Original Article

Combining ability analysis in bitter gourd (*Momordica charantia* L.) for potential quality improvement

Análise de capacidade de combinação em cabaça-amarga (*Momordica charantia* L.) para melhoria potencial da qualidade

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Abstract

Combining ability analysis provides useful information for the selection of parents, also information regarding the nature and magnitude of involved gene actions. Crops improvement involves strategies for enhancing yield potentiality and quality components. Targeting the improvement of respective characters in bitter gourd, combining ability and genetic parameters for 19 characters were estimated from a 6×6 full diallel analysis technique. The results revealed that the variances due to general combining ability (GCA) and specific combining ability (SCA) were highly significant for most of the important characters. It indicated the importance of both additive and non-additive gene actions. GCA variances were higher in magnitude than SCA variances for all the characters studied indicating the predominance of the additive gene effects in their inheritance. The parent P_2 (BG 009) appeared as the best general combiner for earliness; P_1 (BG 006) for number of fruits, average single fruit weight and fruit yield; P_4 (BG 027) for node number of first female flower and days to seed fruit maturity; P_3 (BG 011) for fruit length and thickness of the fruit flesh; P_5 (BG 033) for 100-seed weight; and P_6 for number of nodes per main vine. The SCA effect as well as reciprocal effect was also significant for most of the important characters in different crosses.

Keywords: bitter gourd (*Momordica charanta* L.), genetic parameters, diallel, GCA, SCA.

Resumo

A análise da capacidade de combinação fornece informações úteis para a seleção dos pais, também informações sobre a natureza e a magnitude das ações dos genes envolvidos. A melhoria das safras envolve estratégias para aumentar a potencialidade da produção e os componentes de qualidade. Visando ao aprimoramento dos respectivos caracteres em cabaça-amarga, capacidade de combinação e parâmetros genéticos para 19 caracteres, foram estimados a partir de uma técnica de análise dialélica completa 6 × 6. Os resultados revelaram que as variâncias, devido à capacidade geral de combinação (GCA) e capacidade específica de combinação (SCA), foram altamente significativas para a maioria dos caracteres importantes. Indicou a importância das ações gênicas aditivas e não aditivas. As variâncias GCA foram maiores em magnitude do que as variâncias SCA para todos os caracteres estudados, indicando a predominância dos efeitos do gene aditivo em sua herança. O pai P_2 (BG 009) apareceu como o melhor combinador geral para o início; P_1 (BG 006) para número de frutos, peso médio de um único fruto e produção de frutos; P_4 (BG 027) para número de nó da primeira flor fêmea e dias para a maturidade do fruto da semente; P_3 (BG 011) para comprimento do fruto e espessura da polpa do fruto; P_5 (BG 033) para peso de 100 sementes; e P_6 para o número de nós por videira principal. O efeito SCA, bem como o efeito recíproco, também foi significativo para a maioria dos personagens importantes em cruzamentos diferentes.

Palavras-chave: cabaça-amarga (*Momordica charantia* L.), parâmetros genéticos, dialelo, GCA, SCA.

1. Introduction

Bitter gourd (*Momordica charantia* L.) locally known as Karala/Uchha is an important vegetable and belongs to the family Cucurbitaceae. Compared to other cucurbits, bitter gourd has relatively high nutritional value in respect of iron and ascorbic acid contents with antidiabetic and anti-obesity properties. It is a rich source of antioxidants, flaviooids and other polyphenol compounds (Alam et al., 2015). Rose et al. (2014) reported that 100 grams of the fruit contain about 92 mL water, 25 calories, 1.2 g protein, 0.2 g fat, 5 g carbohydrate, 1.0 g fiber, 13 mg calcium, 32 mg phosphorus, 0.2 mg iron, 0.02 mg thiamine and 0.07 mg riboflavin. The per capita consumption of vegetable in Bangladesh is about 50 g per day, which is the lowest among the countries of South and South East Asia. WHO/FAO recommends intake of a minimum of 400 grams or five servings of fruits and vegetables per day for the prevention of chronic diseases such as heart diseases, cancer, diabetes, and obesity. There is a big gap between the demand and supply of vegetables in Bangladesh. Therefore, from nutrient and health benefit considerations, improvement of crop yield and production of this vegetable crop is desirable and important to mitigate the future demand.

A sound-breeding program provides the opportunity to produce high yielding varieties of a crop with superior quality. However, the development of a meaningful breeding program needs information on the nature of gene actions controlling the economic characters and other characters of importance. Knowledge of genetic architecture of the characters under improvement is essential for adopting appropriate breeding procedure. Such knowledge leads the plant breeder to develop new commercial varieties of the crop. Begna (2021) stressed that information on variation attributable to genetic differences and also on the relationship among various quantitative traits is fundamentally significant in crop improvement program. In a heterosis breeding program, the breeder is often confronted with problems in choosing desirable parents. The common approach of selecting parents on the basis of *per se* performance does not necessarily lead to the best result in hybridization program (Labroo et al., 2021). Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits. Diallel cross analysis provides the estimates of genetic parameters regarding combining ability as well as a rapid overall picture of the dominance relationship of the parents studied using the first filial generation (F_1) with or without reciprocals. Diallel analysis involving parents give the additional information as presence or absence of epistasis, average degree of dominance, distribution of dominant and recessive genes in the parents (Zongo et al., 2019). Bitter gourd being a monoecious crop, there exists bright scope for exploitation of heterosis. The heterozygous nature of bitter gourd and virtually the obligatory out crossing breeding system of bitter gourd opens the scope of development of open-pollinated as well as hybrid variety. A number of superior hybrids of bitter gourd have been developed for cultivation in different countries. Quamruzzaman et al. (2020) observed a high level of heterosis (86.1%) in full diallel cross among 11 diverse parents in bottle gourd. Behera et al. (2020) reported that F_1 hybrid was derived from the crosses between pure-line of bitter gourd having good specific combiners for yield and its components. Valyaie et al. (2021) reported that heterosis was obtained in seed quality character and yield. Mishra and Singh (2018) also reported that superior performance of F_1 hybrids showing high SCA was largely due to epistatic interaction. In Bangladesh, very limited information is available for determining nature of gene effects and inheritance of yield and yield contributing attributes in bitter gourd. In this regard the present experiment was undertaken to reveal the general and specific combining ability in bitter gourd for the development of high yielding variety.

2. Materials and Methods

2.1. Plant materials

The experiment was conducted with six diverse genotypes of bitter gourd, namely BG 006, BG 009, BG 011, BG 027, BG 033 and BG 036 were selected as parents (designated respectively as P_1, P_2, P_3, P_4, P_5, and P_6) based on their performances and some qualitative characters. The six parents were grown and crossed in all possible combinations. The parents were grown along with their F_1's population.

2.2. Experimental design and layout

The field experiment was arranged in a randomized complete block design with three replications. There were three plants per replication. The spacing adopted was (2.0 x 1.0) m². A good drainage system was maintained for draining out of rain water from the field. For better growth and development of the plants, recommended balanced combination of manures (well decomposed cow dung 15000 kg/ha) and fertilizers (Urea 175 kg/ha; TSP 175 kg/ha; MP 150 kg/ha; Gypsum 100 kg/ha; Zinc oxide 12 kg/ha and Borax 7 kg/ha) were applied (Nasreen et al., 2013).

2.3. Data collection for quantitative characters

Days to first male flower opening, node number of first male flower, days to first female flower opening, node number of first female flower, main vine length (cm), numbers of primary branches per vine, numbers of nodes per main vine, number of fruits per vine, average single fruit weight (g), fruit yield per vine (kg), fruit length (cm), fruit diameter (cm), thickness of the fruit flesh (mm), thickness of the rind (mm), days to green fruit maturity, days to seed fruit maturity, number of seeds per fruit, seed weight per fruit (g), and 100-seed weight (g) were recorded accordingly. For every parameters, data were collected three times and average was calculated.

2.4. Analysis of variance (ANOVA)

All the quantitative data taken were subjected to ANOVA. The total variances of each character were partitioned in

two block, genotype and error differences. The differences within the classes of effects were tested by F-test.

