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Gene action and combining ability analysis for horticultural traits in bitter gourd

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ABSTRACT

All traits exhibited higher variance due to *sca* than their respective *gca* variance indicating the predominance of non-additive genes effects in the expression of all the traits. Among parents, gynoecious line PDMGy-201 was good general combiner for earliness, sex ratio and flesh thickness, S-2 for fruit length, S-54 for fruit diameter, Pusa Do Mausami (PDM) for average fruit weight and Pusa Aushadhi (PA) for number of fruits and total yield per plant. The hybrids which showed best *sca* effects were PDMGy201 × S-2 for earliness and sex ratio, S-54 × S-57 for fruit weight and flesh thickness and PDMGy201 × Pusa Vishesh (PV) for number of fruits and total yield per plant. The role of cumulative effect of additive and additive × additive gene effects were found in the crosses PDMGy-201 × S-54 for number of days to first female flower and S-2 × PDM for yield per plant which had high *per se* performance with significant *sca* effects and both the parents of these crosses were good general combiners. The role of dominant gene action denoted in high performed crosses resulted from a combination between one good and one poor general combiner parent such as PDMGy-201 × S-2 for sex ratio, S-32 × PA for fruit length, S-54 × S-57 for fruit diameter, S-54 × S-57 for flesh thickness, S-2 × PA for number of fruits per plant, PDMGy-201 × PDM for average fruit weight and PDMGy-201 × PV for yield per plant. Almost all hybrids with higher *sca* effects have at least one of the most outstanding parental lines, PDMGy-201, PDM, S-2, PV and PA.

Key words: *Momordica charantia*, gynoecious, combining ability, yield, earliness.

INTRODUCTION

Bitter gourd (*Momordica charantia* L. 2n=2x=22) is an economically important vegetable crop of cucurbitaceae family. The crop is considered as prized vegetable because of its high nutritive values particularly ascorbic acid, vitamin A and iron (Behera, 3). Fruits are useful against diseases like cancer, malaria, ulcer, dyslipidemia and hypertension (Alam *et al.* 1) with its anti-inflammatory, antiviral, and antibacterial properties (Joseph and Jini, 10). India is endowed with a wide range of diversity for various morphological traits of bitter gourd i.e. sex expression, growth habit, maturity, fruit shape, size, colour and surface texture, (Behera, 3).

Being a cross-pollinated crop with high levels of heterozygosity heterosis is well exploited in bitter gourd for earliness, higher yield and other agronomic traits. Monoecious is its primitive sex form; however gynoecious sex form has been reported from India, Japan and China (Behera *et al*., 4). The F_1 hybrids developed by utilizing a gynoecious line as a maternal parent showed significant heterosis in desirable directions for several earliness and yield characters in bitter gourd (Dey *et al*. 7; Rao *et al.,* 11; Alhariri *et al*. 2). The identification of best combiners in hybrid breeding has to be based on the complete genetic information and esteemed prepotency of potential parents. Combining ability analysis gives useful information regarding the selection of parents and provides the desired information about the nature and magnitude of different types of gene actions involved in the expression of quantitative characters. Though, interestingly combining ability analyses were recently performed in bitter gourd and many reports are available and information on identification of better parents for hybrid production is lacking. Therefore, the objectives of the present study was to evaluate GCA and SCA effects of eight bitter gourd inbred lines including one gynoecious line and their 28 F_1 hybrids developed using half diallel mating system for earliness and yield traits and also to identify the best combiners among parents for economic traits which would help in adopting future breeding strategy.

MATERIALS AND METHODS

One gynoecious and seven monoecious diverse bitter gourd genotypes *viz*., PDMGy-201 (gynoecious), S-54, S-2, Pusa Do Mousami (PDM), Pusa Vishesh (PV), S-32, Pusa Aushadhi (PA), and S-57 were selected and crossed during *kharif* (August-November, 2015) in diallel mating design (without reciprocal) to develop 28 F_1 crosses. The F_1s and parents were evaluated under complete randomized block design at the experimental field

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of Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi during spring-summer (February to May 2016) with prescribed agronomic practices. The gynoecious line was maintained by spraying silver thiosulphate @ 3mM at different vegetative growth stages. Observations were recorded on five randomly tagged plants in each entry for twelve quantitative traits (Table1). The combining ability analysis in 8 × 8 half-diallel mating (excluding reciprocals) was carried out by Method II and Model I of Griffing (8, 9).

