International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(4): 853-857

Received: 01-05-2019
Accepted: 03-06-2019

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Exploitation of heterosis for yield and yield attributes in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
Seven genotypes and their 21 F_1 crosses obtained from half diallel mating design were investigated to estimate the magnitude of heterosis for yield and its parameters. The extent of heterosis ranged for all the characters under study. Desirable heterosis for days to 1st flowering was observed in Annika X Rajini over both mid parent and better parent while the cross EC359637 X Arka Anamika significant desirable heterosis over standard check. For average fruit weight, the maximum magnitude of heterosis was obtained in cross EC359637 X Arka Anamika over average parent, Annika X IC014026 over better parent and Annika X EC359637 over better parent. Maximum desirable heterosis for yield per plant was observed in EC359637 X IC014026 over mid parent, better parent and standard check followed EC359637 X IC013664 and EC359637 X EC305768. Higher magnitude of heterosis observed in crosses revealed presence of significant genetic diversity among the genotypes.

Keywords: Heterosis, okra, half diallel, yield parameters, hybrids

Introduction
Okra (*Abelmoschus esculentus* (L.) Moench) usually known as bhendi, lady's finger or gumbo is a fast growing vegetable crop of tropical and sub tropical region. It is an annual crop which particularly cultivated for its tender and nutritious green pods (Lamont 1999; Tindall 1983) [14, 27]. Among all, India is the largest producer of okra in the world accounting for around 5.5% under cultivation and 3.6% of total production (NHB, 2010) [19]. Although, India has diverse environmental condition facilitating the existence of numerous okra cultivars still there is unavailability of appropriate high yielding cultivars. To break through yield limiting barrier in okra cultivars, hybridization strategy must be adapted (Medagam *et al.*, 2012) [16]. Okra being as often cross pollinated crop, can open pollinate up to the range of 4% to 42% due to entomophily (Kumar, 2006) [11]. Further, simple process of emasculation and production of numerous seeds per pod leads to extensive commercial exploitation in okra. One of the first reports of hybrid vigor in okra was demonstrated by Vijayaraghavan and Warier (1946) [29]. Moreover, many researchers reported occurrence of considerable magnitude of heterosis in okra for various traits related to fruit yield (Medagam *et al.*, 2012; Shwetha *et al.*, 2018) [24., 16]. The main focus of any breeding programme is to enhance yield which can attain by hybridization of suitable parental lines. Higher the diversity among parental materials more will be the extent of significant heterosis (Jindal *et al.*, 2009; Mohapatra *et al.*, 2007; Reddy, 2010) [4, 18, 23]. The preliminary step for every hybridization programme was selection of appropriate parental genotypes able to produce better hybrids with desirable economic traits. Although, it is a time consuming approach but the magnitude of heterosis act as relevant guide for the screening of appropriate parents which can manifest promising heterotic result during breeding programme. It also assists in selecting significant hybrids that outperform the existing standard check and hence can consider for commercial utilization. Keeping this view, the present investigation aims toward study of magnitude and direction of relative heterosis, heterobeltiosis and standard heterosis for yield and its components in okra.

Materials and Methods
The investigation on heterosis in okra was carried out at the Department of genetics and plant breeding of Lovely Professional University, Phagwara, Punjab during the year 2018-2019. The experimental farm situated at 31° 13' 4"N and 75° 46' 10"E with an altitude of

approximately 246 meters above mean sea level. The experimental materials consists of seven parents (IC014026, IC013664, Arka Anamika, Rajini, EC305768, EC359637 and Annika) were collected from different sources *viz.* NBPGR (Delhi), IIHR (Bengaluru), Local variety (Haryana) and mated in a half diallel fashion. Total twenty one F_1 crosses obtained by hybridizing seven parents and were evaluated on the experimental farm along with a standard check (P-8) in a randomized block design of three replications. Each entry was raised in three rows per replication with spacing of 60 cm row- to-row and 30 cm plant-to-plant accommodating 6 plants per row. Moreover, standard packages and practices were applied to the field throughout the experimental period. Quantitative data *viz*. days to 1st flowering, number of 1st fruiting node, stem diameter (mm), number of branches per plant, pod girth (cm), average fruit weight (g) and yield per plant were recorded from five randomly selected plants per replication and were applied to half diallel analysis as given by Fonseca and Patterson, 1968 [3].

