HortFlora Research Spectrum www.hortflorajournal.com
Vol. 5, Issue 2; 134-140 (June 2016) **ISSN: 2250-2823**

EXPRESSION OF HETEROSIS AND COMBINING ABILITY ANALYSIS IN INTERVARIETAL CROSSES OF EGGPLANT (*Solanum melongena* L.)

K. B. Bhushan[1*], Neelima Pant[2], Y. V. Singh[3] and Lila Bora[4]

[1]*Vigyan Prasar, A-50, Institutional area, Sector-62, Noida UP*
[2]*Academic Officer (Agriculture), NIOS, Sector-62, Noida*
[3]*Department of Vegetable Science, G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand*
[4]*Deptt. of Vegetable Science CCSHAU, Hissar*
**Corresponding Author's E-mail: bharatuhf@gmail.com*

ABSTRACT : Thirty six genotypes (twelve lines, two testers and twenty-four F_1s) of eggplant were studied for heterosis and combining ability. The crosses PR × PS and BARI × PS revealed highest economic heterosis for most of the traits investigated including the yield and yield attributing characters. The crosses PR × PS, BARI × PS, PB 69 × PS and Punjab Sadabahar × PU demonstrated highly significant heterosis, over the standard cultivar, Pant Samrat. The parent PB 69 exhibited highest positive significant gca followed by PB 66 and PB 67, whereas crosses PB 69 × PU, PB 60 × PS, PB 68 × PU, PR × PS and KS 331 × PS showed significant sca effects for total yield.

Keywords : *Heterosis, combining ability, eggplant.*

Solanum melongena L. (Eggplant) has become a crop of commercial importance owing to the round the year demand among consumers. The major objective of eggplant breeding is to develop high-yielding varieties according to market demand having attractive fruit shape, size, and colour. However, heterosis for yield traits in eggplant has been documented for a long time (Kakizaki, 6) and yield improvements of up to 204 % above the means of parents have been recorded (Sidhu *et al.,*14). In consequence, F_1 hybrids have been developed and are used in the commercial production, although the degree of utilization of hybrids varies greatly among growing systems. To formulate any breeding methodology, it is must to have knowledge of gene effects involved in the inheritance of various attributes. The idea that high yielding lines may not necessarily be able to transmit their superiority to the crosses necessitates the identification of promising inbred lines for future exploitation through various biometrical and genetical techniques. Combining ability analysis is considered as one of the essential tools in distinguishing the best combiners (Bisht and Singh, 4; Zaman and Hazarika, 23). The identified combiners may be used for exploring heterosis or for accumulating favourable genes in parents.

MATERIALS AND METHODS

Fourteen diverse genotypes including 12 lines *viz.* PB 60, PB 64, PB 66, PB 67, PB 68, PB 69, PB 70, SMB 115, Pant Rituraj (PR), Punjab Sadabahar (Pb. Sad.), KS 331, BARI and two as male (testers), *viz.* Pant Samrat and Pusa Upkar were taken to raise the F_1s. The morphological characteristics of genotypes under study are presented in Table 1. The experimental site at Vegetable Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar (Uttarakhand), India lies in south of the Shivalik range of Himalayas. It falls in humid sub-tropical zone locally known as 'Tarai' situated at latitude of 29° North, longitude of 79.30 East and altitude of 243.84 meters above mean sea level (MSL). The average rainfall in the experimental area is about 1300 mm annually with maximum precipitation during July to August and recedes by the end of September. The soil of experimental plot was neutral, sandy loam and 1.0 to 1.5 meter deep. The characteristic feature of the soil was high water table and calcareous nature. The experiment was laid out in Randomized Block Design (RBD) with three replications. Each replication consisted of 38 entries and each row consisted of ten plants planted at 60 cm spacing. All cultural operations were followed to raise the healthy seedlings. Recommended cultural and agronomic practices and plant protection measures were followed as per recommendation to raise the normal crop. Parents were crossed in taking lines as female and testers as males so as to produce sufficient seeds of 24 F_1 hybrids and parental seeds were maintained through selfing. All 24 F_1s and 14 parents were evaluated for eleven quantitative characters *viz.*

Article's History:
Received : 13-05-2016 ***Accepted : 17-06-2016***

days to 50 % flowering, number of primary branches per plant, plant height, fruit length (cm), fruit diameter (cm), number of marketable fruits per plant, weight of marketable fruits per plant (kg), number of unmarketable fruits per plant, weight of unmarketable fruits per plant (kg), total number of fruits per plant and total yield (q/ha). Appropriated statistical tool was used to analyse data.

