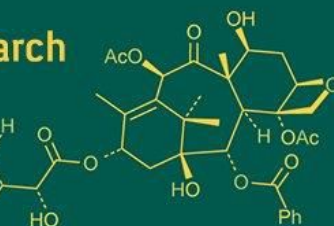


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Study of heterosis and inbreeding depression for fruit yield and its attributing traits in brinjal (*Solanum melongena* L.)

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Abstract

Six different generations viz, P₁, P₂, F₁, F₂, B₁ and B₂ of four different crosses viz, Swarna Mani × NBL-147 (cross-I), Surati Ravaia × NBL-50 (cross-II), NBL-50 × NBL-117 (cross-III) and Surati Ravaia × NBL-117 (cross-IV) were evaluated during the Rabi 2023-24 using Compact Family Block Design (CFBD) to study heterosis and inbreeding depression for fruit yield and its attributing traits. The significant positive heterobeltiosis for the number of fruits per plant and fruit yield per plant was recorded in the cross I (Swarna Mani × NBL-147) and for fruit weight in the cross III (NBL-50 × NBL-117). The significant positive standard heterosis over the check GNRB-1 recorded for fruit weight, fruit girth and fruit yield per plant in the cross I (Swarna Mani × NBL-147), cross III (NBL-50 × NBL-117) and cross IV (Surati Ravaia × NBL-117) it was highly significant for fruit weight and fruit girth while cross II (Surati Ravaia × NBL-50) showed heterosis only for fruit weight. Therefore, heterosis breeding in Swarna Mani × NBL-147 would be a more practical approach to achieving higher fruit yields. Significant positive inbreeding depression was found in all the crosses for most yield and its attributing traits.

Keywords: Heterobeltiosis, inbreeding depression, standard heterosis

Introduction

Vegetables are an important source of nutritional security and diet diversification. It is an essential part of a healthy diet, providing the body with vital nutrients such as vitamins, minerals, fiber and antioxidants. Brinjal (*Solanum melongena* L.) is recognized as one of the most popular and extensively cultivated vegetable crops within the Solanaceae family after potato and tomato (Kumar *et al.*, 2021) [9]. The genus name '*Solanum*' is derived from the Latin word solamen, which means "comforting or soothing," while the species name, *melongena*, refers to the fruit's melon shape. Brinjal is an often cross-pollinated crop and the extent of cross-pollination has been reported up to 48% (Devi *et al.*, 2015) [5]. Flowering pattern in brinjal is highly variable. Individual blooms are alone or in clusters, and they vary in size and shape (Khah *et al.*, 2000) [7]. Krishnamurthi and Subramanian (1954) [8] reported four types of flowers depending upon the length of the style viz, long styled with big size ovary, medium styled with medium size ovary, pseudo-short styled with a rudimentary ovary and true short-styled with a very rudimentary ovary. It is a staple, popular, versatile and contributing significantly to the local economy and food security therefore, it is known as the "king of vegetables" or "poor man's crop" (Choudhary and Gaur, 2009) [4].

Heterosis breeding is a promising technique for enhancing yields in self as well as cross-pollinated crops (Singh *et al.*, 2017) [19]. Exploitation of hybrid vigour in brinjal has been recognised as a practical tool in providing breeders a means of improving fruit yield and other important traits (Shrivastav *et al.*, 2024) [18]. On the other hand, inbreeding depression refers to the reduction of vigour and fertility due to the fixation of unfavourable recessive genes in the F₂ generation (Laboni *et al.*, 2015) [10]. Consequently, the proportion of inbreeding depression in any generation becomes helpful to the plant breeders to avoid undesirable traits and maintain healthy and productive crop lines. Keeping in view the objective of the present study was to assess the extent of heterosis and inbreeding depression in brinjal crosses.

