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Studies on Combining Ability and Heterosis for the Production of Hybrids in Bitter Gourd (*Momordica charantia* L.) under Terai Region

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Abstract Bitter gourd is one of the important cucurbitaceous vegetable crops having immense medicinal value. The objective of study of combining ability is to identify a suitable general combiner and specific combiner particular to a cross. Six genetically diverse parental lines of bitter gourd were taken to develop 15 F_1s following a half diallele mating system excluding raciprocals. Estimates of gca effects of parents for different traits showed that PBIG-4 proved to be best general combiner for 6 out of 12 traits. Based on the sca effects, the cross combinations such as PBIG-2 × PBIG-1 (Good × Poor), PBIG-2 × P. W. (Good× Poor), PBIG-1 × K. S. ((Poor × Poor) were found superior for fruit yield per plant. PBIG-2 × PBIG-1, PBIG-2 × P. W., PBIG-2 × K. B., PBIG-1 × K. S. need to be exploited on commercial scale for development of hybrids.

Keywords Combining ability, Heterosis, Bitter gourd, Production, Terai region.

Introduction

Bitter gourd (*Momordica charantia* L. 2n = 22) is a good source of minerals, protein and vitamins, besides possessing anti-diabetic properties. It still remains an underutilized and underexploited crop from genetics and breeding point of view (Tewari et al. 2001). The regions of eastern India and South China are considered to be possible center of domestication (Stands 1928). In bitter gourd, Indian variability is quite distinct from that of Africa and SE Asian region.

In India, bitter gourd is cultivated in an area of 93,000 ha with total production of 1045.69'000MT with productivity of 11.24 T/ha (Anonymous 2016). In India, it is mostly cultivated in Chhatisgarh (12.17%), Telengana (11.37%), Andhra Pradesh (10.45%), Odisha (10.31%). Considering the importance of this crop, it is essential and desirable to carry out improvement program utilizing the resources available. In this context, the present investigation deals with determination of combining ability and heterosis for yield and yield attributes in 6 parents and 15 crosses.

Materials and Methods

Six genetically diverse parental lines of bitter gourd were taken to develop 15 F_1s following a half diallele mating system excluding raciprocals. The parental lines used were PBIG-4, PBIG-1, PBIG-2, Priya White, Kalyanpur Sona, Kalyanpur Baramasi. The 15 F_1s along with their six parents were evaluated at Vegetable Research Center of G. B. Pant University of Agriculture and Technology, Pantnagar (U.S. Nagar),

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Table 1. Analysis of variance for combining ability for various horticultural traits.

Sources of variation	Degrees of freedom	Nodal position of 1st male flower	Nodal position of 1st female flower	Days to 1st male flower anthesis	Days to 1st female flower anthesis	Vine length	No. of primary branches
GCA	5	4.18	6.54**	33.93**	22.39**	0.38**	12.09**
SCA	15	1.37	3.33**	8.84**	13.08**	0.07**	9.56**
Error	40	2.81	0.50	1.77	1.46	0.009	0.64

Table 1. Continued.

Sources of variation	Avg Fruit Dia	Avg Fruit length	No. of fruit/plant	Avg Fruit weight	Density	Yield/plant (g)
GCA	0.21**	24.12**	16.46**	72.96**	0.002**	174131**
SCA	0.24**	8.33**	74.58**	92.75**	0.002**	377077**
Error	0.02	2.96	3.23	2.77	0.00	14794.09

Uttarakhand. The experiment was laid out in a randomized block design (RBD) using three replications. Each treatment comprised of five plants, spaced at 2m row to row and 75 cm plant to plant distance. There were five hills per entry with one plant at each hill. Observations on twelve horticultural traits were recorded on five randomly selected plants. The traits studied were node number of 1st male flower, node number of 1st female flower, days to 1st male flower, days to 1st female flower, vine length, number of primary branches per plant, fruit diameter, fruit length, number of fruits per plant, average fruit weight, den-

Table 2. Estimates of general combining ability (gca) effects for various horticultural traits.

