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HETEROSIS AND COMBINING ABILITY STUDIES FOR YIELD AND YIELD ATTRIBUTING TRAITS IN BRINJAL (*SOLANUM MELONGENA* L.)

RAGHVENDRA DUBEY[1], ARPITA DAS[2], M. D. OJHA[2], BHOLANATH SAHA[2]*, ASHISH RANJAN[2] AND P. K. SINGH[2]
[1]Thematic Program Executive, BAIF, Vadodara, Gujarat - 390 004, INDIA
[2]College of Horticulture, Bihar Agricultural University, Noorsarai, Nalanda, Bihar- 803 113, INDIA
e-mail: bnsaha1@gmail.com

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***Corresponding author**

ABSTRACT

A study was conducted in brinjal to identify superior parental combination and to estimate the magnitude of heterosis for yield and its eleven yield components. 48 F1 hybrids generated following line x tester mating design comprising of 12 lines and 4 testers and were evaluated in a randomized block design with three replications at Vegetable Farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad (Uttar Pradesh). The analysis revealed that Sel-4 was the best general combiner among the lines and IC-90099 was the best general combiner among the testers. There was high heterosis response in most of the hybrids which supports the role of non-additive gene effects. Among the crosses, DBL-24 x PPC showed high sca effects for yield although the parents were poor general combiners. The maximum heterosis for total yield per plant over better parent was exhibited by the cross KS-314 x IC-90099 (94.72%) followed by KS-314 x PPC (85.10%). Indirect selection for traits such as plant height, long and medium styled flowers per clusters, fruits per plant, fruit length, fruit diameter and primary branches per plant could be done in order to achieve higher yield through heterosis breeding. The present study reveals good scope for isolation of pure lines from the progenies of heterotic F1s as well as commercial exploitation of heterosis in brinjal.

INTRODUCTION

Brinjal or egg plant (*Solanum melongena* L.) belonging to the family Solanaceae is one of the most important vegetable crops grown in India and other parts of the world. It is grown throughout the year under tropical and subtropical conditions and usually finds its place in common men's kitchen. Being a center of origin, Brinjal has a huge genetic divergence in our country which offers much scope for improvement through heterosis breeding. The effort could enhance its quality and productivity without sacrificing the consumers' choice.

Though, the improvement work in brinjal started as early as 1900s but it took long time to start with concentrated efforts on genetic improvement and still exploration for a better cultivar is going on, as most of the commercial cultivars lack one or the other desirable traits (Prabhakaran, 2010). Exploitation of hybrid vigour has become a potential tool for improvement in eggplant. Nagai and Kada (1926) were the first to observe hybrid vigour in brinjal. The commercial exploitation of this phenomenon has been possible in the brinjal because of the low cost of F_1 seed production and the low seed requirement per unit area. With increasing popularity of F_1 hybrids in Brinjal, it is imperative to obtain such hybrids, having excellent quality coupled with high yields. In crop manifestation of heterotic effect for different economically important characters have been reported by many scientists (Joshi and Thakur, 2003; Thakur, 2004; Ajjappalavar, 2006; Sao *et al*., 2010; Kumar *et al*., 2012 and Makani *et al*., 2013).

The development of an effective heterosis breeding programme in brinjal needs to elucidate the genetic nature and magnitude of quantitatively inherited traits and judge the potentiality of parents in hybrid combinations. Selection of parents for hybridization has to be based on the complete genetic information and prepotency of the potential parents. Identification and selection of flexible parental lines are required to be used in any hybridisation programme to produce genetically modified and potentially rewarding germplasm by assembling fixable gene effects more or less in a homozygous line (Pedapati *et al*., 2013, Kumar *et al*., 2013, Singh *et al*., 2013 and Potla *et al*., 2013). With these points in view, heterosis and combining ability studies are prerequisite in any plant breeding programme, which provides the desired information regarding the varietal improvement or exploiting heterosis for commercial purposes (Singh *et al*., 2013). The knowledge of gene action and combining ability helps in proper understanding of inheritance of characters in selection of suitable parents for hybridization programme and for obtaining desirable segregants. Brinjal being in the preliminary stage of breeding, information on good combiner is lacking. Therefore, the present investigation was undertaken to identify the potential combinations in order to have superior hybrids of excellent qualities coupled with high yields and nature of gene action for various characters in brinjal.