2.5. Combining ability

The statistical analysis of data for 6 × 6 diallel crosses including reciprocals were done as quoted in Fasahat et al. (2016). The diallel progenies ($n^2 = 36$) were portioned into parents (P), crosses (F_1), parent vs crosses (P vs. F_1), direct crosses (f), reciprocal crosses (l) and direct vs. reciprocal items. The parents, crosses, direct cross, reciprocal crosses items tested the significant differences among the parents, crosses, direct crosses and reciprocal crosses, respectively. P vs. F_1 item indicated overall heterosis for the respective character. While f vs. l item indicates presence of reciprocal differences, thus necessitates computation of reciprocal differences. For the genetic analysis of Diallel population, data were subjected to Griffing's approaches. An understanding of the general and specific combining ability and the genetic system controlling important traits of bitter gourd was thus attempted.

2.5.1. Griffing's approach (Combining ability analysis)

Griffing's (1956) method 1, Model 2 (Random effects model) was used for combining ability analysis for each of the trait. In model 2, random samples drawn as parents from some populations are dealt with and inferences do not apply to the sample but to the parental populations from which samples are drawn.

The mathematical model for the combining ability analysis in model 2, method 1 is assumed to be (Equation 1):

$$Xij = \mu + gi + gj + Sij + rij + \frac{1}{bc} \sum_{k} \sum_{l} eijkl \qquad (1)$$

Where,
i, j = 1…………………P
k = 1………………….b
l = 1………………….c
p = number of parents
b = number of blocks
c = number of observation in each plot
Xij = mean of Xij the genotypes over k and l
μ = population mean
gi, gj = gca effects
Sij = specific combining ability effect i.e. sca effects
r_{ij} = reciprocal effect
e_{ijkl} = environmental effect particular to the ijklth individual observation
The restriction imposed are- Σ = 0 and Σ (Sij + Sii) = 0 (for each I).

3. Results and Discussion

The analysis of variance (ANOVA) showed highly significant differences among parents and crosses for all the characters studied (Table 1a, 1b, 1c, 1d). The significant mean square due to general combining ability (GCA) and specific combining ability (SCA) for all the characters indicated that both additive and non-additive gene actions played dominant role for the expression of these characters. The higher magnitude of SCA variance than that of GCA variance for only one character out of nineteen characters studied indicated the predominance of the non-additive gene effects for that character. Mean square of reciprocal effect of 11 characters was higher than the SCA, which indicated that reciprocal effect also exists in bitter gourd. Devi et al. (2017a) found both additive and non-additive gene action in snake gourd. Jasim and Esho (2021) reported that additive variance was responsible for vine length whereas, non-additive for yield in summer squash. Similar results were also found in eggplant (Devmore et al., 2016), in bitter gourd (Talukder et al., 2018), in cucumber (Golabadi et al., 2017), and in bottle gourd Quamruzzaman et al. (2020) found non-additive gene effects for first female flowering node as well as female flower number per stem, branches per plant in ridge gourd. Quamruzzaman et al. (2009) studied 45 F_1 crosses of 10 parents of bottle gourd and found the best F_1 hybrid (S 54 x S 52 -7) attributed higher estimates of fruits per plants, fruits weight and fruit size. Kaniti (2016) recorded highly significant variations for genotypes, parents and hybrids in six parents' diallel cross of bitter gourd for yield per plant. He reported highly significant variations for both general and specific combining ability and high GCA:SCA. Shukla et al. (2014a) studied ll parent diallel in bitter gourd and observed that GCA and SCA variances were significant for all 13 characters they studied. They observed that this variance due to GCA were consistently greater than the SCA variances for all the characters. Singh et al. (2013) found that the GCA and SCA variances were highly significant in a 10 × 10 diallel in bitter gourd for days to first female flower opening during three seasons.

The GCA component is primarily a function of the additive genetic variance. GCA and SCA variance with each parent play significant role in parent selection. A parent with higher positive significant GCA effects is considered as a good general combiner. The magnitude and direction of the significant effects for the eight parents in this study provide meaningful comparisons and would give indications to the future breeding program.

The results of GCA effect for 19 different characters of six parental lines are presented in the Table 2a, 2b and 2c. Negative GCA effect is preferable for days to flowering as it indicates the earliness of the parents. Highly significant (2.33**) and the highest positive GCA effect (49.81) was recorded for P_3 for days to first male flower opening (Table 2a). The parent P_6 showed low but positive significant effect. On the other hand, P1 and P_2 showed highly significant and negative GCA effect (-1.51 ** and -1.73 **) followed by P_1 and P_4. Hence, the parent P_1 and P_2 were the best general combiner for promoting early flowering in bitter gourd.

Regarding the node number for bearing the first male flower, parent P_6 had highly significant (1.19**) and positive GCA effect (21.16), while parent P_1 had highly significant (-1.23**) but negative GCA effect (18.74). GCA effect of parents P_2, P_3 and P_4 for this parameter was non-significant. Hence, the parent P_1 was the best general combiner for

Table 1a. Analysis of variance for combining ability of days to flower and growth character in bitter gourd.

Source of variation	d.f	Character (Mean sum of square)						
		Days to first male flower opening	Node number of first male flower	Days to first female flower opening	Node number of first female flower	Main vine length (m)	No. of primary branches per vine	No. of nodes per main vine (no.)
Block	2	38.19**	63.35**	97.69**	13.17**	2.16**	0.96**	1135.39**
Crosses	35	35.79**	22.78**	46.04**	35.67**	0.74**	1.44**	151.80**
GCA	5	94.09**	26.79**	96.54**	81.45**	1.70**	5.03**	428.54**
SCA	15	22.44**	31.60**	27.33**	33.89**	0.51**	0.97**	99.61**
Reciprocal	15	29.72**	12.63**	47.91**	22.20**	0.65**	0.72**	111.75**
Error	70	2.47	3.5	8.16	4.47	0.18	0.23	44.20
SCA/GCA	1	0.24	1.18	0.28	0.42	0.30	0.19	0.23
Rec/GCA	1	0.32	0.47	0.50	0.27	0.38	0.14	0.26

**Significant at 1% level of probability. d.f. - degrees of freedom.

Table 1b. Analysis of variance for combining ability of days to flower and growth character in bitter gourd.

Source of variation	d.f	Character (Mean sum of square)						
		Days to first male flower opening	Node number of first male flower	Days to first female flower opening	Node number of first female flower	Main vine length (m)	No. of primary branches per vine	No. of nodes per main vine (no.)
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SCA/GCA	1	0.24	1.18	0.28	0.42	0.30	0.19	0.23
Rec/GCA	1	0.32	0.47	0.50	0.27	0.38	0.14	0.26

**Significant at 1% level of probability. d.f. - degrees of freedom

Table 1c. Analysis of variance for combining ability of fruit yield and fruit characters in bitter gourd.

Source of variation	d.f	Character (Mean sum of square)						
		Number of fruits per vine (no.)	Av. Single fruit weight (g)	Fruit yield per vine (kg)	Fruit length (cm)	Fruit diameter (cm)	Thickness of fruit flesh (mm)	Thickness of fruit rind (mm)
Block	2	22.54**	521.45**	0.03**	15.87**	0.60**	12.45**	1.34**
Crosses	35	40.9**	1843.41**	0.25**	17.25**	0.41**	14.52**	0.79**
GCA	5	75.68**	7019.63**	0.78**	78.51**	1.08**	27.31**	1.96**
SCA	15	31.23**	1168.61**	0.16**	6.43**	0.18**	12.60**	0.59**
Reciprocal	15	37.80**	792.81**	0.16**	7.66**	0.41**	12.19**	0.59**
Error	70	2.97	62.03	0.01	2.87	0.11	3.76	0.35
SCA/GCA	1	0.41	0.17	0.21	0.08	0.17	0.46	0.30
Rec/GCA	1	0.50	0.11	0.21	0.10	0.38	0.45	0.30

**Significant at 1% level of probability. d.f. - degrees of freedom

using in crosses to promote the lower node number to bear male flower (Table 2a).

The parent P_5 provided highly significant (2.16**) positive GCA effect for days to bear first female flower (52.29 days) followed by P_3 and hence, these two parents were undesirable general combiners to promote the earliness in bitter gourd. On the other hand, P_2 revealed highly significant (-1.73**) and negative GCA effect and lower parental mean (48.40 days) for this trait. Thus P_2 can be selected as the best general combiner for enhancing early fruiting in this crop (Table 2a).