Parents	Nodal position of 1st male flower	Nodal position of 1st female flower	Days to 1st male flower anthesis	Days to 1st female flower anthesis	Vine length	No. of primary branches
PBIG-2	0.072	0.39	−1.30**	−1.58**	− 0.14**	1.44**
PBIG-4	−0.81	−0.76**	1.50**	0.81*	0.05	−1.17
PBIG-1	−0.11	−1.04**	−2.01**	−0.55	0.13**	−1.56**
K.S.	− 0.65	−0.54*	2.24**	−2.12**	−0.35**	1.08**
K.B.	0.18	0.96**	1.78**	1.83**	0.21**	−0.38
P.W.	0.32	1.01**	0.43**	1.62**	0.13**	0.63*

Table 2. Continued.

Parents	Avg Fruit Dia	Avg Fruit length	No. of fruit/ plant	Avg Fruit weight	Density	Yield/ plant (g)
PBIG-2	0.09	−1.45*	1.04**	0.34	− 0.01**	124.45**
PBIG-4	0.15**	−0.44	2.02**	4.84**	0.01	214.21**
PBIG-1	−0.06	0.67	−0.26	0.27	0.00**	−3.43
K.S.	− 0.26**	−1.75**	−1.44**	−3.92**	−0.00**	−184.67**
K.B.	− 0.13*	3.03**	−0.32	−2.40**	0.02**	−106.91**
P.W.	0.08	−0.05**	−1.39*	0.87	0.00**	−43.65

Table 3. Estimates of specific combining ability (sca) effects for various horticultural traits.

Sl. No.	Crosses	Nodal position of 1st male flower	Nodal position of 1st female flower	Days to 1st male flower anthesis	Days to 1st female flower anthesis	Vine length	No. of primary branches
1	PBIG-2×PBIG-4	0.93	3.64*	2.28	2.38*	– 0.0004	– 1.91*
2	PBIG-2×PBIG-1	– 0.85	– 0.08	– 1.43	– 0.18	– 0.1016	– 4.20**
3	PBIG-2×K.S.	– 0.79	– 1.07*	– 3.04**	– 9.32**	– 0.4662**	1.28
4	PBIG-2×K.B.	0.86	1.05*	4.45**	5.08**	0.5110**	– 2.13**
5	PBIG-2×P.W.	– 0.75	– 0.30	– 0.84	– 2.20*	– 0.1452	– 2.61**
6	PBIG-4×PBIG-1	0.51	– 2.27**	– 3.35**	– 0.04	– 0.0404	0.18
7	PBIG-4×K.S.	1.78	2.84**	3.26**	1.00	0.2516**	– 2.75**
8	PBIG-4×K.B.	– 1.09	– 0.71	– 1.91	– 1.95	– 0.1916*	1.33
9	PBIG-4×P.W.	0.33	– 0.334	– 5.08**	– 4.80**	0.1258	– 1.98**
10	PBIG-1×K.S.	– 0.68	0.50	0.28	1.18	0.1937*	1.62*
11	PBIG-1×K.B.	– 0.59	– 1.08*	0.48	– 2.76*	0.1637	– 2.28**
12	PBIG-1×P.W.	– 1.04	– 0.36	0.70	3.08**	– 0.1120	– 1.46*
13	K. S.×K. B.	– 0.99	– 1.95**	0.72	2.01	0.3491	0.44
14	K. S.×P. W.	0.50	– 0.08	1.25	– 2.95**	0.2333*	– 2.32**
15	K. B.×P. W.	– 1.35	– 1.30**	– 2.81*	– 4.22**	– 0.0500	5.87**

Table 3. Continued..