MATERIALS AND METHODS

The experimental material for this study comprised of 16 genotypes which were selected based on their diversity for various traits. Among the 16 genotypes four early maturing genotypes having fruits with different shapes, size and colour *viz*. Pusa Purple Cluster (PPC), Pant Samrat, KS-331 and I.C.-90099 were used as male (tester) and twelve genotypes namely Rajendra Annapurna (RA), KS- 314, Collection Oblong (CO), Punjab-30 (Pb-30), DBL-24, FB-18, Kachpuchia Brinjal (KB), Sel-5, Punjab Sadabahar (Pb. Sadabahar), BB-13, KS-352 and Sel-4 were used as female parent (line). All the genotypes were grown at Main Experiment Station, Vegetable Farm of Narendra Deva University of Agriculture and Technology, Narendra Nagar, Kumarganj, Faizabad (Uttar Pradesh) and crossed in line x tester matting design for producing forty eight crosses. In the next year all the crosses along with their parents were raised in Randomized Block Design (RBD) with three replications with spacing of 60cm x 75 cm. Standard package of practices were followed to raise the crop. Data were recorded on five randomly selected plants in each treatment over replication for all the characters *viz*. days to 50% flowering, number of flowers per cluster, number of long and medium styled flowers per clusters, number of short styled flowers per cluster, number of fruits per cluster, length of fruit (cm), diameter of fruit (cm), plant height (cm), number of primary branches per plant, fruit weight (g) and total yield per plant. The experimental data were analyzed following Model 1 and Method 2 of Griffing (1956). The magnitude of heterosis in hybrids was expressed as percentage of increase or decrease of a character over better parent in the desirable direction was calculated using the following formula:

Heterobeltiosis (BH); (Fonseca and Patterson, 1968)

$$BP = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} X\ 100$$

Where, $\overline{BP}$ = Mean performance of better parent

$\overline{F1}$ = Mean performance of F1 hybrid

RESULTS AND DISCUSSION

The analysis of variance for twelve characters was presented in Table 1. The result revealed that the parents as well as hybrids showed significant differences for all the characters except number of primary branches/ plant. The variance due to the lines were significant for days to 50 % flowering, no. of short styled flower per cluster, length of fruit and no. of primary branches per plant indicating the existence of enormous amount of genetic variability for these characters (females). In contrary, testers (males) exhibited non- significant differences for all characters. The interaction between lines x testers was significant for all characters except for number of primary branches per plant indicating the importance of additive components of genetic variance in the inheritance of these traits. The gca/ sca variance ratio being less than unity for all the characters revealed predominance of non-additive components of variance (Table 2) which is always favourable for heterosis breeding for improvement of this traits. The importance of both additive as well as non-additive components for fruits per plant, branches per plant, days to flowering, plant height and yield per plant in brinjal was

Table 1: Analysis of variance for line x tester analysis for fruit yield and its component characters