Table 1: List of genotypes, their source and features.

S. No.	Parents (Lines/testers)	Origin	Salient features
1.	PB 60	Pantnagar	Semi erect plant with round purple coloured fruit
2.	PB 64	Pantnagar	Semi erect plant , long purple fruit
3.	PB 66	Pantnagar	Erect type plant having long purple fruit
4.	PB 67	Pantnagar	Semi erect, long, green fruited
5.	PB 68	Pantnagar	Erect type plant having long purple fruit
6.	PB 69	Pantnagar	Erect type plant having oblong green fruit
7.	PB 70	Pantnagar	Erect type plant having round green fruit
8.	SMB 115	Cuttack	Erect type plant having small oblong purple fruit, cluster bearing
9.	Pant Rituraj	Pantnagar	Semi erect, round purple
10.	Punjab Sadabahar	Punjab	Erect growth habit, long purple fruits
11.	KS 331	Kalyanpur	Spreading plant type, long fruit having purple colour
12.	BARI	Bangladesh	Erect plant type, extra long fruit having light purple colour
13.	Pusa Upkar	Delhi	Semi erect, round large sized fruits, purplish red fruits.
14.	Pant Samrat	Pantnagar	Erect, long purple fruits, fruits occur in clusters.

RESULTS AND DISCUSSION

Expression of Heterosis

In the present study, the F_1s were observed for relative heterosis, heterobeltiosis, and standard heterosis. The parent Pant Samrat (PS) was used as a check for the study of standard heterosis. The results of all three kinds of heterosis for various characters studied are discussed for the pooled analysis of the two cropping seasons. The yield and related traits were most heterotic characters, whereas, number of primary branches per plant, fruit diameter, number of marketable fruits per plant, weight of marketable fruits per plant, total number of fruits per plant and yield (q/ha) showed high heterosis values (more than 100 %) in desirable direction over mid parent, better parent or standard parent (Table 2). The number of primary branches per plant, number marketable fruits per plant and the total number of fruits per plant showed significant negative heterosis in all the crosses, and this indicates the reduction in performance of the F_1 over the standard parent. The negative heterosis is considered desirable for days to 50% flowering, the number of unmarketable fruits per plant and weight of unmarketable fruits per plant. The reason for significant negative heterosis may be due to the presence of dominant loci in a different direction leading to the cancellation of effects. The crosses showing no heterosis indicated that the parents involved in the cross do not differ in gene frequency about the character under study (Pandey *et. al.,* 11). Best heterotic combinations over standard check for various traits were PB 64 × PU and PB 60 × PS for days to 50% flowering (-23.93 and -21.80 %); BARI × PU and PB 68 × PU for plant height (20.31% and 18.77%); KS 331 × PS and BARI × PS for fruit length and diameter (73.04% and 28.74%), respectively. Highest economic heterosis was observed most of the traits including yield and yield contributing traits. The crosses PR × PS and BARI x PS could be therefore can be advanced for desirable segregants for yield and yield related characters.

In general, the hybrids the with highest yield also expressed heterosis for this trait. The work of several researchers also give credence to the present findings that heterosis in yield was due to number of fruits per plant (Kanthaswamy *et al.,* 7; Prabhu *et al.,* 12; Singh *et al.,* 17). Fruit yield per plant being a complex trait, is a multiplication product of several basic component traits of yield. The increased fruit yield will positively be because of increase in one or more component traits. Heterosis for yield and yield related characters has been reported by various researchers (Pandey et al.,11, Shafeeq *et al.,* 13, Singh *et al.,* 17, Suneetha *et al.,*20; Thangamani and Pugalendhi, 21).