Highly significant (1.84**) positive GCA effect was provided by P_5 for node number for bearing the first female flower (29.97). The parents P_1 and P_2 showed low and positive non-significant effects. On the other hand, P_4 showed highly significant (-2.37**) but negative significant

GCA effects (25.76). Hence, the parent P_4 was the best general combiner for promoting lower node number for bearing the first female flower (Table 2a).

The parent P_6 projected significant (1.15*) highest positive GCA effect (29.28 m) for main vine length, while the parent P_1 showed low but positive non-significant GCA effects for this trait. The parent P_4 showed highly significant (-2.37**) and negative GCA effects (25.76 m) followed by P_3 (- 0.98*). Thus, P_6 was found to be good for using in the breeding programs for long vine and P_4 for short vine (Table 2a).

The parent P_6 was identified with highly significant (0.69**) and the highest positive GCA effects for number of primary branches (5.69) per vine (Table 2a). While P_2 was identified with highly significant (-0.32**) and the lowest negative GCA effects for number of primary branches

Table 1d. Analysis of variance for combining ability of days to maturity and seed characters in bitter gourd.

Source of variation	d.f	Character (Mean sum of square)				
		Days to green fruit maturity	Days to seed fruit maturity	Number of seed per fruit	Seed weight per fruit (g)	100 seed weight (g)
Block	2	7.01**	4.86**	0.11**	0.34**	4.72**
Crosses	35	6.65**	3.75**	58.38**	1.18**	11.25**
GCA	5	12.88**	4.94**	133.76**	1.28**	25.9**
SCA	15	5.64**	2.37**	30.56**	0.86**	7.76**
Reciprocal	15	5.58**	4.73**	61.09**	1.47**	9.85**
Error	70	2.29	1.39	1.82	0.23	1.21
SCA/GCA	1	0.44	0.48	0.23	0.67	0.30
Rec/GCA	1	0.43	0.96	0.46	1.15	0.38

** Significant at 1% level of probability. d.f. - degrees of freedom

Table 2a. General combining ability effects for days to flower and growth character in six bitter gourd genotypes.

Parents	Characters						
	Days to first male flower opening	Node number of first male flower	Days to first female flower opening	Node number of first female flower	Main vine length (m)	No. of primary branches per vine	No. of nodes per main vine (no.)
P_1 (BG 006)	-1.51** (45.97)	-1.23** (18.74)	-1.42* (48.71)	0.14 (28.27)	0.14 (28.27)	-0.17 (4.74)	-0.63 (76.50)
P_2 (BG 009)	-1.73** (45.75)	0.13 (20.10)	-1.73** (48.40)	0.21 (28.37)	0.21 (28.37)	-0.32** (4.59)	-1.78 (74.08)
P_3 (BG 011)	2.33* (49.81)	0.04 (20.01)	1.19* (51.32)	-0.98* (27.15)	-0.98* (27.15)	-0.21* (4.70)	-0.60 (75.28)
P_4 (BG 027)	-0.87* (46.61)	-0.68 (19.29)	-1.18* (48.95)	-2.37** (25.76)	-2.37** (25.76)	-0.16 (4.74)	-4.31** (71.57)
P_5 (BG 033)	1.01** (48.49)	0.56 (20.54)	2.16** (52.29)	1.84** (29.97)	1.84** (29.97)	0.17 (5.07)	-0.02 (75.86)
P_6 (BG 036)	0.77 (48.25)	1.19** (21.16)	0.98 (51.10)	1.15* (29.28)	1.15* (29.28)	0.69** (5.59)	6.08** (81.96)
SE gi	0.24	0.29	0.43	0.32	0.32	0.07	1.01
SE (gi-gj)	0.37	0.44	0.67	0.50	0.50	0.11	1.57

☞ Figures in the parenthesis are the mean values. *Significant at 5% level of probability; **Significant at 1% level of probability. Non staric means non-significant up to 5% level of probability.

(4.59) per vine, followed by P_3. The GCA effects for other parents were not significant. Therefore, P_6 would be a better selection in breeding programs for greater number of primary branches per vine and P_2 would be a better selection for lesser number of primary branches per vine.

The parent P_6 exhibited highly significant (6.08**) and positive and P_5 showed low and positive insignificant GCA effects for number of nodes per main vine with mean values of 81.96 and 75.86, respectively. The parent P_4 showed highly significant (- 4.31**) and the lowest negative GCA effect. Thus, P_6 was found to be good for using in breeding programs for more nodes on main vine (Table 2a).

For numbers of fruits per vine P1 (12.94) exhibited highly significant and positive GCA effects (1.76**) followed by P_4 (1.40**) and P_2 (0.96*), respectively (Table 2b). The lowest significant GCA effects was observed for parent P_2 (0.69*). Highly significant but negative GCA effects (-1.49**) was recorded in parent P_3 followed by P_6 and P_5. Considering these characters, three parents showed positive and other three parents showed negative GCA effects. Thus, P_1 was the best general combiner to use in hybridization program to improve number of fruits per plant in bitter gourd since it had higher mean value along with significant and higher GCA. Parent P_4 may be considered as the second parent for this trait (Table 2b). The estimate of GCA effects for average single fruit weight (107 g) showed that parent P_1 had highly significant highest positive value (17.18**) followed by P_6 and P_3 but both were non-significant (Table 2b). Other parents showed negative significant effects for the trait. Hence, parent P_1 was the good general combiner to use in crossing to improve the average single fruit weight.

The parent P_1 had highly positive significant SCA effects (0.28**) for fruit yield per vine (1.22 kg) (Table 2b). All other parents showed negative significant effects for this trait. Hence, P_1 was the good general combiner to use in crossing to improve the fruit bearing capacity per vine and total yield.

Highly significant (1.43**) and the highest positive GCA effect for fruit length (18.67 cm) was found in P_3 followed by P_1 (1.35**) and P_6 (0.28**) (Table 2b). The other parents showed either insignificant or negative significant values for this trait. Thus, P_3 was the best general combiner to use in hybridization program to improve the length of fruit. Parents P1 and P_6 may be considered as alternate parents for this trait (Table 2b).

The parent P_5 had highly significant (0.22**) and the highest positive GCA effect for fruit diameter (4.50 mm) followed by P_1 (0.19*) (Table 2b). Other parents showed negative significant effects for this trait. Hence, P_5 and P_1 were the good general combiners to use in crossing to improve fruit diameter.

Significant (1.20*) and the highest positive GCA effect for thickness of fruit flesh (26.89 mm) was found in P_5 followed by P_1 (0.83*, 26.52 mm). The other parents showed either insignificant or negative significant values for the trait (Table 2b). Thus P_5 and P_1 can be considered as better general combiners to use in hybridization program to improve thickness of the fruit flesh (mm).

The parent P_5 had significant (0.31*) and the highest positive GCA effect (5.68 mm) for fruit rind thickness followed by P_1 (0.26*, 5.63 mm). Other parents showed negative and insignificant effects for this trait (Table 2b). Hence, P_5 and P_1 were the good general combiners to use in crossing to improve the thickness of fruit rind (mm).

Regarding days to green fruit maturity, three parents (P_2, P_3 and P_6) provided positive GCA effects with parent

Table 2b. General combining ability effects for fruit yield and fruit characters in six bitter gourd genotypes.