Materials and Methods

Four families viz, Swarna Mani × NBL-147 (cross-I), Surati Ravaiya × NBL-50 (cross-II), NBL-50 × NBL-117 (cross-III) and Surati Ravaiya × NBL-117 (cross-IV) were generated at the Vegetable Research Farm, Regional Horticultural Research Station, Navsari Agricultural University, Navsari during the *Rabi* 2021-22. These hybrids along with parents were backcrossed to generate subsequent generations (B_1 and B_2) during *Rabi* 2022-23. During the same season, F_1 plants were self-pollinated to produce the F_2 generation. In brinjal, crop anthesis occurs between 7:30 to 11 am. Therefore, well-developed flower buds likely to open the next morning were emasculated and covered with white tissue paper bags during the evening hours. The following morning (between 7 to 12 am), pollen from the required male parents was collected separately and emasculated flower buds were pollinated by the respective pollen parents. The pollinated flower buds were then covered with red tissue paper bags and labelled accordingly. Seeds from different generations were harvested separately, cleaned, and stored properly in seed bags for field evaluation experiments in the subsequent season.

All six generations (P_1 , P_2 , F_1 , F_2 , B_1 and B_2) of the four families were evaluated during the *Rabi* 2023-24 in Compact Family Block Design (CFBD) with three replications to study the extent of heterotic effects *i.e.*, heterobeltiosis (HB) and standard heterosis (SH) as well as inbreeding depression (ID) of different traits. Each replication was divided into four compact blocks; each block consisted of six generations of each cross. Within replication, each family was allotted to a block randomly and within the block, different generations were allotted to different plots randomly. Each block consisted of two rows of each parent and F_1 ; four rows of each back-cross generation and eight rows of the F_2 generation with each row having 10 plants. Each row was spaced 90 cm apart and plant to plant distance within the row was 60 cm. All the cultural practices were adopted as per the recommendation to raise a good crop.

Estimation of heterosis

Heterosis was estimated as percent increase or decrease in the mean value of the F_1 hybrid over the better parent, *i.e.*, heterobeltiosis (Fonseca and Patterson, 1968)^[6] and over the standard check (GNRB-1), *i.e.*, (Meredith and Bridge, 1972)^[13] economic heterosis for each character.

$$\text{Heterobeltiosis (\%)} = \frac{\bar{F}_1 - \bar{BP}}{\bar{BP}} \times 100$$

$$\text{Standard Heterosis (\%)} = \frac{\bar{F}_1 - \bar{SC}}{\bar{SC}} \times 100$$

Where,

$\bar{F}_1$ = Mean performance of the F_1 hybrid

$\bar{BP}$ = Mean value of the better parent

$\bar{SC}$ = Mean value of the standard check

The standard errors and calculated 't' value for the test of significance for heterobeltiosis and standard heterosis were calculated as under:

Standard errors

$$\begin{aligned} \text{S. E. } (\bar{F}_1 - \bar{BP}) &= \sqrt{\frac{2Me}{2r}} \\ \text{(Standard error for heterobeltiosis)} & \\ \text{S. E. } (\bar{F}_1 - \bar{SC}) &= \sqrt{\frac{2Me}{r}} \\ \text{(Standard error for standard heterosis)} & \end{aligned}$$

Where,

Me = Error mean square

r = Number of replications

t-test for heterosis

The test of significance of the heterobeltiosis and standard heterosis was carried out by comparing the calculated values of 't' with the tabulated values 't' at 5% (1.96) and 1% (2.58) levels of significance, respectively.

$$t = \frac{\bar{F}_1 - \bar{BP}}{\text{S. E. } (\bar{F}_1 - \bar{BP})} \quad \text{(For heterobeltiosis)}$$

$$t = \frac{\bar{F}_1 - \bar{SC}}{\text{S. E. } (\bar{F}_1 - \bar{SC})} \quad \text{(For standard heterosis)}$$

Estimation of inbreeding depression

Inbreeding depression was computed by using the following formulae:

$$\text{Inbreeding depression (\%)} = \frac{\bar{F}_1 - \bar{F}_2}{\bar{F}_1} \times 100$$