By standard heterosis, it can be concluded that the heterosis breeding would be advantageous for the improvement of eggplant for yield and its component quantitative traits. The crosses PR × PS, BARI × PS, PB 69 × PS, Punjab Sadabahar × PU, PB 66 × PS, PB 64 × PS and PB 69 × PU could be exploited as

Table 2: Heterosis values for different quantitative traits in Eggplant

Sl. No.	Character	Best two heterotic combinations for different characters (% heterosis in parenthesis)		
		Relative heterosis	Heterobeltiosis	Standard heterosis
1.	Days to 50 flowering	PB 64 × PU (-23.53) Punjab Sadabahar x PU (-21.67)	PB 64 × PU (-21.43) PB 60 × PS(-21.39)	PB 64 × PU(-23.93) PR x PU (-23.40)
2.	Number of primary branches per plant	PB 68 × PS (18.85) PB 64 × PS (55.29)	All negative	BARI × PS (27.77) PB 60 × PU (26.54)
3.	Plant height (cm)	PB 68 × PU (29.57) KS 331 × PU (16.51)	PB 68 × PU (22.67) KS 331 × PS (8.86)	BARI × PU (20.31) PB 68×PU (18.77)
4.	Fruit length(cm)	KS 331 × PS (76.80) PB 68 × PU (35.97)	PB 68 × PS (23.66) PB 60 × PU (19.79)	KS 331 × PS (73.04) PB 68 × PU (22.90)
5.	Fruit diameter (cm)	PB 68 × PS (37.19) PB 69 × PS (21.83)	KS 331 × PS (72.89)	BARI × PS (28.74) PB 68 × PS (23.67)
6.	Number of marketable fruits per plant	PB 66 × PS (29.27) PR × PU (27.27)	All negative	All negative
7.	Weight of marketable fruits per plant (kg)	BARI × PS (145.98) Punjab Sadabahar × PU (110.91)	BARI×PS (118.37) Punjab Sadabahar × PU (97.73)	BARI×PS (183.07) Punjab Sadabahar x PU (130.16)
8.	Number of unmarketable fruits per plant	Punjab Sadabahar × PU(-38.89) SMB 115 × PU(-36.58)	PB 70 × PU(-36.84) SMB 115 × PU(-36.58)	Punjab Sadabahar×PU (-48.86) PB 70 x PU (-44.21)

commercial hybrids as they demonstrated significant heterosis, over the standard cultivar, Pant Samrat. The cross BARI × PS showed highest economic heterosis for most of the traits studied including the yield and yield attributing characters and can be utilized for commercial exploitation of heterosis for getting maximum yield.

The above findings indicated that some inbreds had strong heterotic capacity compared to other ones during hybridization process. As the performance of hybrids depended on upon the heterotic capability of the parents involved from the economic point of view, it will be useful to select and utilize the parental inbreds with strong heterotic capability for critical traits associated with the yield to achieve higher gains in F_1 hybrids through the exploitation of heterosis.

Combining ability analysis

The choice of parents is of great importance for success in any heterosis breeding programme. The use of the concept of the combining ability helps in choosing the proper parents for hybridization. Good combiners produce superior hybrids. The gca and sca variance contribute to understanding the nature of gene action involved in the expression of a trait, which is essential to plan appropriate breeding programme. The results of analysis of variance revealed that the treatments inclusive of lines, testers and F_1's were significantly different for all the characters. It reflected that there were inherent genetic differences among the genotypes for the characters studied. Partitioning of treatment sum of squares into parents and crosses revealed that the variance due to parents and crosses were significant for all the characters in pooled analysis. Thus, several parents and their crosses were also significantly different from each other. Further partitioning of mean sum of squares due to crosses into lines, testers and lines × testers reflected that the contribution of lines was significant for the expression of the weight of marketable fruits per plant. Greater variances due to males than female were recorded in characters like the weight of marketable fruits per plant, number of unmarketable fruits per plant, total yield per plant and total yield (q/ha). The result showed that there is the presence of wide variability amongst the male parents for yield related traits. Variances due to females were greater than males for rest of the traits indicating greater variability among female parents. The knowledge about general combining ability (gca) effects of the parents is of best value as it helps in successful prediction of genetic potential of lines (Tiwari *et al.,* 22). The perusal of gca effects of the parents as presented in Table 3 and Table 4 represent the ranking of desirable parents based on per se performance, gca and sca effects for 12 economic traits (Table 4) showed that it was difficult to pick-up a single good combiner for all the characters. Pant

