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GENOMIC EXPRESSION OF HETEROSIS FOR YIELD AND SEED PARAMETERS OF OKRA [*ABELMOSCHUS ESCULENTUS* (L.) MOENCH]

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ABSTRACT

A total of 66 F_1 crosses, derived from twelve genotypes using a diallel mating design without reciprocals, were thoroughly examined to gauge the extent of heterosis concerning yield and seed parameters. Across all the traits analysed, the magnitude of heterosis exhibited variability among different cross combinations. Among the 66 hybrids scrutinized, 50, 32 and 38 hybrids displayed noteworthy positive heterosis over the mid-parent, better parent, and standard check, respectively, in terms of both fruit yield per plant and per hectare. The hybrid IC-45831 × IC-43733 (11.36% standard heterosis) stood out with the highest heterosis values, closely followed by IC-45831 × Pusa A-4. Regarding seed yield per plant and per hectare, out of the 66 cross combinations examined, 17 crosses exhibited positive significant heterosis over the mid-parent, while 8 crosses showed the same over the better parent, and 5 crosses over the standard check.

Key words : Diallel analysis, Heterosis, Hybrids, Okra.

Introduction

Cultivated okra (*Abelmoschus esculentus* (L.) Moench) is a vital annual vegetable crop, primarily grown in tropical, subtropical, and warmer temperate regions around the globe (Patil *et al.*, 2015). In India, it is the fifth most cultivated vegetable, just behind tomatoes in terms of cultivation area. Okra, belonging to the Malvaceae family, typically self-pollinates. Its versatility makes it economically valuable for both farmers and marketers, with revenue generated from the sale of immature fresh leaves and both fresh and dried fruits, which are often used in various soup preparations. Additionally, okra is recognized for its nutritional value, being rich in dietary fiber, essential minerals (including sodium, calcium, potassium, zinc and iron), vitamins (A, B and C), antioxidants and folate. Okra seeds are notably high in protein (15–26%) and the seed oil (20–40%) is both edible and nutritionally beneficial. Furthermore, the mature fruit and stems are used in the paper industry, while okra mucilage is a valuable food additive (Kumar *et al.*, 2017; Gemede *et al.*, 2015; Dubey and Mishra, 2017).

Previous studies have aimed at characterizing okra germplasm to facilitate crop improvement (Komolafe *et al.*, 2021). Although open-pollinated okra varieties appear to have reached a yield plateau, there is still potential for enhancement through hybridization. Notable heterosis rates, ranging from 38% to 71% have been documented in okra for yield and its components (Laxmiprasanna, 1996). Heterosis breeding, especially in cross-pollinated vegetable crops, has been highly successful in boosting productivity. Okra, being one such crop, demonstrated heterosis for yield and its components as early as 1946 (Vijayaraghavan and Warrier). Since then, numerous studies have been conducted on heterosis in okra.

In the current study, the selection of parental lines based solely on phenotypic performance is considered insufficient. Instead, the focus is on identifying parents with desirable combining abilities. To systematically evaluate the genetic potential of parents in hybrid combinations, the half diallel mating design has been employed (Griffing, 1956; Kempthorne, 1957). This approach allows for a comprehensive assessment of parental genetic contributions.

Numerous researchers have documented significant heterosis for fruit yield and its components in okra (Lyngdoh *et al*., 2013; Nagesh *et al*., 2014; Tiwari *et al*., 2015; Koli *et al*., 2020). Okra's favorable traits such as ease of emasculation and high fruit setting percentage indicate the potential for harnessing hybrid vigor. Robust hybrid vigor is crucial for successful hybrid variety development, making heterotic studies pivotal in identifying promising hybrid combinations for future breeding and commercial purposes.

Cultivated okra germplasm displays substantial variation in agronomic and horticultural traits (Vani *et al*., 2012). Initial selection of parents for effective hybridization programs hinges on assessing relative heterosis (heterosis over mid-parent), heterobeltiosis (heterosis over the better parent) and economic heterosis (heterosis over a standard check) in genetic stocks. This approach, centered on identifying optimal parent combinations, holds promise for producing superior hybrids through heterosis breeding. However, selecting the most suitable parental matings is a critical and resource-intensive aspect of hybrid development programs (Vani *et al*., 2020).

The primary aim of this investigation is to analyze the magnitude and direction of relative heterosis, heterobeltiosis and economic heterosis for yield and its related traits across 12 × 12 half diallel crosses. This study seeks to leverage existing genetic diversity to cultivate heterotic F_1 hybrids in okra.

Materials and Methods

The investigation into heterosis in okra took place at the Vegetable Research Farm of the Horticulture Department, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The study employed a Randomized Block Design with three replications. Twelve parent varieties (IC-45831, IC-282272, IC-43733, IC-43750, IC-45802, Sel-4, Pusa Mukhmali, Parbhani Kranti, VRO-3, Sel-10, Pusa A-4 and SB-8) were crossed in a diallel fashion, resulting in 66 F_1 crosses without reciprocals. These F_1 hybrids, along with a commercial check variety (Arka Anamika), were evaluated under standard agricultural practices on the experimental farm.

Throughout the experimental period, data were collected on ten yield-related attributes *viz*., fruit length, fruit width, fruit weight, number of fruits per plant, fruit yield per plant, fruit yield per hectare, number of seeds per fruit, hundred seeds weight (g), seed yield per plant (g) and seed yield per hectare. Measurements were taken from five randomly selected plants per replication.

The primary objective was to assess the nature and extent of heterosis concerning mid-parental, better parental, and standard check values. Heterosis was calculated as the percentage increase or decrease of the F1 hybrids over these reference points, using methodologies described by Turner (1953) and Hayes *et al*. (1956). This analysis provided valuable insights into the performance of the F_1 hybrids relative to parental varieties and the standard check, facilitating the identification of promising candidates for further breeding efforts or potential commercial cultivation.

