

Chapter 4

RESULTS AND DISCUSSION

The present investigation was undertaken to finally select the most promising parental lines for hybrids development. Data obtained from the experiments were analyzed to select suitable parents, the best cross combinations, but beforehand studied phenotypic and genotypic correlation, path analysis, combining ability, heterosis, heritability and yield related traits. First of all, 27 inbred lines were evaluated then selected best 7 lines on the basis of ranking value through line x tester analysis and mean value of the inbred lines for diallel cross. Finally, the best crossing combinations from the selected parental lines were identified considering the positive significant for yield and yield contributing traits. Results of the present investigation are presented under the following heads and sub-heads –

4.1 Evaluation of inbred lines under study

4.1.1 Mean performance of parents

4.1.2 Selection of yield contributing traits based on trait association

4.2 Selection of parents based on genetic back ground utilizing Line x Tester analysis

4.2.1 Analysis of variance (ANOVA)

4.2.2 Selection of parents based on combined GCA and mean ranking

4.3 Genetic analysis of the selected parents based on diallel analysis

4.3.1 Analysis of variance (ANOVA) for combining ability

4.3.2 Estimation of GCA and SCA effects of the parents

4.4 Evaluation of experimental hybrids through heterosis study

4.4.1 Estimation of heterosis

4.1 Experiment I: Evaluation of inbred lines under study

4.1.1 Mean performance of parents

Analysis of variance of different characters of bitter gourd

Analysis of variances for yield and different yield contributing traits showed that the inbred lines differed significantly for all the characters under study (Table 4.1.1.1). The results indicated that the materials were genotypically divergent. Parents selected from these genetically different lines may be used in hybridization programs, which is likely to produce wide variability with high heterotic effect.

This result indicated that geographic distribution and genetic divergence did not follow the same trend, which might be due to continuous exchange of genetic materials among the countries of the world. So, the results, suggested that geographic isolation is not the only factor causing genetic diversity, but have different genetic architecture and this point should be considered in selecting parents for hybridization.

The mean performance for different characters of inbred lines for fruit yield and its components are presented in Table 4.1.1.2. The mean data for all the characters showed appreciable differences. The mean values of different inbred lines for 11 characters are shown in Table 4.1.1.2. The morphological view of 27 inbred lines of bitter gourd is shown in Figure 4.1.1.1 and graphical presentation for 11 characters of different inbred lines is shown in Figure 4.1.1.2.

Days to first female flower opening

The inbred line BT-1 showed the lowest mean value for days to female flower opening (28.23) followed by BT-15 (28.63), BT-5 (28.67), BT-23 (28.80), BT-2 (29.20), BT-22 (29.60) and BT-18 (29.67), respectively. These characters are needed for early type of variety development. Earliness is an important trait in a vegetable like bitter gourd. In present study, three characters related to earliness were observed *viz.*, days to opening first female flower, number of node bearing first female flower and days to first harvest.

Table 4.1.1.1 Analysis of variance (ANOVA) for yield and yield contributing traits in 27 of bitter gourd

Source of variation	Df	First female flower opening	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Seeds per fruit	100-seed weight (g)	Yield per plant (kg)
Genotypes	26	16.33**	31.38**	19.24**	24.45**	4999.98**	70.51**	2.39**	86.61**	106.41**	12.29**	1.20**
Replication	2	0.31	0.107	0.10	0.26	1.16	0.20	0.01	0.80	0.24	0.07	0.02
Error	52	0.2720	0.31	0.17	0.22	0.90	0.04	0.02	0.31	0.23	0.07	0.01

*P<0.05, **P<0.01 respectively

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Number of node at which first female flower appeared

BT-5 showed the lowest mean (16.30) for number of node at first female flower appear followed by BT-1 (17.10), BT-7 (18.15), BT-8 (19.23), BT-14 (19.92), BT-06 (20.07) and BT-26 (20.64). Low mean value is desirable for this character that indicates early maturity symptoms. So, this character can be used for making early type variety.

Days to first edible fruit harvest

BT-5 was the most in advance regarding first harvestable fruit (38.80 days) followed by BT-4 (39.37days), BT-1 (40.20days), BT-2 (41.90 days), BT-15 (42.03 days), BT-8 (42.10 days) and BT-24 (42.30 days). This inbred can be used for variety development that can be harvested in the earliest.

Number of branches per plant

Maximum number of branches per plant were observed in BT-1 (21.13) followed by BT-2 (20.23), BT-03 (18.83), BT-04 (18.37), BT-27 (18.10), BT-09 (17.10) and BT-26 (16.93). May be of primary branch is another important growth parameter contributing for productivity (Table 4.1.1.2).

