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Heterosis and combining ability in bitter gourd (*Momordica charantia* L.)

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Abstract
Ten parents of bitter gourd *viz*., Solan Hara, Pusa Do-Mousmi, BG-14, Green Long, MDU-1, IC-85605, IC-45346, IC-68272-1, IC-68237 and Solan Collection and their forty five crosses (using half diallelic system) along with check *viz*., Jhalri, US-6214 and US-6203 were evaluated in field trials in two locations Udaipur and Chittaurgarh in two different seasons which consists four environments. Economical heterobeltiosis for yield per vine (kg) were recorded in IC 85605 x IC 45346 (38.94%) and MDU 1 x IC 85605 (34.98%) over the environments. Good general combiners for various economic traits IC- 68237 for number of primary branches per vine (0.09), fruit length (0.52), fruit diameter (0.17) & number of fruits per vine (0.22) over the pooled environments. *SCA* for economic traits were observed in Solan Collection x IC 68237 (1.24) for number of fruits per vine, IC 68237 x MDU-1 for fruit length (1.82) and fruit weight (7.81). These results indicate that both additive and non-additive gene effects are involved in the inheritance of the studied traits. The additive gene action was more important than the non-additive ones in the genetics of most studied traits.

Keywords: Parents, heterosis, GCA, SCA, yield, Momordica charantia

Introduction

Bitter gourd (*Momordica charantia* L.) is an important commercial cucurbit of family Cucurbitaceae and Genus *Momordica*. It is a large genus with many species of annual and perennial climbers of which *Momordica charantia* L. is widely cultivated. A native of old world tropics, bitter gourd (also known as bitter melon, balsam pear or bitter cucumber) was long ago fanned out into rest of new world. Wild *Momordica charantia* var. *abbreviata*, a native of Asia may be the progenitor of domesticated ones. Heterosis is a useful parameter in introducing new high yielding hybrid varieties. On the basis of high *GCA* estimates, good combiner parental inbred lines can be selected to be involved in hybrid combinations to detect the best hybrids, through the comparison among *SCA* values. A high *SCA* of particular combination means that the parents of this hybrid can produce a superior hybrid. When the additive gene action represents the main component of the total genetic variation, a maximum progress would be expected in selection programs. On the other hand, the presence of a relatively high non-additive gene action as reflected with the estimates of *SCA* indicates that production of F_1 hybrids should be considered. With these points in consideration, heterosis and combining ability studies are important, which give us valuable information pertaining to the improvement or exploiting heterosis for commercial purposes. Though many reports on combining ability and heterosis breeding are available in bitter gourd (Sirohi and Choudhary, 1978; Singh *et al*., 2013) [6, 24], information on identification of better parents for F_1 production is lacking. Therefore this experiment was conducted to draw the results about heterosis and combining ability for different yield contributing and quality traits.

Materials and Methods

Present study were carried out at the Horticulture Farm, Department of Horticulture, Rajasthan College of Agriculture, Udaipur and Farmer field of Chittaurgarh district during *Kharif and zaid* season, 2012-2013 and 2013-14 to find out the suitable germpalsm and their cross combinations for the growers of the regions.

Crossing were made among ten parents of bitter gourd *viz*., Parents and their crosses were evaluated in field trials in two locations: Solan Hara (P_1), Pusa Do-Mousmi (P_2), BG-14 (P_3), Green Long (P_4), MDU-1 (P_5), IC-85605 (P_6), IC-45346 (P_7), IC-68272-1 (P_8), IC-68237 (P_9) and Solan Collection (P_{10}) using partial diallel mating system to produce 45 F_1 crosses. Parents, their crosses and check *viz*., Jhalri, US-6214 and US-6203 were evaluated in field trials in two locations at Udaipur and Chittaurgarh in two different seasons which consists four environments. The experiment was laid out in Randomized Block Design with three replications. Randomization of lines was done with the help of random number table as advocated by Fisher (1954) [8] and observed data were subjected to combining ability analysis according to Griffing (1956) [10].

Results and Discussion

ANOVA tables (1 & 2) indicated that highly significant mean sum of square due to genotypes for all the characters in each individual environment as well as pooled over the environments revealed significant differences among the genotypes for majority of the characters except node number at which first female flower appeared. In pooled analysis over four environments, Genotype x Environment considered as source of variation i.e. mean square values due to G x E interaction were significant for all the characters except node number at which first female flower appeared and number of primary branches which indicated that the genotypes under study responded differently to the environments. The parents significantly differed among themselves for majority of the characters across and over the environments except node number at which first female flower appeared, number of male flower per vine, number of female flower per vine, number of fruits, fruit length and number of primary branches.

The hybrids also significantly differed among themselves for all the characters in each individual environment as well as pooled over the environments except node number at which first female flower appeared. The comparisons of mean sum of squares due to parents vs hybrids were significant for sixteen characters *viz*. days to anthesis of first male flower, days to anthesis of first female flower, number of male flower per vine, number of female flower per vine, number of primary branches, number of fruits per vine, fruit length (cm), fruit weight (g), fruit diameter (cm), specific gravity (g/cc), number of seeds per fruit, yield per vine (kg), vine length (cm), days to maturity, total soluble solids (%) and ascorbic acid (mg/100g) in all the four environments and pooled over the environments while, characters node number at which first female flower appeared mean square values due to parents vs hybrids were significant.