Results and Discussion

The details on the range of heterosis observed and the number of crosses showing significant positive and negative heterosis relative to the mid-parent, better parent and standard control (Arka Anamika) were presented in Table 1. The study revealed considerable variation in heterotic effects, which varied across different traits.

Number of fruits per plant, fruit length (cm), fruit width (cm) and fruit weight (g) are all closely related yield/productivity parameters. The study emphasizes the importance of positive significant heterosis for fruit length (cm), indicating that certain crosses displayed notable heterosis over different comparison standards. Specifically, Pusa Makhmali × VRO-3 exhibited 29.99% heterosis over the mid parent, Pusa Makhmali × Sel-10 showed 23.64% heterosis over the better parent, and IC-43733 × Pusa Makhmali displayed 24.66% heterosis over the standard check, representing the highest levels of heterosis in their respective comparisons. Earlier studies by Bhatt *et al*. (2016), More *et al*. (2017), Gavint *et al*. (2018), Kulkarni *et al*. (2018), Vekariya *et al*. (2019) also observed both positive and negative heterosis for fruit length (cm), aligning with the current findings. These studies collectively contribute to our understanding of the genetic mechanisms influencing fruit length heterosis.

The highest average heterosis for fruit width (cm) was shown by Pusa Makhmali × Parbhani Kranti followed by IC-43733 × Pusa A-4 and IC-45831× Pusa Makhmali in the order of 14.34, 12.41 and 11.30%, respectively. The maximum heterobeltiosis was observed in only one cross combination *i.e.*, IC-43733 × Pusa A-4 (10.39%) and significant positive heterosis over standard check was reported by 15 crosses, out of this maximum was by IC-

Table 1 : Heterosis for ten yield and seed parameters of okra.

F_1	Fruit length			Fruit width			Fruit weight			No. of fruits per plant			Fruit yield per plant		
	MP	BrP	BP	MP	BrP	BP	MP	BrP	BP	MP	BrP	BP	MP	BrP	BP
1×2 IC-45831×IC-282272	-5.1	-5.59	7.16	2.27	-5.99	2.78	31.95**	28.94**	3.32	10.26	8.67	0.53	45.22**	39.83**	3.83
1×3 IC-45831×IC-43733	-2.36	-3.71	8.16	-0.83	-2.00	7.14	23.79**	19.01*	-1.37	28.88**	26.19**	13.37*	59.01**	56.1**	11.36*
1×4 IC-45831×IC-43750	0.27	-1.83	10.28	5.62	0.54	9.92*	25.35**	18.86*	1.4	13.22*	9.44	5.35	41.53**	29.99**	6.75
1×5 IC-45831×IC-45802	1.25	-1.15	16.56*	5.23	-0.32	21.83**	16.75**	2.37	3.87	26.97**	20.21**	20.86**	46.71**	22.79**	25.24**
1×6 IC-45831×Sel-4	-5.16	-7.21	4.23	-1.75	-3.45	5.56	11.33	1.48	-5.7	1.72	-1.93	-5.08	12.61*	-0.69	-10.63*
1×7 IC-45831×PM	10.22	4.34	17.2*	11.30**	6.35	16.27**	2.25	-15.01**	-1.86	10.98	7.87	2.67	12.85**	-8.27	0.77
1×8 IC-45831×PK	-8.79	-11.08	-0.12	-12.38**	-13.99**	-2.38	0.07	-22.31**	7.5	11.6	4.12	8.02	9.18*	-19.24**	15.77**