Rituraj, SMB 115, BARI, KS 331, PB 70 and Pusa Upkar appeared as best general combiners for earliness (days to 50% flowering). The best specific crosses were KS 331 × PS, PB 64 × PU, PR × PU, PB 60 × PS, Punjab Sadabahar × PU, PB 66 × PS, BARI × PS, PB67 × PU, PB70 × PU. The early maturity was found to be controlled by both additive and non-additive gene effects. KS 331 and PB 64 were considered best combiner for number of primary branches per plant. However, PB 68 × PU and PB 70 × PS were the specific crosses found promising for numbers of primary branches per plant. The top ranking general combiners for plants height were PB 69, PB 64, PB 68, KS 331 and Pusa Upkar. The crosses PB 67 × PU, PB 60 × PS, PB 66 × PS, Punjab Sadabahar x PU, SMB 115 x PS and PB 70 × PU showed promise for this trait. PB 64, Punjab Sadabahar, KS 331 and BARI were observed as the best combiners found for fruit length based on high gca effects. Among the crosses, PB64 × PU, PB67 × PU, PB69 × PS, PB66 × PS, PR × PS, Punjab Sadabahar × PS and SMB115 × PS were found best for fruit length. Various researchers also reported the similar results (Babu and Thirumunyam 2; Biradar *et al.,* 3; Panda *et al.,* 10; Singh *et al.,* 15, Singh *et al.,* 16). Among the parents SMB 115, BARI and PB 66 were the best combiners for fruits diameter. Whereas round-fruited parents showed significant gca effect but in negative direction. The crosses found best for this character were PB 60 ×PS, Punjab Sadabahar × PU, BARI × PS, PB 64 × PS, PB 69 × PU, PB 70 × PU and KS 331 × PU. The parents PB 67, SMB 115 and PB 66 were the best general combiners for number of marketable fruits and PB 66, PB 68, PB 69 and Pusa Upkar for the weight of marketable fruits per plant. Crosses showing significant sca effects for the number of marketable fruits per plant were SMB 115 × PS, PB 67 × PS, BARI × PU and cross PB 69 × PU revealed significant sca for the weight of marketable fruits per plant. Good combiners found for the total number of fruits per plant were PB 70, PB 66, PB 67, SMB 115 and Pant Samrat. BARI × PS, BARI × PU, PB 60 × PS, PB 64 × PU were the best crosses found as estimated by high sca effects. The findings of various researches are in agreement of present findings (Biradar *et al.,* 3; Panda *et al.,* 10; Singh *et al.,* 16; Singh and Maurya 18). The parent PB 69 exhibited highest positive significant gca followed by PB 66, PB 67, PR, PB 70, PB 68 and Pusa Upkar for total yield per plant and yield

Table 3: Performance of genotypes based on general combining ability effects

S. No.	Treatment	Days to 50% flowering	No. of primary branches	Plant height	Fruit length	Fruit diameter	No. of marketable fruits /plant	Wt. of marketable fruits /plant	No. of unmarketable fruit / plant	Wt. of unmarketable fruits / plant	Total no. of fruits/ plant	Total yield per plant	Total yield (q/ha)
1.	PB60	P	P	P	A	P	A	A	G	G	A	A	A
2.	PB68	P	A	G	P	A	P	G	G	P	P	G	G
3.	PB64	A	G	G	G	A	P	P	P	P	A	P	P
4.	PB67	P	P	A	A	P	G	P	P	P	G	P	P
5.	PB69	A	P	G	A	P	P	G	G	A	A	G	G
6.	BARI	G	A	P	G	G	A	A	P	P	A	A	A
7.	SMB115	G	P	A	P	G	G	A	P	P	G	A	A
8.	KS331	G	G	G	G	P	P	P	P	P	P	A	A
9.	Pb. Sad.	A	P	P	G	P	P	A	P	G	P	A	A
10.	PB70	G	P	A	P	P	P	P	A	A	G	G	G
11.	PR	G	A	P	A	P	P	G	P	A	P	G	G
12.	PB66	A	P	A	A	G	G	G	A	A	G	G	G
13.	PS	A	P	A	P	P	P	A	A	P	G	A	A
14.	PU	G	P	G	P	P	P	G	G	P	A	G	G