Table 1: Mean square for different characters

SN	Characters	Env	Source					
			Rep	**Genotype**	**Parent**	**F1**	**P vs F1**	**Error**
			[2]	[54]	[9]	[44]	[1]	[108]
1	Days to anthesis of first male flower	1	8.12	19.54**	13.17**	17.73**	156.61**	3.18
		2	1.50	18.93**	13.80**	17.97**	107.48**	5.04
		3	20.10**	19.50**	13.17**	19.12**	93.16**	3.21
		4	3.75	19.61**	14.63**	19.78**	56.88**	3.77
2	Days to anthesis of first female flower	1	22.26**	29.54**	27.99**	28.48**	90.34**	2.70
		2	13.99*	23.62**	14.60**	25.74**	11.52	4.12
		3	21.35**	30.78**	27.99**	30.14**	84.18**	2.41
		4	10.30	26.06**	21.32**	26.00**	71.25**	3.92
3	Node number at which I female flower appeared	1	0.87	2.62	3.41	2.50	0.46	2.69
		2	0.04	2.42	1.71	2.60	0.68	2.89
		3	2.08	2.64	3.41	2.53	0.57	2.58
		4	0.19	2.31	2.58	2.22	3.93	2.74
4	Number of male flowers per vine	1	34.66	536.08**	9.93	155.06**	22036.40**	11.53
		2	171.35	615.60**	18.90	340.72**	18080.67**	133.26
		3	11.39	521.72**	48.26**	199.18**	18974.76**	8.31
		4	21.57	721.24**	16.80	508.48**	16422.98**	61.13
5	Number of female flowers per vine	1	14.44**	3.44	2.96	3.38	10.43	2.84
		2	127.44**	2.64	1.72	2.78	4.61	2.70
		3	5.82	5.82**	3.63	3.22*	140.08**	2.14
		4	8.66	12.58**	1.76	15.07**	0.16	5.38
6	Number of primary branches	1	0.04	0.57**	0.18	0.29**	16.29**	0.13
		2	0.65	0.37	0.31	0.38	0.32	0.82
		3	0.32	0.92**	0.40	0.46*	25.83**	0.30
		4	1.06	0.39	0.31	0.42	0.15	0.78
7	Number of fruits per vine	1	7.85	1.96	0.92	2.17	2.43	3.24
		2	182.31**	1.95	0.89	2.17	1.94	3.14
		3	1.02	6.04**	5.47**	1.37	216.57**	1.47
		4	1.32	15.36**	4.00	17.68**	15.28*	3.19
8	Fruit length (cm)	1	17.04*	7.97*	1.99	5.05	190.41**	4.88
		2	2.62	11.74**	8.70**	10.80**	80.51**	2.57
		3	3.01	8.93**	10.05**	2.75**	270.55**	1.30
		4	2.84	9.25**	0.98	7.90**	143.13**	2.48
9	Fruit weight (g)	1	86.62*	618.67**	730.45**	609.78**	4.15	20.19
		2	28.44	602.33**	756.77**	583.98**	19.88	16.93
		3	27.29	529.52**	781.11**	486.33**	165.45**	19.03
		4	17.39	568.04**	909.04**	509.84**	59.68	15.81

10	Fruit diameter (cm)	1	0.14	0.64**	0.08	0.49**	12.20**	0.12
		2	0.40*	0.57**	0.62**	0.50**	3.39**	0.11
		3	0.10	0.45**	0.08	0.21**	14.15**	0.12
		4	0.24	0.66**	0.76**	0.60**	2.34**	0.11
11	Specific gravity (g/cc)	1	0.00	0.00**	0.00**	0.00**	0.01**	0.00
		2	0.00	0.00**	0.00**	0.00**	0.00	0.00
		3	0.00	0.00**	0.00**	0.00**	0.00	0.00
		4	0.00	0.00**	0.00**	0.00**	0.01**	0.00
12	Number of seeds per fruit	1	0.78	55.86**	52.18**	51.78**	268.50**	2.39
		2	3.81	55.50**	29.27**	51.94**	448.39**	2.29
		3	11.58**	58.13**	52.18**	54.49**	272.12**	1.84
		4	6.48	55.07**	48.52**	50.74**	304.51**	2.21
13	Yield per vine (kg)	1	0.07	0.27**	0.29**	0.27**	0.01	0.03
		2	1.25**	0.28**	0.33**	0.27**	0.00	0.03
		3	0.02	0.28**	0.31**	0.25**	1.10**	0.02
		4	0.01	0.26**	0.39**	0.24**	0.02	0.02
14	Vine length (cm)	1	2428.87*	5358.28**	6930.91**	5129.32**	1278.99	589.98
		2	1065.04	5681.12**	6029.35**	5704.42**	1521.84*	358.47
		3	307.66	6337.30**	3498.98*	6767.46**	12955.29**	1510.08
		4	42.02	1157.70**	223.44**	516.11**	37795.97**	19.27
15	Days to maturity	1	4.09	94.29**	107.22**	79.49**	629.19**	3.99
		2	13.68	83.38**	113.96**	67.49**	506.91**	7.57
		3	29.19**	90.96**	88.16**	77.86**	692.38**	3.66
		4	31.75*	88.67**	91.24**	74.73**	678.92**	6.89
16	Total soluble solids (%)	1	0.03	0.32**	0.47**	0.28**	0.67**	0.01
		2	0.01	0.28**	0.36**	0.27**	0.42**	0.01
		3	0.02	0.31**	0.35**	0.29**	0.86**	0.01
		4	0.03	0.31**	0.45**	0.27**	0.69**	0.01
17	Ascorbic acid (mg/100g)	1	3.35*	41.91**	22.69**	22.52**	1068.00**	0.94
		2	2.92*	39.05**	26.39**	22.37**	886.91**	0.95
		3	4.26*	29.11**	25.56**	23.39**	312.89**	1.25
		4	3.35*	41.91**	22.69**	22.52**	1068.00**	0.94

