Standard heterosis

Marketable yield/plant varied from 170.92 to 252.21g and 171.28 to 272.46 g among the parents and crosses, respectively. FSB infestation on fruits among the parents and crosses varied from 2.41 to 3.09% and from 2.37 to 3.06%, respectively. Similarly, FSB infestation on shoots among the parents and crosses varied from 1.99 to 2.65% and 1.98 to 2.62%, respectively. YVMV infestation on fruits among the parents and crosses varied from 2.38 to 3.18 and 2.21 to 3.40%, respectively. Similarly, YVMV infestation on plants among the parents and crosses varied from 37.19 to 50.83% and 33.65 to 59.80%, respectively.

Heterosis

The hybrids, in general, manifested highest average heterosis in desirable positive direction (**Table 2**) for total yield/plant (7.15%), followed by marketable yield/plant (6.83%), total number of fruits/plant (3.96%) and number of marketable fruits/plant (3.58%). Similarly, the hybrids, in general, exhibited highest standard heterosis in desirable negative direction for internode length (-5.21%) followed by days to 50% flowering (-1.73%).

The range of heterosis of 45 single crosses for 17 growth, earliness and yield attributes determined as percent increase or decrease over the mid parent, better parent and standard check (Mahyco Hybrid No. 10) are presented in **Table 3**. Significant relative heterosis in a favourable direction was observed for the most of the traits except for FSB infestation on fruits and shoots. Significant heterobeltiosis in a favourable direction was observed for the majority of traits except for plant height and number of branches/plant. Significant economic heterosis in a favourable direction was observed for the majority of the traits except for plant height, total number of fruits/plant, number of marketable fruits/plant, total yield/plant, marketable yield/plant, FSB infestation on fruits and shoots and YVMV infestation on fruits and plants. For plant height, heterosis over mid parent, better parent and standard check ranged from -18.80 to 15.13%, -20.91 to 10.00% and -24.13 to 0.38%, respectively. For number of branches/plant, average heterosis, heterobeltiosis and standard heterosis ranged from -30.61 to 38.53%, -45.60 to 27.71% and -45.92 to 59.10%, respectively. Heterosis over mid parent, better parent and standard check varied from -30.06 to 40.42%, -31.70 to 30.90% and -24.79 to 12.08%, respectively for internode length. For days to 50% flowering, relative heterosis, heterobeltiosis and standard heterosis ranged from -2.29 to 4.97%, -3.66 to 4.06% and -5.08 to 1.41%, respectively. For first flowering and fruiting node, heterosis over mid parent, better parent and standard check ranged from -13.22 to 20.92%, -14.07 to 16.32% and -16.14 to 15.66%, respectively. For fruit length, relative heterosis, heterobeltiosis and standard heterosis ranged from -14.19 to 19.26%, -14.57 to 9.91% and -12.14 to 17.27%, respectively. For fruit width, heterosis over mid parent, better parent and standard check ranged from -5.77 to 10.26%, -14.04 to 4.27% and -8.34 to 8.70%, respectively. For fruit weight, heterosis over mid parent, better parent and standard check ranged from -13.19 to 12.31%, -16.42 to 9.80% and -16.18 to 8.25%, respectively. For number of fruits/plant, heterosis over mid parent, better parent and standard check ranged from -18.73 to 37.39%, -23.84 to 36.03% and 32.94 to 6.84%, respectively. For number of marketable fruits/plant, average heterosis, heterobeltiosis and standard heterosis ranged from -19.81 to 39.14%, -24.49 to 36.82% and -37.78 to -0.42%, respectively. For total yield/plant, heterosis over mid parent, better parent and standard check ranged from -15.23 to 39.78%, -22.78 to 37.85% and -36.21 to 8.78%, respectively. For marketable yield/plant, average heterosis, heterobeltiosis and standard heterosis ranged from -16.42 to 41.69%, -23.80 to 35.97% and -41.00 to -6.14%, respectively. For FSB infestation on fruits, heterosis over mid parent, better parent and standard check ranged from -7.55 to 4.13%, -12.99 to 1.49% and -5.52 to 21.95%, respectively. For FSB infestation on shoots, heterosis over mid parent, better parent and standard check ranged from -9.88 to 5.36%, -19.07 to 4.95% and 0.67 to 33.11%, respectively. For YVMV infestation on fruits, heterosis over mid parent, better parent and standard check ranged from -22.99 to 31.03%, -25.62 to 23.04% and 51.83 to 133.47%, respectively. For YVMV infestation on plants, heterosis over mid parent, better parent and standard check ranged from -24.70 to 38.84%, -27.32 to 29.15% and 14.37 to 103.24%, respectively.