The standard error and 't' value for the test of significance for inbreeding depression were estimated as under:

$$\text{S. E. } (\bar{F}_1 - \bar{F}_2) = \sqrt{\frac{[V(F_1)(n_1 - 1)] + [V(F_2)(n_2 - 1)]}{n_1 + n_2 - 2}}$$

t-test for inbreeding depression

$$t (\bar{F}_1 - \bar{F}_2) = \frac{\bar{F}_1 - \bar{F}_2}{\text{S. E. } (\bar{F}_1 - \bar{F}_2)}$$

Where,

$\bar{F}_1$ = Mean value of the F_1 hybrid

$\bar{F}_2$ = Mean value of the F_2 generation

$V(F_1)$ = Variance of the F_1 generation

$V(F_2)$ = Variance of the F_2 generation

n_1 = Number of observations in the F_1 generation

n_2 = Number of observations in the F_2 generation

The significance of the inbreeding depression was tested by comparing the calculated 't' value with the table 't' value at 5% (1.96) and 1% (2.58) levels of significance, respectively.

Results and Discussion

The extent of heterotic effects *i.e.*, heterobeltiosis (HB) and standard heterosis (SH) as well as inbreeding depression (ID) was estimated for all eight characters of four crosses under study are presented in Table 1.

Days to first flowering

For this character, a parent having early flowering was considered the better parent. Highly significant and negative heterobeltiosis was obtained only in one cross viz, cross IV (-7.57%). The negative trait values suggest the early flowering hybrid for this cross. Similar findings were also reported by Varma *et al.* (2019) [20], Mahla J.S. (2024) [11] and Mavani S. V. (2024) [12].

Significant and negative standard heterosis was obtained in none of the crosses. Similar findings by Vora *et al.* (2019) [21].

Significant positive inbreeding depression was found for cross II (12.33%), while significant negative found in cross I (-7.37%) and cross III (-10.48%), while non-significant inbreeding depression was found for cross IV (-2.94%). The significant inbreeding depression for days to first flowering was also reported by Savaliya *et al.* (2017) [17], Varma *et al.* (2019) [20], Barik *et al.* (2022) [2], Mahla J.S. (2024) [11] and Mavani S. V. (2024) [12].

Plant height

The perusal of heterobeltiosis showed significant positive results for none of the crosses, while non-significant found in cross I (2.18%) and cross III (1.34%). Significant negative heterobeltiosis found in cross II (-11.11%). The results are in accordance with the findings of Savaliya *et al.* (2017) [17], Varma *et al.* (2019) [20] and Mavani S. V. (2024) [12].

Significant and positive standard heterosis was obtained in none of the crosses. Similar results were reported by Vora *et al.* (2019) [21].

The inbreeding depression was significantly positive for all the crosses viz, cross I (10.84%), cross II (6.73%), cross III (7.74%) and cross IV (9.67%). The similar results reported earlier by Savaliya *et al.* (2017) [17], Varma *et al.* (2019) [20], Barik *et al.* (2022) [2], Mahla J.S. (2024) [11] and Mavani S. V. (2024) [12].

Branches per plant

A greater number of branches per plant is desirable for obtaining a high yield in brinjal. Significant positive heterobeltiosis (%) was found in none of the crosses. Similar results were reported earlier by Savaliya *et al.* (2017) [17] and Mavani S. V. (2024) [12].

The estimates of significant positive standard heterosis were obtained for none of the crosses under study. Similar findings were also reported by Vora *et al.* (2019) [21] and Naveen *et al.* (2022) [14].

The results of inbreeding depression showed positive significance for three crosses viz, cross II (20.83%), cross III (13.48%) and cross IV (11.36%). The cross I (1.08%) was found non-significant for relative inbreeding depression. Similar findings were observed by Savaliya *et al.* (2017) [17], Mahla J.S. (2024) [11] and Mavani S. V. (2024) [12].

Table 1: Estimates of heterobeltiosis (HB%), standard heterosis (SH%) and inbreeding depression (ID%) for various traits in four crosses of brinjal.