Table 2: Mean square over the environments for different characters

SN	Characters	Source											Bartlet
		Env	**Rep/Env**	**Genotype**	**Parents**	**F1**	**P vs F1**	**GxE**	**PxE**	**F1xE**	**PvsF1xE**	**Error**	
		[3]	[8]	[54]	[9]	[44]	[1]	[162]	[27]	[132]	[3]	[432]	[3]
1	Days to anthesis of first male flower	8.76	8.37*	33.96**	15.59**	29.36**	401.50**	14.54**	13.06**	15.08**	4.21	3.80	7.84*
2	Days to anthesis of first female flower	10.40*	16.97**	26.62**	18.42**	25.70**	140.73**	27.80**	24.49**	28.22**	38.85**	3.29	11.48**
3	Node number at which I female flower appeared	0.07	0.80	2.21	0.59	2.48	4.49	2.59	3.50	2.46	0.38	2.73	0.35
4	Number of male flowers per vine	270.64**	59.74	1803.64**	30.04	496.08**	75298.68**	197.00**	21.28	235.78**	72.04	53.56	254.39**
5	Number of female flowers per vine	5.17	39.09**	8.78**	5.43	7.90**	77.58**	5.23**	1.55	5.52**	25.90**	3.26	27.28**
6	Number of primary branches	303.26**	0.52	1.05**	0.85	0.54	25.37**	0.40	0.12	0.33	5.74**	0.51	104.04**
7	Number of fruits per vine	27.45**	48.13**	5.26**	3.23	4.72**	47.35**	6.68**	2.69	6.22**	62.96**	2.76	21.17**
8	Fruit length (cm)	663.08**	6.38*	19.96**	4.05	8.78**	654.95**	5.98**	5.89**	5.91**	9.88*	2.81	46.23**
9	Fruit weight (g)	1722.72**	39.94*	2095.30**	2717.63**	2014.86**	33.83	74.42**	153.25**	58.36**	71.78**	17.99	1.98
10	Fruit diameter (cm)	137.80**	0.22	1.32**	0.64**	0.85**	28.22**	0.33**	0.30**	0.32**	1.29**	0.11	0.70
11	Specific gravity (g/cc)	0.02**	0.00	0.01**	0.01**	0.01**	0.01**	0.00**	0.00**	0.00**	0.00**	0.00	4.59
12	Number of seeds per fruit	0.12	5.66**	117.78**	62.89**	102.63**	1278.33**	35.59**	39.76**	35.43**	5.06	2.19	2.10
13	Yield per vine (kg)	1.46**	0.34**	0.89**	1.05**	0.87**	0.25**	0.06**	0.09**	0.05**	0.29**	0.03	16.49**
14	Vine length (cm)	561649.90**	960.90	11126.28**	7983.28**	11884.88**	6034.52**	2469.38**	2899.80**	2077.48**	15839.19**	619.45	342.88**
15	Days to maturity	28.81**	19.68**	153.82**	75.44**	116.57**	2498.38**	67.83**	108.38**	61.01**	3.01	5.53	22.02**
16	Total soluble solids (%)	0.31**	0.02	0.92**	1.58**	0.74**	2.60**	0.10**	0.02	0.12**	0.01	0.01	0.67
17	Ascorbic acid (mg/100g)	89.33**	3.47**	124.59**	49.84**	70.38**	3182.68**	9.13**	15.83**	6.81**	51.04**	1.02	3.52

*,** Significant at 5 and 1 percent respectively (Model I)

Table 3: Five best hybrids identified on the basis of heterobeltiosis for total yield and its contributing traits on pooled basis.

Hybrids	Heterobeltiosis (%)
P_6xP_7	43.85
P_5xP_6	41.38
P_1xP_8	22.18
P_6xP_9	24.72
P_9xP_{10}	51.53

Heterosis

Heterosis for growth parameters is an indication of heterosis for yield and yield associated traits. Significant and higher magnitude of heterosis over mid parent and better parent was reported in majority of the traits. For improving yield potential of varieties and hybrids, selection of potential type of parents in very important. This can only be done by testing the genetic worth of the parents, because many times the high yielding parents may not mix well to give desirable segregates. The phenomenon of heterosis has provided the most important genetic tool for improving yield potential of crop plant.