The number of crosses displaying significant heterosis in favorable direction for the 17 characters under study is presented in **Table 3**. For days to 50% flowering, two crosses over mid parent, one cross over better parent and eight crosses over standard check manifested significantly negative heterosis. For first flowering and fruiting node, five crosses over mid parent, thirteen crosses over better parent and 10 crosses over commercial check manifested significant heterosis in desirable direction (negative). Twenty nine crosses over mid parent, eleven crosses over better parent and 27 crosses over standard check manifested significantly positive heterosis for fruit length. For fruit width, 22 crosses over mid parent, 6 crosses over better parent and 5 crosses over commercial check manifested positively significant heterosis. For fruit weight, 22 crosses over mid parent, 6 crosses over better parent and 5 crosses over commercial check manifested positively significant heterosis. For total number of fruits/plant, 10 crosses over mid parent and two crosses over better parent manifested

Table 3 Ranges of heterosis over three bases and number of crosses with significantly positive and negative heterosis for seventeen traits in okra.

Heterosis	Range	No. of heterotics		Heterosis	Range	No. of heterotics	
		Positive	Negative			Positive	Negative
Plant height (cm)				Total number of fruits/plant			
RH	-18.80 to 15.13	2	3	RH	-18.73 to 37.39	10	2
HB	-20.91 to 10.00	-	3	HB	-23.84 to 36.03	2	4
SH	-24.13 to 0.38	-	15	SH	32.94 to 6.84	-	17
Number of branches/plant				Number of marketable fruits/plant			
RH	-30.61 to 38.53	4	2	RH	-19.81 to 39.14	7	2
HB	-45.60 to 27.71	-	10	HB	-24.49 to 36.82	3	3
SH	-45.92 to 59.10	2	5	SH	-37.78 to -0.42	-	32
Internode length (cm)				Total yield/plant (g)			
RH	-30.06 to 40.42	3	4	RH	-15.23 to 39.78	18	3
HB	-31.70 to 30.90	1	7	HB	-22.78 to 37.85	6	9
SH	-24.79 to 12.08	-	3	SH	-36.21 to 8.78	-	27
Days to 50% flowering				Marketable yield/plant (g)			
RH	-2.29 to 4.97	-	2	RH	-16.42 to 41.69	2	17
HB	-3.66 to 4.06	1	1	HB	-23.80 to 35.97	4	6
SH	-5.08 to 1.41	-	8	SH	-41.00 to -6.14	-	43
First flowering node				FSB infestation on fruits (%)			
RH	-13.22 to 20.92	22	5	RH	-7.55 to 4.13	-	-
HB	-14.07 to 16.32	14	13	HB	-12.99 to 1.49	-	6
SH	-16.14 to 15.66	21	10	SH	-5.52 to 21.95	16	-
First fruiting node				FSB infestation on shoots (%)			
RH	-13.22 to 20.92	22	5	RH	-9.88 to 5.36	-	-
HB	-14.07 to 16.32	14	13	HB	-19.07 to 4.95	-	13
SH	-16.14 to 15.66	21	10	SH	0.67 to 33.11	20	-
Fruit length (cm)				YVMV infestation on fruits (%)			
RH	-14.19 to 19.26	29	5	RH	-22.99 to 31.03	9	2
HB	-14.57 to 9.91	11	24	HB	-25.62 to 23.04	4	6
SH	-12.14 to 17.27	27	9	SH	51.83 to 133.47	45	-
Fruit width (cm)				YVMV infestation on plants (%)			
RH	-5.77 to 10.26	12	16	RH	-24.70 to 38.84	7	2
HB	-14.04 to 4.27	3	35	HB	-27.32 to 29.15	2	5
SH	-8.34 to 8.70	30	6	SH	14.37 to 103.24	43	-
Fruit weight (g)							
RH	-13.19 to 12.31	22	5				
HB	-16.42 to 9.80	6	22				
SH	-16.18 to 8.25	5	32				

RH = relative heterosis; HB = heterobeltiosis; SH = standard heterosis

positively significant heterosis. For number of marketable fruits/plant, seven crosses over mid parent and three crosses over better parent manifested positively significant heterosis. Eighteen crosses over mid parent and six crosses over better parent manifested significantly positive heterosis for total yield/plant. Two crosses over mid parent and four crosses over better parent manifested significantly positive heterosis for marketable yield/plant. Thirteen crosses over better parent manifested significantly negative heterosis for FSB infestation on shoots.