Sl. No.	Crosses	Avg fruit dia	Avg fruit length	No. of fruit/ plant	Avg fruit weight	Density	Yield/ plant (g)
1	PBIG-2×PBIG-4	0.48**	3.33**	– 6.46**	9.56**	– 0.07**	– 241.35
2	PBIG-2×PBIG-1	0.27	– 0.22	9.61**	14.99**	0.02**	1029.04
3	PBIG-2×K.S.	0.29	– 1.11	4.80**	– 5.46**	– 0.04**	66.82
4	PBIG-2×K.B.	0.29*	– 2.29	5.38**	– 4.74**	0.001**	142.74
5	PBIG-2×P.W.	0.04	1.85	10.87**	11.85**	0.001**	995.26
6	PBIG-4×PBIG-1	0.21	0.12	– 12.12**	2.14	0.03**	– 749.38
7	PBIG-4×K.S.	– 0.20	2.98	5.27**	– 7.55**	– 0.04**	104.62
8	PBIG-4×K.B.	0.88**	– 2.65	– 1.95	1.27	0.09**	– 58.80
9	PBIG-4×P.W.	– 0.44**	– 1.15	7.53**	– 13.25**	– 0.08**	60.73
10	PBIG-1×K.S.	– 0.22	1.92	7.79**	2.96	– 0.06**	501.49
11	PBIG-1×K.B.	0.82**	3.70**	– 8.16**	2.94	– 0.01**	– 505.19
12	PBIG-1×P.W.	– 0.23	0.14	– 9.89**	– 9.85**	0.009**	– 765.01
13	K. S.×K. B.	– 0.01	0.33	– 1.95	13.44**	0.007**	197.22
14	K. S.×P. W.	0.11	2.22	– 8.80**	– 7.20**	0.03**	– 606.63
15	K. B.×P. W.	0.31*	– 5.64**	– 4.47**	1.80	0.04**	– 231.10

sity, fruit yield per vine. The mean data obtained for quantitative traits on per plant basis were analyzed statistically for combining ability and heterosis as suggested by Griffing (1956).

Results and Discussion

The general combining ability (gca) and specific combining ability (sca) mean squares calculated from the six parental cultivars and the 15 F_1 hybrids are presented in Table 1. The analysis showed that the mean squares due to general and specific combining ability effects were highly significant for all the traits studied except nodal position of 1st male flower, indicating that both additive and non additive genetic variances were involved in determining the traits. Similar results have been reported by Rao et al. (2017). It is interesting to note that the sca mean squares were more than

Table 4. Estimates of heterobeltiosis and standard heterosis for various horticultural traits. *(p=0.01), **(p=0.05).

Sl. No.	Crosses	Nodal position of 1st male flower Hetero-beltio-sis	Nodal position of 1st male flower Standard hetero-sis	Nodal position of 1st female flower Hetero-beltio-sis	Nodal position of 1st female flower Standard hetero-sis	Days to 1st male flower anthesis Hetero-beltio-sis	Days to 1st male flower anthesis Standard hetero-sis
1	PBIG-2×PBIG-4	74.69	34.55	114.03**	– 5.13	16.41	– 3.57**
2	PBIG-2×PBIG-1	– 18.84	– 44.59*	1.40	– 136.96**	– 3.98	– 20.47
3	PBIG-2×K.S.	– 2.85	– 48.96*	00.18	– 40.87**	– 6.24	– 24.75
4	PBIG-2×K.B.	22.68	– 16.81	41.69**	– 11.91	24.66	3.25**
5	PBIG-2×P.W.	– 11.00	– 39.66	24.78	– 22.42**	8.32	– 10.22
6	PBIG-4×PBIG-1	60.08	– 401.03	017.86	– 63.59**	– 4.92	– 18.88
7	PBIG-4×K.S.	77.63	– 33.45	82.79**	– 18.98*	20.34	– 3.42**
8	PBIG-4×K.B.	52.24	– 42.96	46.17**	– 35.21**	– 5.08	– 5.08
9	PBIG-4×P.W.	66.20	– 37.73	52.86**	– 32.24**	– 16.50	– 13.57**
10	PBIG-1×K.S.	– 4.25	– 49.69*	1.60	– 39.82**	1.38	– 18.62
11	PBIG-1×K.B.	– 7.78	– 31.89	08.78	– 40.37**	8.19	– 7.69
12	PBIG-1×P.W.	– 24.18	– 44.00*	0.48	– 34.31**	7.53	– 8.25
13	K. S.×K. B.	12.98	– 40.64	04.38	– 43.36**	15.08	– 7.63**
14	K. S.×P. W.	24.18	– 34.77	21.36	– 28.11**	7.97	– 13.34
15	K. B.×P. W.	– 27.77	– 34.92	– 21.53*	– 25.73**	6.37	– 6.53

Table 4. Continued.