Among 45 crosses significant per cent negative heterobeltiosis on days to anthesis of first male flower in pooled only three hybrids which showed were P_6xP_{10} (-0.19), P_3xP_7 (-1.67) and P_7xP_8 (-1.48) per cent over environments. Economic heterosis (%) for days to anthesis of first male flower was observed in some of the hybrids *viz*.- P_1xP_9 (-2.31), P_1xP_{10} (-3.08), P_2xP_3 (-1.54), P_4xP_5 (-0.77), P_4xP_6 (-3.85), P_7xP_8 (-3.08) and P_7xP_9 (-2.31) in environment 1 which had significant economic heterosis for the character and also highlight that these hybrids are superior over check in E_1. Out of 45 hybrids significant per cent heterobeltiosis for female earliness was observed in P_3xP_5 (-0.15), P_3xP_6 (-1.90), P_3xP_7 (-1.14) and P_4xP_7 (-4.58) per cent over pooled environments. Hybrid P_1xP_7 (-4.20%) exhibited negative significant economic heterosis for days to anthesis of first female flower over the environment. Similar finding was reported by Maurya *et al.* (2003) [6] for earliness for days to first male and female opening in bitter gourd.

Among 45 hybrids significant per cent heterobeltiosis in desired direction on node number at which first female flower appeared was recorded in few hybrids which showed heterobeltiosis were P_3xP_6 (-05.56), P_2xP_3 (-2.96) and P_2xP_4 (-2.94) per cent over environments as well as better parents on pooled basis. Economic heterosis (%) were observed in P_1xP_3, P_1xP_4, P_3xP_4, P_4xP_6, P_5xP_{10} and P_7xP_9 (-6.25). A similar finding was reported by Bairagi *et al.* (2002) [2].

Pooled data on heterosis (%) on fruit length (cm) was reported in P_6xP_{10} (24.72), P_5xP_9 (23.58), P_7xP_{10} (21.92), P_9xP_{10} (21.04) and P_6xP_9 (19.61), on fruit weight (g) P_6xP_7 (38.94), P_5xP_6 (34.98) and P_7xP_7 (12.62). Significant economic heterosis on fruit weight was observed in a hybrid P_1xP_8 (3.66). Heterobeltiosis (%) on fruit diameter (cm) reported in P_2xP_{10} (20.00) and P_1xP_{10} (18.12). In environment E_3 crosses depict economic heterosis that were P_3xP_8 (81.89) and P_2xP_4 (80.37). Negative significant per cent heterobeltiosis for number of seeds per fruit were recorded in a hybrid *viz*., P_2xP_9 (-4.08) in E_1. In E_2 hybrids showed significantly maximum heterosis over better parent were P_4xP_6 (-17.54) and P_2xP_7 (-10.53), whereas, in E_3 P_3xP_4 (-22.97), P_4xP_{10} (-19.67), P_4xP_5 (-17.39) and P_3xP_5 (-11.59). However, in E_4 P_5xP_7 (-26.09) and P_5xP_6 (-17.39), whereas, in pooled hybrids were P_4xP_6 (-3.67) and P_5xP_7 (0.83). Significant per cent heterobeltiosis on yield (kg) per vine recorded upto 62.92 per cent for yield per vine (kg) in in E_3 environments and in hybrids were P_6xP_7 (43.85) and P_5xP_6 (41.38) on pooled basis. These results are in agreement with the findings of Ram *et al.* (1997) [23] where the results indicated that the yield per vine was a potential character for heterosis breeding in bitter gourd. They observed 98% better parent heterosis for yield per plant. In the majority of the crosses for fruit diameter, the role of additive and additive × additive was more pronounced which suggests that this character can be fixed in the progeny by proper selection methods revealed by Celine and Sirohi (1996) [4] and Chowdhury and Sikdar (2005) [6] also support to the results. Bahera (2005) [1] also reported heterosis in bittergourd for yield/vine ranges from 27.3 to 86.1% over better parent. Eleven hybrids showed significant positive economic heterosis (%) on total soluble solids over the environments (pooled basis). Out of them maximum significant economic heterosis possessing hybrids were P_7xP_{10} (7.76%), P_7xP_9 (6.94%) and P_8xP_9 (6.94%) over best check for TSS in individual as well as over the environments. The highest estimates of positive significant heterobeltiosis on ascorbic acid (mg/100g) was exhibited by hybrid P_1xP_3 (12.71%) in E_1, and P_1xP_2 (12.55%) in E_2, P_1xP_2 (13.39%) in E_3, P_1xP_3 (12.55%) in E_4 and P_1xP_2 (10.84%) on pooled basis (29.29%).

Combining ability

The concept of combining ability in terms of genetic variation was first given by Sprague and Tatum (1942) [27] using single crosses in maize. Combining ability analysis is one of the powerful tools available which give the estimates of combining ability effect and aids in selecting desirable parents and crosses for further exploitation, either to exploit for heterosis or to combine favourable fixable genes. This analysis provides information on i) the nature and amount of genetic parameters and ii) general and specific combining ability of parents and crosses, respectively. The term combining ability is defined as the relative ability of a genotype to transmit its desirable trait to its progenies. General combining ability (*GCA*) may be defined as the average performance of a line (or population) in a series of crosses while specific combining ability (*SCA*) is the deviation of the crosses from the performance predicted on the basis of general combining ability of the parent involved. The former is a measure of additive genetic factors while the latter is due to non additive genetic factors (Sprague and Tatum, 1942) [27]. Griffing (1956) [10] suggested that *GCA* included both additive effects as well as additive X additive interaction. The high yielding lines may not be necessarily being able to transmit their superiority to their hybrids.