Particulars	Days to first flowering		Plant height (cm)		Branches per plant		Number of fruits per plant	
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
Cross I (Swarnamani × NBL 147)								
HB%	-1.31	±0.81	2.18	±1.28	4.49	±0.27	7.12**	±0.40
SH%	9.74**	±0.81	-7.98**	±1.28	-1.59	±0.27	-1.38	±0.40
ID%	-7.37**	±0.67	10.84**	±1.16	1.08	±0.22	14.16**	±0.41
Cross II (Surti Ravaiya × NBL 50)								
HB%	18.57**	±2.87	-11.11**	±1.17	1.12	±0.37	-27.34**	±0.57
SH%	36.24**	±2.87	-13.50**	±1.17	-4.76	±0.37	-28.34**	±0.57
ID%	12.33**	±2.53	6.73**	±1.00	20.83**	±0.29	0.34	±0.58
Cross III (NBL 50 × NBL 117)								
HB%	0.57	±1.59	1.34	±0.85	7.23	±0.34	-4.65	±0.53
SH%	17.03**	±1.59	-0.88	0.85	-5.87	±0.34	-5.28**	±0.53
ID%	-10.48**	±0.84	7.74**	±0.83	13.48**	±0.26	9.36**	±0.51
Cross IV (Surti Ravaiya × NBL 117)								
HB%	-7.57**	±1.84	-3.63**	±1.02	3.53	±0.28	-28.09**	±0.69
SH%	31.86**	±1.84	-11.25**	±1.02	-6.83	±0.28	-32.24**	±0.69
ID%	-2.94	±1.94	9.67**	±0.78	11.36**	±0.22	-2.24	±0.72
Particulars	Fruit length (cm)		Fruit weight (g)		Fruit girth (cm)		Fruit yield per plant (kg)	
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
Cross I (Swarnamani × NBL 147)								
HB%	-1.91	±0.13	-2.33	±1.25	0.52	±1.54	10.83**	±0.08
SH%	-4.26**	±0.13	13.68**	±1.25	26.64**	±1.54	11.64**	±0.08
ID%	3.67*	±0.14	6.42**	±0.92	8.38**	±0.41	17.06**	±0.07
Cross II (Surti Ravaiya × NBL 50)								
HB%	-6.80	±0.35	-6.15**	±0.89	0.14	±0.68	-19.33**	±0.12
SH%	-8.93**	±0.35	9.60**	±0.89	19.69	±0.68	-17.46**	±0.12
ID%	4.41*	±0.19	2.10*	±0.71	2.89	±0.39	5.25	±0.08
Cross III (NBL 50 × NBL 117)								
HB%	-6.39**	±0.29	2.82*	±0.89	1.46	±0.47	5.39	±0.15
SH%	-9.65**	±0.29	9.60**	±0.89	14.36**	±0.47	4.76	±0.15
ID%	3.74	±0.20	4.07**	±0.71	5.62*	±0.45	14.92	±0.09
Cross IV (Surti Ravaiya × NBL 117)								
HB%	0.22	±0.19	-3.33**	±1.36	2.31	±0.59	-17.02**	±0.11
SH%	-3.43*	±0.19	9.89**	±0.19	13.96**	±0.59	-20.63**	±0.11
ID%	5.90**	±0.11	2.49	±1.33	9.13	±0.27	8.12	±0.10
*, ** = Significant at 5% and 1% levels, respectively.								
HB-Heterobeltiosis, SH-Standard heterosis, ID-Inbreeding Depression, SE-Standard error								

Number of fruits per plant

For the number of fruits per plant, only one cross found positive significance heterobeltiosis viz, cross I (7.12%) while cross III (-4.65%) recorded non-significant. Negative significant heterobeltiosis was found in cross II (-27.34%) and cross IV (-28.09%). The findings are supported by Savaliya *et al.* (2017)^[17], Varma *et al.* (2020)^[20] and Mahla J. S. (2024)^[11]. The significant positive standard heterosis was obtained in none of the crosses.