Parents	Number of fruits per vine (no.)	Av. Single fruit weight (g)	Fruit yield per vine (kg)	Fruit length (cm)	Fruit diameter (cm)	Thickness of fruit flesh (mm)	Thickness of fruit rind (mm)
P_1 (BG 006)	1.76**	17.18**	0.28**	1.35**	0.19*	0.83*	0.26*
	(12.94)	(107.03)	(1.22)	(18.59)	(4.47)	(26.52)	(5.63)
P_2 (BG 009)	0.69*	-8.46**	-0.01	0.30	-0.08	-0.45	-0.23
	(11.87)	(81.39)	(0.93)	(17.54)	(4.20)	(25.24)	(5.14)
P_3 (BG 011)	-1.49**	0.67	-0.04	1.43**	-0.20*	-0.85*	-0.15
	(9.70)	(90.52)	(0.90)	(18.67)	(4.08)	(24.84)	(5.22)
P_4 (BG 027)	1.4**	-22.07**	-0.15**	-2.48**	-0.15*	-0.86*	-0.18
	(12.58)	(67.79)	(0.78)	(14.77)	(4.13)	(24.83)	(5.19)
P_5 (BG 033)	-1.12**	-10.84**	-0.03	-0.87**	0.22**	1.20*	0.31*
	(10.07)	(100.69)	(0.90)	(16.38)	(4.50)	(26.89)	(5.68)
P_6 (BG 036)	-1.24**	1.84	-0.05	0.28**	0.02	0.12	-0.01
	(9.94)	(91.69)	(0.89)	(17.52)	(4.30)	(25.81)	(5.36)
SE gi	0.26	1.2	0.03	0.26	0.05	0.29	0.09
SE(gi-gj)	0.41	1.86	0.04	0.40	0.08	0.46	0.14

☞ Figures in the parenthesis are the mean values. *Significant at 5% level of probability; **Significant at 1% level of probability. Non staric means non-significant up to 5% level of probability.

P_2 only having significant (0.84*) GCA effects with the maximum days (16.27 days) to green fruit maturity. While the other three parents (P_1, P_4 and P_5) provided non-significant negative GCA effects (Table 2c). However, since positive GCA effects are undesirable for general combiner to promote earliness, from among the parents with negative GCA effects, parent P4 had the least days to green fruit maturity (14.75 days), followed by P5 (14.89 days) and P1 (15.22 days). Therefore, P4 can be considered as the best general combiner for early fruit maturity in this crop. Parents P_5 may be considered as alternate parent for this trait.

Regarding days to seed fruit maturity, parents P_2, P_5 and P_6 had positive GCA effects and thus were undesirable general combiner for early seed fruit maturity for bitter gourd (Table 2c). While parents P_1, P_3 and P_4 provided negative GCA effects with parent P_4 only having significant (-0.67*) GCA effects with the earliest 21.91 days to seed fruit maturity. Hence, P_4 was the best general combiner for early seed fruit maturity for this crop.

GCA effects for number of seeds per fruit were not significant for any parents (Table 2c). Parent P_5 showed the highest and positive GCA effects (22.96 seeds per fruit) followed by P_2 and P_1 which were undesirable for this trait. The parent P_3 showed highest negative GCA effect (15.89 seeds per fruit) for this character, followed by P_6 (16.58 seeds per fruit) and P_4 (17.10 seeds per fruit). Hence, P_3 was the good general combiner for less seeded type.

Four parents, namely P_1, P_2, P_5 and P_6 had positive GCA effects for seed weight per fruit, having P_5 only with significant (0.24*) and the maximum seed weigh per fruit (2.91 g) and thus these parents were undesirable general combiner for this trait (Table 2c). While parents P_3 and P_4

provided with significant negative GCA effects with 2.44 and 2.47 g seeds per fruit. Hence, P_3 and P_4 were the best general combiner for fruits with lesser number of seeds.

The parent P_6 showed highly significant (1.37**) and the highest positive GCA effects for 100 seed weight (16.41 g) followed by P_1 and P_3. The other parents showed negative significant or non-significant effects for the trait. As positive GCA effects are desirable for this trait, P_6 was the good general combiners for this character.

Considering GCA effects, the parent P_2 was the best for early male and female flower opening. The parents P_4 and P_5 were found good combiner for dwarf plant type, more number of fruits and higher yield per plant. The parent P_3 was the best combiner for long type fruit. The parents P_1 was found good for average fruit weight and fruit yield. Taking all these characters into account, the parent P_1 was identified as the best general combiner.

Podder et al. (2010) noted that general combiner for fruits per plant, fruit length, node number of first male and female flower among the six varied lines of snake gourd. They concluded that the parental line SG001 was the best general combiner for fruit weight. Balat et al. (2021) reported from a combining ability analysis of long fruited bottle gourd with the highest GCA effects for days to open first male flower, days to open first female flower, days to first harvest, number of fruits per plant, and total yield per plant. Mishra and Singh (2018) noted that the bitter gourd (VNR-28) showed the highest GCA effects for the total yield, fruit length, and fruit number per plant. The parent VNR-22 had maximum GCA effects for fruit weight, seeds per fruit, seed weight per fruit, fruit length, and vine length in bitter gourd. Valyaie et al. (2021) observed that the parent No. 484 was a good general combiner for fruit

Table 2c. General combining ability effects for days to fruit maturity and seed characters in six bitter gourd genotypes.

Parents	Characters						
	Number of fruits per vine (no.)	Av. Single fruit weight (g)	Fruit yield per vine (kg)	Fruit length (cm)	Fruit diameter (cm)	Thickness of fruit flesh (mm)	Thickness of fruit rind (mm)
P_1 (BG 006)	1.76**	17.18**	0.28**	1.35**	0.19*	0.83*	0.26*
	(12.94)	(107.03)	(1.22)	(18.59)	(4.47)	(26.52)	(5.63)
P_2 (BG 009)	0.69*	-8.46**	-0.01	0.30	-0.08	-0.45	-0.23
	(11.87)	(81.39)	(0.93)	(17.54)	(4.20)	(25.24)	(5.14)
P_3 (BG 011)	-1.49**	0.67	-0.04	1.43**	-0.20*	-0.85*	-0.15
	(9.70)	(90.52)	(0.90)	(18.67)	(4.08)	(24.84)	(5.22)
P_4 (BG 027)	1.4**	-22.07**	-0.15**	-2.48**	-0.15*	-0.86*	-0.18
	(12.58)	(67.79)	(0.78)	(14.77)	(4.13)	(24.83)	(5.19)
P_5 (BG 033)	-1.12**	-10.84**	-0.03	-0.87**	0.22**	1.20*	0.31*
	(10.07)	(100.69)	(0.90)	(16.38)	(4.50)	(26.89)	(5.68)
P_6 (BG 036)	-1.24**	1.84	-0.05	0.28**	0.02	0.12	-0.01
	(9.94)	(91.69)	(0.89)	(17.52)	(4.30)	(25.81)	(5.36)
SE gi	0.26	1.2	0.03	0.26	0.05	0.29	0.09
SE(gi-gj)	0.41	1.86	0.04	0.40	0.08	0.46	0.14

☞ Figures in the parenthesis are the mean values. *Significant at 5% level of probability; **Significant at 1% level of probability. Non static means non-significant up to 5% level of probability.

weight, yield per plot, days to first female flower, first female flowering node and fruits per plant in bitter gourd. Rajkumar et al. (2019) obtained information on line X tester analysis on seven yield components in snake gourd. They noted that GCA effects for yield per plant and fruits per plant were significant for the lines TA-102, TA-100 and TA-89. The lines TA-82 and TA-77 were good combiners for earliness. In combining ability analysis of bitter gourd, Malve et al. (2021) noted that Phule Green Gold were the best general combiners for number of seeds per fruit. They also reported Phule Green Gold, Preethi and Arka Harit were good combiners for 100-seed weight. Thangamani et al. (2011) observed that the parents Preethi, CO-1, MC-30, Uchha Bolder, Green Long, MC-105 had highly significant and positive GCA effects for yield per vine, fruit weight, fruit length and fruit diameter in bitter gourd. Mishra and Singh (2018) noted that US-33 was the best general combiner for yield, fruit weight and fruit size in a five line and two testers cross in bitter gourd. The variety VNR-22 had the highest number of fruits per plant and consistent values of GCA effects followed by VNR-28 and MC-84.

3.1. Specific combining ability effects (SCA)

The SCA effects signify the role of non-additive gene action in the expression of the characters. It indicates the highly specific combining ability leading to highest performance of some specific cross combinations. That is why it is related to a particular cross. High SCA effects may arise not only in crosses involving high combiners but also in those involving low combiners. Thus in practice, some of the low combiners should also be accommodated in hybridization program. The SCA effects of 15 F_1 crosses for 19 characters studied are presented in Table 3a, 3b and 3c.