Earliness is desirable, hence, parents and crosses with significant and negative *GCA* and *SCA* effects were considered as good general combiner and specific combiner, respectively. Among ten pistillate parents, *viz.* Solan Hara {E_1 (-0.72), E_2 (-1.08), E_3 (-0.51), E_4 (-0.53) and PEVs (-0.71)} and IC-85605 exhibited significant and negative *GCA* effect across and over the environments. The cross Solan Collection x IC-85605 exhibited significant and negative *SCA* effect in each individual environment and pooled over the environments for days to anthesis of first male flower. Whereas, crosses BG-14 x Pusa Do Mausmi in E_1 (-4.58), E_4 (-3.52) and PEVs (-1.78) and IC-45346 x BG-14 in E_2 (-3.60), E_3 (-3.98) and PEVs (-2.07) exhibited significant and negative *SCA* effect in either of two environments and PEVs; hence, these were considered as good specific combiners.

Earliness in days to anthesis of first female flower is a desirable trait; hence, parents and crosses with significant and negative *GCA* and *SCA* effect were considered as good general combiner and specific combiner, respectively. Out of ten female parents, only parent MDU-1 {E_1 (-0.52), E_2 (-0.23), E_3 (-1.72) and PEVs (-0.45)} and Green Long {E_2 (-1.56), E_3 (-0.83), E_4 (-0.55) and PEVs (-0.43)} showed significant and negative *GCA* effect in at least three environments and pooled. Among of 45 crosses, 12 in E_1, 10 in E_2, 14 in E_3, 10 in E_4 and 12 in PEVs registered significant and negative estimates of *SCA* effect. The cross IC-45346 x Green Long exhibited significant and negative *SCA* effect in each individual environment and pooled over the environments, and the estimates were E_1 (-1.00), E_2 (-5.36), E_3 (-3.04), E_4 (-4.17) and PEVs (-3.39); hence, these were considered as good specific combiners. The negative estimates of *GCA* for days to first female flowering and indicate that these can be utilized in hybridization programmes for developing earliness in bitter gourd it being monoecious with earliness as an important trait. Rahman (2004) [22] and Vahab (1989) [29] found similar results in snakegourd and bittergourd, respectively. Mishra *et al.* (1994) [17] and Chaudhary (1987) [5] also recorded similar genetic structure in bitter gourd.

In present findings parent Solan Hara (P_1) showed significant *GCA* effects in all the environments, which indicated good general combiner for less number of male flowers per plant. The cross Pusa Do Mausmi x Solan Hara exhibited significant and negative *SCA* effect in each individual environment and pooled over the environments. Whereas, crosses IC 85605 x Solan Hara, BG-14 x PDM, Green Long x Solan Hara and IC 68237x IC 68272-1 showed significant and negative *SCA* affect either in of two environments and PEVs; hence, these were considered as good specific combiners in two environments. Results pertaining to number of female flower per vine on general combining effects revealed that, parent Solan Collection (P_{10}) showed significant *GCA* effects in all the environments, which indicated good general combiner for more number of female flowers per plant. *SCA* effect indicated that the cross IC45346 x IC 85605 (1.84) and MDU-1x PDM (1.78) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments. Whereas, crosses Solan Collection x IC 45346 (1.59) and IC 68237x IC 68272-1 (0.99) showed significant and positive *SCA* affect either in of two environments and PEVs; hence, these were considered as good specific combiners in two environments. Thus, the above combinations were the best specific combinations to improve the respective characters in bitter gourd. Banik (2003) and Latif (1993) found similar results in snake gourd and bitter gourd, respectively.

Out of these, parent IC 68237 (P_1) showed significant *GCA* effects in all the environments, which indicated good general combiner for more number of primary branches per plant. *SCA* effect indicated that the cross MDU -1 x Solan Hara (0.66) and Solan Collection x IC 68237 (0.40) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments. Whereas, crosses IC 85605 x BG 14 and Green Long x PDM showed significant and positive *SCA* affect either in of two environments and PEVs; hence, these were considered as good specific combiners in two environments.

GCA pertaining to the number of fruit per vine revealed that out of ten parents *GCA* was significant for parents, MDU-1, IC-68237 & Solan Collection in the entire environment as well as pooled over the environment in desired direction. Out of these, parent IC 68237 (P_9) showed significant *GCA* effects in all the environments, which indicated good general combiner among the parents used in study programme for more number of fruits per vine. *SCA* on number of fruits per vine indicated that cross Solan Collection x IC 68237 (1.24) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. High *GCA* and *SCA* values of parents and crosses of bitter gourd for these characters have also been reported by Ram *et al*. (1997) [23].

Fruit length directly contributes in the production of bitter gourd. *GCA* pertaining to the fruit length depicted that out of ten parents significant and positive *GCA* observed for parents, IC-68237 & Solan Collection in the entire environment as well as pooled over the environment in desired direction, which indicated best general combiner among the parents under studied for more fruits length. Specific Combining Ability (*SCA*) on fruits length indicated that cross IC 68237 x MDU-1 (1.82) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. Laxuman *et al.* (2012) [15], Panda *et al.* (2008) [20] Kumara *et al.* (2011) [14] and Tak *et al.* (2017) [28] in *Cucumis* have also reported significant positive and negative *GCA* and *SCA* effects for this trait.