Result and Discussion

In the present investigation, 21 F1 hybrids developed from seven parents were assessed using half diallel analysis with a standard check (P-8). The variance due to genotypes (parents and crosses) was significant for yield and its parameters *viz*. stem diameter (mm), number of branches per plant, pod girth (cm), average fruit weight (g) and yield per plant except number of 1st fruiting node in case of parents. It indicated presence of significant variability among parents for traits under study. However, genotypic difference among hybrids was highly significant for all characters. Variance due to parents vs. hybrids for days to 1st flowering, number of branches per plant and stem diameter were found significant while for all other characters were not significant as mentioned in table 1. Further, analysis of variance due to treatments was found significant for all traits considered which signified the existence of diversity among the parental genotypes and their crosses. Heterosis for yield and yield parameters was tabulated in table 2, table 3 and table 4.

Table 1: Analysis of variance of half diallel analysis for various characters in okra

Source of variation	d. f.	Days to 1st flowering	Number of 1st fruiting node	Number of branches per plant	Stem diameter (mm)	Fruit girth (cm)	Average fruit weight (g)	Fruit yield plant^{-1} (g)
Replicates	2	3.190	0.128	0.063	0.031	0.001	0.653	1683.01
Treatments	27	44.32**	0.504**	0.693**	13.11**	0.39**	3.14**	4444.72**
Parents	6	27.56**	0.357	0.427*	15.16**	0.27**	3.30**	1502.04
Hybrids	20	48.85**	0.571**	0.770**	11.05**	0.44**	3.22**	5535.78**
Parent Vs. Hybrids	1	54.32**	0.063	0.756	41.83**	0.024	0.498	279.513
Error	54	3.660	0.165	0.110	0.198	0.032	0.262	607.761

'*' and '**" signifies level of significance at 5% and 1% respectively

Table 2: Magnitude of heterosis for days to 1st flowering and number of 1st fruiting node in okra

Genotypes	Days to 1st flowering			Number of 1st fruiting node		
	RH	HB	SH	RH	HB	SH
IC013664 X IC014026	6.17*	5.52	6.83*	13.68	28.57*	8.00
Arka Anamika X IC014026	16.61**	15.53**	17.72**	6.12	23.81	4.00
Rajini X IC014026	-6.87**	-10.34**	-3.11	-8.51	2.38	-14.00
EC305768 X IC014026	-7.02**	-12.15**	-1.24	-9.28	4.76	-12.00
EC359637 X IC014026	12.93**	11.18**	14.74**	4.00	23.81	4.00
Annika X IC014026	10.30**	7.69 *	13.04**	41.67**	61.90**	36.00**
Arka Anamika X IC013664	14.02**	12.27**	15.82**	-0.92	1.89	8.00
Rajini X IC013664	12.17**	8.62**	15.95**	18.10*	19.23	24.00*
EC305768 X IC013664	-8.14**	-12.71**	-3.07	-9.26	-7.55	-2.00
EC359637 X IC013664	10.97**	8.59**	13.46**	0.90	5.66	12.00
Annika X IC013664	8.43**	6.51*	10.43**	2.80	3.77	10.00
Rajini X Arka Anamika	6.63**	1.72	12.01**	-3.70	0.00	4.00
EC305768 X Arka Anamika	2.65	-3.87	10.13**	-4.50	-3.64	6.00
EC359637 X Arka Anamika	-2.55	-3.16	-1.92	-26.32**	-25.00**	-16.00
Annika X Arka Anamika	10.70**	7.10*	14.56**	-16.36*	-14.81	-8.00
EC305768 X Rajini	7.04**	4.97	9.20**	-2.80	0.00	4.00
EC359637 X Rajini	-0.61	-5.75*	5.13	-21.82**	-17.31	-14.00
Annika X Rajini	-9.62**	-10.92**	-8.28**	11.32	13.46	18.00
EC359637 X EC305768	-5.64*	-12.15**	1.92	-6.19	-3.64	6.00
Annika X EC305768	-8.57**	-11.60**	-5.33	-15.60	-14.81	-8.00
Annika X EC359637	4.00	0.00	8.33**	-1.79	1.85	10.00
Min.	-9.62	-8.28	2.15	-26.32	-25.00	-16.00
Max.	16.61	17.72	-17.74	41.67	61.90	36.00