The list of top five single cross hybrids for each of the 17 characters (**Table 4**) indicated that mostly the same cross combinations exhibited significant heterotic effects in desirable direction for majority of the growth, earliness and yield attributes. There was huge amount of variation in heterotic effects of 45 single cross F_1 hybrids as they varied differently for different characters. Significant heterosis was observed for all the growth, earliness and yield attributes. It is inferred that the magnitude of economic heterosis was higher for most of the growth and earliness characters under study. In the present study, the estimates of relative heterosis, heterobeltiosis and standard heterosis were found to be highly variable in direction and magnitude among crosses for all the characters under study. Several researchers also reported such a variation in heterosis for different characters (Weerasekara *et al*. 2007; Jindal *et al*. 2009). The negative heterosis observed in some of the crosses may be attributed to non-additive interaction which can either increase or decrease to expression of heterosis.

Of the 17 characters under study, plant height, number of branches/plant and internode length largely determine the fruit-bearing surface and are thus considered as growth attributes. Okra bears pods at almost all nodes on main stem and primary branches. The taller the plant is with more branches on the main stem, the higher is the number of fruits/plant because more nodes can be accommodated for a given internode length. Shorter distance between nodes accommodates more nodes on the main stem, which will ultimately lead to higher fruit number and higher fruit production. Hence, positive heterosis is desirable for plant height and number of branches, while negative heterosis is desirable for internode length to accommodate more number of nodes and to get higher fruit yield in okra. Most of the crosses displayed negative standard heterosis for plant height, which is in the undesirable direction. However, appreciable amount of standard heterosis in desirable direction was observed for number of branches/plant (up to 59.10%) and internode length (up to -24.79%). Several researchers also reported similar projections for number of branches/plant in okra. Ahmed *et al*. (1999) observed -5.82 to 52.50% heterobeltiosis, Dhankar and Dhankar (2001) observed 80.00 to 130.00% standard heterosis, Rewale *et al*. (2003) observed -20.00 to 151.72% relative heterosis and -33.33 to 121.21% heterobeltiosis, Singh *et al*. (2004) observed 0.32 to 24.80% heterobeltiosis, Weerasekara *et al*. (2007) observed -3.13 to 67.86% relative heterosis and 17.50 to 34.29% heterobeltiosis and Jindal *et al*. (2009) reported -62.04 to 39.47% heterobeltiosis and -46.97 to 72.73% standard heterosis for number of branches/plant in okra. For internode length, similar projections were also made by earlier researchers in okra. Ahmed *et al*. (1999) observed -26.11 to 20.53% heterobeltiosis, Dhankar and Dhankar (2001) observed -34.00 to 16.00% standard heterosis and Jindal *et al*. (2009) observed -25.68 to 33.96% hete-

Table 4 Top five crosses with significant heterosis in desirable direction for seventeen traits in pooled analysis of okra.