Table 4.1.1.2 Mean performance for eleven characters of 27 inbred lines of bitter gourd

Parents	First female flower opening	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Seeds per fruit	100-seed weight (g)	Yield per plant (kg)
BT-1	28.23	17.10	40.20	21.13	251.17	30.40	5.55	14.53	17.73	9.23	3.69
BT-2	29.20	26.93	41.90	20.23	178.83	25.70	5.83	14.13	33.93	15.13	2.47
BT-3	34.67	25.40	48.27	18.83	175.60	23.13	7.03	10.93	33.23	13.57	1.93
BT-4	32.03	23.47	39.37	18.37	147.80	15.95	7.00	19.70	28.23	13.23	2.86
BT-5	28.67	16.30	38.80	6.43	156.73	16.43	5.95	17.87	27.90	13.03	2.78
BT-6	29.72	20.07	42.47	16.10	213.33	22.45	6.70	11.50	35.50	12.70	2.45
BT-7	31.40	18.15	44.70	14.10	207.80	27.37	5.30	17.63	19.00	12.18	3.23
BT-8	30.90	19.23	42.10	11.80	187.20	23.09	6.55	18.10	29.20	14.40	3.10
BT-9	36.57	22.24	44.53	17.10	179.20	20.65	7.51	11.90	34.50	15.70	2.05
BT-10	32.17	23.00	43.63	19.17	167.30	26.13	5.20	13.83	24.03	13.33	2.25
BT-11	31.90	22.60	43.90	14.63	152.10	19.60	5.79	21.73	18.87	15.30	2.99
BT-12	31.60	27.70	42.57	14.40	219.70	24.78	7.31	14.30	35.90	15.00	3.12
BT-13	29.90	22.28	43.00	14.30	158.40	25.47	5.67	15.50	30.60	14.63	2.42
BT-14	32.90	19.92	43.90	14.43	164.87	23.00	6.61	19.37	31.10	12.43	3.01
BT15	28.63	21.11	42.03	15.40	236.87	24.75	7.80	15.97	25.50	10.07	3.37
BT-16	32.67	26.63	49.10	14.90	176.27	25.47	4.79	18.67	26.72	13.80	3.08
BT-17	37.27	28.07	49.23	14.90	127.73	18.07	5.88	10.30	21.53	12.43	1.32
BT-18	29.67	25.07	46.63	14.50	126.70	15.69	5.57	26.13	26.90	14.69	3.01
BT-19	30.70	25.13	43.10	16.30	160.03	31.24	4.86	15.80	21.90	14.50	2.52
BT-20	34.37	24.19	44.37	14.77	145.10	18.89	6.07	17.80	24.58	17.13	2.44
BT-21	32.03	23.07	43.13	13.90	147.90	16.83	5.62	11.93	26.87	15.43	1.72
BT-22	29.60	28.42	43.20	17.63	82.80	13.92	5.63	37.20	32.30	16.40	2.93
BT-23	28.80	22.82	45.40	16.27	111.87	24.78	4.70	16.57	27.33	11.33	1.81
BT24	32.13	21.09	42.30	15.63	150.37	17.27	6.81	16.17	31.77	15.80	2.48
BT-25	33.50	22.87	45.60	15.37	94.93	13.60	4.93	13.97	33.02	18.03	1.33
BT-26	31.70	20.64	43.70	16.93	106.13	25.87	4.91	14.30	18.44	15.30	1.51
BT-27	29.97	22.93	44.70	18.10	178.90	19.72	6.91	14.90	39.90	13.13	2.67



BT-01



BT-02



BT-03



BT-04



BT-05



BT-06



BT-07



BT-08



BT-09



BT-10



BT-11



BT-12

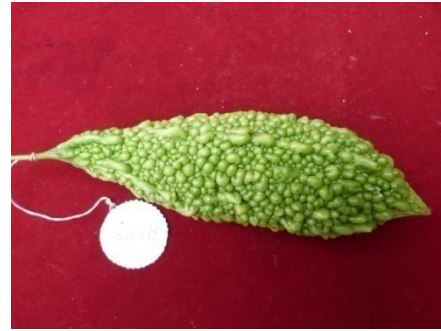
Figure: 4.1.1.1 Morphological view of different inbred lines of bitter gourd