Out of the 15 F_1s, six showed negative SCA values (Table 3a) indicating that there was considerable heterosis for this character and at least 40% of the hybrids flowered earlier than the means of their parents. Out of the crosses, four crosses showed highly significant negative SCA values with the largest negative values in crosses P_2 x P_6 (-2.94**), P_3 x P_5 (-2.07**), P_1 x P_3 (-1.55*), P_5 x P_6 (1.26*) and was the best specific combiner for early flowering. While the crosses P_4 x P_6 (3.78**) and P_1 x P_5 (2.02**) showed significant positive SCA effect which produced later flowering than their mean value.

The highest significant and positive SCA effects for this trait was exhibited by the cross P_4 x P_6 (3.02**). The other combinations showing significant and positive SCA effects were P_3 x P_5 (2.59**), P_4 x P_5 (2.48**) and P_2 x P_3 (1.78*). The cross combination P_2 x P_5 showed highest and negative SCA effects (-2.94**). Thus the cross, P_2 x P_5 was the best specific combination for this trait because flower in lower node is desirable.

Out of the 15 F_1s, seven showed negative SCA values indicating that these hybrids produced early female flower than the mean of the better parent. The highest positive significant SCA value was obtained from hybrid P_1 x P_5 (3.30*) followed by P_3 x P_4 (2.69*) and P_2 x P_5 (2.61*), which delayed the female flowering. So, P_1 x P_2 (-2.65*) and P_3 x P_5 (-2.17*) was the best specific combination for early flowering and fruiting (Table 3a).

Table 3a. Estimates of SCA effects of crosses for days to flower and growth characters in six bitter gourd genotypes.

Crosses	Days to first male flower opening	Node number of first male flower	Days to first female flower opening	Node number of first female flower	Main vine length (m)	No. of primary branches per vine	No. of nodes per main vine (no.)
P_1xP_2	0.93	0.63	-2.65*	-2.79*	-0.14	0.30	-0.28
P_1xP_3	-1.55*	-0.36	-1.57	-2.43**	-0.25	0.19	-2.60
P_1xP_4	-0.01	-0.23	0.30	0.93	0.38**	-0.02	-0.49
P_1xP_5	2.02**	0.03	3.30**	0.72	-0.43*	0.21	-7.01**
P_1xP_6	-0.60	0.10	-0.27	3.50**	-0.16	-0.67**	-0.38
P_2xP_3	0.83	1.78*	0.91	-1.20	-0.17	-0.26	-6.08*
P_2xP_4	0.70	0.67	-0.06	0.19	-0.002	-0.71**	-1.79
P_2xP_5	0.85	-2.94**	2.61*	0.32	0.35*	-0.07	3.09
P_2xP_6	-2.94**	-0.92	-1.30	-0.30	0.31	0.81**	5.03*
P_3xP_4	1.31*	1.00	2.69*	0.54	-0.09	0.16	-0.35
P_3xP_5	-2.07**	2.59**	-2.17*	3.23*	0.18	-0.08	3.63
P_3xP_6	0.72	0.36	0.87	-2.08*	0.19	0.35	1.41
P_4xP_5	0.46	2.48**	-0.69	0.40	0.16	-0.05	4.37
P_4xP_6	3.78**	3.02**	2.53*	2.67*	-0.10	0.15	0.35
P_5xP_6	-1.26*	-0.72	0.07	-0.70	-0.26	-0.09	-2.69
SE(sij)	0.54	0.65	0.99	0.73	0.15	0.17	2.31

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

Table 3b. Estimates of SCA effects of crosses for fruit yield and fruit characters in six bitter gourd genotypes.

Crosses	Characters						
	Number of fruits per vine (no.)	Av. Single fruit weight (g)	Fruit yield per vine (kg)	Fruit length (cm)	Fruit diameter (cm)	Thickness of fruit flesh (mm)	Thickness of fruit rind (mm)
$P_1 \times P_2$	0.47	7.03*	-0.19**	-0.43	0.18	1.91*	0.47
$P_1 \times P_3$	-0.38	19.07**	0.11**	0.96*	-0.23	-1.92*	-0.08
$P_1 \times P_4$	-0.63	-0.65	0.23**	0.81*	-0.003	0.27	-0.22
$P_1 \times P_5$	-2.86**	10.69*	-0.22**	0.54	-0.08	-1.80*	0.26
$P_1 \times P_6$	0.21	-7.18*	-0.01	-0.14	0.04	0.63	-0.14
$P_2 \times P_3$	-2.97**	12.31**	-0.15**	1.08*	-0.19	-2.21	0.17
$P_2 \times P_4$	3.57**	1.38	0.15**	-0.21	-0.02	-0.21	0.28
$P_2 \times P_5$	2.63**	-22.67**	-0.02	0.56	-0.06	-0.31	-0.42
$P_2 \times P_6$	-0.17	2.05	0.10**	-1.25*	-0.09	-0.78	-0.10
$P_3 \times P_4$	0.32	-8.05*	-0.13**	-0.11	-0.11	-0.85	0.03
$P_3 \times P_5$	2.47**	14.52**	0.35**	-0.23	0.44	2.82**	0.01
$P_3 \times P_6$	0.32	-19.66**	-0.02	-1.66*	0.13	0.63	0.46
$P_4 \times P_5$	-2.19**	4.16	-0.04	0.62	-0.01	-0.04	0.31
$P_4 \times P_6$	2.66**	1.83	0.14**	0.40	0.15	1.13	0.02
$P_5 \times P_6$	-0.16	-4.56	-0.10**	0.36	-0.20	-1.17	-0.32
SE(sij)	0.60	2.73	0.02	0.59	0.12	0.79	0.34

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

Table 3c. Estimates of SCA effects of crosses for days to maturity and seed characters in six bitter gourd genotypes.

Crosses	Character				
	Days to green fruit maturity	Days to seed fruit maturity	Number of seed per fruit	Seed weight per fruit (g)	100-seed weight (g)
$P_1 \times P_2$	-0.22	-0.23	2.91**	0.44*	-0.05
$P_1 \times P_3$	-0.73	-0.04	-0.57	-0.36*	-1.65**
$P_1 \times P_4$	1.07	-0.25	-4.24**	0.42*	1.21**
$P_1 \times P_5$	-0.97	0.77	0.50	-0.11	-1.08*
$P_1 \times P_6$	-0.30	0.70	1.25*	0.02	-0.08
$P_2 \times P_3$	-1.58*	-0.55	-2.16*	-0.19	1.09*
$P_2 \times P_4$	-0.05	0.47	-1.47*	-0.21	-0.26
$P_2 \times P_5$	1.22*	-1.05*	3.08**	0.54**	0.13
$P_2 \times P_6$	0.97	-0.16	-1.80*	-0.19	0.65
$P_3 \times P_4$	1.06	-0.32	1.89*	0.09	-1.12**
$P_3 \times P_5$	0.57	0.86	-1.01*	-0.13	0.24
$P_3 \times P_6$	0.79	-0.41	2.19**	0.30	0.47
$P_4 \times P_5$	-0.62	-0.24	0.08	-0.06	0.33
$P_4 \times P_6$	-0.09	0.42	0.81	0.53**	1.61**
$P_5 \times P_6$	-1.30*	-0.28	-3.56**	-0.71**	-1.09**
SE(sij)	0.52	0.41	0.47	0.17	-0.38

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

The cross combinations, $P_1 \times P_6$ (3.50 **) followed by $P_3 \times P_5$ (3.23**) and $P_4 \times P_6$ showed maximum significant and positive SCA effect for this trait which is undesirable.

On the other hand, $P_1 \times P_2$ (-2.79*) followed by $P_1 \times P_3$ (-2.43**) and $P_3 \times P_6$ (-2.08*) showed significant negative heterosis than the mean of the better parent. So cross

combination which had negative SCA value is the best for improving this trait.

Among the cross combinations about 60% F_1s showed negative SCA values for this trait (Table 3a). This indicates that these F_1s produced shorter vine compared to the mean of the better parents. Most of the negative SCA value was insignificant except one P_1 X P_5 (-0.43*). Rest five crosses showed positive SCA value but two was significant.

SCA value of the three crosses (one positive and two negative) was significant among the 15 crosses. In other 12 combinations, six showed positive and six showed negative but insignificant SCA effect. So the cross P_1 X P_6 (0.67**) was the best for this trait.

