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Gene Action for Fruit Yield and its Components in Brinjal (*Solanum melongena* L.)

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ABSTRACT

Generation mean analysis using ten parameters (m, [d], [h], [i], [j], [l], [w], [x], [y] and [z]) was carried out to assess the presence of inter-allelic interaction and to estimate the importance of various gene effects for inheritance of twelve generations, namely P_1, P_2, F_1, F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_1s and B_2s of three crosses of brinjal viz., JBG-10-208 x GOB-1 (cross 1), NSR-1 x GBL-1 (cross 2) and JB-12-06 x Pant Rituraj (cross 3) for twelve characters in brinjal viz., days to opening of first flower, days to first picking, fruit length (cm), fruit girth (cm), fruit weight (g), number of fruit per plant, number of branches per plant, plant height (cm), total fruit yield per plant (kg), plant spread (cm), total soluble solids (°B) and fruit borer infestation (%). Experiment was laid-out in Compact Family Block Design (CFBD) with three replications. The crosses and the traits which were found significant digenic interaction (weighted least square technique) subjected to trigenic ten-parameter model. The trigenic ten-parameter model was found significant χ^2 values with two degrees of freedom for all the traits in all the three crosses showing the presence of higher order epistasis and /or linkage. Besides this, all ten-parameters were significant for fruit weight, plant spread and fruit borer infestation in all the crosses; fruit girth in JBG-10-208 x GOB-1; number of fruits per plant in JBG-10-208 x GOB-1 and NSR-1 x GBL-1; total fruit yield per plant in JBG-10-208 x GOB-1 and JB-12-06 x Pant Rituraj and total soluble solids in NSR-1 x GBL-1 and JB-12-06 x Pant Rituraj. Duplicate epistasis was observed in all the crosses for all the traits except for fruit girth in NSR-1 × GBL-1 (cross 2) and number of fruits per plant in JB-12-06 × Pant Rituraj (cross 3).

Key words: *Brinjal, gene action, epistasis, generation mean analysis*

INTRODUCTION

Brinjal (*Solanum melongena* L.) is one of the major vegetable crops in India, China and several other countries of Asia, Africa and Europe. Brinjal is grown in almost all parts of India except higher altitude. In India, it is grown in an area of 6.63 lakh ha with production of 12.51 million tones and productivity of 18868 kg/ha[1]. The major objective in most brinjal breeding programme is to improve the genetic potential for fruit yield. The knowledge about nature and magnitude of fixable and non-fixable type of gene effects, in the control of components of yield, is essential in order to achieve the genetic improvement in this crop.

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The information on the nature of gene action could be helpful in predicting the effectiveness of selection in a segregating material. A distinct knowledge of the type of gene effect, its magnitude and composition of genetic variance are of fundamental importance to a plant breeder. The efficient partitioning of genetic variance into its components *viz.*, additive, dominance and epistatis help in formulating an effective and sound breeding programme. Improvement of quantitative traits through selection depends upon the nature and magnitude of gene effects involved in inheritance of that particular trait. Generation mean analysis is a simple and useful technique for characterizing gene effects for quantitative traits[4,5].

MATERIALS AND METHODS

The field experiment was conducted at Instructional Farm, Junagadh Agricultural University, Junagadh during late *kharif* 2016-17. Geographically, Junagadh is situated at 21^0N latitude and 70.5^0E longitude with an altitude of 60 meters above the mean sea level. Temperature ranges from 36.6°C to 10.2°C in winter. The experimental material consists of twelve generations *viz.*, P_1, P_2, F_1, F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_1s and B_2s derived from following three crosses of brinjal.

1. Cross-1 : JBG-10-208 × GOB-1
2. Cross-2 : NSR-1 × GBL-1
3. Cross-3 : JB-12-06 × Pant Rituraj

On the basis of parental characteristics and performance of field grown F_1 plants, three crosses were selected. The seeds of F_1 of three crosses were used to prepare F_2, B_1, B_2, B_{11}, B_{12}, B_{21}, B_{22}, B_1s and B_2s generations during *kharif* 2015-16 and evaluated at Instructional Farm, College of Agriculture, Junagadh Agricultural University, Junagadh. The twelve generations of the three crosses were raised in compact family block design (CFBD) with three replications during late *kharif* 2016-17. Each replication was divided in to three compact blocks, each consists of single cross and blocks were consisted of twelve plots of twelve basic generations of each cross. The crosses were assigned to each block and twelve generations of a cross were relegated to individual plot within the block. Each block was comprised of nineteen rows consisting single row each of P_1, P_2, F_1, B_1 and B_2; two rows of F2, B_{11}, B_{12}, B_{21}, B_{22}, B_1s and B_2s generations. Each hybrid and parents represented single rows of 8.5-meter length spaced at 90 cm between rows and 60 cm between plants. Recommended agronomic practices and plant protection operations were followed to raise good crop. Fertilizers were applied at the rate of 100 kg N/ha, 50 kg P_2O_5/ha and 50 kg K_2O/ha. P_2O_5 and K_2O were applied as basal dose with 50 kg of nitrogen before one week of transplanting, while, remaining 50 kg nitrogen was top dressed at the time of flowering.