source of Variation	d.f.	Characters											
		1	2	3	4	5	6	7	8	9	10	11	12
Replication	2	98.755**	0.119	1.174**	0.992**	0.068	1.052**	5.650**	0.598**	44.830**	0.279**	9.849	0.0001
Treatment	63	50.478**	0.779**	0.495**	0.585**	0.743**	0.677**	23.982**	1.405**	190.196**	0.050**	5430.90**	1.012**
Parents	15	57.622**	1.109**	0.581**	0.735**	0.967**	0.764**	47.391**	2.156**	233.545**	0.067	4384.74**	1.032**
Hybrids	47	49.248**	0.670**	0.488**	0.549**	0.650**	0.662**	16.665**	1.191**	154.698*	0.046	5803.89**	0.784**
Parents vs hybrids	1	1.174	0.932**	0.087	0.058	1.773**	0.056	16.752**	0.153	1208.43**	0	3580.02**	11.419**
Lines	11	134.316**	0.918	0.64	0.704	1.229*	0.936	46.306**	1.182	248.201	0.084*	5309.27	1.196
Testers	3	26.25	0.282	0.706	0.653	0.194	0.505	8.702	1.644	8.455	0.038	12477.95	0.052
Lines x Testers	33	22.982**	0.623**	0.401**	0.488**	0.498**	0.585**	7.508**	1.153**	136.825**	0.034	5362.04**	0.714**
Error	126	5.522	0.127	0.096	0.129	0.147	0.083	0.759	0.118	6.996	0.051	9.665	0.002

*,**, significant at 5 and 1 per cent probability levels, respectively; 1. Days to 50% flowering 2. No. of flowers per clusters, 3. No. of long styled flowers/ clusters 4. No. of medium styled flowers/ clusters 5. No. of short styled flowers/ clusters 6. No. of fruits per clusters, 7. Length of fruit, 8. Diameter of fruit; 9. Plants height, 10. No. of primary branches/ plant, 11. Fruit weight, 12. Total yield per plant.

Table 2: Magnitude of gca variance and sca variance for fruit yield and other characters

source of Variation	Characters 1	2	3	4	5	6	7	8	9	10	11	12
GCA	2.4	-0.001	0.011	0.007	0.008	0.005	0.833	0.011	-0.354	0.001	147.14	-0.003
SCA	5.7	0.17	0.1	0.12	0.12	0.17	2.25	0.35	43.28	-0.01	1784.5	0.24
var. gca/var.sca	0.42	-0.01	0.11	0.06	0.07	0.03	0.37	0.03	-0.01	-0.1	0.08	-0.01

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Table 3: General Combining Ability (GCA) effects of lines and testers for fruit yield and its components

Parents	Characters 1	2	3	4	5	6	7	8	9	10	11	12
Lines												
R. A.	7.76**	0.05	-0.04	-0.01	0.18	-0.15	-1.78**	0.1	-5.03**	-0.09	-19.20**	-0.51**
KS-314	-0.24	-0.21*	-0.08	-0.09	-0.33**	-0.15	-0.19	-0.58**	4.20**	-0.05	-25.03**	-0.30**
C.O.	-3.49**	-0.21*	0.07	-0.36**	-0.38**	-0.26**	0.76**	0.28**	-1.22	0.03	24.55**	-0.28**
Pb. 30	-2.82**	-0.17	-0.18*	-0.26*	0.23*	-0.08	1.42**	-0.05	0.2	0.05	7.05**	-0.07**
DBL- 24	2.10**	0.02	0.24**	0.17	-0.28*	0.29**	0.25	-0.07	-7.38**	-0.1	-4.62**	0.45**
FB- 18	-0.07	-0.44**	0.05	-0.03	-0.1	-0.13	4.01**	-0.26**	1.68*	0.16*	16.22**	-0.09**
K.B.	1.85**	-0.08	-0.32**	0.52**	-0.28*	0.12	-2.86**	0.04	-6.25**	-0.09	-19.20**	0.31**
Sel.- 5	-0.74	-0.21*	-0.45**	0.16	-0.11	-0.20*	-2.38**	0.45**	5.23**	0.06	-5.45**	-0.14**
Pb. Sadabahar	-2.82**	0.17	0.19*	-0.16	0.30**	-0.25**	1.41**	0.04	-1.12	0.03	11.63**	-0.14**
BB-13	3.51**	0.23*	0.19*	0.05	-0.01	0.37**	-1.12**	-0.33**	6.47**	-0.05	-14.20**	0.04**
KS-352	-1.74**	0.29**	0.01	-0.20*	0.72**	-0.15	1.53**	0.51**	-0.76	-0.05	44.13**	0.20**
Sel-4	-3.32**	0.56**	0.32**	0.22*	0.05	0.60**	-1.04**	-0.13	3.97**	0.1	-15.87**	0.53**
Testers												
PPC	0.01	0.11*	-0.04	0.19**	0.08	0.06	0.07	-0.03	-0.06	-0.01	-2.81**	-0.03**
Pant Samrat	0.68*	-0.05	0.08	-0.03	0.04	-0.01	-0.41**	-0.24**	-0.3	-0.01	-18.92**	-0.03**
KS-331	-1.21**	-0.09	-0.18**	-0.12*	-0.08	-0.16**	0.67**	0.28**	-0.35	0.05	25.66**	0.02**
IC-90099	0.51	0.03	0.14**	-0.05	-0.04	0.11*	-0.33*	0	0.7	-0.03	-3.92**	0.04**
SE(gi) ±	0.34	0.05	0.04	0.05	0.06	0.04	0.13	0.05	0.38	0.03	0.45	0.01
SE(gi-gj) ±	0.48	0.07	0.06	0.07	0.08	0.06	0.18	0.07	0.54	0.05	0.63	0.01