Heterosis (%)			Heterosis (%)		
Relative heterosis	**Heterobeltiosis**	**Standard heterosis**	**Relative heterosis**	**Heterobeltiosis**	**Standard heterosis**
Plant height (cm)			Total number of fruits/ plant		
C_{24}(15.13)	-	-	C_{23}(37.39)	C_{23}(36.03)	-
C_{23}(3.42)	-	-	C_{24}(24.67)	C_{24}(17.94)	-
-	-	-	C_{36}(19.46)	-	-
-	-	-	C_{19}(19.33)	-	-
-	-	-	C_{43}(17.09)	-	-
No. of branches/ plant			No. of marketable fruits/ plant		
C_{36}(38.53)	-	C_{31}(59.10)	C_{23}(39.14)	C_{23}(36.82)	-
C_{6}(37.66)	-	C_{36}(54.08)	C_{24}(25.62)	C_{24}(16.44)	-
C_{24}(30.12)	-	-	C_{36}(22.01)	C_{36}(15.33)	-
C_{31}20.00)	-	-	C_{19}(15.73)	-	-
-	-	-	C_{43}(12.78)	-	-
Internode length (cm)			Total yield/ plant (g)		
C_{44}(-30.06)	C_{44}(-31.70)	C_{44}(-24.79)	C_{23}(39.78)	C_{23}(37.85)	-
C_{22}(-18.43)	C_{22}(-20.68)	C_{14}(-21.37)	C_{43}(27.05)	C_{43}(25.71)	-
C_{30}(-16.31)	C_{30}(-20.52)	C_{2}(-19.01)	C_{24}(25.65)	C_{22}(19.58)	-
C_{43}(-15.32)	C_{9}(-17.50)	-	C_{42}(22.01)	C_{17}(15.23)	-
-	C_{2}(-18.33)	-	C_{17}(21.46)	C_{31}(13.67)	-
Days to 50% flowering			Marketable yield/plant (g)		
-	C_{17}(-3.66)	C_{25}(-5.08)	C_{23}(41.69)	C_{23}(35.97)	-
-	-	C_{16}(-4.80)	C_{24}(26.61)	C_{43}(22.13)	-
-	-	C_{23}(-4.52)	C_{43}(22.40)	C_{28}(16.20)	-
-	-	C_{19}(-4.24)	C_{17}(20.48)	C_{31}(15.73)	-
-	-	C_{4}(-4.24)	C_{28}(20.29)	-	-
First flowering node			FSB infestation on fruits (%)		
C_{4}(-13.22)	C_{45}(-14.07)	C_{4}(-16.14)	-	C_{28}(-12.99)	-
C_{39}(-6.51)	C_{4}(-13.86)	C_{11}(-12.53)	-	C_{44}(-11.39)	-
C_{45}(-5.70)	C_{9}(-10.17)	C_{2}(-8.19)	-	C_{22}(-10.62)	-
C_{11}(-5.35)	C_{11}(-8.33)	C_{19}(-6.27)	-	C_{3}(-10.43)	-
C_{9}(-4.16)	C_{17}(-8.01)	C_{16}(-6.02)	-	C_{7}(-10.39)	-
First fruiting node			FSB infestation on shoots (%)		
C_{4}(-13.22)	C_{45}(-14.07)	C_{4}(-16.14)	-	C_{7}(-19.07)	-
C_{39}(-6.51)	C_{4}(-13.86)	C_{11}(-12.53)	-	C_{13}(-14.03)	-
C_{45}(-5.70)	C_{9}(-10.17)	C_{2}(-8.19)	-	C_{26}(-13.75)	-
C_{11}(-5.35)	C_{11}(-8.33)	C_{19}(-6.27)	-	C_{12}(-13.52)	-
C_{9}(-4.16)	C_{17}(-8.01)	C_{16}(-6.02)	-	C_{8}(-13.35)	-
Fruit length (cm)			YVMV infestation on fruits (%)		
C_{35}(19.26)	C_{11}(9.91)	C_{35}(17.27)	C_{14}(-22.99)	C_{14}(-25.62)	-
C_{23}(12.17)	C_{35}(9.75)	C_{33}(15.31)	C_{2}(-15.04)	C_{2}(-18.21)	-
C_{33}(11.75)	C_{22}(9.71)	C_{4}(14.96)	-	-	-
C_{11}(10.52)	C_{33}(7.91)	C_{21}(11.40)	-	-	-
C_{22}(10.115)	C_{4}(7.59)	C_{25}(11.11)	-	-	-
Fruit width (cm)			YVMV infestation on plants (%)		
C_{22}(10.26)	C_{22}(4.27)	C_{25}(8.70)	C_{14}(-24.70)	C_{14}(-27.32)	-
C_{42}(3.81)	C_{19}(2.75)	C_{16}(6.90)	C_{2}(-18.84)	C_{2}(-22.21)	-
C_{28}(3.78)	C_{25}(1.40)	C_{18}(6.78)	-	C_{3}(-19.74)	-
C_{25}(3.63)	-	C_{42}(6.18)	-	C_{4}(-18.43)	-
C_{33}(2.91)	-	C_{41}(6.12)	-	C_{5}(18.42)	-
Fruit weight (g)					
C_{35}(12.31)	C_{35}(9.80)	C_{35}(8.25)			
C_{33}(12.00)	C_{11}(8.53)	C_{39}(6.34)			
C_{4}(11.43)	C_{4}(7.67)	C_{4}(6.14)			
C_{22}(10.89)	C_{15}(6.35)	C_{42}(4.69)			
C_{11}(10.35)	-	C_{31}(3.64)			