'*' and '**" signifies level of significance at 5% and 1% respectively

Table 3: Magnitude of heterosis for number of branches per plant and stem diameter in okra

Genotypes	Number of branches per plant			Stem diameter (mm)		
	RH	HB	SH	RH	HB	SH
IC013664 X IC014026	3.80	-2.38	5.13	-22.08**	-27.06**	-12.58**
Arka Anamika X IC014026	-16.48*	-29.63**	-2.56	-10.12**	-12.72**	-8.76**
Rajini X IC014026	-16.88	-20.00	-17.95	-6.28**	-9.92**	-5.84**
EC305768 X IC014026	-10.00	-16.28	-7.69	-7.25**	-10.22**	-6.15**
EC359637 X IC014026	18.07*	6.52	25.64*	-11.03**	-15.19**	-2.19
Annika X IC014026	13.16	10.26	10.26	-6.03**	-10.05**	-5.97**
Arka Anamika X IC013664	-18.75*	-27.78**	0.00	-20.11**	-27.23**	-12.79**
Rajini X IC013664	-17.07	-19.05	-12.82	-13.44**	-21.91**	-6.41**
EC305768 X IC013664	8.24	6.98	17.95	-1.84	-10.85**	6.84**
EC359637 X IC013664	6.82	2.17	20.51	-1.95	-3.79**	15.30**
Annika X IC013664	-1.23	-4.76	2.56	-10.50**	-19.56**	-3.59*
Rajini X Arka Anamika	-14.89	-25.93**	2.56	-6.76**	-7.75**	-9.14**
EC305768 X Arka Anamika	1.03	-9.26	25.64*	-5.02**	-5.33**	-6.76**
EC359637 X Arka Anamika	-22.00**	-27.78**	0.00	1.62	-5.80**	8.65**
Annika X Arka Anamika	-24.73**	-35.19**	-10.26	-7.52**	-8.88**	-10.26**
EC305768 X Rajini	-25.30**	-27.91**	-20.51	-3.90**	-4.60**	-6.66**
EC359637 X Rajini	41.86**	32.61**	56.41**	-10.65**	-17.98**	-5.41**
Annika X Rajini	-1.27	-2.50	0.00	0.65	0.23	-3.37*
EC359637 X EC305768	-37.08**	-39.13**	-28.21**	-8.83**	-15.74**	-2.82
Annika X EC305768	-17.07	-20.93*	-12.82	-1.98	-3.10	-5.19**
Annika X EC359637	-22.35**	-28.26**	-15.38	11.96**	2.38	18.08**
Min.	-37.08	-39.13	-28.21	-22.08	-27.23	-12.79
Max.	41.86	32.61	56.41	11.96	2.38	18.08

'*' and '**" signifies level of significance at 5% and 1% respectively

Table 4: Magnitude of heterosis for fruit girth (cm), average fruit weight (g) and yield per plant (g) in okra