*,**, significant at 5 and 1 per cent probability levels, respectively; 1. Days to 50% flowering 2. No. of flowers per clusters, 3. No. of long styled flowers/ clusters 4. No. of medium styled flowers/ clusters 5. No. of short styled flowers/ clusters 6. No. of fruits per clusters, 7. Length of fruit, 8. Diameter of fruit; 9. Plants height, 10. No. of primary branches/ plant, 11. fruit weight, 12. Total yield per plant.

reported by several workers (Das and Barua, 2001; Indiresh and Kulkarni, 2002; Patel, 2003; Shafeeq, 2005; Suneetha and Kathiria, 2006; Chowdhury *et al.*, 2010; Nalini *et al.*, 2011). The general combining ability (gca) effects of the parents were presented in Table 3. It was found that out of fifteen parental lines C.O., BB 13, Sel-4, K.B., Sel.-5, KS-352, Pb-30, DBL-24, FB-18 and Pb. Sadabahar were good general combiner for as many as seven to nine characters on the strength of the magnitude of gca effects for various traits. This indicated the preponderance of additive gene effects in these ten parents. The results were in agreement with the works of Dixit and Gautam (1987); Singh *et al.* (1996) and Makani *et al.* (2013) in brinjal. The basic idea of hybridization is to combine favourable genes present in different parents into a single genotype. The utilization of hybrids thus obtained are utilized in two different ways *viz.*, (i) forwarding to further generations and selecting superior segregants and releasing best recombinants after attaining homozygosity and (ii) utilizing the F_1 hybrids commercially with a view to exploit heterosis. To get outstanding recombinants in segregating generations, the parents of the hybrids must be good general combiners for the characters to which improvement is sought. In case of hybrids with significant *sca* effects, selection in early segregating generation is likely to fail as the *sca* effects mask the true performance of the selected plants. Therefore, it will be useful to select only those hybrids showing parents with significant *gca* effects and non significant *sca* effects for recombination breeding, since it is likely to throw segregants with favourable genes derived from both the parents (Kumar *et al.*, 2012). Parent with high gca were found to produce high yielding cross combinations (Hassan *et al.*, 2000 and Lukonge *et al.*, 2007).