Among the cross combinations, P_2 x P_6 (5.03**) showed the highest significant and positive SCA effect for this character followed by P_4 x P_6, P_3 x P_5 and P_2 x P_5. On the other hand, the cross P_1 x P_5 showed the highest significant and negative SCA effect (7.01) followed by P_2 x P_3 (-6.08*), P_5 x P_6 (-2.69) and P_1 x P_3 (-2.60) (Table 3a). Thus, the combination P_2 x P_6 may be considered as the best specific combiner to enhance the nodes on main vine.

Out of the 15 F_1s, eight showed the positive and six showed the negative SCA values (Table 3a). Among the cross combinations, P_2 x P_4 (3.57**) showed the highest significant and positive SCA effects for this character followed by P_4 x P_6, P_2 x P_5 and P_3 x P_5. On the other hand, the cross P_2 x P_3 (-2.97**) showed the highest significant but negative SCA effects for this trait followed by P_1 x P_5 (-2.86**) and P_4 x P_5 (-2.19**). Other combinations showed insignificant values for this parameter. Hence, the cross combination P_2 x P_4 was the best specific combiner to increase number of fruits per vine (Table 3b)

The cross combination P_1 x P_3 (19.07**) exhibited the highest significant and positive SCA effect followed by P_3 x P_5 (14.52**) and P_2 x P_3 (12.31**) for average single fruit weight. Significant and positive moderate values for this parameter were obtained from combinations P_1 x P_5 and P_1 x P_2. On the other hand, P_2 x P_5 showed the highest negative SCA effect (-22.67**) followed by the cross P_3 x P_6 (-19.66**), P_3 x P_4 (-8.05**). The crosses P_2 x P_4, P_2 x P_6, P_4 x P_5 and P_4 x P_6 showed positive but insignificant SCA effect. Hence, P_1 x P_3 was the best specific combinations to increase the average single fruit weight but P_1 x P_2 and P_1 x P_5 was the best combinations if we desire moderate average single fruit weight.

The cross combination P_1 x P_3, P_1 x P_4, P_2 x P_4, P_2 x P_6, P_3 x P_5 and P_4 x P_6 exhibited significant and positive SCA effects of which P_3 x P_5 provided maximum value (0.35**) for the parameter fruit yield per vine (kg) (Table 3b). The other combination showed the negative significant or insignificant SCA effects. Thus, P_3 x P_5 was the best specific combination followed by P_1 x P_4 and P_2 x P_4.

Among 15 F_1 hybrids, only three revealed significant and positive SCA values for this trait. The combination P_2 x P_3 (1.08**) exhibited the highest significant and positive value followed by P_1 x P_3 (0.96*) and P_1 x P_4 (0.81*). The combination of P_3 x P_6 (-1.66*) showed highest significant and negative values for this trait followed by P_2 x P_6. Here, five combinations showed insignificant positive values and five combinations showed insignificant negative values.

Hence, the cross combination P_2 x P_3 was the best specific combination to get longest fruit in this crop.

All the crosses showed insignificant SCA effect but among them five were positive and ten was negative. There was less scope of changing the trait in this crop.

The highest significant and positive SCA effect for this trait was provided by the cross P_3 x P_5 (2.82**) followed by P_1 x P_2. The cross P_1 x P_3 provided the highest significant and negative SCA effect (-1.92**) followed by P_1 x P_5. Other combinations showed insignificant positive and negative values for the trait. Thus, P_1 x P_3 was the best combination for reducing the fruit flesh thickness which is desirable.

There was no significant positive or negative SCA value for this trait. Out of 15 F_1s, nine showed positive and six showed negative SCA values. So, there was less scope of changing the trait in this crop. Only three crosses showed significant SCA values, the cross combinations P_2 x P_5 showed significant positive value (1.22*), on the other hand, the crosses P_2 x P_3 (-1.58*) and P_5 x P_6 (-1.30*) showed negative significant value. Hence, the cross showing negative SCA value was the best cross for improving this trait. So, the cross combinations P_2 x P_3 and P_5 x P_6 provided opportunity for early maturity in this crop (Table 3c)

Nine crosses showed the negative SCA effect, but the only one cross (P_2 x P_5) was significant. Other six crosses showed insignificant positive SCA effects for this trait. So, this cross combination P_2 xP_5 was the best because it provides opportunity to early seed fruit maturity in this crop.

The cross combination P_2 x P_5 provided maximum value of the parameter followed by P_1 x P_2, P_3 x P_6, P_3 x P_4 and P_1 x P_6. On the other hand, cross P_1 x P_4 showed the highest negative significant value (-4.24**) followed by P5 x P_6, P_2 x P_3, P_2 x P_6, P_2 x P_4 and P_3 x P_5. The remaining four cross combinations had the insignificant SCA effect. Hence, the cross with high negative significant SCA effect, such as P_1 x P_4, P_5 x P_6, P_2 x P_3 was considered as the best specific combiner for less seeded fruit development.

Highest significant and positive SCA effects were observed in seed weight per fruit by the combination P_2 x P_5 (0.54**) followed by P_4 x P_6 (0.53**), P_1 x P_2 (0.44**). On the other hand, the highest negative significant SCA effect was observed by the crosses P_5 x P_6 (-0.71**) followed by P_1 x P_3 (-0.36**), P_1 x P_4 (0.42*). Remaining nine crosses provided insignificant positive or negative SCA effect. Thus crosses P_5 x P_6, P_1 x P_3 and P_1 x P_4 was the best combinations for fruit development which contain small size fruit considering the weight (Table 3c).

Out of 15 F_1s, seven crosses had significant positive or negative SCA value in 100-seed weight. The cross P_4 x P_6 showed the highest significant and positive value (1.61**) followed by P_1 x P_4 and P_2 x P_3. On the other hand, the cross combination P_1 x P_5 (-2.72**) showed the highest significant and negative value followed by P_3 x P_4 and P_5 x P_6. Thus, the crosses P_1 x P_5, P_3 x P_4 and P_5 x P_6 were the best combinations for developing fruit which contain lesser weight of seed.

Based on SCA effects, the cross combination P_1 x P_3 was found superior for node number of first female flower, average single fruit weight, fruit yield per vine, fruit length, thickness of the fruit flesh, seed weight per fruit and 100

seed weight. The cross P_1 x P_2 was found better for the characters days to first female flower and node number of first female flower. The cross combination P_3 x P_5 was best for most of the characters which were days to first male and female flower, node number of first female flower, number of fruits per vine, average single fruit weight and fruit yield per vine. The cross P_2 x P_4 may be selected for the number of fruits per vine and fruit yield per vine. Ahsan et al. (2011) reported that among the six diallel cross in snake gourd P_1 xP_5 had significant SCA effects for days to first male and female flower opening with longest vine. The crosses P_2 x P_3 for earliness and P_1 x P_2 for weight of fruits per plant fruit length and 100-seed weight. The cross P_3 x P_6 was the best for total fruits per plant. Devi et al. (2017b) observed that the cross combinations L2xT3, L7xT2, L2xT4, L5xT1 and L8xT4 exhibited high SCA effects for yield per plant and fruits per plant in snake gourd. Bahari et al. (2012) noted that specific combining ability accounted for a greater portion of the variability among crosses for vine length, number of fruits per plant and fruit weight in watermelon. Malve et al. (2021) reported that four parental lines of bitter gourd crosses viz., P1 x P2 (Phule Green Gold x Preethi), P2 X P5 (Preethi x DVBTG-7), P1x P3 (Phule Green Gold x Arka harit) and P6 x P7 (Hirkani x Konkan Tara) recorded high positive SCA effect as well as high mean performance for most of the characters. Jasim and Esho (2021) stated that the cross combination Kabak Sakiz x Mulla ahmad prolific had higher estimates of SCA for number of fruits as well as yield per plant in summer squash. They also reported that the cross vegetable Marrow

x E.C. 33683 had the highest number of branches. Rani and Reddy (2017) observed the best specific combiners for vine length, days to first male and female flower, fruit length and girth were Arka Bahar x Pusa Summer Prolific Long, Arka Bahar x IC-92330, Arka Bahar x Tirupati local, Pusa Summer Prolific Long x Pratik, Pratik x IC-92330 and Pratik x Tirupati local, respectively, in bottle gourd. Napolitano et al. (2020) indicated that the combination PI414723 or PI161375 was the best specific combiner for yield per plot in melon (*Cucumis melo* L.)