For fruit weight significant and positive *GCA* observed for parent, Solan Hara, PDM, BG 14, Green Long, IC 68272-1 and IC-68237 in the entire environment as well as pooled over the environment in desired direction. Out of these, parent Solan Hara and PDM showed significant *GCA* effects in all the environments, which indicated best general combiner among the parents under studied for more fruits weight. Specific Combining Ability (*SCA*) on fruits weight indicated that cross IC 68237 x MDU-1 (1.82) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. The positive significant estimates of *GCA* effects for fruit diameter (cm) varied from 0.06 (P_8) to 0.17 (P_9) on pooled basis. The inbred lines P_9 exhibited significant positive *GCA* effects in E_2, E_4 environment as well as on pooled basis. Out of 45 hybrids, sixteen hybrids expressed positive significant *SCA* effects on pooled basis, with range varied from 0.18 (P_5xP_1) to 0.50 (P6 x P_5). The maximum estimates of positive *SCA* effects was exhibited by hybrids P_6xP_4 (0.79) in E_1, P_5xP_1 (0.82) in E_2, P_6xP_4 (0.62) in E_3 and P_6xP_5 (0.72) in E_4, (Table 3). For fruit weight significant *GCA* and *SCA* effects were also reported by Laxuman *et al.* (2012) [15], Panda *et al.* (2008) [20] and Tak *et al.* (2017) [28] in *Cucumis*.

For number of seeds per fruit inbred line P_6, P_7 and exhibited positive significant *GCA* effects in majority of the environment as well as on pooled basis. The highest magnitude of positive significant *SCA* effects was expressed by hybrids P_5xP_2 (8.67) in E_1, P_4xP_2 (8.72) in E_2, $P_{10}xP_6$ (7.19) in E_3, P_5xP_2 (8.21) in E_4 and P_3xP_2 (5.29) on pooled basis for number of seeds per fruit. Similar results of significant *GCA* and *SCA* effects were also reported by Kumara *et al.* (2011) [14] for number of seeds per fruit in bitter gourd.

The inbred line P_1 and P_2 exhibited positive significant *GCA* effects in all the environments as well as over the environment for yield per vine. The estimates of significant positive *SCA* effects was observed in seventeen hybrids on pooled basis with range varied from 0.12 (P_9xP_5) to 0.42 (P_8xP_1). The maximum estimates of positive significant *SCA* effects was exhibited by hybrid P_5xP_3 (0.51) in E_1, P_5xP_3 (0.46) in E_2, P_8 xP_1 (0.47) in E_3 and P_8xP_1 (0.67) in E_4 environment. These results are in accordance to the Singh *et al*. (2006) [25] who reported non additive type of gene action for yield and yield related traits in their material. However, Mishra *et al.* (1994) [17] found that both additive and non additive gene actions involved in the expression of yield and yield related characters. The differences in the results might havedue to the differences in the genetic material studied. The significant *GCA* and *SCA* effects for this trait were also reported by Kumara *et al.* (2011) [14] and Laxuman *et al.* (2012) [15]. Inbred line P_2 exhibited significant positive *GCA* effects in majority of environments as well as pooled analysis for vine length. The significant positive *SCA* effects was observed hybrid P_7xP_3 on pooled basis. Panda *et al.* (2008) [20], Kumara *et al.* (2011) [14] and Laxuman *et al.* (2012) [15] were also reported significant *GCA* and *SCA* effects for vine length in bitter gourd.

Earliness is a desirable direction for days to maturity. The parental line P_8 expressed significant *GCA* effects in negative direction in majority of environments as well as pooled basis. Eleven hybrids exhibiting negative significant *SCA* effects on pooled basis with the range of negative significant *SCA* effects varied from -7.46 (P_7xP_1) to -1.28 (P_6xP_4). This study reveals that the high *SCA* effects in these crosses was mainly through additive gene effects. Therefore, the best option for improvement is the identification of transgressive segregants based on *SCA* effects which may lead to isolation of promising lines of high total yield in bitter gourd. These results are in conformity with those of Niyaria and Bhalala (2001) [19]. Five inbred lines *viz*., P_1, P_2, P_6, P_9 and P_{10} exhibited positive significant *GCA* effects in all the environments as well as on pooled basis for TSS. Positive significant *SCA* effects on pooled basis was recorded in 17 hybrids with range varied from 0.07 (P_2xP_1) to 0.39 (P_8xP_4). The estimates of positive significant *GCA* effects varied from 0.55 (P_6) to 1.37 (P_8) on pooled basis. Five inbred lines *viz*., P_6, P_8, P_9 and P_{10} exhibited positive significant *GCA* effects in all the environments as well as on pooled basis for ascorbic acid content. Estimates of *SCA* effects revealed that 28 hybrids exhibited positive significant *SCA* effects on pooled basis with range varied from 0.90 (P_9 x P_4) to 5.01 (P_2xP_1).