Genotypes	Fruit girth (cm)			Average fruit weight (g)			Yield per plant (g)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
IC013664 X IC014026	3.26	2.74	6.86**	-4.17*	-8.01**	9.96 **	5.19	3.43	25.82*
Arka Anamika X IC014026	-5.44**	-6.97**	0.00	1.63	-2.09	7.66 **	5.40	4.43	25.09*
Rajini X IC014026	3.43	0.91	4.96*	4.63*	2.44	12.64 **	5.62	1.73	29.12*
EC305768 X IC014026	8.21**	7.61**	11.92**	3.96*	2.72	15.71 **	8.34	-2.84	43.96**
EC359637 X IC014026	-6.41**	-7.51**	-3.80	-1.87	-4.30	10.73 **	61.98**	50.13**	76.78**
Annika X IC014026	-4.51*	-9.84**	-6.22**	9.12**	8.36**	19.16 **	16.55	14.64	34.80**
Arka Anamika X IC013664	4.36*	2.16	9.81**	2.77	-4.81*	13.79 **	-1.84	-2.59	18.50
Rajini X IC013664	-6.69**	-8.50**	-5.80*	2.21	-3.85	14.94 **	-0.38	-2.45	23.81*
EC305768 X IC013664	-8.66**	-8.71**	-6.01*	-9.90**	-12.50**	4.6	-7.55	-15.82*	24.73*
EC359637 X IC013664	-1.50	-2.15	0.74	-11.40**	-12.82**	4.21	16.93*	10.11	51.65**
Annika X IC013664	5.08*	-0.31	2.64	-0.84	-5.45**	13.03 **	-0.09	-3.34	17.58
Rajini X Arka Anamika	-4.45 *	-8.24**	-1.37	-2.40	-4.00	1.15	8.24	5.19	33.52**
EC305768 X Arka Anamika	2.91	0.69	8.23**	2.86	-2.04	10.34 **	-9.09	-17.80*	21.79
EC359637 X Arka Anamika	-1.72	-4.42	2.74	10.56**	3.97	20.31 **	7.97	0.93	39.01**
Annika X Arka Anamika	-0.37	-7.36**	-0.42	-6.01**	-8.83**	-1.15	-9.65	-11.93	5.49
EC305768 X Rajini	1.62	-0.31	2.53	2.99	-0.34	12.26 **	-25.70**	-31.03**	2.20
EC359637 X Rajini	7.10**	5.71*	7.38**	-8.84**	-12.91**	0.77	-20.28**	-23.40**	5.49
Annika X Rajini	-5.73**	-8.85**	-9.81**	2.51	1.06	9.58 **	-1.07	-6.20	19.05
EC359637 X EC305768	1.96	1.33	4.22	-5.03**	-6.29**	8.43 **	5.70	1.98	51.10**
Annika X EC305768	7.62**	2.15	5.06*	-0.87	-2.72	9.58 **	2.52	-9.39	34.25**
Annika X EC359637	13.54**	8.41**	10.13**	-9.40**	-12.25**	1.53	-27.17**	-33.51**	-8.42
Min.	-8.66	-9.84	-9.81	-11.40	-12.82	20.31	-27.17	-33.51	-8.42
Max.	13.54	8.41	11.92	10.56	8.36	-1.15	61.98	50.13	76.78

'*' and '**" signifies level of significance at 5% and 1% respectively

For days to 1st flowering, heterosis was estimated for earliness and hence negative heterosis was desirable. In this case, maximum desirable heterosis over mid parent and heterobeltiosis was recorded in Annika X Rajini (-9.62% and -8.28%) respectively. However, desirable significant standard heterosis was recorded in EC359637 X Arka Anamika (-17.74%). Total six crosses over mid parent, seven crosses over better parent and eleven crosses over standard check manifested significant desirable heterosis. Similar findings were reported by Mehta *et al.,* (2008) [17], Kishor *et al.,* (2013) [9], Singh *et al.,* (2013) [25], Bhatt (2016) [2], Singh *et al.,* (2016) [26], and Paul *et al.,* (2017) [21].

For number of 1st fruiting node, the desirable estimates of heterosis over mid parent was in EC359637 X Arka Anamika (-26.32%), heterosis over better parent was in EC359637 X Arka Anamika (-25.00%) and further heterosis over standard check in EC359637 X Arka Anamika (-16.00%). Heterosis towards negative direction was beneficial for this character, hence total negatively significant crosses observed were three hybrids over mid parent, one hybrid over better parent and none over standard check. Highest estimates of negative

standard heterosis for number of 1st fruiting node were observed in EC359637 X Arka Anamika but it was insignificant. Such extent of heterosis was also reported by Baldeorao (2012) [1], Reddy *et al.,* (2013) [22], Joshi (2015) [6], Singh *et al.,* (2016) [26], Vani (2016) [28].