1×9 IC-45831×VRO-3	13.04	-2.56	9.45	-9.52*	-12.89**	-4.76	1.28	-16.11**	-2.29	21.25**	15.68*	14.44*	21.4**	-3.04	11.57*
1×10 IC-45831×Sel-10	6.47	0.63	13.04	-7.87*	-11.80**	-3.57	11.5	-1.61	-1.61	1.97	-3.21	-3.21	12.69**	-4.92	-4.92
1×11 IC-45831×Pusa A-4	2.1	-4.81	6.93	-5.50	-6.09	3.97	29.33**	24.34**	3.05	16.48**	8.16	13.37*	50.03**	34.56**	16.53**
1×12 IC-45831×SB-8	-7.41	-8.94	2.29	-18.03**	-20.48**	-7.54	27.3**	20.44**	3.23	16.25**	8.21	12.83	47.45**	30.58**	16.38**
2×3 IC-282272×IC-43733	4.67	2.69	16.56*	-4.00	-10.78*	-4.76	25.35**	23.27**	2.16	19.76**	15.61*	6.95	49.71**	46.77**	8.98
2×4 IC-282272×IC-43750	-5.26	-7.71	4.76	-0.83	-4.42	-5.56	24.31**	20.54**	2.83	13.31*	11.11	6.95	40.47**	33.75**	9.83*
2×5 IC-282272×IC-45802	-0.18	-2.04	15.5*	-7.61	-19.16**	-1.19	11.44	-0.27	1.19	14.68*	10.11	10.7	26.76**	9.53*	11.71*
2×6 IC-282272×Sel-4	-4.81	-7.35	5.17	-8.65*	-14.66**	-9.92*	28.17**	19.34**	10.91*	12.99*	10.5	6.95	43.98**	31.4**	18.24**
2×7 IC-282272×PM	-4.17	-9.73	2.47	2.07	-1.99	-2.38	-0.16	-15.44**	-2.35	16.81**	15.17*	9.63	16.02**	-2.77	6.8
2×8 IC-282272×PK	0.05	-2.95	10.16	-5.22	-14.34**	-2.78	-12.98**	-31.29**	-4.94	6.81	1.03	4.81	-8.52*	-30.57**	-0.47
2×9 IC-282272×VRO-3	7.47	-7.76	4.7	2.06	-2.75	-1.59	5.04	-11.35*	3.26	14.8*	11.08	9.89	19.7**	-1.53	13.31**
2×10 IC-282272×Sel-10	1.82	-4.24	8.69	-9.32*	-13.10**	-13.10**	4.23	-6.12	-6.12	9.44	5.35	5.35	13.16**	-1.4	-1.4
2×11 IC-282272×Pusa A-4	13.19*	5.02	19.2*	-4.71	-12.90**	-3.57	20.97**	18.97*	-1.4	5.15	-1.02	3.74	26.97**	17.92**	2.12
2×12 IC-282272×SB-8	-7.38	-9.36	2.88	-15.65**	-24.57**	-12.30*	26.88**	22.75**	5.21	11.41	5.13	9.63	40.72**	28.97**	14.96**
3×4 IC-43733×IC-43750	9.02	8.23	18.2*	-1.54	-5.20	1.19	20.72**	19**	1.52	12.61*	6.67	2.67	35.62**	26.72**	4.06
3×5 IC-43733×IC-45802	2.59	-1.2	16.5*	3.99	-2.60	19.05**	22.38**	11.17	12.8*	15.19*	6.91	7.49	39.91**	18.89**	21.26**
3×6 IC-43733×Sel-4	-3.96	-4.73	4.05	-7.66	-8.18	-1.98	10.29	4.33	-3.05	17.54**	11.05	7.49	29.11**	15.73**	4.14
3×7 IC-43733×PM	18.97**	14.14*	24.66**	-6.92	-10.04*	-3.97	8.97	-6.41	8.07	8.55	3.37	-1.6	17.19**	-3.35	6.17
3×8 IC-43733×PK	1.99	0.81	10.1	-6.67	-9.44*	2.78	-0.15	-20.17**	10.45*	5.92	-3.09	0.53	3.41	-22.57**	11*
3×9 IC-43733×VRO-3	12.97	-1.45	7.63	3.82	1.12	7.94	3.78	-11.2*	3.44	3.47	-3.24	-4.28	5.85	-14.27**	-1.35
3×10 IC-43733×Sel-10	6.65	2.15	11.57	-7.10	-10.04*	-3.97	20.29**	9.99	9.99	6.32	-1.07	-1.07	25.99**	7.94	7.94
3×11 IC-43733×Pusa A-4	1.82	-3.82	5.05	12.41**	10.39*	22.22**	21.18**	21.18**	0.43	5.88	-3.57	1.07	28.28**	16.98**	1.31
3×12 IC-43733×SB-8	7.06	6.77	16.62*	-3.20	-7.17	7.94	23.84**	21.79**	4.39	9.55	0	4.28	35.25**	21.76**	8.52
4×5 IC-43750×IC-45802	6.27	1.64	19.85*	10.23**	-0.32	21.83**	12.2*	3.27	4.78	8.7	6.38	6.95	20.97**	9.18*	11.36*