Data was recorded on randomly selected five competitive plants from P_1, P_2 and F_1; 10 plants from B_1 and B_2; 20 plants from F_2, B_{11}, B_{12}, B_{21}, B_{22}, B_1s and B_2s generations in each replication for twelve characters *viz.*, days to opening of first flower, days to first picking, fruit length (cm), fruit girth (cm), fruit weight (g), number of fruit per plant, number of branches per plant, plant height (cm), total fruit yield per plant (kg), plant spread (cm), total soluble solids and fruit borer infestation (%). Mean and variances were calculated for each generation using the data recorded on individual plants in each replication. Data were subjected to individual scaling test as given by Mather[9] and Hayman and Mather[6], who devised four simple scaling test *viz.*, A, B, C, and D, for the detection of presence or absence of epistasis. Further, simple scaling tests B11, B12, B21, B22, B1s and B2s[7] and X and Y[13] were also computed. Cavalli[3] joint scaling test was used for the precise estimates of different parameters. When the simple additive-dominance model failed to explain variation among generation means, a six parameter perfect fit model involving digenic interaction parameter proposed by Hayman[5] was applied. Various gene effects including first order and second order epistasis were estimated using ten-parameter model as suggested by Hill[7]. The degree of freedom (d.f.) equals to number of generation means used (n) minus the number of parameters (p) estimated. The significance of parameters was tested with related standard errors at 1% and 5% probability levels.

RESULTS AND DISCUSSION

The results of simple scaling tests revealed significant values of A, B, C, D, B_{11}, B_{12}, B_{22}, B_1s, B_2s and Y (cross 1); A, B, C, D, B_{11}, B_{21}, B_{22}, B_1s, B_2s and Y (cross 2) and A, B, C, B_{11}, $B_{12,}$ B_{21}, B_{22}, B_1s, B_2s, X and Y (cross 3) for days to opening of first flower; A, B, C, D, B_{11}, B_{12}, B_{22}, B_1s, B_2s, X and Y (cross 1); A, B, C, D, B_{11}, B_{12}, B_{21}, B_1s, B_2s, X and Y (cross 2) and A, B, C, D, B_{11}, $B_{21,}$ B_{22}, B_1s, B_2s and Y (cross 3) for days to first pocking; A, B, C, D, B_{11}, B_{21} and B_1s (cross 1); C, B_{12}, B_{22}, B_1s and X (cross 2) and B_{11}, B_1s, X and Y (cross 3) for fruit length (cm); C, D and B_2s (cross 1); B_{21}, B_{22}, B_1s and Y (cross 2) and only D (cross 3) for fruit girth (cm); B_{11}, B_{12}, B_{22}, B_1s, B_2s and X (cross 1); B, C, D, B_{11}, B_{12}, B_{22}, B_1s and Y (cross 2) and B_{12}, B_{22} and X (cross 3) for fruit weight (g); A, B, C, B_{11}, B_{21} B_{22}, B_1s, B_2s, X and Y (cross 1); A, B, C, D, B_{11}, B_{21}, B_{22}, B_1s, B_2s and X (cross 2) and A, B, C, D, B_{11}, B_{12}, B_{22}, B_1s, B_2s, X and Y (cross 3) for number of fruits per plant; B_1s, B_2s and X (cross 1); B_1s, B_2s and Y (cross 2) and B_{12}, B_2s and X (cross 3) for number of branches per plant; B, D, B_{22} and X (cross 1); C, D, B_{12}, B_1s and Y (cross 2) and A, B, B_{12}, B_{21}, B_{22}, B_2s, X and Y (cross 3) for plant height (cm); B, C, B_{21}, B_{22}, B_1s, B_2s and X (cross 1); C, D, B_1s and B_2s (cross 2) and A, B, C, B_{11}, B_{22}, B_1s, B_2s and Y (cross 3) for total fruit yield per plant (kg); A, B, C, D, B_{11}, B_{12}, B_{21}, B_{22}, B_1s, B_2s and Y (all the three crosses) for plant spread; B_{21}, B_2s and Y (cross 1); B_{22} and B_1s (cross 2) and B_{22} and B_2s (cross 3) for total soluble solids (°B) and A, B, C, D, B_{11}, B_{12}, B_{21}, B_{22}, B_1s, B_2s, X and Y (cross 1); C, D, B_{12}, B_{21}, B_{22}, B_1s, B_2s, X and Y (cross 2); A, B, C, D, B_{11}, B_{12}, B_{22}, B_1s, B_2s, X and Y (cross 3) for fruit borer infestation (%) (Table 1).

The additive-dominance model was not found adequate for any the traits in the present study. The failure of additive-dominance model was attributed mainly to the epistasis. The results obtained from six parameter model of Hayman[5] (1958) revealed that 'm', [d], [h] and digenic ([i], [j] and [l]) were significant in all the crosses for days to opening of first flower, days to first picking, fruit weight, number of fruits per plant and plant spread; fruit length in NSR-1 x GBL-1 (cross 2) and JB-12-06 x Pant Rituraj (cross 3), total fruit yield per plant in JBG-10-208 x GOB-1 (cross 1) and NSR-1 x GBL-1 (cross 2), total soluble solids in JBG-10-208 x GOB-1 (cross 1) and fruit borer infestation in JBG-10-208 x GOB-1 (cross 1) and NSR-1 x GBL-1 (cross 2). The χ^2 values were significant for all the traits in three crosses indicating inadequacy of digenic six-parameter model.