Sl. No.	Crosses	Days to1st female flower anthesis Hetero-beltio-sis	Days to1st female flower anthesis Standard hetero-sis	Vine length Hetero-beltio-sis	Vine length Standard hetero-sis	No. of primary branches/plant Hetero-beltio-sis	No. of primary branches/plant Standard hetero-sis
1	PBIG-2×PBIG-4	9.83*	– 5.99	– 3.46	– 3.47	– 32.01	3.89
2	PBIG-2×PBIG-1	0.54	– 13.94**	– 9.07*	– 4.18	– 41.07**	– 9.95
3	PBIG-2×K.S.	– 17.64**	– 29.51**	– 26.19**	– 30.62**	– 13.59**	32.05**
4	PBIG-2×K.B.	18.58**	1.49	16.98**	16.97**	– 30.02**	6.92
5	PBIG-2×P.W.	0.90	– 13.63**	– 11.09**	– 5.40	– 28.89**	8.65
6	PBIG-4×PBIG-1	5.35	– 8.82*	– 1.92	3.34	– 12.59*	– 0.86
7	PBIG-4×K.S.	4.04	– 9.87**	– 3.05	– 3.66	– 23.72**	– 2.59
8	PBIG-4×K.B.	– 5.48	– 7.78**	1.22	1.22	– 1.90	11.25
9	PBIG-4×P.W.	– 11.81**	– 14.04**	2.00	8.53*	– 20.96**	– 0.43
10	PBIG-1×K.S.	2.86	– 10.98**	7.43	– 2.40	– 7.45	18.18**
11	PBIG-1×K.B.	1.38	– 12.26**	8.59**	14.43**	– 19.30**	– 9.52
12	PBIG-1×P.W.	14.53**	– 0.88	– 2.58	3.65	– 20.61**	0.00
13	K. S.×K. B.	8.77*	– 5.78	4.77	4.77	– 7.45**	18.18**
14	K. S.×P. W.	– 3.29	– 16.23**	– 7.07	– 1.12	– 13.40**	9.09
15	K. B.×P. W.	– 10.82**	– 10.82**	1.52	8.02	– 14.52**	44.27**

Table 4. Continued.

Sl. No.	Crosses	Average fruit diameter Hetero-beltio-sis	Average fruit diameter Standard hetero-sis	Average fruit length Hetero-beltio-sis	Average fruit length Standard hetero-sis	No. of fruits/plant Hetero-beltio-sis	No. of fruits/plant Standard hetero-sis
1	PBIG-2×PBIG-4	26.95**	78.95**	23.19	– 29.11**	– 34.92**	0.26
2	PBIG-2×PBIG-1	19.53**	65.96**	3.00	– 38.10**	16.70	6.04**
3	PBIG-2×K.S.	10.07**	52.82**	– 4.43	– 50.31**	– 66.02**	38.62**
4	PBIG-2×K.B.	– 3.86	33.47**	– 37.01**	– 37.02**	46.98**	47.01**
5	PBIG-2×P.W.	– 1.15	57.48**	– 4.30	– 33.13**	49.13**	68.72**

Table 4. Continued.

Sl. No.	Crosses	Average fruit diameter Hetero-beltio-sis	Standard hetero-sis	Average fruit length Hetero-beltio-sis	Standard hetero-sis	No. of fruits plant Hetero-beltio-sis	Standard hetero-sis
6	PBIG-4×PBIG-1	17.93**	66.24**	11.27	−33.13**	−58.34**	−35.81**
7	PBIG-4×K.S.	−4.50	34.60**	18.54	−31.76**	−6.55	44.02**
8	PBIG-4×K.B.	31.86**	85.87**	−34.62**	−34.63**	−26.06**	13.94**
9	PBIG-4×P.W.	−1.10	39.40**	14.83	−40.48**	0.80	55.36**
10	PBIG-1×K.S.	3.96	30.08**	18.65	−31.33**	0.76	45.10**
11	PBIG-1×K.B.	32.63**	79.66**	−7.12	−7.14**	−49.94**	−27.92**
12	PBIG-1×P.W.	−9.38**	44.35**	−20.16	−31.64**	−59.49**	−41.66**
13	K. S.×K. B.	3.35	30.36**	28.46**	−28.47**	−3.16	−3.15
14	K. S.×P. W.	−8.77**	45.33**	−3.98	−32.91**	−48.81**	−42.1**
15	K. B.×P. W.	0.17	59.03**	−44.20**	−44.21**	−25.14**	−15.31**

Table 4. Continued.