Table 1 continued...

Table 1 continued...

4×6 IC-43750×Sel-4	5.32	5.24	13.27	4.85	1.50	7.14	12.1*	7.51	-0.09	18.56**	18.23**	14.44*	32.65**	26.85**	14.15**
4×7 IC-43750×PM	2.94	-0.55	7.05	9.60*	9.16	8.73	-0.33	-13.35*	0.06	13.41*	12.78	8.56	13**	-1.26	8.46
4×8 IC-43750×PK	4.16	3.71	11.63	-2.06	-8.39*	3.97	-6.74	-24.62**	4.3	7.49	3.61	7.49	-0.72	-21.93**	11.92*
4×9 IC-43750×VRO-3	12.87	-0.93	6.64	7.14	5.88	7.14	0.38	-13.05*	1.28	7.95	6.49	5.35	8.01	-7.46	6.49
4×10 IC-43750×Sel-10	4.3	0.6	8.28	4.19	3.57	3.57	13.02*	4.72	4.72	9.54	7.49	7.49	23.27**	12.25**	12.25**
4 ×11 IC-43750×Pusa A-4	12.42	6.93	15.09	0	-5.38	4.76	30.94**	29.07**	10.42*	2.39	-1.79	2.94	34.03**	30.56**	13.07**
4 ×12 IC-43750×SB-8	1.28	0.81	9.51	-9.23*	-16.04**	-2.38	29.73**	29.43**	10.94*	4	0	4.28	35.07**	29.76**	15.65**
5 ×6 IC-45802×Sel-4	2.19	-2.34	15.15	3.48	-3.57	17.86**	13.54*	8.77	10.36*	13.82*	11.7	12.3	28.98**	21.38**	23.8**
5 ×7 IC-45802×PM	3.95	-3.78	13.45	-3.4	-12.34**	7.14	-3.46	-9.31	4.72	19.67**	16.49*	17.11**	15.11**	10.99*	21.92**
5 ×8 IC-45802×PK	-0.5	-5.23	11.74	-14.14**	-17.21**	1.19	-7.25	-19.62**	11.21*	17.02**	15.21*	19.52**	8.39*	-7.24*	32.97**
5 ×9 IC-45802×VRO-3	5.87	-10.56	5.46	-13.32**	-20.78**	-3.17	-0.71	-7.11	8.2	22.25**	21.28**	21.93**	21.33**	14.43**	31.68**
5 ×10 IC-45802×Sel-10	-6.12	-13.25*	2.29	-10**	-18.18**	0	7.65	6.88	8.44	12*	11.7	12.3	20.26**	19.09**	21.46**
5 ×11 IC-45802×Pusa A-4	10.6	0.85	18.91*	2.21	-2.6	19.05**	34.45**	22.13**	23.92**	9.37	7.14	12.3	47.45**	36.33**	39.05**
5 ×12 IC-45802×SB-8	7.05	2.84	21.26**	-1.16	-3.57	17.86**	28.73**	18.74**	20.48**	13.84*	11.79	16.58*	47.19**	37.91**	40.66**
6 ×7 Sel-4×PM	9.58	5.96	13.86	-6.38	-9.02*	-3.97	0.09	-9.68	4.3	14.21*	13.26	9.63	14.25**	3.92	14.16**
6 ×8 Sel-4×PK	4.69	4.32	12.1	-7.61*	-10.84*	1.19	-10.71*	-25.37**	3.26	5.6	2.06	5.88	-6.37	-23.8**	9.24
6 ×9 Sel-4×VRO-3	8.49	-4.7	2.41	-7.87	-9.77*	-4.76	3.39	-7.06	8.26	-0.55	-1.62	-2.67	2.46	-8.71*	5.05
6 ×10 Sel-4×Sel-10	7.16	3.44	11.16	-7.72	-10.15*	-5.16	4.58	0.88	0.88	8.15	6.42	6.42	12.74**	7.09	7.09
6 ×11 Sel-4×Pusa A-4	9.76	4.48	12.27	-6.42	-8.6*	1.19	19.9**	13.41*	5.39	1.33	-2.55	2.14	22**	19.71**	7.72
6 ×12 Sel-4 ×SB-8	4.73	4.16	13.15	-7.33	-11.6**	2.78	15.57*	11.08	3.23	1.06	-2.56	1.6	16.56**	16**	4.39
7 ×8 PM×PK	13.16*	9.8	17.15*	14.34**	7.34	21.83**	-15.54**	-22.53**	7.19	4.3	0	3.74	-12.56**	-22.78**	10.7*
7 ×9 PM× VRO-3	29.99**	17.67*	18.09*	-2.37	-3.14	-1.98	-5.92	-6.33	9.11	3.58	1.62	0.53	-2.55	-4.76	9.59*
7 ×10 PM×Sel-10	23.86**	23.64**	24.08**	0.2	0	0	-4.24	-10.66	3.17	1.37	-1.07	-1.07	-3.05	-7.4	1.72
7 ×11 PM ×Pusa A-4	23.16**	21.18**	21.61**	-8.3*	-12.9**	-3.57	9.68	-5.8	8.78	4.28	-0.51	4.28	15.25**	3.05	13.2**
7×12 PM×SB-8	15.76*	11.35	20.96**	0	-7.17	7.94	7.47	-6.39	8.1	-3.49	-7.69	-3.74	4.28	-5.55	3.75
8×9 PK×VRO-3	16.61*	2.75	9.63	5.36	-0.35	13.1**	-17.62**	-24.14**	4.97	6.07	3.61	7.49	-12.83**	-21.43**	12.64**
8×10 PK× Sel-10	20.06**	16.29*	24.08**	1.49	-4.55	8.33	-12.36**	-24.51**	4.45	5.51	3.61	7.49	-7.48*	-21.47**	12.57**
8×11 PK×Pusa A-4	5.62	0.88	7.63	7.96*	6.64	21.03**	-2.44	-22**	7.92	-0.26	-0.77	4.01	-2.47	-21.78**	12.13*
8×12 PK×SB-8	1.88	0.97	9.69	-0.17	-1.37	14.68**	-5.47	-23.45**	5.91	-3.34	-3.59	0.53	-8.44*	-25.75**	6.43
9 ×10 VRO-3× Sel-10	23.9**	12.33	12.33	6.51	5.88	7.14	1.14	-6.02	9.48	4.84	4.28	4.28	5.83	-1.1	13.8**
9 ×11 VRO-3× Pusa A-4	24.19**	14.09	10.8	3	-1.43	9.13	6.13	-9.18	5.79	6.04	3.06	8.02	13.15**	-0.84	14.1**
9 ×12 VRO-3× SB-8	24.14**	8.54	17.91*	7.66*	0.68	17.06**	4.97	-8.89	6.12	4.21	1.54	5.88	9.62*	-2.74	11.92*
10 ×11 Sel-10× Pusa A-4	13.2	11.57	11.57	2.07	-2.87	7.54	12.2*	2.59	2.59	0.26	-2.04	2.67	12.65**	5.1	5.1
10 ×12 Sel-10× SB-8	13.59*	9.08	18.5*	-0.55	-7.51	7.54	19.05**	13.54*	10.54*	-0.52	-2.56	1.6	18.49**	12.05*	12.05*
11 ×12 Pusa A-4 × SB-8	10.56	4.7	13.74	6.99	4.44	21.43**	41.41**	39.07**	19.2**	-3.32	-3.57	1.07	37.09**	35.14**	20.45**

Table 1 continued...

Table 1 continued...