High general combining ability effects observed for different characters may be helpful in identifying sorting out outstanding parents with favourable alleles for different components of yield. Therefore, high general combining ability of the parents seems to be a reliable criterion for prediction of specific combining ability. Similar findings in cucumber were reported by Golabadi *et al.* (2015) and Kumar *et al*. (2013) [13] for yield and its components and for fruit texture by Yoshioka *et al*. (2010). Out of these, parent IC 68237 (P_1) showed significant *GCA* effects in all the environments, which indicated good general combiner for more number of primary branches per plant. *SCA* effect indicated that the cross MDU -1 x Solan Hara (0.66) and Solan Collection x IC 68237 (0.40) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments. Whereas, crosses IC 85605 x BG 14 and Green Long x PDM showed significant and positive *SCA* affect either in of two environments and PEVs; hence, these were considered as good specific combiners in two environments.

GCA pertaining to the number of fruit per vine revealed that out of ten parents *GCA* was significant for parents, MDU-1, IC-68237 & Solan Collection in the entire environment as well as pooled over the environment in desired direction. Out of these, parent IC 68237 (P_9) showed significant *GCA* effects in all the environments, which indicated good general combiner among the parents used in study programme for more number of fruits per vine. *SCA* on number of fruits per vine indicated that cross Solan Collection x IC 68237 (1.24) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. High *GCA* and *SCA* values of parents and crosses of bitter gourd for these characters have also been reported by Ram *et al*. (1997) [23].

Fruit length directly contributes in the production of bitter gourd. *GCA* pertaining to the fruit length depicted that out of ten parents significant and positive *GCA* observed for parents, IC-68237 & Solan Collection in the entire environment as well as pooled over the environment in desired direction, which indicated best general combiner among the parents under studied for more fruits length. Specific Combining Ability (*SCA*) on fruits length indicated that cross IC 68237 x MDU-1 (1.82) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. Laxuman *et al.* (2012) [15], Panda *et al.* (2008) [20] Kumara *et al.* (2011) [14] and Tak *et al.* (2017) [28] in *Cucumis* have also reported significant positive and negative *GCA* and *SCA* effects for this trait.

For fruit weight significant and positive *GCA* observed for parent, Solan Hara, PDM, BG 14, Green Long, IC 68272-1 and IC-68237 in all the environment as well as pooled over the environment in desired direction. Out of these, parent Solan Hara and PDM showed significant *GCA* effects in all the environments, which indicated best general combiner among the parents under studied for more fruits weight. Specific Combining Ability (*SCA*) on fruits weight indicated that cross IC 68237 x MDU-1 (1.82) exhibited significant and positive *SCA* effect in each individual environment and pooled over the environments and considered best specific combiner among all the crosses made. The positive significant estimates of *GCA* effects for fruit diameter (cm) varied from 0.06 (P_8) to 0.17 (P_9) on pooled basis. The inbred lines P_9 exhibited significant positive *GCA* effects in E_2, E_4 environment as well as on pooled basis. Out of 45 hybrids, sixteen hybrids expressed positive significant *SCA* effects on pooled basis, with range varied from 0.18 (P_5xP_1) to 0.50 (P6 x P_5). The maximum estimates of positive *SCA* effects was exhibited by hybrids P_6xP_4 (0.79) in E_1, P_5xP_1 (0.82) in E_2, P_6xP_4 (0.62) in E_3 and P_6xP_5 (0.72) in E_4, (Table 4). For fruit weight significant *GCA* and *SCA* effects were also reported by Laxuman *et al.* (2012) [15], Pradhan *et al*. (2016), Panda *et al.* (2008) [20], Tak *et al.* (2017) [28] in *Cucumis* and Kumara *et al*. (2011) [14].

For number of seeds per fruit inbred line P_6, P_7 and exhibited positive significant *GCA* effects in majority of the environment as well as on pooled basis. The highest magnitude of positive significant *SCA* effects was expressed by hybrids P_5xP_2 (8.67) in E_1, P_4xP_2 (8.72) in E_2, $P_{10}xP_6$ (7.19) in E_3, P_5xP_2 (8.21) in E_4 and P_3xP_2 (5.29) on pooled basis for number of seeds per fruit. Similar results of significant *GCA* and *SCA* effects were also reported by Kumara *et al.* (2011) [14] for number of seeds per fruit in bitter gourd.

The inbred line P_1 and P_2 exhibited positive significant *GCA* effects in all the environments as well as over the environment for yield per vine. The estimates of significant positive *SCA* effects was observed in seventeen hybrids on pooled basis with range varied from 0.12 (P_9xP_5) to 0.42 (P_8xP_1). The maximum estimates of positive significant *SCA* effects was exhibited by hybrid P_5xP_3 (0.51) in E_1, P_5xP_3 (0.46) in E_2, P_8xP_1 (0.47) in E_3 and P_8xP_1 (0.67) in E_4 environment. These results are in accordance to the Singh *et al*. (2006) [25] who reported non additive type of gene action for yield and yield related traits in their material. However, Mishra *et al.* (1994) [17] found that both additive and non additive gene actions involved in the expression of yield and yield related characters. The differences in the results might have due to the differences in the genetic material studied. Dubey and Maurya (2006) [7] and Khattra *et al*. (2000) [12] also reported *SCA* effects on yield and yield related characters.