Significant inbreeding depression was found in two crosses viz, cross I (14.16%) and cross III (9.36%) while in the other two crosses it was found non-significant. Similar results were also reported by Savaliya *et al.* (2017)^[17], Mahla J. S. (2024)^[11] and Mavani S. V. (2024)^[12].

Fruit length (cm)

Experimental data for fruit length indicated a significant heterobeltiosis found none of the crosses. Similar results were also reported by Balwani *et al.* (2017)^[1], Savaliya *et al.* (2017)^[17], Vora *et al.* (2019)^[21], Varma *et al.* (2020)^[20] and Mavani S. V. (2024)^[12].

Positive significant standard heterosis was found for none of the crosses.

The inbreeding depression was found significant for cross I (3.67%), cross II (4.41%) and cross IV (5.90%) while it was recorded as non-significant for cross III (3.74%). Similar results were also observed by Savaliya *et al.* (2017)^[17], Mahla J.S. (2024)^[11] and Mavani S. V. (2024)^[12].

Fruit weight (g)

The positive significant heterobeltiosis was found only in cross III (2.82%). The positive heterobeltiosis was also reported by Varma *et al.* (2020)^[20], Barik *et al.* (2022)^[2] and Mavani S. V. (2024)^[12].

Positive significant standard heterosis was found for all the crosses viz, cross I (13.68%), cross II (9.60%), cross III (9.60%) and cross IV (9.89%). Similar findings were also reported by Patel *et al.* (2025)^[15].

The significant inbreeding depression for cross I (6.42%), cross II (2.10%) and cross III (4.07%), while non-significant for cross IV (2.49%) was obtained. Similar findings for fruit weight were also reported by Varma *et al.* (2020)^[20], Barik *et al.* (2022)^[2] and Mavani S. V. (2024)^[12].

Fruit girth (cm)

The data given in revealed non-significant heterobeltiosis (%) for fruit girth in all the crosses. The results are in accordance with the findings of Savaliya *et al.* (2017)^[17], Bhatt *et al.* (2019)^[3], Vora *et al.* (2019)^[21] and Mavani S. V. (2024)^[12].

Standard heterosis was found significant for three crosses studied viz, cross I (26.64%), cross III (14.36%) and cross IV (13.96%). Similar results for fruit girth were also reported by Vora *et al.* (2019)^[21].

For fruit girth (cm), the inbreeding depression was found significant for two crosses viz, cross I (8.38%) and cross III (5.62%). The results are like those of Mavani S. V. (2024)^[12].

Fruit yield per plant (kg)

The significant positive heterobeltiosis was reported only in one cross viz, cross I (10.83%) which is desirable. Similar results for fruit yield per plant were also observed by

Savaliya *et al.* (2017)^[17], Vora *et al.* (2019)^[21], Barik *et al.* (2023)^[2] and Mahla J. S. (2024)^[11].

The perusal of standard heterosis showed significant positive only in one cross under study viz, cross I (11.64%). Similar findings were also reported by Sao and Mehta (2011)^[16], Naveen *et al.* (2022)^[14] and Patel *et al.* (2025)^[15].

The inbreeding depression was significant only in one cross viz, cross I (17.06%). Similar results were also found by Sao and Mehta (2011)^[16] and Savaliya *et al.* (2017)^[17].

Conclusion

This investigation revealed that the heterosis for fruit yield per plant was observed due to heterosis of the three important yield attributing traits viz, number of fruits per plant, fruit weight and fruit girth which resulted in increased yield. Therefore, attention should be given to these traits when aiming to improve yield. The results revealed significant positive and negative better parent heterosis and standard heterosis in many crosses for different characters under study. The cross I (Swarna Mani × NBL-147) had highly significant heterotic effects for fruit yield per plant, number of fruits per plant, fruit weight and fruit girth along with significant inbreeding depression which suggests the importance of non-additive type of gene action. So, the heterosis breeding seems to be beneficial for further improvement of the fruit yield and its attributes.

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