Sl. No.	Crosses	Average fruit weight Hetero-beltio-sis	Standard hetero-sis	Density Hetero-beltio-sis	Standard hetero-sis	Yield/plant (g) Hetero-beltio-sis	Standard hetero-sis
1	PBIG-2×PBIG-4	1.56	47.83**	−12.82**	−13.28**	33.89**	7.68
2	PBIG-2×PBIG-1	33.28**	49.55**	−1.46**	−3.37**	55.53**	82.86**
3	PBIG-2×K.S.	−5.82	0.34	−11.27**	−13.56**	55.82**	1.20
4	PBIG-2×K.B.	32.08**	32.08**	−2.38**	−2.38**	41.20*	41.20**
5	PBIG-2×P.W.	4.31	44.49**	−4.26**	−6.32**	55.74**	77.57**
6	PBIG-4×PBIG-1	−8.71*	32.88**	1.99**	−1.22**	−61.77**	−37.72**
7	PBIG-4×K.S.	−27.74**	5.17	−10.46**	−11.13**	−32.28**	10.31
8	PBIG-4×K.B.	−13.56**	25.81**	10.08**	11.21**	−36.03**	4.19
9	PBIG-4×P.W.	−29.00**	28.33**	−7.14**	−7.84**	−10.97	45.02
10	PBIG-1×K.S.	4.30	42.12**	−11.92**	−13.64**	27.43*	50.02**
11	PBIG-1×K.B.	−3.55	8.25	−1.67**	−1.67**	−51.76**	−43.22**
12	PBIG-1×P.W.	−27.06**	1.03	−3.57**	−5.45**	−63.98**	−57.26**
13	K. S.×K. B.	24.43**	32.60**	−2.30**	−2.30	−7.59	−6.00
14	K. S.×P. W.	−29.29**	−2.06	−0.93**	3.06**	−63.94**	−58.89**
15	K. B.×P. W.	−14.12**	18.94**	−6.44**	−6.44	−35.55**	−26.52*

their corresponding gca values for yield per plant and other yield contributing traits such as average fruit weight, number of fruits per plant, average fruit diameter suggesting more importance of sca mean squares than gca for these traits. Similar results have been reported by Tewari et al. (2001) in bitter gourd for yield per plant.

Estimates of gca effects of parents for different traits is given in Table 2. It showed that for the traits such as nodal position of 1st male flower, nodal position of 1st female flower, days to 1st male flower anthesis, days to 1st female flower anthesis, some of the parents showed negative values. The negative gca effects were considered to be desirable, as it indicates earliness. In terms of better general combiner, the parent PBIG-4 proved to be best general combiners for 6 out of 12 traits such as yield per vine, density, number of fruits, average fruit weight, average fruit diameter, nodal position of first female flower. Another parent PBIG-2 exhibited combining ability for five characters. Islam et al. (2012) reported that among parents, Pusa Sneha was found the best general combiner for imparting earliness ; PSG-9 for ratio of male and female flowers and NSG-1-11 for total yield per plant in sponge gourd.

Table 5. Top F_1 hybrids for yield per vine and corresponding standard heterosis for major yield components. *and ** indicates probability at 1% and 5% respectively.