Comparison of F_1 with	S.E.D.	C.D. 95%	C.D. 99%	S.E.D.	C.D. 95%	C.D. 99%	S.E.D.	C.D. 95%	C.D. 99%	S.E.D.	C.D. 95%	C.D. 99%	S.E.D.	C.D. 95%	C.D. 99%
Mid Parent	0.752	1.503	1.963	0.069	0.137	0.179	1.173	2.342	3.059	0.706	1.410	1.841	11.045	22.058	28.806
Better Parent	0.869	1.735	2.266	0.079	0.158	0.207	1.354	2.705	3.532	0.815	1.628	2.126	12.753	25.470	33.263
Best Parent/Checks	0.869	1.735	2.266	0.079	0.158	0.207	1.354	2.705	3.532	0.815	1.628	2.126	12.753	25.470	33.263
F_1	**Fruit yield per ha**			**Number of seeds per fruit**			**Hundred seeds weight (g)**			**Seed yield per plant(g)**			**Seed yield per ha**		
	MP	**BrP**	**BP**	**MP**	**BrP**	**BP**	**MP**	**BrP**	**BP**	**MP**	**BrP**	**BP**	**MP**	**BrP**	**BP**
1×2 IC-45831 ×IC-282272	45.22**	39.82**	3.83	15.42**	12.89*	-2.23	11.81**	11.53**	6.32*	1.74	0.49	-4.85	1.74	0.48	-4.84
1 ×3 IC-45831 ×IC-43733	59**	56.1**	11.36*	35.48**	33.56**	10.6*	11.22**	10.6**	4.91	20.14**	14.74*	5.97	20.16**	14.74*	5.98
1 ×4 IC-45831 ×IC-43750	41.53**	30**	6.75	19.95**	19.95**	-0.67	8.59**	6.52*	5.03	9.26	8.89	0.57	9.25	8.88	0.57
1 ×5 IC-45831 ×IC-45802	46.71**	22.79**	25.23**	18.08**	9.86	5.69	11.14**	6.96*	9.71**	16.83**	14.12*	10.53*	16.83**	14.12*	10.54*
1 ×6 IC-45831 ×Sel-4	12.61*	-0.69	-10.63*	21.41**	20.21**	1.56	8.53**	5.86*	5.61*	4.96	2.97	-1.14	4.96	2.97	-1.14
1 ×7 IC-45831 ×PM	12.85**	-8.26	0.77	22.51**	21.46**	2.34	9.41**	7.08*	6.08*	32.79**	12.89	4.26	32.8**	12.89	4.27
1 ×8 IC-45831 ×PK	9.18*	-19.24**	15.77**	23.46**	18.63**	6.58	11.93**	8.93**	9.18**	9.59	8.46	2.28	9.58	8.46	2.28
1 ×9 IC-45831 ×VRO-3	21.4**	-3.04	11.57*	22.03**	16.56**	6.03	12.89**	10.37**	9.59**	4.83	-0.51	2.32	4.85	-0.5	2.34
1 ×10 IC-45831 ×Sel-10	12.69**	-4.92	-4.92	10.74*	1.23	1.23	8.28**	5.5*	5.5*	6.45	2.38	2.38	6.46	2.39	2.39
1 ×11 IC-45831 ×Pusa A-4	50.03**	34.56**	16.53**	17.52**	13.75*	0.67	9.07**	6.32*	6.2*	6.35	3.43	1.08	6.35	3.44	1.08
1 ×12 IC-45831 ×SB-8	47.45**	30.58**	16.38**	20.3**	13.03*	6.47	7.07**	1.78	7.13*	6.8	3.73	1.65	6.79	3.72	1.65
2 ×3 IC-282272 ×IC-43733	49.71**	46.77**	8.98	15.3**	11.21*	-3.68	10.95**	10.06**	4.91	10.37	4.17	-1.37	10.36	4.15	-1.37
2 ×4 IC-282272 ×IC-43750	40.48**	33.75**	9.83*	13.18**	10.7	-4.13	5.91*	4.15	2.69	4.64	3.01	-2.47	4.65	3.01	-2.45
2 ×5 IC-282272 ×IC-45802	26.76**	9.53*	11.71*	6.23	0.93	-2.9	6.5**	2.74	5.38	10.3	9.06	5.63	10.29	9.06	5.64
2 ×6 IC-282272 ×Sel-4	43.98**	31.4**	18.24**	19.24**	17.78**	2.01	7.55**	5.16	4.91	4.88	4.15	0	4.87	4.15	0
2 ×7 IC-282272 ×PM	16.02**	-2.77	6.8	20.05**	18.43**	2.57	7.7**	5.67*	4.68	29.85**	9.27	3.46	29.85**	9.27	3.48
2 ×8 IC-282272 ×PK	-8.52*	-30.57**	-0.47	14.48**	12.42*	1	8.73**	6.07*	6.32*	8.53	8.31	2.55	8.53	8.3	2.56
2 ×9 IC-282272 ×VRO-3	19.7**	-1.53	13.31**	11.75*	9.08	-0.78	9.5**	7.3**	6.55*	2.51	-1.56	1.24	2.51	-1.55	1.25
2 ×10 IC-282272 ×Sel-10	13.16**	-1.4	-1.4	10.05*	2.68	2.68	5.99*	3.51	3.51	3.66	0.91	0.91	3.66	0.91	0.91
2 ×11 IC-282272 ×Pusa A-4	26.97**	17.92**	2.12	11.41*	10.21	-2.46	4.61	2.22	2.11	8.73	7.04	4.6	8.74	7.06	4.62
2 ×12 IC-282272 ×SB-8	40.71**	28.97**	14.95**	4.32	0.12	-5.69	1.46	-3.33	1.75	8.05	6.22	4.09	8.04	6.22	4.1
3 ×4 IC-43733 ×IC-43750	35.62**	26.72**	4.06	12.78*	11.19	-7.92	3.83	1.3	-0.12	7.61	3.11	-5.42	7.62	3.11	-5.41
3 ×5 IC-43733 ×IC-45802	39.91**	18.89**	21.26**	5.37	-3.25	-6.92	5.9*	1.37	3.98	16.41*	8.71	5.3	16.41*	8.71	5.3
3 ×6 IC-43733 ×Sel-4	29.11**	15.73**	4.14	23.14**	20.21**	1.56	8.64**	5.39	5.15	14.29*	7.16	2.89	14.3*	7.18	2.91
3 ×7 IC-43733 ×PM	17.19**	-3.35	6.17	21**	18.28**	-0.33	9.16**	6.26*	5.26	36.38**	20.66**	1.41	36.4**	20.68**	1.42
3 ×8 IC-43733 ×PK	3.41	-22.57**	11*	22.41**	16.02**	4.24	10.43**	6.88*	7.13*	11.88	5.8	-0.23	11.88	5.8	-0.23

Table 1 continued...