The 'm' gene effect found significant in all the three crosses of most of the traits i.e., fruit length, fruit weight, number of fruits per plant, number of branches per plant, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation (Table 2). Based on ten-parameter model, it was observed that additive [d] gene effect was significant in all the crosses for days to first picking, fruit length, fruit girth, fruit weight, number of fruits per plant, plant spread and fruit borer infestation, while it was significant in two crosses for days to opening of first flower, total fruit yield per plant and total soluble solids. The additive [d] gene effect was also found significant in one cross only for number of branches per plant. Dominance [h] gene effect was significant for days to opening of first flower, days to first picking, fruit length, fruit weight, number of fruits per plant, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation in all the crosses; fruit girth and number of branches per plant in two crosses. Rai and Asati[11] were observed preponderance of both additive and non-additive gene effects for yield and its contributing characters.

Among the digenic interactions, additive × additive [i] gene effect found significant in all the crosses for days to opening of first flower, days to first picking, fruit girth, fruit weight, number of fruits per plant, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation; in two crosses for number of branches per plant as well as in one cross only for plant height. Likewise, additive x dominance [j] gene effect was significant in all the crosses each for characters like days to first picking, fruit girth, fruit weight, total fruit yield per plant, plant spread and fruit borer infestation and two crosses each for days to opening of first flower, fruit length, number of fruits per plant, number of branches per plant and total soluble solids. Dominance x dominance [1] gene effect was significant for days to opening of first flower, days to first picking, fruit length, fruit weight, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation in all the crosses and fruit girth, number of fruits per plant and number of branches per plant in two crosses. Naulsri *et al*[10]., observed dominance x dominance [l] interaction for yield per plant. Lawande *et al*[8]., reported the impact of additive and additive x additive gene effects were more prominent for the number of fruits per plant, fruit weight and fruit yield per plant. Shinde *et al*[12]., indicated that epistatic component additive x additive and dominance x dominance was involved in the expression of fruit weight, fruit diameter, fruit girth, height of plant and seeds per fruit. Triallelic epistasis was found to be significant in various crosses for different characters in the present study. Additive x additive x additive [w] gene effect was significant in all the crosses each for fruit girth, fruit weight, number of fruits per plant, plant spread, total soluble solids and fruit borer infestation; two crosses each for days to opening of first flower, days to first picking, fruit length and total fruit yield per plant and one cross for number of branches per plant. Additive x additive x dominance [x] was observed to be significant for days to opening of first flower, days to first picking, fruit length, fruit girth, fruit weight, number of fruits per plant, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation in all the crosses each and number of branches per plant in two crosses. Whereas, Additive x dominance x dominance [y] gene effect was found significant in all the crosses each for fruit girth, fruit weight, number of fruits per plant, total fruit yield per plant, plant spread and fruit borer infestation; two crosses each for days to opening of first flower, fruit length, number of branches per plant and total soluble solids and one cross for days to first picking. In case of dominance x dominance x dominance [z] gene effect, it was significant in all the crosses each for days to opening of first flower, days to first picking, fruit length, fruit weight, number of fruits per plant, total fruit yield per plant, plant spread, total soluble solids and fruit borer infestation; two crosses each for fruit length and number of branches per plant and one cross for plant height. All the types of digenic and trigenic interactions were significant in all the crosses for fruit weight, plant spread and fruit borer infestation; cross 1 (JBG-10-208×GOB-1 and cross 2 (NSR-1 × GBL-1) for number of fruits per plant; cross 1 (JBG-10-208 × GOB-1) and cross 3 (JB-12-06 × Pant Rituraj) for total fruit yield per plant, cross 2 (NSR-1 × GBL-1) and cross 3 (JB-12-06 × Pant Rituraj) for total soluble solids and only in cross 1 (JBG-10-208 × GOB-1) for fruit girth.

Table 1: Estimation of scaling tests for various characters in three crosses of brinjal

	Days to opening of first flower			Days to first picking		
Scaling tests	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
A	-11.53** ± 1.58	-15.93** ± 1.58	-13.27** ± 0.90	-9.33** ± 1.09	-9.07** ± 1.23	-8.27** ± 1.06
B	-10.73** ± 1.54	15.93** ± 1.79	-8.93** ± 1.66	-10.47** ± 1.23	-5.27** ± 1.39	-8.00** ± 1.53
C	-33.67** ± 2.38	-21.53** ± 2.55	-26.07** ± 1.61	-31.40** ± 1.95	-9.93** ± 2.56	-24.07** ± 1.63
D	-5.70** ± 0.82	-10.77** ± 0.89	-1.93 ± 1.06	-5.80** ± 0.76	2.20* ± 0.92	-3.90** ± 1.05
B_{11}	18.07** ± 3.94	15.60** ± 3.88	21.53** ± 2.09	10.07** ± 2.65	9.20** ± 1.82	10.53** ± 1.96
B_{12}	-10.80** ± 3.40	1.00 ± 2.42	12.53** ± 3.07	-9.13** ± 3.25	-10.00** ± 3.35	3.47 ± 2.91
B_{21}	-2.33 ± 2.18	4.80* ± 1.97	7.60** ± 2.18	-2.73 ± 2.01	-11.93** ± 3.38	6.53** ± 1.94
B_{22}	14.67** ± 4.35	20.73** ± 5.09	11.47** ± 1.81	14.40** ± 3.92	-0.33 ± 1.86	8.60** ± 1.80
B_1s	70.80** ± 6.96	81.87** ± 7.00	58.13** ± 3.61	56.67** ± 4.84	81.60** ± 3.70	36.13** ± 3.60
B_2s	56.67** ± 7.43	71.20** ± 8.75	20.40** ± 3.56	50.40** ± 5.98	57.87** ± 3.92	30.27** ± 3.54
X	-1.27 ± 1.30	-2.23 ± 1.21	3.75** ± 1.02	-2.68* ± 1.22	2.87** ± 0.68	-0.28 ± 0.93
Y	-11.47** ± 1.37	-7.63** ± 1.26	-3.22** ± 1.09	-9.08** ± 1.28	-7.70** ± 1.23	-2.28* ± 1.01