Sl. No.	Name of hybrid	Yield/ vine (g)	Average fruit weight (g)	No. of fruits/ vine	Fruit length (cm)	Average fruit diameter (cm)	No. of primary branches/ vine	Vine length (cm)
1	PBIG-2×PBIG-1	82.86**	49.55**	38.62**	– 38.10**	65.96**	– 9.95	– 4.18
2	PBIG-2×P. W.	77.57**	44.49**	68.72**	– 33.13**	57.48**	8.65	– 5.41
3	PBIG-1×K. S.	50.02**	42.12**	45.10**	– 31.33**	30.08**	18.18**	– 2.40
4	PBIG-4×P. W.	45.02**	28.33**	55.36**	– 40.49**	39.40**	– 0.43	8.53**
5	PBIG-2×K. B.	41.20**	32.08**	47.01**	– 37.02**	33.47**	6.92	16.47**

Parental *per se* performance has been suggested as a useful index for selecting parents for hybridization. However, observations from the present study indicated that parents showing higher *per se* performance were not necessarily good general combiners except one i.e. PBIG-4 which exhibited good combining ability for 6 out of the 12 characters. PBIG-2 exhibited good combining ability for 5 out of 12 characters. Remaining parents having higher *per se* performance i.e. PBIG-1, Priya White did not prove to be good general combiner.

Specific combining ability effects for crosses pertaining to different traits are given in Table 3. The sca represents the predominance of non-additive gene action. None of the crosses expressed significant desirable sca effect simultaneously for all the traits. Different cross combinations were found to be superior for different traits. However based on the sca effects, the cross combinations such as PBIG-2 × PBIG-1 (Good × Poor), PBIG-2 × P. W. (Good × Poor), PBIG-1 × K. S. (Poor×Poor) were found superior for fruit yield per plant and could be exploited for producing F_1 hybrids.

In bitter gourd position of first male and female flower is a good index of earliness (Table 4). Certain crosses such as PBIG-4 × PBIG-1, Kalyanpur Sona × Baramasi showed highly significant negative standard heterosis for nodal position of 1st female flower indicating earliness of crosses. The best hybrids for yield per vine showed earliness for nodal position of first female flower and days required to first female flower anthesis satisfying the basic assumption of production of hybrids. Sureja et al. (2010) reported high estimates of broad sense heritability for all traits except rind thickness, TSS and crude fiber with heritability ranging from 44.22% for rind thickness to 99.12% for calcium in ash gourd. Mahmud et al. (2016) reported that the heterosis was negative for days to first harvest, fruit length and diameter and single fruit weight and positive for number of fruit / plant and fruit yield / plant.

For the trait yield per plant, some of the crosses showed high heterosis as shown in Table 4. The yield ranged from 575.63 g/plant to 2560.65 g/plant in F_1 hybrids and from 663.23 g to 2281.12 g/plant for the parents. The highest yielding cross PBIG-2 × PBIG-1 (2.56 kg / vine) showed 55.54% heterosis over better parent and 82.36% over local check. It is imperative to note that the highest sca effect (PBIG-2 × PBIG-1) also produced the highest heterosis for yield per plant, thus satisfying the assumption that the cross showing high sca effect can be utilized for heterosis breeding. The other crosses noted to be heterotic for yield / plant were PBIG-2× P.W., PBIG-2× K. B., PBIG-1× K.S. Rao et al. (2017) also reported that crosses DBGS-54 × DBGS-2 (43.00%), DBGS-54 × Pusa Vishesh (37.89%) and Pusa Aushadhi × DBGS-54 (34.57%). Pusa Aushadhi × DBGS-54, Pusa Aushadhi × DBGS-57 and Pusa Aushadhi × DBGS-37 were best yielding hybrids. Verma et al. (2010) also reported that the specific crosses, $P_3 \times P_8$ (DAG-1× DAG-5), $P_2 \times P_{10}$ (DAG-4 × DAG-11), $P_5 \times P_{10}$ (DAG-6 × DAG-11), $P_4 \times P_5$ (DAG-9 × DAG-6) and $P_9 \times P_{10}$ (DAG-12 × DAG-11) can be utilized in heterosis breeding program for the improvement of yield per vine in ash gourd.

In view of above results (Table 5), it can be concluded that heterosis breeding proved to be an important breeding method in bitter gourd and PBIG-2× PBIG-1, PBIG-2 × P. W., PBIG-2 × K. B., PBIG-1 × K. S. need to be exploited on commercial scale for development of hybrids. Janaranjani et al. (2016) reported based on mean performance, heterosis and sca effects, hybrids from the crosses Pusa Naveen× NDBG-164, Pusa Naveen × Punjab Komal and NDBG-121 × Samrat could be promising for commercial exploitation of fruit yield in F_1 hybrids.

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