robeltiosis and -31.06 to 11.74% standard heterosis for internode length in okra.

The highest economic heterosis for days to 50% flowering was observed in C_{25} (-5.08%), followed by C_{16} (-4.80%) and C_{23} (-4.52%). For first flowering and fruiting node, the maximum commercial heterosis for these traits was manifested by C_4 (-16.14%) followed by C_{11} (-12.53%) and C_2 (-8.19%). Days to 50% flowering, first flowering node and first fruiting node are the indicators of earliness in okra. Early flowering not only gives early pickings and better returns but also widens fruiting period of the plant. Flowering and fruiting at lower nodes are helpful in increasing the number of fruits/plant as well as getting early yields. Negative heterosis is highly desirable for all these three attributes of earliness under study. In the present study, cross C_4, displaying high negative heterosis over standard check for days to 50% flowering (-4.24%) and first flowering and fruiting node (-13.22%) is, therefore, important to exploit heterosis for earliness in okra. Mehta *et al*. (2007) Weerasekara *et al*. (2007) and Jaiprakashnarayan *et al*. (2008) also noticed heterosis in desirable direction for days to 50% flowering in okra. The positive estimates of heterobeltiosis and economic heterosis for earliness revealed the presence of genes for the development of earliness in okra. The estimates of heterosis over mid parent, better parent and standard check for both first flowering node and first fruiting node were of equal magnitude in all the crosses, indicating 100 percent fruit set in the early stages of flowering. Tippeswamy *et al*. (2005) and Jindal *et al*. (2009) also noticed desirable heterosis for first flowering node in okra. Mandal

Table 5 Top five crosses on the basis of *per se* performance and heterotic effects for total and marketable yield per plant and their fruit quality in okra.

Hybrid	Heterosis (%)			Mean performance ($g\ plant^{-1}$)
	Standard heterosis	Heterobeltiosis	Relative heterosis	
Total yield per plant				
$C_{42}(P_7xP_{10})$	8.78	13.65*	22.01**	345.28
$C_{31}(P_5xP_6)$	-0.65	13.67*	14.64*	315.35
$C_{35}(P_5xP_{10})$	-2.85	11.15	14.29*	308.35
$C_{25}(P_4xP_5)$	-4.00	9.83	19.17**	304.69
$C_{17}(P_2xP_{10})$	-4.82	15.23*	21.46**	302.09
Mahyco Hybrid No. 10				290.28
				CD (5%) =37.13
Marketable yield per plant				
$C_{42}(P_7xP_{10})$	-6.14	8.03	14.44*	272.46
$C_{31}(P_5xP_6)$	-7.59	14.95*	15.73*	268.26
$C_{35}(P_5xP_{10})$	-11.22*	10.43	12.71*	257.73
$C_{36}(P_6xP_7)$	-11.76*	1.55	6.18	256.13
$C_{17}(P_2xP_{10})$	-11.99*	14.09	20.48**	255.49
Mahyco Hybrid No. 10				290.28
				CD (5%) =32.54

*, ** Significant at 5 and 1 per cent levels, respectively

and Das (1991) also noticed desirable heterosis for first flowering and fruiting nodes in okra.