	Fruit length (cm)			Fruit girth (cm)		
Scaling tests	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
A	-1.95** ± 0.65	-0.03 ± 0.58	0.77 ± 0.83	-1.07 ± 0.62	0.92 ± 0.72	-1.20 ± 0.68
B	-4.03** ± 0.59	-0.55 ± 0.65	-0.33 ± 0.59	-0.38 ± 0.65	-1.45 ± 0.78	0.10 ± 0.66
C	-3.82** ± 1.00	-2.65** ± 0.98	-1.39 ± 1.03	2.59* ± 1.14	1.87 ± 1.10	1.79 ± 1.04
D	1.08* ± 0.51	-1.04 ± 0.54	-0.91 ± 0.54	2.02** ± 0.57	1.20 ± 0.64	1.44** ± 0.54
B_{11}	3.74** ± 1.04	0.18 ± 0.92	4.61** ± 1.29	1.77 ± 1.13	-0.34 ± 0.98	0.61 ± 1.20
B_{12}	-0.92 ± 1.17	3.23** ± 1.07	-0.68 ± 1.15	0.21 ± 1.20	1.06 ± 1.08	-2.00 ± 1.19
B_{21}	3.47** ± 1.08	0.82 ± 1.03	-1.21 ± 1.25	1.53 ± 1.15	-2.53* ± 1.23	-1.02 ± 1.25
B_{22}	0.49 ± 1.17	7.06** ± 1.04	0.37 ± 1.08	-2.01 ± 1.26	3.33** ± 1.06	-1.77 ± 1.21
B_1s	-14.25** ± 2.13	5.71** ± 1.88	8.23** ± 2.43	-3.34 ± 2.11	6.50** ± 1.91	-1.05 ± 2.41
B_2s	0.25 ± 2.25	2.01 ± 2.19	2.27 ± 2.05	-7.06** ± 2.41	0.53 ± 2.13	-0.65 ± 2.23
X	-0.29 ± 0.41	-1.12** ± 0.39	1.19** ± 0.42	0.61 ± 0.44	-0.02 ± 0.40	0.35 ± 0.45
Y	-0.42 ± 0.48	-0.80 ± 0.45	-1.72** ± 0.52	0.49 ± 0.52	-1.12* ± 0.48	-0.47 ± 0.53

Scaling tests	Fruit weight (g) JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)			Number of fruits per plant JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)		
A	-19.05	±	10.25	7.69	±	11.21	8.39	±	11.19	9.13**	±	1.69	13.27**	±	2.38	9.13**	±	1.53
B	15.36	±	8.24	-30.61**	±	8.81	11.96	±	8.79	24.93**	±	0.97	18.40**	±	2.30	12.73**	±	1.49
C	-8.71	±	17.62	88.72**	±	17.98	-3.24	±	17.94	37.80**	±	1.67	25.93**	±	3.54	43.07**	±	1.70
D	-2.51	±	7.44	55.82**	±	8.53	-11.79	±	8.52	1.87	±	1.07	-2.87*	±	1.34	10.60**	±	1.16
B_{11}	67.37**	±	21.95	-60.59**	±	20.39	-18.87	±	20.41	-9.67**	±	1.44	-27.00**	±	1.99	-22.13**	±	2.06
B_{12}	-76.24**	±	21.63	92.85**	±	20.23	-67.23**	±	20.16	-2.67	±	2.16	-8.80	±	4.70	-3.47*	±	1.72
B_{21}	-6.26	±	22.26	1.74	±	22.89	6.77	±	22.81	-30.33**	±	1.89	-32.67**	±	4.52	-2.00	±	1.91
B_{22}	-114.81**	±	14.95	55.36**	±	10.96	-35.94**	±	10.98	-54.67**	±	2.03	-26.07**	±	4.28	-41.80**	±	1.86
B_1s	-142.74**	±	41.50	-120.03**	±	40.21	-36.14	±	40.20	-119.27**	±	3.24	-153.00**	±	4.51	-124.20**	±	3.94
B_2s	-134.43**	±	28.89	-41.37	±	26.89	18.45	±	26.92	-142.87**	±	3.77	-118.20**	±	7.65	-152.07**	±	3.68
X	28.05**	±	7.15	-6.21	±	6.61	-14.23*	±	6.60	18.17**	±	0.71	5.73**	±	0.85	4.55**	±	0.69
Y	-8.76	±	9.15	24.96**	±	8.69	-1.41	±	8.67	7.83**	±	0.85	2.90	±	1.69	14.62**	±	0.81