G = Good general combiner (Significance in desirable direction)
A = Average general combiner (Significance in undesirable direction)
P = Poor general combiner (non significance + ve / - ve)

Table 4: Analysis of variance (mean squares) for combining ability.

Source of Variation	df	Days to 50% flowering	No. of primary branches/ plant	Plant height	Fruit length	Fruit diameter	No. of marketable fruits / plant	Weight of marketable fruits / plant	No. of un marketable fruits / plant	Weight of un marketable fruits / plant	Total no. of fruits / plant	Total yield per plant	Total yield (q/ha)
2007-2008													
Replications	2	4.22	0.13	190.07	4.35	0.79	0.85	0.02	1.60	0.02	2.01	0.08	4073.00
Treatments	37	56.88**	2.51**	792.54**	107.32**	8.23**	12.69**	0.27**	11.39**	0.22**	30.43**	0.56**	27800.67**
Parents	13	56.85**	1.19	755.25**	108.23**	14.32**	11.57**	0.50**	16.33**	0.16**	36.91**	0.76**	37504.55**
Parent Vs. Crosses	1	52.79**	1.57	4296.31**	208.54**	2.44**	0.39**	0.26**	13.23**	0.03**	18.16**	0.11**	5690.50**
Crosses	23	57.08**	3.31**	661.27**	102.41**	5.05**	13.85**	0.15**	8.51**	0.26**	27.30**	0.47**	23277.19**
Lines	11	67.03	4.28	923.35	67.35	3.77	15.68	0.19*	8.43	0.19	36.28	0.67	33040.54
Testers	1	0.35	0.77	191.26	0.56	2.61	0.35	0.81**	3.56	0.00	6.13	0.80	39612.17
L x T	11	52.29**	2.57**	441.93**	146.72**	6.54**	13.26**	0.04	9.04**	0.35**	20.25**	0.24**	12028.84**
Error		1.50	0.74	89.23	1.82	0.55	1.73	0.03	0.78	0.02	2.65	0.06	2797.45
2008-2009													
Replications	2	1.72	0.03	45.46	3.80	0.12	3.53	0.04	6.90	0.02	18.67	0.11	5298.50
Treatments	37	60.40**	2.45**	770.83**	116.33**	4.14**	4.42**	0.25**	5.81**	0.15**	10.19**	0.48**	23953.48**
Parents	13	61.59**	1.93*	814.81**	120.92**	4.76**	3.65**	0.35**	4.83**	0.07**	11.98**	0.42**	20726.86**
Parent Vs. Crosses	1	66.50**	2.48**	2447.25**	318.65**	11.40**	9.52**	0.75**	19.58**	0.41**	1.79**	0.05**	2423.00**
Crosses	23	64.30**	2.74**	673.09**	104.95**	3.47**	4.64**	0.18**	5.77**	0.18**	9.54**	0.54**	26713.33**
Lines	11	88.05	3.23	483.83	56.75	1.67	5.54	0.27*	5.71	0.15	11.07	0.66	32602.24
Testers	1	144.50	0.32	1020.00	11.16	0.44	0.50	0.15	10.13	0.07	15.12	0.42	20596.11
L x T	11	33.26**	2.47**	830.80**	161.67**	5.55**	4.11**	0.09**	5.43*	0.22**	7.49*	0.43**	21380.54**
Error		2.51	0.78	58.65	1.51	0.36	1.32	0.02	1.73	0.02	3.13	0.04	2231.96
Pooled													
Replications	2	2.81	0.02	14.52	3.65	0.07	1.43	0.02	3.79	0.02	7.92	0.09	4348.97
Treatments	37	53.03**	1.54**	653.27**	102.41**	5.18**	3.98**	0.21**	6.26**	0.12**	12.67**	0.40**	20028.86**
Parents	13	56.57**	1.08**	543.35**	94.43**	7.92**	4.62**	0.37**	8.19**	0.08**	18.57**	0.52**	25591.71**
Parent Vs. Crosses	1	594.45**	0.03**	3307.56**	260.73**	6.09**	3.44**	0.47**	0.15	0.17**	2.13	0.08	3884.00
Crosses	23	50.75**	1.87*	600.00**	100.04**	3.591**	3.64**	0.10**	5.43**	0.14**	9.79**	0.36**	17586.59**
Lines	11	70.47	2.43	656.88	56.39	1.900	4.17	0.15*	5.11	0.10	11.08	0.44	21530.93
Testers	1	32.67	0.52	523.65	4.19	0.224	0.42	0.42**	6.42	0.02	10.12	0.60	29335.89
L x T	11	32.66**	1.44**	550.06**	152.41**	5.588**	3.41**	0.03	5.66**	0.20**	8.47**	0.25**	12574.14**
Error		1.05	0.39	35.08	0.75	0.27	0.73	0.01	0.73	0.01	1.45	0.03	1293.33