RESULTS AND DISCUSSION

Analysis of variance for combining ability (Table 1) revealed that, variance due to general combining ability (*gca*) and specific combining ability (*sca*) were highly significant for all traits which indicated the importance of both additive and non-additive gene effects in the expression of these traits. Therefore, both selection and heterosis breeding could be effective for the genetic improvement of these quantitative traits. However, all traits exhibited greater magnitudes of specific combining ability variances (σ^2sca) than their respective general combining ability variances (σ^2gca), indicating the importance of non-additive gene action in the expression of all the traits under study.

The estimated effects for the *gca* of the eight parental lines and *sca* effects of the 28 F_1 hybrids for yield and yield attributing traits are presented in Tables 2 and Table 3 respectively. Among eight parents, gynoecious line PDMGy-201 was good general combiner for earliness and showed maximum *gca* effects in desirable direction for node number to first male flower appearance (-1.77), days to first male flower appearance (-13.07), node number to first female flower appearance (-2.42), days to first female flower appearance (-7.10), days to first harvesting (-8.22), sex ratio (m/f) (-3.98) and flesh thickness (0.70). This gynoecious line also exhibited desirable *gca* effect for fruit diameter and number of fruits per plant. The parental line, S-2 exhibited highest *gca* effect for fruit length (1.77). However, S-54 found to be good general combiner for fruit diameter and had highest *gca* effect (0.55). The parent, PDM showed maximum *gca* effect for average fruit weight (8.26) whereas PA was found to be good general combiner for number of fruits per plant (2.75) and total yield per plant (0.17).

Two hybrid combinations, PDMGy-201 × PA and S-2 × PDM showed significant *sca* effects in desirable direction for number of nodes to first male flower (-2.99 and -1.89 respectively). The cross PDMGy-201 × PA had maximum *sca* effects for number of days to first male flower (-21.88). Among 28 F_1 crosses, S-2 × S-32 showed significant and

Table 1. ANOVA of combining ability for different traits.

Sourced of variation	D.F.	Node No. to 1st male flower appearance	Days to 1st male flower appearance	Node No. to 1st female flower appearance	Days to 1st female flower appearance	Days to first harvesting	Sex ratio m/f	Fruit length (cm)	Fruit diameter (cm)	Flesh thickness (mm)	No. of fruits/ plant	Average fruit weight (g)	Yield/ Plant (kg)
GCA	7	13.97**	308.77**	62.69**	104.43**	152.80**	58.17**	13.26**	1.09**	2.21**	44.06**	132.84**	0.11**
SCA	28	2.86**	42.29**	3.72**	10.04**	12.79**	3.11**	2.54**	0.15**	0.91**	5.74**	68.51**	0.12**
EROR	70	0.26	2.01	1.63	3.58	2.12	0.25	1.02	0.04	0.14	1.73	7.19	0.02
GCA/SCA		4.88	7.30	16.85	10.40	11.94	18.70	5.22	7.26	2.42	7.68	1.94	0.92
σ^2_{gca}		0.023	0.176	0.142	0.313	0.186	0.023	0.090	0.004	0.012	0.151	0.629	0.001
σ^2_{sca}		0.265	1.654	1.337	2.942	1.746	0.209	0.841	0.033	0.113	1.420	5.909	0.013

*, ** significant at 5% and 1% levels respectively

Table 2. Estimation of *GCA* effects in parents for yield and yield components in bitter gourd.