Scaling tests	Number of branches per plant JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)			Plant height (cm) JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)		
A	0.27	±	0.92	0.00	±	1.12	-0.53	±	0.92	-5.73	±	4.91	-0.14	±	4.05	-14.90**	±	5.11
B	-0.67	±	0.87	-0.07	±	1.08	0.20	±	0.90	-15.32**	±	4.33	0.81	±	5.05	-14.14**	±	4.95
C	0.00	±	1.39	1.07	±	1.73	2.20	±	1.54	16.69	±	9.06	18.45*	±	8.09	-13.01	±	8.93
D	0.20	±	0.69	0.57	±	0.81	1.27	±	0.78	18.87**	±	3.93	8.89*	±	3.68	8.02	±	4.10
B_{11}	0.87	±	1.20	0.40	±	1.50	1.33	±	1.64	9.78	±	9.14	-13.24	±	7.28	18.13	±	9.28
B_{12}	2.40	±	1.62	3.67	±	2.09	3.40*	±	1.60	15.84	±	10.54	20.29*	±	9.23	56.75**	±	10.20
B_{21}	-1.60	±	1.63	3.60	±	2.10	1.73	±	1.67	-8.87	±	10.81	11.12	±	9.24	92.08**	±	10.27
B_{22}	-2.00	±	1.70	0.00	±	1.63	-1.93	±	1.77	-22.69*	±	9.07	3.53	±	8.47	44.79**	±	8.42
B_1s	-11.27**	±	2.82	-9.27**	±	3.36	-5.27	±	3.18	2.69	±	18.22	-45.11**	±	14.31	11.58	±	17.32
B_2s	-10.07**	±	3.29	-10.73**	±	3.31	7.93*	±	3.23	-27.70	±	17.16	-22.12	±	15.90	73.97**	±	15.81
X	1.72**	±	0.52	0.12	±	0.53	1.23*	±	0.62	14.30**	±	3.44	-1.90	±	2.77	-15.50**	±	3.18
Y	0.48	±	0.67	1.72*	±	0.81	1.43	±	0.73	4.97	±	4.41	10.28**	±	3.75	21.48**	±	4.22

Scaling tests	Total fruit yield per plant (kg)			Plant spread (cm)		
	JBG-10-208 × GOB-1 (Cross 1)	NSR-1 × GBL-1 (Cross 2)	JB-12-06 × Pant Rituraj (Cross 3)	JBG-10-208 × GOB-1 (Cross 1)	NSR-1 × GBL-1 (Cross 2)	JB-12-06 × Pant Rituraj (Cross 3)
A	0.72 ± 0.45	0.47 ± 0.50	1.65** ± 0.51	-17.53** ± 1.74	-42.51** ± 1.72	8.71** ± 0.80
B	2.48** ± 0.50	0.98 ± 0.58	1.45* ± 0.57	-40.80** ± 1.37	-37.21** ± 1.41	-41.11** ± 1.30
C	3.41** ± 0.82	4.94** ± 0.93	3.57** ± 0.94	27.09** ± 1.89	27.53** ± 2.55	55.22** ± 1.77
D	0.11 ± 0.45	1.75** ± 0.46	0.23 ± 0.46	42.71** ± 1.13	53.63** ± 1.07	43.81** ± 0.99
B_{11}	-0.24 ± 0.82	-1.59 ± 0.82	-3.48** ± 0.83	68.87** ± 4.83	61.77** ± 3.98	46.66** ± 3.57
B_{12}	-1.64 ± 0.89	0.41 ± 1.08	-1.15 ± 1.09	62.34** ± 3.65	76.53** ± 4.15	113.43** ± 3.41
B_{21}	-3.32** ± 0.87	-0.66 ± 1.06	-1.37 ± 1.07	95.96** ± 3.63	94.35** ± 4.17	116.34** ± 3.70
B_{22}	-7.62** ± 0.81	-1.77 ± 0.94	-3.17** ± 0.91	40.29** ± 3.56	38.48** ± 3.00	45.21** ± 3.39
B_1s	-16.84** ± 1.55	-14.16** ± 1.60	-16.50** ± 1.61	17.54** ± 5.36	119.27** ± 7.53	-30.23** ± 6.27
B_2s	-16.26** ± 1.66	-19.54** ± 1.88	-15.50** ± 1.82	98.61** ± 4.23	83.77** ± 6.31	130.94** ± 6.30
X	2.26** ± 0.34	0.31 ± 0.34	-0.02 ± 0.34	-1.26 ± 1.81	1.37 ± 1.52	-0.37 ± 1.67
Y	0.73 ± 0.39	0.78 ± 0.44	1.03* ± 0.44	12.28** ± 1.86	17.66** ± 1.79	34.48** ± 1.71