Table 1 continued...

3 ×9 IC-43733×VRO-3	5.85	-14.27**	-1.35	17.84**	11.04*	1	8.42**	5.42	4.68	5.18	-4.43	-1.71	5.18	-4.43	-1.71
3 ×10 IC-43733×Sel-10	25.99**	7.94	7.94	17.38**	5.92	5.92	9.6**	6.2*	6.2*	10.02	1.24	1.24	10.03	1.25	1.25
3 ×11 IC-43733×Pusa A-4	28.29**	16.98**	1.31	24.57**	18.92**	5.25	11.23**	7.85**	7.72**	10.66	2.92	0.57	10.66	2.92	0.57
3 ×12 IC-43733×SB-8	35.25**	21.76**	8.52	19.74**	11.02*	4.58	9.17**	3.22	8.65**	4.97	-2.5	-4.45	4.98	-2.5	-4.44
4 ×5 IC-43750×IC-45802	20.97**	9.18*	11.36*	15.84**	7.77	3.68	7.56**	5.47*	8.19**	11.67	8.71	5.3	11.66	8.71	5.3
4 ×6 IC-43750×Sel-4	32.65**	26.85**	14.15**	28.35**	27.08**	7.37	9.67**	9.03**	8.77**	10.17	7.71	3.42	10.17	7.72	3.42
4 ×7 IC-43750×PM	13**	-1.26	8.46	22.11**	21.06**	2.01	6.04*	5.79*	4.8	27.15**	8.4	-0.57	27.14**	8.39	-0.57
4 ×8 IC-43750×PK	-0.72	-21.93**	11.92*	29.54**	24.47**	11.83*	10.71**	9.8**	10.06**	10.98	9.47	3.23	11	9.49	3.25
4 ×9 IC-43750×VRO-3	8.01	-7.46	6.49	15.61**	10.43	0.45	6.38**	6.01*	5.26	1.9	-3.61	-0.87	1.9	-3.6	-0.85
4 ×10 IC-43750 ×Sel-10	23.27**	12.25**	12.25**	10.13*	0.67	0.67	4.36	3.63	3.63	3.59	-0.7	-0.7	3.6	-0.68	-0.68
4 ×11 IC-43750×Pusa A-4	34.03**	30.56**	13.07**	24.56**	20.55**	6.7	9.61**	8.9**	8.77**	11.38	7.97	5.51	11.4	7.99	5.53
4 ×12 IC-43750×SB-8	35.07**	29.76**	15.65**	18.92**	11.73*	5.25	4.99*	1.67	7.02*	4.39	1.06	-0.97	4.38	1.05	-0.97
5 ×6 IC-45802×Sel-4	28.97**	21.38**	23.8**	15.5**	8.47	4.35	6.71**	5.25	7.95**	7.18	6.71	3.36	7.18	6.71	3.36
5 ×7 IC-45802×PM	15.11**	10.99*	21.92**	23.81**	16.13**	11.72*	7.89**	6.04*	8.77**	33.32**	11.18	7.7*	33.33**	11.18	7.7*
5 ×8 IC-45802×PK	8.39*	-7.24*	32.97**	17.58**	13.69**	9.38	5.77*	4.56	7.25**	12.24*	10.76	7.28	12.25*	10.76	7.29
5 ×9 IC-45802×VRO-3	21.33**	14.43**	31.68**	10.67*	7.66	3.57	3.82	2.17	4.8	6.3	3.2	6.14	6.31	3.21	6.15
5 ×10 IC-45802×Sel-10	20.26**	19.09**	21.46**	15.81**	13.62**	13.62**	7.04**	5.7*	8.42**	9.36	7.64	7.78*	9.35	7.64	7.78*
5 ×11 IC-45802 ×Pusa A-4	47.46**	36.33**	39.04**	23.99**	19.03**	14.51**	8.03**	6.61*	9.36**	10.1	9.61	7.11	10.1	9.62	7.12
5 ×12 IC-45802×SB-8	47.19**	37.91**	40.66**	20.4**	19.14**	14.62**	6.36**	5	10.53**	9.88	9.24	7.05	9.88	9.24	7.07
6 ×7 Sel-4 ×PM	14.25**	3.92	14.16**	34.13**	33.95**	13.17**	9.88**	9.5**	9.24**	33.89**	12.04	7.58	33.9**	12.05	7.58
6 ×8 Sel-4 ×PK	-6.37	-23.8**	9.24	31.24**	27.33**	14.4**	8.42**	8.17**	8.42**	14.36*	13.34	8.82*	14.37*	13.35	8.83*
6 ×9 Sel-4 ×VRO-3	2.46	-8.71*	5.05	29.26**	24.66**	13.39**	7.05**	6.8*	6.55*	4.69	1.21	4.09	4.7	1.22	4.1
6 ×10 Sel-4×Sel-10	12.74**	7.09	7.09	23.41**	13.84**	13.84**	7.49**	7.37**	7.37**	4.3	2.22	2.22	4.3	2.22	2.22
6 ×11 Sel-4 ×Pusa A-4	22**	19.7**	7.72	31.61**	28.63**	13.84**	7.91**	7.85**	7.72**	4.28	3.37	1.01	4.29	3.38	1.03
6 ×12 Sel-4 × SB-8	16.56**	16**	4.39	24.05**	17.65**	10.83*	6.1**	3.33	8.77**	2.2	1.16	-0.87	2.2	1.16	-0.85
7 ×8 PM ×PK	-12.55**	-22.77**	10.7*	30**	25.96**	13.17**	8.1**	7.47**	7.72**	29.44**	9.11	2.89	29.46**	9.12	2.91
7 ×9 PM × VRO-3	-2.55	-4.76	9.59*	27.13**	22.45**	11.38*	10.44**	10.31**	9.53**	18.63**	-3.39	-0.63	18.64**	-3.38	-0.63
7 ×10 PM × Sel-10	-3.05	-7.4	1.72	22.47**	12.83**	12.83**	6.58**	6.08*	6.08*	27.4**	4.9	4.9	27.4**	4.9	4.9
7 ×11 PM × Pusa A-4	15.25**	3.05	13.2**	23.13**	20.18**	6.36	10.88**	10.42**	10.29**	24.19**	3.2	0.84	24.21**	3.21	0.85
7 ×12 PM × SB-8	4.28	-5.55	3.74	17.7**	11.49*	5.02	4.87*	1.78	7.13*	23.7**	2.67	0.61	23.71**	2.67	0.63
8 ×9 PK × VRO-3	-12.83**	-21.43**	12.64**	21.23**	20.49**	9.6*	8.56**	8.05**	8.3**	8.59	4.08	7.05	8.61	4.1	7.07
8 ×10 PK × Sel-10	-7.48*	-21.47**	12.57**	18.52**	12.5**	12.5**	7.94**	7.82**	8.07**	5.28	2.28	2.28	5.28	2.28	2.28
8 ×11 PK × Pusa A-4	-2.47	-21.78**	12.13*	22.9**	21.99**	9.6*	7.19**	7*	7.25**	5.93	4.08	1.71	5.93	4.08	1.71
8 ×12 PK × SB-8	-8.44*	-25.75**	6.44	15.71**	13.03*	6.47	5.52*	3	8.42**	9.1	7.04	4.9	9.1	7.03	4.9