The highest economic heterosis for fruit length was observed in C_{35} (17.27%), followed by C_{33} (15.31%) and C_4 (14.96%). The maximum commercial heterosis fruit width trait was manifested by C_{25} (8.70%) followed by C_{16} (6.90%) and C_{18} (6.78%). The maximum commercial heterosis for fruit weight was manifested by C_{35} (8.25%) followed by C_{39} (6.34%) and C_4 (6.14%). Total number of fruits/plant and fruit length, width and weight are considered to be associated directly with total yield per plant, for which positive heterosis is desirable. The cross C_{35} displayed highest positively significant relative heterosis (19.26%) and standard heterosis (17.27%), while the cross C_{11} exhibited highest positively significant relative heterosis (9.91%) for fruit length. The cross C_{22} exhibited highest positively significant relative heterosis (10.26%) and heterobeltiosis (4.27%), while the cross C_{25} exhibited highest positively significant standard heterosis (8.70%) for fruit width. For average fruit weight, highest positively significant relative heterosis (12.31%) and heterobeltiosis (9.80%) and standard heterosis (8.25%) was displayed by the cross C_{35}. Similar results were also reported by More and Patil (1997), Ahmed *et al.* (1999) and Jaiprakashnarayan *et al.* (2008) in okra. For fruit length, Ahmed *et al.* (1999) reported -18.78 to 17.92% heterobeltiosis, while Jaiprakashnarayan *et al.* (2008) reported -20.96 to 8.00% heterobeltiosis and -20.99 to 7.04% standard heterosis. For fruit width, More and Patil (1997) reported -9.36 to 11.95% relative heterosis and -2.87 to 27.65% heterobeltiosis. Ahmed *et al.* (1999) observed -46.17 to 62.59% heterobeltiosis, while Jaiprakashnarayan *et al.* (2008) observed -25.78 to 6.71% heterobeltiosis and -26.90 to 5.11% standard heterosis for fruit weight. Cross combinations C_{23} (37.39%), C_{24} (24.67%), C_{36} (19.46%), C_{19} (19.33%) and C_{43} (17.09%) were the top five crosses on the basis of average heterosis, while cross C_{23} (36.03%) and C_{24} (17.94%) were the top two on the basis of heterobeltiosis for total number of fruits/plant. Similar results have been reported by Weerasekara *et al.* (2007) and Jaiprakashnarayan *et al.* (2008), wherein the former reported 2.33 to 58.15% relative heterosis and -7.36 to 46.61% heterobeltiosis, while the later reported -16.35 to 42.55% heterobeltiosis and -18.46 to 47.25% standard heterosis for total number of fruits/plant in okra.

For number of marketable fruits/plant, the crosses C_{23}, C_{24}, C_{36}, C_{19} and C_{43} displaying a relative heterosis of 39.14, 25.62, 22.01, 15.73 and 12.78%, respectively were the top five crosses, while the crosses C_{23}, C_{24} and C_{36} manifesting a heterobeltiosis of 36.82, 16.44 and 15.33 % were the top three crosses for this trait. Cross C_{23} displayed highest positively significant heterosis over mid parent (39.14%) and better parent (36.82%) for number of marketable fruits/plant. Maximum significantly negative heterosis over better parent was displayed by the cross C_{28} (-12.99%) and C_7 (-19.07%) for FSB infestation on fruits and shoots, respectively. The cross C_{14} not only displayed highest negatively significant heterosis over mid parent (-22.99%) and better parent (-25.62%) for YVMV infestation on fruits, but also displayed highest negatively significant heterosis over mid parent (-24.70%) and better parent (-27.32%) for YVMV infestation on plants.

Significantly positive heterosis was observed mainly in terms of total yield/plant in crosses over their mid and better parents. The crosses C_{23}, C_{43}, C_{24}, C_{42} and C_{17} were the top five heterotic crosses, manifesting an average heterosis of 39.78, 27.05, 25.65, 22.01 and 21.46%, respectively, while the crosses C_{23}, C_{43}, C_{22}, C_{17} and C_{31} were the top five crosses, displaying a heterobeltiosis of 37.85, 25.71, 19.58, 15.23 and 13.67%, respectively for total yield/plant. These results are in agreement with the findings of Weerasekara *et al.* (2007) and Jaiprakashnarayan *et al.* (2008), wherein the former reported 21.73 to 75.68% relative heterosis and 19.47 to 56.48% heterobeltiosis, while the later reported -28.70 to 35.90% heterobeltiosis and -32.79 to 42.07% standard heterosis for total yield/plant in okra.