Scaling tests	Total Soluble Solids (TSS)			Fruit borer infestation (%)		
	JBG-10-208 × GOB-1 (Cross 1)	NSR-1 × GBL-1 (Cross 2)	JB-12-06 × Pant Rituraj (Cross 3)	JBG-10-208 × GOB-1 (Cross 1)	NSR-1 × GBL-1 (Cross 2)	JB-12-06 × Pant Rituraj (Cross 3)
A	0.12 ± 1.02	0.73 ± 0.92	-0.48 ± 0.99	7.29** ± 0.92	-0.15 ± 0.94	12.43** ± 1.00
B	0.64 ± 1.05	0.29 ± 0.92	1.83 ± 0.96	10.91** ± 1.06	1.98 ± 1.03	8.04** ± 1.02
C	0.95 ± 1.21	0.06 ± 1.22	1.39 ± 1.18	40.59** ± 1.67	12.90** ± 1.75	16.95** ± 1.62
D	0.09 ± 0.77	-0.48 ± 0.69	0.02 ± 0.66	11.20** ± 0.84	5.54** ± 0.88	-1.76* ± 0.83
B_{11}	-0.22 ± 1.09	-0.49 ± 1.10	1.39 ± 1.43	-9.89** ± 1.50	-2.74 ± 1.90	-21.08** ± 1.90
B_{12}	0.56 ± 1.41	-0.97 ± 1.43	-2.17 ± 1.44	-5.93** ± 1.93	10.00** ± 1.78	-7.17** ± 1.79
B_{21}	2.77* ± 1.38	0.68 ± 1.39	1.18 ± 1.45	-7.77** ± 1.84	4.88** ± 1.70	0.37 ± 1.82
B_{22}	-1.12 ± 1.27	-2.98* ± 1.27	-4.76** ± 1.26	-17.37** ± 1.98	-4.90** ± 1.81	-13.60** ± 1.85
B_1s	-3.41 ± 2.07	-6.04** ± 2.09	-1.91 ± 2.52	-63.99** ± 3.12	-54.05** ± 3.67	-76.98** ± 3.64
B_2s	-7.98** ± 2.43	-4.05 ± 2.39	-6.65** ± 2.31	-85.54** ± 3.70	-56.37** ± 3.38	-75.78** ± 3.35
X	-0.33 ± 0.41	0.21 ± 0.41	0.70 ± 0.42	2.33** ± 0.67	1.82** ± 0.66	-3.76** ± 0.68
Y	1.17* ± 0.57	0.80 ± 0.57	0.60 ± 0.59	3.39** ± 0.81	5.63** ± 0.78	6.97** ± 0.80

Table 2: Estimation of gene effects based on ten parameter model for various characters in three crosses of brinjal

	Days to opening of first flower			Days to first picking		
Gene effects	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
m	25.06** ± 2.26	-17.57** ± 2.53	-3.46 ± 2.25	49.36** ± 2.26	56.26** ± 2.53	4.20 ± 2.25
(d)	4.24* ± 1.78	-2.36 ± 1.88	-9.66** ± 1.77	-15.96** ± 1.78	-8.69** ± 1.88	7.69** ± 1.77
(h)	175.98** ± 11.58	353.46** ± 13.11	357.14** ± 11.56	109.35** ± 11.58	-83.87** ± 13.11	389.82** ± 11.56
(i)	-24.40** ± 2.27	23.30** ± 2.53	56.00** ± 2.26	-47.99** ± 2.27	16.88** ± 2.53	63.58** ± 2.26
(j)	-28.59** ± 4.87	-0.13 ± 5.21	-34.06** ± 4.92	48.77** ± 4.87	17.73** ± 5.21	-86.44** ± 4.92
(l)	-397.52** ± 17.95	-544.22** ± 20.21	-735.39** ± 17.85	-264.85** ± 17.95	337.84** ± 20.21	-810.45** ± 17.85
(w)	0.79 ± 1.76	3.85* ± 1.88	9.58** ± 1.75	24.87** ± 1.76	3.62 ± 1.88	-5.76** ± 1.75
(x)	113.81** ± 6.47	-30.06** ± 7.33	-215.47** ± 6.50	170.07** ± 6.47	23.75** ± 7.33	-240.03** ± 6.50
(y)	105.96** ± 4.68	-6.74 ± 5.26	203.42** ± 4.70	6.96 ± 4.68	4.48 ± 5.26	279.63** ± 4.70
(z)	246.41** ± 8.90	254.85** ± 9.78	433.31** ± 8.77	170.16** ± 8.90	-295.92** ± 9.78	480.36** ± 8.77
χ^2 (2 df)	5770.18**	4139.89**	4479.22**	14727.65**	4986.64**	7944.75**
Types of epistasis	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate

Gene effects	Fruit length (cm)			Fruit girth (cm)		
	JBG-10-208 × GOB-1 (Cross 1)	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
m	54.38** ± 2.26	17.59** ± 2.53	23.98** ± 2.25	50.58** ± 2.26	27.74** ± 2.53	0.36 ± 2.25
(d)	7.52** ± 1.78	-4.93** ± 1.88	-9.80** ± 1.77	6.39** ± 1.78	-8.68** ± 1.88	-15.57** ± 1.77
(h)	-152.81** ± 11.58	46.44** ± 13.11	-22.75* ± 11.56	-174.15** ± 11.58	-18.20 ± 13.11	81.06** ± 11.56
(i)	-36.50** ± 2.27	-1.69 ± 2.53	-3.13 ± 2.26	-39.13** ± 2.27	-16.85** ± 2.53	15.23** ± 2.26
(j)	-7.65 ± 4.87	19.60** ± 5.21	28.54** ± 4.92	-20.99** ± 4.87	26.01** ± 5.21	47.44** ± 4.92
(l)	200.50** ± 17.95	-68.44** ± 20.21	73.03** ± 17.85	250.12** ± 17.95	-5.98 ± 20.21	-108.46** ± 17.85
(w)	-16.32** ± 1.76	2.42 ± 1.88	8.18** ± 1.75	-9.83** ± 1.76	9.88** ± 1.88	15.88** ± 1.75
(x)	105.72** ± 6.47	-17.73* ± 7.33	14.53* ± 6.50	108.22** ± 6.47	24.93** ± 7.33	-40.25** ± 6.50
(y)	-3.17 ± 4.68	-18.22** ± 5.26	-21.03** ± 4.70	21.00** ± 4.68	-47.34** ± 5.26	-29.49** ± 4.70
(z)	-77.87** ± 8.90	24.02* ± 9.78	-62.27** ± 8.77	-109.45** ± 8.90	8.44 ± 9.78	38.57** ± 8.77
χ^2 (2 df)	65205.79**	64306.50**	60016.21**	23885.72**	36956.21**	25922.63**
Types of epistasis	Duplicate	Duplicate	Duplicate	Duplicate	Complementary	Duplicate