S. No.	Parents	Node No. to 1st male flower appearance	Days to 1st male flower appearance	Node No. to 1st female flower appearance	Days to 1st female flower appearance	Days to first harvesting	Sex ratio m/f	Fruit length (cm)	Fruit diameter (cm)	Flesh thickness (mm)	No. of fruits/ plant	Average fruit weight (g)	Yield/ Plant (kg)
1	PDMGy-201	-1.77**	-13.07**	-2.42**	-7.10**	-8.22**	-3.98**	-2.06**	0.26**	0.70**	1.18*	-1.17	0.06
2	S-54	0.06	0.69	-3.05**	-1.40*	-2.95**	-1.47**	-0.05	0.55**	0.63**	0.98	-2.61**	-0.05
3	S-2	1.46**	3.32**	1.82**	2.27**	3.45**	1.68**	1.77**	-0.52**	-0.55**	-0.12	0.98	0.03
4	PDM	0.43*	2.29**	-0.02	1.43*	1.18*	1.56**	1.02*	-0.15*	-0.40**	-3.35**	8.26**	0.06
5	PV	-0.37*	3.53**	0.12	1.20	3.05**	1.14**	-0.30	0.11	0.10	0.95	-3.62**	-0.07
6	S-32	1.13**	3.33**	3.45**	2.70**	1.85**	1.69**	0.46	0.12	0.08	-2.92**	-0.29	-0.19**
7	PA	-1.57**	-1.61**	-2.55**	-1.03	-0.48	-2.87**	-0.09	-0.20*	-0.37*	2.75**	0.02	0.17**
8	S-57	0.66**	1.53**	2.65**	1.93*	2.12**	2.25**	-0.74	-0.17*	-0.20	0.52	-1.57	-0.03
	SE (d)	0.15	0.42	0.38	0.56	0.43	0.15	0.30	0.06	0.11	0.389	0.792	0.037
	CD at 5%	0.36	0.99	0.89	1.32	1.02	0.35	0.71	0.14	0.26	0.919	1.874	0.088
	CD at 1%	0.53	1.47	1.32	1.96	1.50	0.52	1.05	0.21	0.38	1.360	2.773	0.131

*, ** significant at 5% and 1% levels respectively

highest *sca* effect in desirable direction for number of nodes to first female flower (-3.21). For days to first female flower appearance and first fruit harvesting, PDMGy-201 × S-2, showed maximum and significant *sca* effects (-9.02 and -10.03 respectively) followed by PDMGy-201 ×PV (-6.62 and -7.926 respectively). The highest significant and negative *sca* effects for sex ratio was observed in hybrid S-54 × S-32 (-3.64) followed by PDMGy-201 × S-2 (-3.03). For fruit length, S-32 × PA showed highest *sca* effects (3.68). The hybrids, S-54 × S-57 and S-32 × S-57 showed maximum and positive significant *sca* effects for fruit diameter (0.73). Moreover, S-54 × S-57 had highest *sca* effect for flesh thickness (2.50). Highest significant and positive *sca* effects were recorded in the cross PDMGy-201 × PV for number of fruit per plant (4.44). For average fruit weight, S-54 × S-57 recorded maximum *sca* effect (16.4) followed by PDMGy-201 × S-54 (12.41) and PDMGy-201 × PV (9.76). The three best combinations with higher *sca* effects for yield per plant were PDMGy-201 × PV (0.66), S-2 × PA (0.47) and S-54 × PDM (0.38).

Best performing hybrids with highest specific combining ability (*sca*) effects developed by crossing parents with general combining ability (*gca*) (high × high), (high × low) and (low × low) effects denotes presence of additive, dominance and epistatic gene actions respectively.