Among all the 21 crosses, two crosses exhibited significant and desirable relative heterosis; one cross exhibited desirable heterobeltiosis whereas three crosses exhibited desirable standard heterosis for number of branches per plant. Further, the maximum heterosis was observed in cross EC359637 X Rajini (41.86%) over mid parent, EC359637 X Rajini (32.61%) over better parent and in cross EC359637 X Rajini (56.41%) over standard check. These findings were comparable to that of previous findings by Medagam *et al.,* (2012) [16], Lyngdoh *et al.,* (2013) [15] and Kumar and Reddy (2016) [12].

For stem diameter, the highest magnitude of heterosis over mid parent was observed in cross Annika X EC359637 (11.96%), maximum estimate over better parent was recorded in cross Annika X EC359637 (2.38%) while that over standard check was recorded in cross Annika X EC359637 (18.08%). Heterosis towards positive direction was considered beneficial for this character, hence total positively significant crosses observed were one hybrid over mid parent, none over better parent whereas four hybrids over standard check. Similar findings were reported by the researchers *viz.* Khanokar (2008) [8], Joshi (2015) [6] and Kerure and pitchaimuthu, (2019) [7] for this character.

The result revealed that total six crosses over average parent, three crosses over better parent and eight crosses over standard check exhibited positively significant heterosis for this pod girth. Maximum magnitude of relative heterosis and heterobeltiosis for this trait was recorded in Annika X EC359637 (13.54% and8.41%) respectively. However, maximum estimate for standard heterosis was recorded in cross EC305768 X IC014026 (11.92%). Comparable extent of heterosis was reported by Jindal *et al.,* (2010) [5], Patel and Patel, (2016) [20] and Kerure and pitchaimuthu (2019) [7].

In case of average fruit weight, positive heterosis is desirable since it is directly related to total fruit yield. The maximum extent of heterosis was observed in hybrid EC359637 X Arka Anamika (10.56%) over mid parent, Annika X IC014026 (8.36%) over better parent while in Annika X EC359637 (20.31%) over standard check variety. The outcome showed overall four crosses for relative heterosis, one cross for heterobeltiosis and fifteen crosses for standard heterosis recorded positively significant estimates. Similar kind of results were reported by Mehta *et al.,* (2008) [17], Kumar and Sreeparvathy (2010) [10], Medagam *et al.,* (2012) [16], Kumar and Reddy (2015) [13], Patel and Patel (2016) [20], Paul *et al.,* (2017) [21], Shwetha *et al.,* (2018) [24] and Kerure and pitchaimuthu (2019) [7].

Yield per plant is the main parameter of focus in any breeding programme. This trait is a dependent character, depends on many yield components for its expression. Among all twenty one crosses, two crosses for relative heterosis, one for heterobeltiosis and thirteen crosses for standard heterosis exhibited positively significant estimates. The highest magnitude of relative heterosis, heterobeltiosis and standard heterosis was observed in hybrid EC359637 X IC014026 (61.98%, 50.13% and 76.78%) respectively. Similar results with agreement to this finding were reported by Mehta *et al.,* (2008) [17], Kumar and Reddy (2015) [13] and Paul *et al.,* (2017) [21].

Conclusion

The cross EC359637 X IC014026 was the best hybrid selected for yield per plant exhibiting significant standard heterosis over standard check (P-8) and also showed significant heterosis in desirable for number of branches per plant. The cross EC359637 X IC013664 was the second best hybrid opted for yield per plant and also revealed significant standard heterosis in the desirable direction for number of number of branches per plant. The third best hybrid was recorded to be EC359637 X EC305768 for yield per plant over standard check. These hybrids can further be evaluated for their yield stability and adaptability to validate their performance on different agro-climatic environment before processing for commercial exploitation.

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