None of the hybrids showed positively significant heterosis over standard check for total yield/plant. However, crosses C_{42}, C_{31}, C_{35}, C_{25} and C_{17}, displaying 8.78, -0.65, -2.85, -4.00 and -4.82% non-significant standard heterosis in any given direction are as promising as that of standard check (**Table 5**). It is apparent that the high heterosis for total fruit yield may probably be due to the dominant nature of genes. The significantly positive heterobeltiosis for total yield/plant could be apparently due to preponderance of fixable gene effects, which was also reported by Elangovan *et al.* (1981) in a study following 14 × 4 line × tester mating design and Singh *et al.* (1996) in a study following 8 × 8 half diallel mating design in okra. It is obvious that high heterosis for yield was built up by the yield components. Hybrid vigour of even a small magnitude for individual components may result in significant hybrid vigour for yield *per se*. The contribution of components of yield is through a component compensation mechanism (Adams 1967). This was confirmed by the present investigation where none of the cross combinations showed hybrid vigor for yield alone. The high heterosis for fruit yield observed in these crosses could probably be due to combined heterosis of their component characters, as these hybrids were not only heterotic in respect of fruit yield but were also found superior for one or the other yield components. The high heterosis for fruit yield observed in these crosses could probably be due to combined heterosis of their component characters, as these hybrids were not only heterotic with respect to fruit yield but were also superior for one or an-

Table 6 Pod quality traits of top five crosses in okra.

Hybrid	No. of ridges on fruit	Fruit pubescence	Fruit colour	Fruit tip	Fruit shape	Fruit straightness	Fruit ribbing	No. of seeds / fruit
Total yield/plant (g)								
$C_{42}(P_7xP_{10})$	5	Downy	Green	Blunt	Angular	Straight	Non ribbed	50
$C_{31}(P_5xP_6)$	5	Downy	Green	Blunt	Angular	Curved	Ribbed	42
$C_{35}(P_5xP_{10})$	5	Downy	Green	Blunt	Angular	Curved	Non ribbed	49
$C_{25}(P_4xP_5)$	5	Downy	Green	Blunt	Angular	Curved	Non ribbed	47
$C_{17}(P_2xP_{10})$	5	Downy	Green	Blunt	Angular	Curved	Non ribbed	48
Mahyco Hybrid No. 10	5	Downy	Dark green	Blunt	Angular	Straight	Non ribbed	37
Marketable yield/plant (g)								
$C_{42}(P_7xP_{10})$	5	Downy	Green	Blunt	Angular	Straight	Non ribbed	50
$C_{31}(P_5xP_6)$	5	Downy	Green	Blunt	Angular	Curved	Ribbed	42
$C_{35}(P_5xP_{10})$	5	Downy	Green	Blunt	Angular	Straight	Non ribbed	52
$C_{36}(P_6xP_7)$	5	Downy	Green	Blunt	Angular	Curved	Non ribbed	49
$C_{17}(P_2xP_{10})$	5	Downy	Green	Blunt	Angular	Curved	Non ribbed	48
Mahyco Hybrid No. 10	5	Downy	Dark green	Blunt	Angular	Straight	Non ribbed	37

other yield component. Thus, the observed high heterosis for total yield/plant seems to be due to an increase in the total number of fruits/plant rather than an increase in the size and weight of fruits, which is a desirable requirement for okra improvement.

The major components of marketable yield are not only the total number of fruits/plant, pod size and weight but also the percent infestation of fruits and shoots by FSB and fruits and plants by YVMV. In the present investigation, in general, positively high heterosis for marketable yield/plant was associated with positively high heterosis for total number of fruits/plant, size (length and width) and weight of fruits and negatively high heterosis for FSB infestation on fruits and shoots and YVMV infestation on fruits and plants. Thus, the observed high heterosis for marketable yield seems to be due to decrease in the incidence of FSB on fruits and shoots and YVMV on fruits and plants. Most of the hybrids showing positive heterosis for marketable yield also showed significantly negative heterosis for FSB on fruits and shoots and YVMV on fruits and plants.