Gene effects	Fruit weight (g)			Number of fruits per plant		
	JBG-10-208 × GOB-1 (Cross 1)	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
m	16.45** ± 2.26	10.36** ± 2.53	16.54** ± 2.25	63.57** ± 2.26	89.43** ± 2.53	52.41** ± 2.25
(d)	-34.66** ± 1.78	-27.23** ± 1.88	-45.37** ± 1.77	12.16** ± 1.78	15.82** ± 1.88	-5.35** ± 1.77
(h)	-117.60** ± 11.58	-90.62** ± 13.11	-126.76** ± 11.56	-139.69** ± 11.58	-271.80** ± 13.11	-40.64** ± 11.56
(i)	24.83** ± 2.27	29.45** ± 2.53	37.71** ± 2.26	-50.25** ± 2.27	-81.25** ± 2.53	-39.58** ± 2.26
(j)	198.17** ± 4.87	168.72** ± 5.21	255.29** ± 4.92	-81.59** ± 4.87	-83.45** ± 5.21	-8.39 ± 4.92
(l)	246.55** ± 17.95	212.54** ± 20.21	273.10** ± 17.85	161.69** ± 17.95	374.58** ± 20.21	-26.16 ± 17.85
(w)	-6.30** ± 1.76	-12.18** ± 1.88	-7.72** ± 1.75	-12.94** ± 1.76	-13.18** ± 1.88	3.49* ± 1.75
(x)	-83.20** ± 6.47	-81.19** ± 7.33	-123.99** ± 6.50	94.41** ± 6.47	193.95** ± 7.33	39.61** ± 6.50
(y)	-213.92** ± 4.68	-198.66** ± 5.26	-269.88** ± 4.70	102.41** ± 4.68	97.26** ± 5.26	16.31** ± 4.70
(z)	-146.48** ± 8.90	-132.58** ± 9.78	-163.90** ± 8.77	-67.36** ± 8.90	-183.02** ± 9.78	41.98** ± 8.77
χ^2 (2 df)	9811.66**	9610.06**	11259.23**	61.15**	269.58**	7.96*
Types of epistasis	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate	Complementary

Gene effects	Number of branches per plant			Plant height (cm)		
	JBG-10-208 × GOB-1 (Cross 1)	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
m	11.43** ± 2.26	5.32* ± 2.53	12.28** ± 2.25	4.10 ± 2.26	6.72** ± 2.53	4.90* ± 2.25
(d)	-3.15 ± 1.78	-8.23** ± 1.88	-1.43 ± 1.77	-1.63 ± 1.78	-2.17 ± 1.88	-0.17 ± 1.77
(h)	-28.46* ± 11.58	15.69 ± 13.11	-32.39** ± 11.56	-14.06 ± 11.58	-12.36 ± 13.11	-13.96 ± 11.56
(i)	-7.36** ± 2.27	-2.61 ± 2.53	-8.24** ± 2.26	-2.17 ± 2.27	-5.48* ± 2.53	-2.51 ± 2.26
(j)	11.72* ± 4.87	19.25** ± 5.21	-1.32 ± 4.92	6.96 ± 4.87	5.79 ± 5.21	2.12 ± 4.92
(l)	44.11* ± 17.95	-23.20 ± 20.21	48.90** ± 17.85	29.06 ± 17.95	17.41 ± 20.21	24.07 ± 17.85
(w)	2.15 ± 1.76	7.89** ± 1.88	1.80 ± 1.75	0.61 ± 1.76	1.98 ± 1.88	0.21 ± 1.75
(x)	23.09** ± 6.47	-7.23 ± 7.33	20.08** ± 6.50	10.93 ± 6.47	10.06 ± 7.33	8.50 ± 6.50
(y)	-11.60* ± 4.68	-17.38** ± 5.26	8.90 ± 4.70	-7.79 ± 4.68	-4.62 ± 5.26	-0.18 ± 4.70
(z)	-22.38* ± 8.90	5.05 ± 9.78	-24.00** ± 8.77	-17.71* ± 8.90	-10.34 ± 9.78	-13.78 ± 8.77
χ^2 (2 df)	1125.76**	655.32**	286.82**	10712.48**	11916.74**	9920.92**
Types of epistasis	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate

Gene effects	Total fruit yield per plant (kg)			Plant spread (cm)		
	JBG-10-208 × GOB-1 (Cross 1)	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**	**JBG-10-208 × GOB-1 (Cross 1)**	**NSR-1 × GBL-1 (Cross 2)**	**JB-12-06 × Pant Rituraj (Cross 3)**
m	57.60** ± 2.26	39.76** ± 2.53	43.13** ± 2.25	14.68** ± 2.26	-280.98** ± 2.53	-257.65** ± 2.25
(d)	20.70** ± 1.78	-2.02 ± 1.88	10.95** ± 1.77	68.34** ± 1.78	-13.08** ± 1.88	-82.67** ± 1.77
(h)	-197.16** ± 11.58	-83.23** ± 13.11	-156.75** ± 11.56	628.40** ± 11.58	1726.98** ± 13.11	1480.95** ± 11.56
(i)	-46.67** ± 2.27	-35.48** ± 2.53	-34.46** ± 2.26	19.02** ± 2.27	320.28** ± 2.53	307.47** ± 2.26
(j)	-70.25** ± 4.87	-11.37* ± 5.21	-30.54** ± 4.92	-68.85** ± 4.87	81.41** ± 5.21	290.63** ± 4.92
(l)	252.49** ± 17.95	78.04** ± 20.21	232.71** ± 17.85	-1445.26** ± 17.95	-2494.57** ± 20.21	-2195.22** ± 17.85
(w)	-24.93** ± 1.76	1.59 ± 1.88	-7.35** ± 1.75	-96.11** ± 1.76	-16.24** ± 1.88	68.39** ± 1.75
(x)	114.42** ± 6.47	28.36** ± 7.33	86.84** ± 6.50	-643.53** ± 6.47	-1222.85** ± 7.33	-903.51** ± 6.50
(y)	72.10** ± 4.68	22.83** ± 5.26	42.66** ± 4.70	-23.50** ± 4.68	-109.78** ± 5.26	-58.98** ± 4.70
(z)	-99.13** ± 8.90	-30.21** ± 9.78	-114.98** ± 8.77	893.28** ± 8.90	1058.17** ± 9.78	1061.08** ± 8.77
χ^2 (2 df)	47999.11**	22035.08**	27521.31**	35581.70**	52493.84**	33353.57**
Types of epistasis	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate

Gene effects	Total Soluble Solids (TSS) JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)			Fruit borer infestation (%) JBG-10-208 × GOB-1 (Cross 1)			NSR-1 × GBL-1 (Cross 2)			JB-12-06 × Pant Rituraj (Cross 3)		
m	53.70**	±	2.26	44.04**	±	2.53	39.45**	±	2.25	54.14**	±	2.26	87.84**	±	2.53	66.25**	±	2.25
(d)	3.49	±	1.78	10.89**	±	1.88	10.37**	±	1.77	-14.57**	±	1.78	-23.84**	±	1.88	-34.83**	±	1.77
(h)	-189.35**	±	11.58	-125.56**	±	13.11	-97.92**	±	11.56	-103.36**	±	11.58	-252.86**	±	13.11	-162.78**	±	11.56
(i)	-43.37**	±	2.27	-38.10**	±	2.53	-32.27**	±	2.26	-39.29**	±	2.27	-80.08**	±	2.53	-52.70**	±	2.26
(j)	1.05	±	4.87	-37.18**	±	5.21	-38.89**	±	4.92	16.67**	±	4.87	18.00**	±	5.21	85.48**	±	4.92
(l)	273.62**	±	17.95	167.79**	±	20.21	133.59**	±	17.85	118.07**	±	17.95	319.39**	±	20.21	205.33**	±	17.85
(w)	-5.23**	±	1.76	-10.37**	±	1.88	-9.17**	±	1.75	15.50**	±	1.76	21.70**	±	1.88	35.99**	±	1.75
(x)	94.86**	±	6.47	65.70**	±	7.33	60.10**	±	6.50	63.06**	±	6.47	152.50**	±	7.33	133.56**	±	6.50
(y)	-7.19	±	4.68	34.57**	±	5.26	50.63**	±	4.70	14.10**	±	4.68	41.73**	±	5.26	-26.47**	±	4.70
(z)	-127.24**	±	8.90	-80.41**	±	9.78	-69.01**	±	8.77	-49.96**	±	8.90	-138.57**	±	9.78	-89.86**	±	8.77
χ^2 (2 df)	16527.72**			15951.78**			31308.68**			998.74**			4501.42**			3356.97**		
Types of epistasis	Duplicate			Duplicate			Duplicate			Duplicate			Duplicate			Duplicate		

While fitting trigenic epistasis model, the χ^2 value at two degrees of freedom was significant in ten-parameter model for all the traits in all the three crosses suggesting the non-adequacy of the trigenic interaction model of Hill[7] and Van Der Veen[13]. The opposite signs of either two or all the three gene effects *viz.*, dominance [h], dominance × dominance [l] and dominance × dominance × dominance [z] gene effects suggests the presence of duplicate type of epistasis. In present study, duplicate epistasis was observed in all the crosses for all the traits except for fruit girth in cross 2 (NSR-1 × GBL-1) and number of fruits per plant in cross 3 (JB-12-06 × Pant Rituraj). Ansari and Singh[2] (2015) observed duplicate dominance type of epistasis for six fruit characters in brinjal *viz.*, fruit length, fruit diameter, average fruit weight, total number of fruits per plant, early yield per plant and yield per plant. Overall, it can be concluded from the present study that fruit yield per plant and its component traits recorded in three brinjal crosses were governed by additive, dominance and digenic and/or trigenic epistasis gene effects along with duplicate type of gene action. When additive as well as non-additive effects are involved, a breeding scheme efficient in exploiting both types of gene effects should be employed. Hence, bi-parental mating or few cycles of recurrent selection may give fruitful results for genetic improvement of these traits in brinjal.

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