Three best performed hybrids based on *per se* performance, *sca* effects and mode of gene action involved in each trait based on the high or low parental *gca* effects are presented in Table 4. For node number to first male flower, in hybrids S-54 × PA and PA × S-57 (high × low) dominant gene action was detected, whereas in cross PV × PA (high × high) additive gene action was found. For number of days to first male flower, dominant gene action (high × low) was observed in the crosses PDMGy-201 × S-54, PDMGy-201 × S-2 and PDMGy-201 × PV. For node number to first female flower, additive gene action (high × high) was detected in the crosses S-54 × PA and PDMGy-201 × S-54, whereas dominant gene action (high × low) was observed in the cross S-54 × PV. For number of days to first female flower and first fruit harvest, dominant gene action (high × low) was found in crosses PDMGy-201 × S-2 and PDMGy-201 × PV, whereas additive gene action (high × high) was found in PDMGy-201 × S-54. For sex ratio, additive gene action (high × high) was observed in the crosses PDMGy-201 × PA and S-54 × PA, whereas dominant gene action (high × high) was observed in the cross PDMGy-201 × S-2.

For fruit length, additive gene action (high × high) was observed in the crosses S-2 × PDM and PDM × S-32 and dominant gene action (high × low) was

Table 3. Estimation of *SCA* effects in hybrids for yield and yield components in bitter gourd.

S. No.	Hybrids	Node No. to 1st male flower appearance	Days to 1st male flower appearance	Node No. to 1st female flower appearance	Days to 1st female flower appearance	Days to first harvesting	Sex ratio m/f	Fruit length (cm)	Fruit diameter (cm)	Flesh thickness (mm)	No. of fruits/ plant	Average fruit weight (g)	Yield/ Plant (kg)
1	PDMGy201 × S-54	1.37**	7.15**	1.52	-0.69	0.70	1.28**	1.73	0.10	0.54	-2.93*	12.41**	0.26*
2	PDMGy201 × S-2	3.64**	5.19**	-0.68	-9.02**	-10.03**	-3.03**	-2.73**	-0.23	-0.84*	0.51	-0.98	-0.03
3	PDMGy201× PDM	3.01**	9.55**	2.16	-0.19	-1.76	-1.14*	0.12	0.20	1.21**	0.74	6.21*	0.29*
4	PDMGy201× PV	1.47**	5.65**	-0.31	-6.62**	-7.96**	-0.65	1.94*	-0.03	0.04	4.44**	9.76**	0.66**
5	PDMGy201× S-32	-0.36	7.52**	-0.98	-1.79	-1.76	-0.40	-0.89	0.16	0.73*	-0.69	5.99*	0.14