As regard to specific combining ability (sca) effects the cross Pb. Sadabahar x KS-331 significantly scored for maximum no. of characters *viz.* no. of long styled flower per cluster, length of fruit, plants height and fruit weight (Table 4). Other cross combination viz., Sel-4 x Pant Samrat, C.O. x KS-331, Sel- 5 x KS-331, FB-18 x KS-331 and Pb. 30 x Pant Samrat were also significant for yield and most of the yield related traits. Evaluation of the hybrids on the basis of sca effects is the second most important criteria because sca effect of hybrid has been attributed to the combination of positive favourable genes from different parents or might be due to the presence of linkage in repulsion phase (Sarsar, 1986). Hence, selection of hybrids based on *sca* effects would excel in their heterotic effect. The cross DBL-24 x PPC exhibited highest sca effect regarding total yield per plant. These crosses exhibited significant sca effects indicating the presence of dominance and epistatic (non-additive) type of gene action. Similar results were also reported by Dixit *et al.* (1982), Kale *et al.* (1992), Kumar *et al.* (2012) and Makani *et al.* (2013). Cross KB-x KS-331, DBL 24 x KS-331 and KS-314 x IC-90099 recorded the negative and significant sca effects for earliness. According to Rawlings and Thompson (1962) sca effect is due to genes with

Table 4: Top three hybrids selected separately on the basis of heterosis over better parent and sca effects

S.No.	Characters	Cross	Heterosis	Cross	sca effects
1	Days to 50 % flowering	FB-18 x Pant Samrat	-12.50**	K.B. x KS-331	-4.88**
		Sel-4 x PPC	-6.29*	DBL-24 x KS-331	-4.68**
		DBL-24 x Pant Samrat	-4.17	KS-314 x IC-90099	-4.51**
2	No. of Flowers per clusters	DBL-24 x KS-331	23.08*	K.B. x PPC	0.85**
		KS-352 x IC-90099	19.51*	C.O.x Pant Samrat	0.63**
		K.B. x PPC	17.39*	BB-13 x Pant Samrat	0.54**
3	No. of Long styled flowers per clusters	R.A. x PPC	76.92**	Sel-4 x Pant Samrat	0.99**
		Pb Sadabahar x KS-331	71.43**	R.A. x PPC	0.61**
		BB-13 x PPC	58.77*	Pb Sadabahar x KS-331	0.41**
4	No. of Medium styled flowers per clusters	Sel-4 x Pant Samrat	50.00**	Sel-4x Pant Samrat	0.98**
		KS-314 x KS-331	25.00	K.B. x PPC	0.78**
		R.A. x KS-331	16.67	Pb Sadabahar x Pant Samrat	0.60**
5	No. of short styled flowers per clusters	K.B.xPant Samrat	150.00**	Sel-4 x KS-331	1.01**
		DBL24x IC-90099	141.00**	Sel-5 x IC-90099	0.47**
		KS-352x PPC	135.71**	KS-352 x IC-90099	0.39**
6	No. of fruits per clusters	DBL24x IC-90099	45.05*	Sel-4x Pant Samrat	1.12**
		Sel-4x Pant Samrat	40.43**	Sel-4x PPC	0.55**
		KS-314 x IC-90099	25.00	Pb-30 x PPC	0.33**
7	Length of fruit	KS-352 x PPC	24.56**	C.O.x KS-331	2.72**
		KS-352 x Pant Samrat	19.47**	K.B. x IC-90099	2.48**
		KS-352 x IC-90099	16.46**	Pb Sadabahar x KS-331	2.34**
8	Diameter of fruit	FB-18 x IC-90099	31.12**	Sel-5 x KS-331	1.18**
		FB-18 x PPC	22.48*	K.B. x KS-331	1.02**
		KS-314 x IC-90099	8.58	Pb Sadabahar x KS-331	0.94**
9	Plants Height	Sel-5 xPPC	32.35**	Pb. 30 x Pant Samrat	11.43**
		C.O.x PPC	29.46**	KS-314 x IC-90099	10.43**
		FB-18 x PPC	28.22**	R.A. x KS-331	8.78**
10	No. of primary branches per plant	FB-18 x PPC	10.53	Sel-5x Pant Samrat	0.20
		FB-18 x KS-331	10.26	KS-352 x Pant Samrat	0.18
		Sel-5x Pant Samrat	10.00	Pb Sadabahar x IC-90099	0.16
11	Fruit weight	FB-18 x Pant Samrat	48.42**	FB-18 x KS-331	80.73**
		KS-352 x Pant Samrat	43.42**	Pb Sadabahar x KS-331	78.09**
		KS-352x KS-331	23.14**	C.O.x KS-331	65.17**
12	Total yield per plants	KS-314 x IC-90099	94.72**	DBL-24 x PPC	1.36**
		KS-314 x PPC	85.10**	Sel-4x Pant Samrat	0.66**
		DBL-24 x PPC	73.99**	K.B. x PPC	0.57**