per hectare (q). Results revealed that crosses PB 69 × PU, PB 60 × PS, PB 68 × PU, PR × PS and KS 331 × PS showed significant sca effects for total yield per plant and yield per hectare (q). Similar results were also observed by several scientists (Ashwani and Khandelwal, 1; Suneetha *et al.,* 20). The ultimate aim of a breeder is to improve total yield in eggplant (Chitra meenal and Debaraj, 5; Kumar *et al.,* 8, Luxman *et al.* 9) crosses showing highly significant positive sca effects for this trait were PB 69 × PU, PB 60 × PS, PB 68 × PU, PR × PS and KS 331 × PS. These crosses involved the parents with good × good, average × poor,

poor × poor and average × average, indicating the association of additive, dominance and epistatic effects for total yield. Thus, to improve total yield these crosses can be exploited following recurrent selection. It has been also reported (Biradar *et al.,* 3; Singh and Maurya 18) in various crosses showing high sca values for total yield (q/ha). It is quite evident that the cross combinations exhibiting high sca effects for fruit yield have invariably expressed desirable sca effects for one or more yield related characters also, and it would be important to give weightage to these yield-related traits.

The magnitudes of specific combining ability variance were higher than the gca variance for all the character except for weight of marketable fruits per plant (during cropping season 2007-2008 only). The weight of marketable fruits per plant seems under the control of additive gene action, hence, can be improved through pedigree method of selection. The improvement in all other characters could be brought about through selection in the progenies of biparental matings and crossing between the selected progenies. The wider difference in the magnitude of gca and sca variance were noticed for all the character except the weight of marketable fruits per plant. This indicated that the nature of gene action controlling all characters was predominantly non-additive in nature except for the weight of marketable fruits per plant during both cropping season and pooled data over the years.

CONCLUSION

The contribution of lines to the total variance was greater than testers for all the characters studied and towards the lines × testers. The testers contributed more than the lines × testers toward the variance only for the weight of unmarketable fruits per plant. So, line × tester interaction contributed more than the testers towards all characters except for the weight of unmarketable fruits per plant. The line × tester contributed more than lines towards the variance of for characters like fruit length, fruit diameter, the number of unmarketable fruits per plant and weight of unmarketable fruits per plant. Therefore, the lines contributed maximum towards genetic variability. The data also revealed that the lines, tester and lines × tester interactions showed differential contribution for various characters under study.

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Citation : Bhushan K.B., Pant N., Singh Y.V., and Bora L. Meena M.K., Jain M.C., Singh J., Sharma M., Singh B., Maurya I.B. (2016). Expression of heterosis and combining ability analysis in intervarietal crosses of eggplant. *HortFlora Res. Spectrum,* **5**(2) : 134-140.