6	PDMGy201× PA	-2.99**	-21.88**	3.36**	2.61	2.90*	1.28**	-0.10	0.05	0.18	2.31	-1.92	0.04
7	PDMGy201× S-57	-0.56	7.65**	1.82	0.31	3.30*	-2.14**	-0.88	0.05	1.07	-1.46	3.81	0.02
8	S-54 × S-2	-1.19*	-2.25	-0.38	0.61	0.37	-0.10	0.56	-0.39*	-0.24	1.04	-2.97	-0.04
9	S-54 × PDM	0.84	-5.88**	0.12	0.45	1.97	-0.43	-0.95	0.07	0.00	1.94	5.45	0.38**
10	S-54 × PV	-0.36	0.55	-0.34	0.01	0.10	-1.29**	1.00	-0.32	-0.53	-1.36	-0.11	-0.09
11	S-54 × S-32	-0.19	1.42	1.66	3.51	3.64*	-3.46**	-2.56**	0.10	-0.44	1.84	3.46	0.26*
12	S-54 × PA	-0.49	-0.65	-1.34	-1.75	-2.03	-0.46	-1.87	0.25	-0.09	1.17	4.65	0.27*
13	S-54 × S-57	2.27**	-4.45**	-0.21	-4.05*	-3.63*	-2.67**	2.88**	0.73**	2.50**	-3.59**	16.04**	0.37**
14	S-2 × PDM	-1.89**	1.15	-0.41	0.11	-1.76	-1.58**	0.99	0.31	0.36	2.04	6.20*	0.37**
15	S-2 × PV	1.57**	-5.08**	4.46**	1.35	1.70	0.11	0.91	0.62**	0.95**	-0.93	1.48	0.02
16	S-2 × S-32	-0.59	-1.88	-3.21**	-0.49	1.24	2.06**	-2.32*	-0.49*	-0.09	2.61*	-7.49**	-0.12
17	S-2 × PA	0.44	0.72	0.46	0.58	-2.43	-1.93**	0.27	0.19	-0.17	3.61**	5.43*	0.47**
18	S-2 × S-57	1.87**	1.92	2.26	0.95	1.64	-0.93	0.69	-0.03	-0.38	0.17	-0.87	-0.02
19	PDM × PV	-0.39	-0.71	-1.04	0.51	-0.03	1.22*	0.63	-0.02	0.53	1.97	2.20	0.24*
20	PDM × S-32	0.11	-3.85**	-1.38	-0.65	0.50	-0.15	1.00	0.24	0.03	-0.83	3.86	0.04
21	PDM × PA	-0.19	3.75**	-0.71	-0.59	-1.50	0.32	-1.08	-0.41*	-0.29	1.17	-7.35**	-0.15
22	PDM × S-57	0.24	-6.38**	2.42*	-2.22	-0.43	0.24	1.34	0.36	0.77*	1.74	-9.05**	-0.19
23	P.V × S-32	1.24	-1.08	0.82	1.58	3.30*	-0.02	-0.28	-0.19	-0.01	0.21	1.58	0.07
24	P.V × PA	-0.06	3.19*	-0.51	-0.02	1.97	0.64	-0.79	-0.04	-0.43	-0.46	-0.44	-0.07
25	P.V × S-57	-0.96	0.72	-1.38	2.35	2.04	0.68	-1.31	-0.43*	-1.00**	0.77	-0.47	0.02
26	S-32 × PA	1.44**	1.72	1.49	-0.52	-1.83	0.06	3.68**	0.19	0.46	-2.26	3.46	-0.02
27	S-32 × S-57	-1.79	-6.75**	0.62	-3.82*	-3.43*	1.88**	0.40	0.73**	-0.37	1.64	2.19	0.19
28	P.A × S-57	-1.09	1.85	0.29	0.58	1.24	-0.44	0.35	0.38*	1.41**	-0.36	6.41**	0.24*
	SE (d)	0.46	1.29	1.16	1.71	1.32	0.46	0.92	0.18	0.34	1.19	2.43	0.11
	CD at 5%	0.95	2.64	2.37	3.52	2.71	0.94	1.88	0.37	0.69	2.45	4.99	0.24
	CD at 1%	1.28	3.56	3.20	4.75	3.66	1.26	2.54	0.50	0.93	3.30	6.74	0.32