Table 1 continued...

Table 1 continued...

9 ×10 VRO-3 × Sel-10	5.82	-1.11	13.8**	15.72**	10.49*	10.49*	4.11	3.74	3.74	3.92	2.48	5.4	3.93	2.49	5.41
9 ×11 VRO-3 × Pusa A-4	13.15**	-0.85	14.1**	18.91**	17.3**	6.7	9.45**	9.13**	9.01**	9.71	6.98	10.02*	9.72	6.98	10.03*
9 ×12 VRO-3 × SB-8	9.62*	-2.74	11.92*	23.45**	21.33**	14.29**	7.15**	4.11	9.59**	2.46	0.04	2.89	2.47	0.06	2.91
10 ×11 Sel-10 × Pusa A-4	12.65**	5.1	5.1	16.16**	9.49	9.49	7.2**	7.13*	7.13*	-1.79	-2.91	-2.91	-1.79	-2.91	-2.91
10 ×12 Sel-10 × SB-8	18.49**	12.05*	12.05*	17.59**	14.17**	14.17**	1.88	-0.67	4.56	-0.44	-1.43	-1.43	-0.43	-1.42	-1.42
11 ×12 Pusa A-4 × SB-8	37.09**	35.15**	20.45**	25.6**	21.8**	14.73**	6.5**	3.78	9.24**	4.97	4.82	2.72	4.98	4.83	2.74
Comparison of F_1 with	**S.E.D.**	**C.D. 95%**	**C.D. 99%**	**S.E.D.**	**C.D. 95%**	**C.D. 99%**	**S.E.D.**	**C.D. 95%**	**C.D. 99%**	**S.E.D.**	**C.D. 95%**	**C.D. 99%**	**S.E.D.**	**C.D. 95%**	**C.D. 99%**
Mid Parent	8.181	16.339	21.338	2.475	4.942	6.454	0.136	0.271	0.354	0.910	1.817	2.373	0.674	1.346	1.758
Better Parent	9.447	18.867	24.639	2.857	5.707	7.452	0.157	0.313	0.409	1.051	2.098	2.740	0.778	1.554	2.029
Best Parent/Checks	9.447	18.867	24.639	2.857	5.707	7.452	0.157	0.313	0.409	1.051	2.098	2.740	0.778	1.554	2.029

43733 × Pusa A-4 (22.22%) followed by Pusa Makhmali × Parbhani Kranti (21.83%) and IC-43750 × IC-45802 (21.83%). Reported positive heterosis for this trait by Patel and Patel (2016), Devi *et al.* (2017), More *et al.* (2017), Kerure and Pitchaimuthu (2018) and Vekariya *et al.* (2019).

The study reports that heterosis for single fruit weight (g) was noticed in both positive and negative directions. This suggests that some hybrid combinations exhibited an increase in fruit weight compared to the parental lines (positive heterosis), while other hybrids showed a decrease (negative heterosis). Such variation in heterotic effects underscores the complex genetic interactions influencing fruit weight in the studied okra hybrids. Among the 66 hybrids examined, 29, 19 and 11 hybrids demonstrated positive and significant heterosis over the mid parent, better parent, and standard check, respectively. The data suggests that high heterosis for yield is associated with an increase in the size and weight of fruits rather than a rise in the number of fruits. These findings are consistent with previous studies by Patel *et al.* (2015) Patel and Patel (2016), Devi *et al.* (2017), More *et al.* (2017), Kerure and Pitchaimuthu (2018), Makdoomi *et al.* (2018), Suganthi *et al.* (2019) and Vekariya *et al.* (2019), further supporting the notion that understanding and harnessing heterosis can contribute to improving single fruit weight and overall productivity.