dominance and epistatic effect. A comparison of the sca effects of the crosses and the gca effects of the parents were not related to the sca effects of their crosses. Higher gca of parent does not necessarily confer higher sca and the gca and sca were independent (Khan *et al.*, 2007b).

The third important criteria to assess the hybrids for heterosis breeding was through mid parent (Relative heterosis), better parent (Heterobeltiosis) and standard variety (Standard heterosis). Heterosis for growth parameters is an indication of heterosis for yield as growth and yield parameters are strongly associated (Lyngdoh *et al.*, 2003). Among the twelve attributes studied highly significant heterotic effects was observed for days to 50% flowering while significant and positive heterosis over better parent was observed in order of magnitude by number of short styled flowers per cluster (150%) followed by total yield per plant (94.72%), number of long styled flowers per clusters (76.92%), number of medium styled flowers per clusters (50%), fruit weight (48.42%), number of fruits per clusters (45.05%), plant height (32.35%), diameter of fruits (31.12%), length (24.56%), number of flowers per clusters (23.08%) and days to 50 % flowering(-12.50%). Dixit *et al.*, 1982 also reported highly significant heterosis for fruit yield and its contributing traits for brinjal. The maximum heterosis for total yield per plant over better parent was exhibited by the cross KS-314 x IC-90099 (94.72%) followed by KS-314 x PPC (85.10%) and DBL-24 x PPC (73.99%). The heterotic response over better parent in brinjal was also reported by Singh *et al.* (2004), Shafeeq (2005), Singh and Maurya (2005), Suneetha and Kathiria (2006), Bisht *et al.* (2009), Shanmugapriya *et al.* (2009), Chowdhury *et al.* (2010), Sao and Mehta (2010), Kumar (2012), Makani (2013), Reddy and Patel (2014) .

The parents have been ranked on the basis of their gca effects with respect to various characters. Sel-4 was found to be the best general combiner among the lines and IC-90099 was the best general combiner among the testers. Among the lines, BB-13, KS-352, K.B., Sel-5 and DBL-24 and among the tester KS-331 was also good combiners. The sca effects, represents dominance and certain epistatic gene action and can be related to heterosis. The crosses DBL-24 x PPC showed high sca effects for yield although the parents were poor general combiners. Combining ability analysis for yield revealed that, both additive and non-additive effects were important in the expression of the trait with the preponderance of non-additivity as evidenced by combining ability variances and estimates. This was further confirmed by the significant sca effects of the crosses studied. Majority of the crosses which showed sca effects in desirable direction for yield had at least one parent with positive gca effect. This elucidates the importance of interaction between the parents for these crosses. Further, the parents selected for the present investigation comprised of some cultivated varieties which have been subjected to various selection pressures, hence, predominance of specific combining ability effect was also observed (Singh *et al.,* 1979). From the gca and sca effect it can be concluded that characters like days to 50% flowering may be improved through selection while yield and its contributing traits *viz.* number of fruits per plant, fruit length, fruit diameter, fruits per clusters, long and medium styled flowers per clusters may be improved through heterosis breeding. The results of the present study for this trait were supported by the earlier findings of Ingale and Patil (1997), Patil (1998), Chaudhary and Malhotra (2000), Singh and Maurya (2005) and Aswani and Khandelwal (2005). The superior crosses attempted through line x tester mating design utilizing local germplasm of brinjal on the basis of significant heterosis over better parent and sca effects and can be further exploited for commercial, cultivation after multilocation testing.

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