*, ** significant at 5% and 1% levels respectively

Table 4. Overall performances of superior crosses based on *per se* performance and *sca* effects for horticultural traits in bitter gourd.

S. No.	crosses	*per se* performance	*sca* effect	*gca* effect
1	Node number to first male flower			
	S-54 × PA	4.33	-0.49	L × H
	PV × PA	4.33	-0.06	H × H
	PA × S-57	4.33	-1.09	H × L
2	Number of days to first male flower			
	PDMGy201 × S-54	31.33	7.15**	H × L
	PDMGy201 × S-2	32.00	5.19**	H × L
	PDMGy201× PV	32.67	5.65**	H × L
3	Node number to first female flower			
	S-54 × PA	6.00	-1.34	H × H
	PDMGy201 × S-54	9.00	1.52	H × H
	S-54 × PV	9.67	-0.34	H × L
4	Number of days to first female flower			
	PDMGy-201 × S-2	29.67	-9.02**	H × L
	PDMGy201 × PV	31.00	-6.62**	H × L
	PDMGy201 × S-54	34.33	-0.69	H × H
5	Number of days to first harvesting			
	PDMGy-201 × S-2	51.67	-10.03**	H × L
	PDMGy201 × PV	53.33	-7.96**	H × L
	PDMGy201 × S-54	56.00	0.70	H × H
6	Sex ratio (m/f)			
	PDMGy201 × PA	0.07	1.28**	H × H
	PDMGy201 × S-2	0.24	-3.03**	H × L
	S-54 × PA	0.78	-0.46	H × H
7	Fruit length (cm)			
	S-32 × PA	17.67	3.68**	H × L
	S-2 × PDM	17.40	0.99	H × H
	PDM × S-32	16.10	1.00	H × H
8	Fruit diameter (cm)			
	S-54 × S-57	5.10	0.73**	H × L
	PDMGy-201 × S-54	4.90	0.10	H × H
	S-54 × S-32	4.77	0.10	H × H
9	Flesh thickness (mm)			
	S-54 × S-57	11.10	2.50**	H × L
	PDMGy-201 × S-54	10.03	0.54	H × H
	PDMGy-201 × S-57	9.73	1.07	H × L
10	Number of fruits per plant			
	PDMGy-201 × PV	44.00	4.44**	H × H
	PDMGy-201 × PA	43.67	2.31	H × H
	S-2 × PA	43.67	3.61**	L × H
11	Average fruit weight (g)			
	S-2 × PDM	78.57	6.20*	H × H
	PDMGy-201 × PDM	76.43	6.21*	L × H
	S-54 × S-57	75.00	16.04**	L × L
12	Yield per plant (kg)			
	S-2 × PA	3.03	0.47**	L × H
	PDMGy201 × PV	3.01	0.66**	H × L
	S-2 × PDM	2.82	0.37**	H × H

observed in the cross S-32 × PA. For fruit diameter, additive gene action (high × high) was observed in the crosses PDMGy-201 × S-54 and S-54 × PA, whereas dominant gene action (high × low) was observed in the cross S-54 × S-57. For flesh thickness, dominant gene action (high × low) was found in the crosses S-54 × S-57 and PDMGy-201 × S-57, whereas additive gene action (high × high) was found in the cross PDMGy-201 × S-54. For number of fruits per plant, additive gene action (high × high) was observed in the crosses PDMGy-201 × PV and PDMGy-201 × PA, whereas dominant gene action (low × high) was observed in S-2 × PA. For average fruit weight, dominant gene action (low × high) was found in the cross PDMGy-201 × PDM, additive gene action (high × high) was found in the cross S-2 × PDM and epistatic gene action (low × low) in the cross S-54 × S-57. For yield per plant and yield/ha, dominant gene action (low × high) was found in the cross S-2 × PA and high × low in the cross PDMGy-201 × PV, whereas additive gene action (high × high) was found in the cross S-2 × PA. These results were in conformity with those of Dey *et al*., (6), Singh *et al*., (13) and Shukla *et al*., (12).

The yield related traits exhibited dominant and epistatic gene action are best exploited by heterosis breeding, whereas crossing between superior lines for traits with additive gene effects may provide promising transgressive segregants.