3.2. Reciprocal effects

The reciprocal effects (rij) of 15 F_1 crosses for nineteen different characters studied are presented in Table 4, 5 and 6. The entire reciprocal cross performed better in some cases better than SCA effect. For that character wise reciprocal effect has been discussed in the following manner.

3.3. Days to first male flower opening

Highly significant and negative reciprocal effect was exhibited by the cross P_3 x P_1 (-4.42**) followed by the crosses P_5 x P_4 (-3.92**), P_5 x P_1 (-3.83*), P_5 x P_2 (-3.45*), and P_6 x P_2 (-1.42*). The only one cross P_4 x P_3 showed the significant positive reciprocal effect (1.69*). Rest of the crosses had insignificant positive or negative effect. Negative significant reciprocal effect is desirable in this case because it provides opportunity for promoting early flowering in this crop (Table 4).

Table 4. Estimates of reciprocal effects in 15 crosses for days to flower and growth characters in bitter gourd.

Crosses	Characters						
	Days to first Male flower opening	Node number of first male flower	Days to first female flower opening	Node number of first female flower	Main vine length (m)	No. of primary branches per vine	No. of nodes per main vine (no.)
P_2xP_1	1.33	1.50	-1.11	-3.08**	0.07	-0.11	-2.06
P_3xP_1	-4.42**	0.75	-4.00**	0.86	0.43**	0.28	7.81*
P_4xP_1	0.58	3.67	1.50	5.00**	0.23	-0.45**	4.04
P_5xP_1	-3.83**	0.67	-1.67	0.67	-0.003	-0.55**	-0.36
P_6xP_1	0.14	-0.47	-1.58	1.08	0.16	0.42	0.96
P_3xP_2	-0.92	-0.75	-0.33	1.17	-0.27	0.31	-1.75
P_4xP_2	-0.75	0.25	0.67	2.00**	0.39*	-0.28	5.33
P_5xP_2	-3.45**	1.28	-6-.61	-0.33	-0.66*	-0.43	3.83
P_6xP_2	-1.42*	0.03	-0.58	0.86	0.18	-0.42	-1.13
P_4xP_3	1.69*	0.06	1.11	0.00	0.37*	-0.30	0.25
P_5xP_3	-0.92	-0.17	-2.69*	-1.45	0.70**	0.39	10.55**
P_6xP_3	0.14	-1.45	-3.83**	-3.11**	-0.15	-0.32	-3.39
P_5xP_4	-3.92**	-2.50**	-4.92**	0.50	0.11	0.15	-4.08
P_6xP_4	-1.50	1.33	-1.53	0.58	0.06	0.08	-0.50
P_6xP_5	1.17	1.50	-0.83	0.25	0.05	0.33	3.08
SE (rij)	0.64	0.77	1.17	0.86	0.17	0.20	2.71

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

Table 5. Estimates of reciprocal effects in 15 crosses for fruit yield and fruit characters in bitter gourd.

Crosses	Characters						
	Number of fruits per vine (no.)	Av. Single fruit weight(g)	Fruit yield per vine (kg)	Fruit length (cm)	Fruit diameter (cm)	Thickness of fruit flesh (mm)	Thickness of fruit rind (mm)
P_2xP_1	-2.15**	20.51**	0.07*	1.50**	-0.03	0.25	-0.28
P_3xP_1	2.42**	-4.18	0.27**	-0.86	0.63**	0.84	0.21
P_4xP_1	-0.46	5.46	0.10**	0.37	-0.16	-1.82*	0.05
P_5xP_1	-0.36	-0.58	-0.07*	-1.23	-0.21	0.95	-0.02
P_6xP_1	-0.42	13.61**	0.13**	-1.20	-0.27	0.41	-0.19
P_3xP_2	0.75	-16.63**	-0.01	-0.07	-0.33*	1.85*	0.20
P_4xP_2	0.00	-0.54	-0.002	1.94	0.08	-0.83	-0.09
P_5xP_2	-3.45**	4.79	-0.23**	0.37	-0.08	-0.86	-0.22
P_6xP_2	-2.54**	3.46	-0.32**	1.04	-0.05	-0.39	-0.14
P_4xP_3	-5.92**	10.88**	-0.23**	0.70	0.10	1.33	-0.44
P_5xP_3	1.56*	-4.76	0.18**	2.06**	-0.28	-2.49**	-0.49
P_6xP_3	1.78*	-18.61**	-0.13**	0.05	0.12	0.43	0.48
P_5xP_4	3.50**	-20.46**	0.13**	-0.03	-0.43**	-3.16**	-0.55**
P_6xP_4	3.00**	-7.53*	0.06*	-1.73	0.06	1.06	-0.25
$P_6 xP_5$	1.67*	7.39*	-0.16**	-0.59	0.26	1.00	0.38
SE (rij)	0.70	3.22	0.03	0.69	0.14	0.79	0.24

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

Table 6. Estimates of reciprocal effects in 15 crosses for days to maturity and seed characters in bitter gourd.

Crosses	Character				
	Days to green fruit maturity	Days to seed fruit maturity	Number of seed per fruit	Seed weight per fruit (g)	100-seed weight (g)
P_2xP_1	-0.29	1.39*	7.43**	1.02**	-0.16
P_3xP_1	0.17	0.39	2.07**	0.55*	1.30
P_4xP_1	-1.42*	-0.44	1.69**	0.37	0.20
P_5xP_1	0.80	-0.33	1.34*	0.31	0.56
P_6xP_1	0.74	-0.04	5.47**	0.41	-2.68**
P_3xP_2	0.18	1.11	0.75	0.28	1.22*
P_4xP_2	1.13	0.85	-1.29*	-0.26	-0.38
P_5xP_2	-0.06	-1.66*	2.08**	0.44*	0.25
P_6xP_2	2.37**	0.12	-1.47**	-0.28	-0.19
P_4xP_3	-0.33	0.74	0.38	0.05	-0.04
P_5xP_3	-1.52*	-0.95	-4.64**	-0.56*	0.61
P_6xP_3	0.34	0.17	-0.59	-0.26	-1.38**
P_5xP_4	0.38	-1.37*	-2.75**	-0.19	1.67**
P_6xP_4	0.48	-0.70	4.49**	0.92**	1.18*
P_6xP_5	0.90	-0.94	-0.43	-0.50*	-2.67**
SE(rij)	0.62	0.48	0.55	0.20	0.45

*Significant at 5% level of probability; **Significant at 1% level of probability. Non-strike means non-significant up to 5% level of probability.

3.4. Node number of first male flower

All reciprocal crosses showed insignificant negative or positive reciprocal effect except one. The cross $P_5 x P_4$ showed significant and negative reciprocal value (-3.92**), which was desirable for improving this character because it provided male flower in lower node.

3.5. Days to first female flower opening

The cross combination P_5 x P_4 showed ×highly significant and negative reciprocal value (-4.92**) followed by P_3 x P_1 (-4.00**), P_6 x P_3 (-3.83**) and P_5 x P_3 (-2.69*) for the character days to first female flower opening, other crosses had positive or negative reciprocal effects (Table 4). No cross had significant positive reciprocal effect. It was good for improving this trait. Early female flowering is desirable. So the crosses which had negative significant reciprocal effect were the best for improving this trait.

3.6. Node number of first female flower

Out of the 15 reciprocal crosses, only four showed significant reciprocal effects (two showed positive and two showed negative) (Table 4). The cross combinations, P_4 x P_1 (-3.11**), P_4 x P_2 (2.00**) showed positive and P_6 x P_3 (-3.11**) and P_2 x P_1 (-3.08**) showed negative reciprocal effect. Other crosses were insignificant. For improving this trait crosses P_6 x $P_{3\,and}$ P_2 x P_1 were the best because this two crosses provided female flower in lower node.

3.7. Main vine length (m)

The cross combination P_5 x P_3 exhibited maximum significant and positive reciprocal effect (0.70**) followed by P_3 x P_1 (0.43**), P_4 x P_2 (0.39*) and P_4 x P_3 0.37**) (Table 4). Only one cross combination P_5 x P_2 showed negative reciprocal effect significantly. This indicates that this cross provides shorter vine length than their parents. Rest of the crosses had insignificant positive (seven) or negative (three) reciprocal value.