The study indicates that certain crosses exhibited heterosis in desirable directions for various productivity parameters related to fruit yield. Specifically, 24 crosses demonstrated significant heterosis when compared against the mid parent, 9 crosses against the better parent, and 9 crosses against the standard check. Among these, the hybrid IC-45831 × IC-43733 displayed the most significant positive heterosis, with 28.88% over the mid parent, 26.19% over the better parent, and 13.37% over the standard check. The findings of Kumar (2011), and Bassey *et al.* (2012) corroborated these findings, suggesting that heterosis in yield primarily stemmed from an increase in the number of fruits.

Reddy *et al.* (2013) highlighted that increasing fruit length, diameter and weight can lead to higher fruit yield. This is commonly observed in agricultural practices, where selecting for or enhancing these characteristics in fruits can result in improved productivity. However, it's essential to implement these strategies in conjunction with other agricultural practices to ensure optimal growth conditions and maximize yield potential. Out of 66 hybrids, 50 hybrids over mid parent, 32 hybrids over better parent and 38 hybrids over standard check expressed significantly positive heterosis. The cross IC-45831 × IC-43733 (59.01per cent) showed highest significant positive heterosis over mid parent followed by IC-45831 × Pusa A-4 (50.03%) and IC-282272 × IC-43733 (49.71%). Similarly, hybrids IC-45831 × IC-43733, IC-282272 × IC-43733 and IC-45831 × IC-282272 showed 56.10, 46.77 and 39.83 per cent heterobeltiosis, respectively. The maximum standard heterosis was found in the cross IC-45802 × SB-8 followed by IC-45802 × Pusa A-4 and IC-45802 × Parbhani Kranti to the extent of 40.66, 39.05 and 32.97 per cent, respectively. The positive direction of heterosis values for these yield attributes suggests that the hybrids are exhibiting improved performance, likely due to the combination of favorable genetic factors from different parental lines. This highlights the effectiveness of hybridization in breeding programs aimed at enhancing agricultural productivity. Positive heterosis for fruit yield has been previously documented by Patel and Patel (2016), Devi *et al*. (2017), Gavint *et al*. (2018), Makdoomi *et al*. (2018), Kerure and Pitchaimuthu (2018), Suganthi *et al*. (2019) and Vekariya *et al*. (2019). These studies further corroborate the notion that heterosis plays a significant role in enhancing fruit yield.

The study highlights the importance of positive significant heterosis for the number of seeds per fruit, which is a desirable trait for edible fruit. Among the hybrids evaluated, IC-45831 × IC-43733 exhibited the highest average heterosis (35.48%), followed by Sel-4 × Pusa Makhmali (34.13%) and Sel-4 × Pusa A-4 (31.61%). Furthermore, the highest magnitude of heterobeltiosis was observed in the hybrid Sel-4 × Pusa Makhmali (33.95%), followed by IC-45831 × IC-43733 (33.56%) and Sel-4 × Pusa A-4 (28.63%). On the other hand, the standard heterosis was highest in Pusa A-4 × SB-8, followed by IC-45802 × SB-8 and IC-45802 × Pusa A-4, exhibiting heterosis levels of 14.73%, 14.62% and 14.51%, respectively. Only three hybrids showed negative significant heterosis for this trait. These findings are consistent with previous research by Patel *et al*. (2015), Kumar *et al*. (2017), Patel and Patel (2016) and Makdoomi *et al*. (2018), further underlining the significance of positive significant heterosis in enhancing the number of seeds per fruit.

Seed-related traits such as the number of seeds per fruit and the weight of 100 seeds are critical quality parameters in okra breeding. These traits directly influence the seed yield and overall seed quality of okra varieties. Breeders often focus on improving these characteristics to enhance the economic value and productivity of okra crops. By selecting for optimal combinations of these traits in breeding programs, they can develop varieties that meet market demands and agricultural requirements effectively. The study underscores the importance of positive heterosis for hundred seed weight (g), indicating its desirability. Among the 66 hybrids evaluated, 59 hybrids exhibited positive heterosis over the mid parent, 41 hybrids over the better parent, and 44 hybrids over the standard check. These findings are consistent with previous research conducted by Patel *et al*. (2015), Kumar *et al*. (2017), Patel and Patel (2016) and Makdoomi *et al*. (2018) further supporting the notion that positive heterosis plays a crucial role in enhancing hundred seed weight.

The study emphasizes the importance of positive heterosis for seed yield per plant (g) and seed yield per hectare (q). Among the 66 cross combinations examined, 17 crosses demonstrated positive significant heterosis over the mid parent, 8 crosses over the better parent, and 5 crosses over the standard check. Specifically, crosses such as IC-43733 × Pusa Makhmali, Sel-4 × Pusa Makhmali, and IC-45802 × Pusa Makhmali exhibited significant positive heterosis over the mid parent. Meanwhile, crosses including IC-43733 × Pusa Makhmali, IC-45831 × IC-43733 and IC-45831 × IC-45802 showed significant positive heterosis over the better parent, and crosses like IC-45831 × IC-45802, VRO-3 × Pusa A-4, and Sel-4 × Parbhani Kranti exhibited significant positive heterosis over the standard check. Only 5 out of 66 hybrids displayed negative significant heterosis. These findings closely align with the research of Patel *et al*. (2015), Kumar *et al*. (2017), Patel and Patel (2016) and Makdoomi *et al*. (2018), further supporting the importance of positive heterosis in enhancing seed yield per plant and per hectare.

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