In the present study, general combining ability (*gca*) effects of parental lines revealed that gynoecious line PDMGy-201 was good general combiner for earliness and other traits such as node number to first male and female flower appearance, number of days to first male and female flower, number of days to first fruit harvest, sex ratio (m/f) and flesh thickness. S-2 was found to be good general combiner for fruit length, S-54 for fruit diameter, PDM for average fruit weight and PA for number of fruits per plant and total yield per plant. In bitter gourd, *per se* performance of the parents may be given due consideration because the parent with good *gca* effects for a particular trait showed high performance for the same trait (Dey *et al*., 5) in present study this may be true for traits related to sex ratio, fruit length and diameter. For earliness, gynoecious parent PDMGy-201 was found to be the earliest with female flower at ~5th node, days to first female flower appearance (~37 days) and days to first fruit harvesting (~57 days), whereas among the hybrids the gynoecious × monoecious hybrids were the most promising for earliness, PDMGy-201 × S-54 (31 days) and PDMGy-201 × S-2 (32 days) required minimum days to first male flower appearance and PDMGy-201 × S-2 (30 days) and PDMGy-201 × PV (31 days) required minimum days to first female flower appearance and minimum days to first fruit harvesting (~52 days and ~53 days, respectively). For sex ratio (m/f), gynoecious parent PDMGy-201 bore only female flowers (100% female flowers), whereas gynoecious × monoecious hybrids PDMGy-201 × PA and PDMGy-201 × S-2 had the lowest and desired sex ratio of 0.07 and 0.24 respectively. It was revealed that combinations with gynoecious line PDMGy-201 as female parent showed early picking and lower sex ratio (m/f). This might have resulted due to the transfer of earliness character and some other minor genes located near (*gy-1*) locus from the gynoecious parent to the hybrid. These results were in conformity with those of Behera *et al*. 4 and Dey *et al*. 6. For fruit length, longest fruit recorded in parent S-2 (~18 cm) followed by S-32 (~15 cm), whereas in hybrids S-32 × PA (~18 cm) had longest fruit followed by S-2 × PDM (~17 cm) and S-2 × PV (~16 cm), therefore it was evident that hybrids with long fruits derived from combination of parents with longer fruits. The maximum fruit diameter was recorded in parent S-54 (~5 cm) followed by PDMGy-201 (~4 cm), whereas in hybrids PDMGy-201 × S-54 and S-54 × S-57 (~5 cm) had maximum fruit diameter. This was in consonance with previous reports of Dey *et al*. (7) and Rao (11) for fruit length but dissonance for fruit diameter. However, parent may show high *per se* performance for particular trait but not always exhibits good *gca* effects for the same trait and it was similar for flesh thickness in current investigation. The maximum fruit flesh thickness was recorded in PV and S-54 (~9 mm), whereas hybrid, S-54 × S-57 (~11 mm) had maximum fruit flesh thickness followed by PDMGy-201 × S-54 and PDMGy-201 × S-57 (~10 mm), but parent PDMGy-201 exhibited highest *gca* effects for flesh thickness. It indicate that combining ability of parents cannot always be judged accurately by their *per se* performance.

For manifestation of heterosis, specific combining ability (*sca)* effect is used as an indicator to denote the presence of dominance and epistatic gene interaction effects and to determine the merits of a particular cross combination in hybrid breeding program. The superiority of combinations with high × low or average × low *gca* effects (additive × dominance) type of gene interactions may be due to complementary and duplicate gene actions (Griffings, 9) The role of cumulative effect of additive and additive × additive gene effects were found in the crosses PDMGy-201 × S-54 for number of days to first female flower, S-54 × S-57 for sex ratio and S-2 × PDM for yield per plant which had high *per se* performance with significant *sca* effects and both the parents of these crosses were good general combiners. The results were in agreement with the result of Dey *et al*. (6) and Rao (11).

Highly significant specific combining ability (*sca*) effect coupled with high *per se* performance was observed in the cross S-54 × S-57 for average fruit weight. This cross was combination between two parents with poor *gca* effects for average fruit weight which indicated the presence of high magnitude of non-additive especially complementary epistatic effects which can be used for hybrid vigour exploitation. This finding was in the line with the result of Dey *et al*. (6, 7), Shukla *et al*. (12) and Rao (11). From the other hand, two parents with high *gca* effects for a trait might not always result in a combination showing high *sca* effects, it may be due to absence of any type of interactions among favourable alleles contributed by the parents (Singh *et al*., 13). This was true in our study in the crosses PDMGy-201 × S-54 for number of fruits per plant and fruit diameter, S-2 × S-32 for fruit length and PDMGy-201 × PA for number of days to first female flower and node number to first female flower.

The best heterotic crosses with higher *sca* effects indicated the importance of *sca* effects and non-additive gene actions in hybrid breeding program. Moreover, selecting parental lines with high *sca* effects helps in development of heterotic hybrids. Therefore, development of hybrids for earliness and higher yield in bitter gourd should be based on *sca* effects. Therefore, crosses between two good general combiners were mostly the best specific combinations, whereas only in few cases the crosses between two good general combiners were not best specific combiners. Almost all hybrids with higher *sca* effects have at least one of the most outstanding parental lines, PDMGy-201, PDM, S-2, PV and PA.

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