3.8. Number of primary branches per vine

Among the cross combinations only two crosses P_5 x P_1 (-0.55**) and P_4 x P_1 (-0.45**) were negatively significant for reciprocal effects of number for primary branches per vine. Other crosses had positive or negative insignificant Reciprocal value.

3.9. Number of nodes per main vine (no.)

The highest significant positive value of reciprocal effects for this character were manifested by P_5 x P_3 (10.55**) followed by P_3 x P_1 (7.81*) (Table 4). Rest of the crosses was positively or negatively insignificant. Hence, the cross combination P_5 x P_3 was the best reciprocal combination to enhance the nodes on main vine.

3.10. Number of fruits per vine (no.)

Among the cross combinations, P_5 x P_4 (3.50**) showed the highest significant and positive reciprocal effect followed by P_6 x P_4 (3.00*), P_3 x P_1 (2.42**), P_6 x P_3 (1.78*), P_6 x P_5 (1.67**), and P_5 x P_3 (1.56*). On the other hand the cross P_4 x P_3 (-5.92**) had the highest significant negative reciprocal effect followed by P_5 x P_2 (-3.45**) and P_6 x P_2 (-2.54**). Rest of the five crosses had insignificant positive or negative reciprocal value (Table 5). Thus the reciprocal cross combination P_5 x P_4 was the best combination to increase the number of fruits per vine followed by P_6 x P_4 and P_3 x $P_1.$

3.11. Average single fruit weight (g)

Out of the 15 reciprocal cross combinations the crosses P_2 x P_1 (20.51**) exhibited the highest significant and positive reciprocal effects for average single fruit weight followed by P_6 x P_1 (13.61**), P_4 x P_3 (10.88**), and P_6 x P_5 (4.39*). On the other hand, the cross P_5 x P_4 showed the highest significant but negative Rec. effects (-20.46**) followed by P_6 x P_3 (-18.61**), P_3 x P_2 (-16.33**) and P_6 x P_4 (-7.55*) (Table 5). The F1 of P_2 x P_1 was the best for maximum weighted fruit and P4 x P_3 was the best reciprocal combination for moderate weighted fruit.

3.12. Fruit yield per vine (kg)

Among the cross combinations, P_3 x P_1 (0.27**) exhibited the highest significant and positive reciprocal effects for this trait followed by P_5 x P_3, P_6 x P_1 and P_5 x P_4 (Table 5). On the other side, the cross P_6 x P_2 (-0.32) showed the highest but negative reciprocal effect followed by P_4 x P_3, P_5 x P_2 and P_6 x P_3. Hence, P_3 x P_1 was the best for reciprocal combinations for increasing the fruit yield per vine.

3.13. Fruit length (cm)

Most of reciprocal crosses showed insignificant positive or negative reciprocal effects. Only two crosses P_2 x P_1 and P_5 x P_3 exhibited the positively significant reciprocal effects for this character. Thus, the cross combination P_2 x P_1 was the best for reciprocal combination to increase the fruit length in this crop.

3.14. Fruit diameter (cm)

Only three crosses provided significant (one was positive and two was negative) reciprocal effects (Table 5). Other crosses had positive or negative insignificant reciprocal value. Considering the findings of the character, cross P_5 x P_4 was the best for reducing the diameter of the fruit in this crop.

3.15. Thickness of the fruit flesh (mm)

The cross combination P_5 x P_4, P_5 x P_3, and P_4 x P_1 exhibited significant and negative reciprocal effects of which P_5 x P_4 provided the maximum negative value (-3.16**) for the parameter thickness of the fruit flesh (Table 5). Only one reciprocal cross P_3 x P_2 (1.85*) showed significant and positive reciprocal effect (Table 5). Hence, the P_5 x P_4 was the best reciprocal cross for reducing the thickness of the fruit flesh which is desirable.

3.16. Thickness of fruit rind (mm)

All of the reciprocal crosses were insignificant except one, which was P_5 x P_4 but had negative value (-0.55**), is not desirable. So there was no chance for improving the thickness of the fruit rind effectively.

3.17. Days to green fruit maturity

The cross combination P_6 x P_2 showed the highest significant and positive reciprocal effect (2.37**), while significant and negative value for this trait was obtained from P_5 x P_3 (-1.52*) and P_4 x P_1 (-1.42*). Rest twelve crosses

had insignificant positive or negative reciprocal value. Hence, the cross combination P_5 x P_3 and P_4 x P_1 provided opportunity for early maturing in this crop (Table 6).

3.18. Days to seed fruit maturity

Only one cross P_2 x P_1 (1.39*) showed positive significant reciprocal effect for days to seed fruit maturity. On the other hand two crosses P_5 x P_2 (-1.66*) and P_5 x P_4 (-1.37*) exhibited negatively significant reciprocal effect. Other crosses were insignificant positive or negative reciprocal effect. Thus the reciprocal cross combination P_5 x P_2 and P_5 x P_4 provides opportunity for early seed fruit maturity in this crop (Table 6).

3.19. Number of seed per fruit

Highest significant and positive Rec. effects was observed in the combination P_2 x P_1 (7.43**) followed by P_6 x P_4 (4.49**), P_5 x P_2 (2.08**), and P_3 x P_1 (2.07**). Whereas the highest negatively significant reciprocal effect (-4.46**) was obtained by the cross P_5 x P_3, which was followed by P_5 x P_4 (-2.75**) and P_6 x P_2 (-1.47**). So, reciprocal cross P_5 x P_3 considered the best reciprocal cross combination for less seeded type fruit development in this crop as less seeded type fruit is more preferable (Table 6)

3.20. Seed weight per fruit (g)

In Table 5 the cross combination P_2 x P_1 (1.02**) provided maximum reciprocal value of the parameter followed by P_6 x P_4, P_3 x P_1 and P_5 x P_2. But the cross P_5 x P_3 (-0.56*) showed the negatively highest significant reciprocal effect followed by P_6 x P_5 (-0.50*). Remaining cross combinations showed non-significant positive or negative reciprocal effects. Thus the reciprocal cross combination P_5 x P_3 and P_6 x P_5 were superior considering the small seeded type fruit development.

3.21. 100-seed weight (g)

The reciprocal cross combination P_5 x P_4 indicated the maximum reciprocal effect (1.67*), which was followed by P_6 x P_4 (1.18*) and P_3 x P_2 (1.22*). On the other hand the cross combination P_6 x P_1 provided the maximum significant but negative reciprocal effect (-2.68**) followed by P_6 x P_5 (-2.67**) and P_6 x P_3 (-1.38**). Rest reciprocal cross combinations were non-significant (Table 6). Hence, the reciprocal cross combinations P_6 x P_1, P_6 x P_5 and P_6 x P_3 were the better for developing fruit which contained lesser weight of seed.

Considering the reciprocal effect of the all 19 characters studied, it may be said that characters having significant reciprocal effect indicated the controlled genes also present in the cytoplasm. Earlier, similar type of result was reported by Khan et al. (2016) in snake gourd. Shukla et al. (2014b) reported significant reciprocal effect for seeds per fruit and 100-seed weight in bitter gourd. Similar findings were also reported by Nyadanu et al. (2017) in brinjal.

4. Conclusions

Combining ability studies involving 6 x 6 full diallel crosses indicated both additive and non-additive gene action in the expression of different characters. Additive gene action was found to be predominant. The genotype BG 009 was the best general combiner for promoting earliness. Genotype BG 006 was good for promoting earliness as well as most other important characters, namely, number of fruits per vine, average single fruit weight and fruit yield per vine. BG 027 was the best for female flower at lower node. BG 036 was best for main vine length, number of primary branches per vine and number of nodes per main vine. Significant SCA effects were displayed for early female flowering in crosses P_1xP_2 and P_3xP_5; fruits per vine in P_2xP_4, P_4xP_6, P_2xP_5 and P_3xP_5; average single fruit weight in P_1xP_3, P_3xP_5, P_2xP_3 and P_1xP_5. So, these are the important specific combinations which may be used for the improvement of the respective characters. Significant reciprocal effects were also observed in most important traits namely, days to first male and female flower (which is very desirable), number of fruits per vine, average fruit weight and fruit yield. Reciprocal crosses can be utilized for improvement of the desired traits.

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