Significantly positive heterosis was observed mainly in terms of marketable yield/plant in crosses over their respective mid and better parents. The crosses C_{23}, C_{24}, C_{43}, C_{17} and C_{28} were the top five heterotic hybrids, manifesting an average heterosis of 41.69, 26.61, 22.40, 20.48 and 20.29%, respectively, while the crosses C_{23}, C_{43}, C_{28} and C_{31} were the top four heterotic hybrids, displaying a heterobeltiosis of 35.97, 22.13, 16.20 and 15.73%, respectively for this trait. Similar results were also found by Tippeswamy *et al*. (2005) and Jindal *et al*. (2009), wherein the former reported -15.01 to 96.84% heterobeltiosis and -14.10 to 90.97% standard heteroosis, while the later reported -23.13 to 67.82% heterobeltiosis and -9.55 to 57.81% standard heterosis for marketable yield/plant. None of the hybrids showed positively significant heterosis over standard check for this trait. However, crosses C_{42} and C_{31} displaying -6.14 and -7.59% non-significant standard heterosis in negative direction are as promising as that of the standard check for this trait.

In the present study, it is apparent that high heterosis for yield may probably be due to the dominance nature of genes. For yield attributes, some crosses were non-heterotic which may be ascribed to cancellation of positive and negative effects exhibited by the parents involved in a cross combination and can also happen when the dominance is not unidirectional, as also pointed out by Gardner and Eberhart (1966) and Mather and Jinks (1982).

Although the range of average heterosis and heterobeltiosis manifested by the crosses for different characters was comparatively wide, but it might not be of much significance unless it shows sufficient gain over the standard check. In the present study, the moderate extent of relative heterosis and heterobeltiosis as observed for yield and yield components could be attributed to its often-cross pollinated nature. The extent of heterosis over standard check for total yield/plant (8.78%) and marketable yield/plant (-6.14%) appears to be sufficient for exploitation of heterosis commercially. F_1 hybrids C_{42}, C_{31}, C_{35}, C_{25} and C_{17} with non-significant standard heterosis in any direction for total yield/plant and F_1 hybrids C_{42} and C_{31} with non-significant standard heterosis in any direction for marketable yield/plant, were statistically on par with the standard check in their mean performance and are found to be as promising as that of the standard check (Mahyco Hybrid No. 10) under comparison (**Table 5**). For both total yield and marketable yield per plant, the crosses C_{42} and C_{31} were found to be as promising as that of the standard check (Mahyco Hybrid No. 10).

Fruit quality of F_1 hybrids

In okra breeding programmes, besides enhanced productivity, the fruit quality characters that need to be given emphasis include pod color (dark green/green), pod shape (angular), pod pubescence (downy), pod straightness (straight), number of ridges on pod (five) and pod ribbing (non-ribbing), which may be desirable to combine in the hybrids. The top two promising hybrids *viz*., C_{42} and C_{31} identified for high yield potential, the F_1 hybrid C_{42} was also found to be of good fruit quality (**Table 6**), which can be exploited for commercial cultivation after further testing at different locations for the entire *kharif* season after further testing at different locations in Andhra Pradesh.

CONCLUSION

From the pooled analysis of variance, it is evident that there were highly significant differences among parents, crosses and parents vs. crosses for all the traits except for parents × crosses for number of branches/plant and internode length indicating wide range of variability in the genotypes. In the present study, the moderate extent of relative heterosis and heterobeltiosis as observed for yield and yield components could be attributed to its often-cross pollinated nature. The extent of heterosis over standard check for total yield/plant (8.78%) and marketable yield/plant (-6.14%) appears to be sufficient for exploitation of heterosis commercially. Cross C_4 ($P_1×P_5$), displaying high negative heterosis over standard check for days to 50% flowering (-4.24%) and first flowering and fruiting node (-13.22%) is important to exploit heterosis for earliness in okra. The crosses with non-significant standard heterosis in any direction for total yield per plant C_{42} ($P_7×P_{10}$), C_{31} ($P_5×P_6$), C_{35} ($P_5×P_{10}$), C_{25} ($P_4×P_5$) and C_{17} ($P_2×P_{10}$) and marketable yield per plant C_{42} ($P_7×P_{10}$), C_{31} ($P_5×P_6$), were statistically on par with the standard check in their mean performance and were found to be as promising as that of the standard check under comparison (Mahyco Hybrid No. 10). Of the two comparable hybrids identified for both total yield and marketable yield/plant (C_{42} and C_{31}), the F_1 hybrid C_{42} ($P_7×P_{10}$) was also found to be of good fruit quality, which can be exploited for commercial cultivation for the entire *kharif* season after further testing at different locations in Andhra Pradesh.

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