Inbred line P_2 exhibited significant positive *GCA* effects in majority of environments as well as pooled analysis for vine length. The significant positive *SCA* effects was observed hybrid P_7xP_3 on pooled basis. Munshi and Sirohi (1994) [26], Panda *et al.* (2008) [20], Kumara *et al.* (2011) [14] and Laxuman *et al.* (2012) [15] were also reported significant *GCA* and *SCA* effects for vine length in bitter gourd.

Earliness is a desirable direction for days to maturity. The parental line P_8 expressed significant *GCA* effects in negative direction in majority of environments as well as pooled basis. Eleven hybrids exhibiting negative significant *SCA* effects on pooled basis with the range of negative significant *SCA* effects varied from -7.46 (P_7xP_1) to -1.28 (P_6xP_4). This study reveals that the high *SCA* effects in these crosses was mainly through additive gene effects. Therefore, the best option for improvement is the identification of transgressive segregants based on *SCA* effects which may lead to isolation of promising lines of high total yield in bitter gourd. These results are in conformity with those of Niyaria and Bhalala (2001) [19].

Five inbred lines *viz*., P_1, P_2, P_6, P_9 and P_{10} exhibited positive significant *GCA* effects in all the environments as well as on pooled basis for TSS. Positive significant *SCA* effects on pooled basis was recorded in 17 hybrids with range varied from 0.07 (P_2xP_1) to 0.39 (P_8xP_4).The estimates of positive significant *GCA* effects varied from 0.55 (P_6) to 1.37 (P_8) on pooled basis. Five inbred lines *viz*., P_6, P_8, P_9 and P_{10} exhibited positive significant *GCA* effects in all the environments as well as on pooled basis for ascorbic acid content. Estimates of *SCA* effects revealed that 28 hybrids exhibited positive significant *SCA* effects on pooled basis with range varied from 0.90 (P_9 x P_4) to 5.01 (P_2xP_1).

Table 4: General and specific combiners for the various traits of bitter gour gourd.

S.N	Characters	General Combiners			Specific Combiner		
		Good	Average	Poor	Good	Average	Poor
1	Days to anthesis of first male flower	Solan Hara	BG-14, IC-45346	IC-68272-1	SCxIC-85605	-	IC-85605x SH
2	Days to anthesis of first female flower	MDU-1, GL	IC-68237, IC-68272-1, and Pusa Do Mausmi	SH and BG-14	IC-45346 x Green Long	IC-85605 x BG-14, MDU-1 x BG-14	IC-85605 x MDU-1, Solan Collection x Green Long andIC-45346 x MDU-1
3	Node at which first female flower appeared	Solan Hara, BG-14, Green Long	-	-	Solan Collection x IC 68272-1	Solan Collection x MDU-1, IC 68237x IC 45346	-
4	Number of male flower per vine	Solan Hara	-	-	PDM x SH	IC 85605 x Solan Hara, BG-14 x PDM	-
5	Number of female flower per vine	Solan Collection	MDU-1, IC-68237	-	IC45346 x IC 85605, MDU-1x PDM	Solan Collection x IC 45346, IC 68237x IC 68272-1	-
6	Number of primary branches	IC-68237	-	-	MDU -1 x Solan Hara, SL x IC 68237	-	-
7	Number of fruits per vine	IC-68237	MDU-1 & Solan Collection	-	Solan Collection x IC 68237	Solan Collection x IC 68272-1	-
8	Fruit length (cm)	IC-68237	Solan Collection	-	IC 68237 x MDU-1	Green Long x BG 14, BG 14 x PDM	-
9	Fruit weight (g)	Solan Hara and PDM	BG 14, Green Long, IC 68272-1		IC 68237 x MDU-1	Green Long x BG 14, BG 14 x PDM	
10	Fruit diameter (cm)	IC-68237	BG-14, IC-68272-1	-	IC-85605xMDU-1	SCxSH, SCxPDM, IC-68272-1xMDU-1	
11	Specific gravity	MDU-1	IC-85605	-	GLxPDM, IC-68237xIC-68272-1	-	-
12	Number of seeds per fruit	PDM	-	-	IC-68237xPDM,IC-45346xSH	SCxGL	-
13	Yield per vine (kg)	SH, PDM	-	-	MDU-1xBG-14, SCxIC-68237	-	-
14	Vine length (cm)	BG-14	PDM	-	IC-45346xBG-14	IC-68237xBG-14	-
15	Days to maturity	IC45346	IC-68272-1	-	IC-68272-1xGL, MDU-1xBG-14	IC-68272-1xMDU-1	-
16	Total soluble solids (%)	IC-68237, SC	-	-	IC-68272-1xGL, SCxIC-45346	MDU-1 xPDM, SC x BG-14	-
17	Ascorbic acid (mg/100 g)	IC-68272-1, IC-68237, SC	-	-	PDMxSH	BG-14 x SH	-

The results assumed that a good combiner for any economic character need not be a good combiner for all other characters (Haripriya, 1991) [11]. High general combining ability effects observed for different characters may be helpful in identifying sorting out outstanding parents with favourable alleles for different components of yield. Therefore, high general combining ability of the parents seems to be a reliable criterion for prediction of specific combining ability (Brar and Sidhu, 1977) [3]. Similar findings in cucumber were reported by Golabadi *et al.* (2015) [9], and Kumar *et al*. (2013) [13] for yield and its components.

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