BT-13



BT-14



BT-15



BT-16



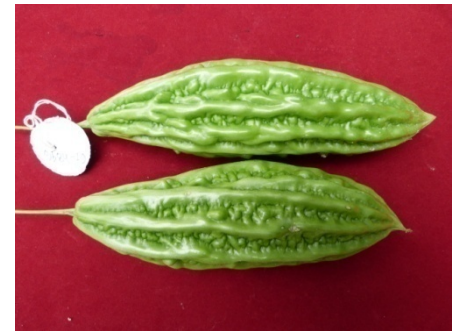
BT-17



BT-18



BT-19



BT-20



BT-21



BT-22



BT-23



BT-24

Figure: 4.1.1.1 Morphological view of different inbred lines of bitter gourd (continued)



BT-25



BT-26



BT-27

Figure: 4.1.1.1 Morphological view of different inbred lines of bitter gourd (continued)

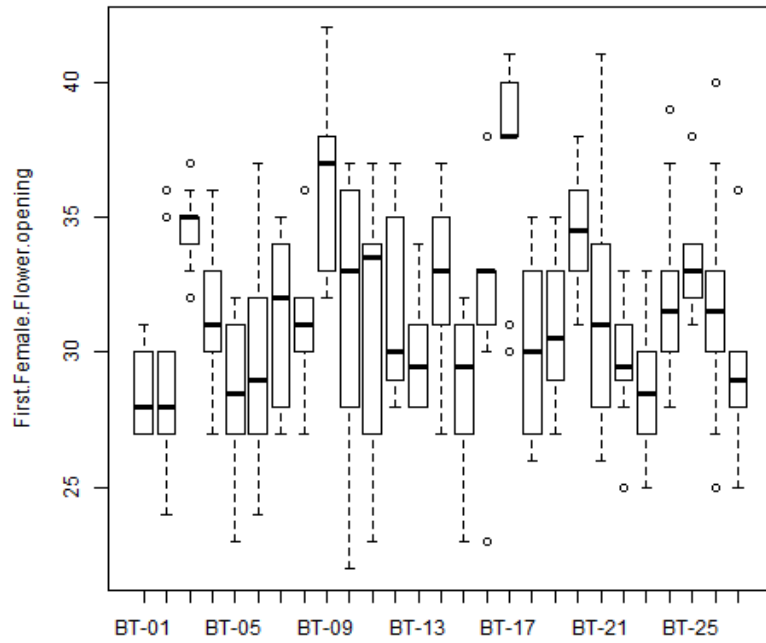


Figure 4.1.1.2a Box plots showing the distribution of data of first female flower opening

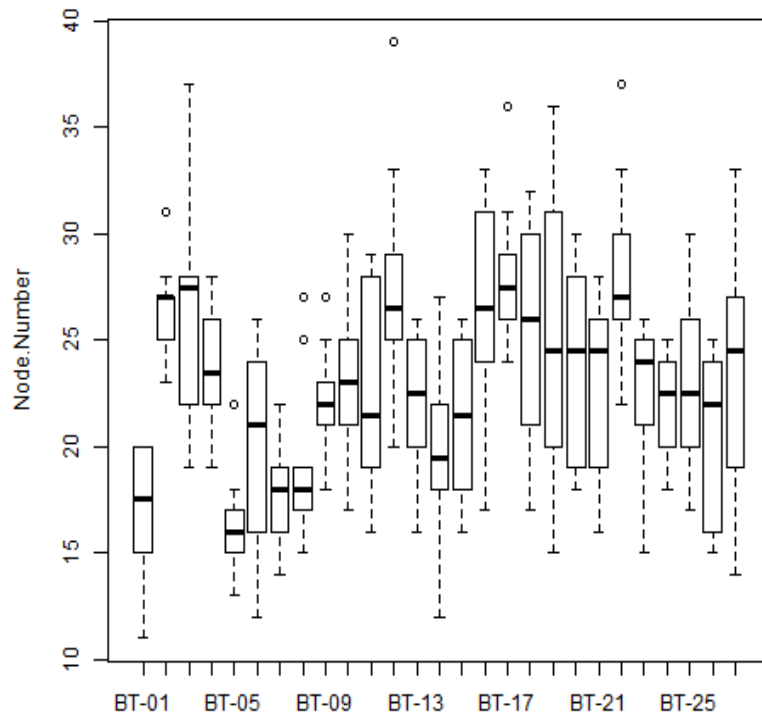


Figure 4.1.1.2b Boxplots showing the distribution of data of node number at which female flower open

Figure: 4.1.1.2 Graphical presentation for 11 characters of 27 inbred lines of bitter gourd

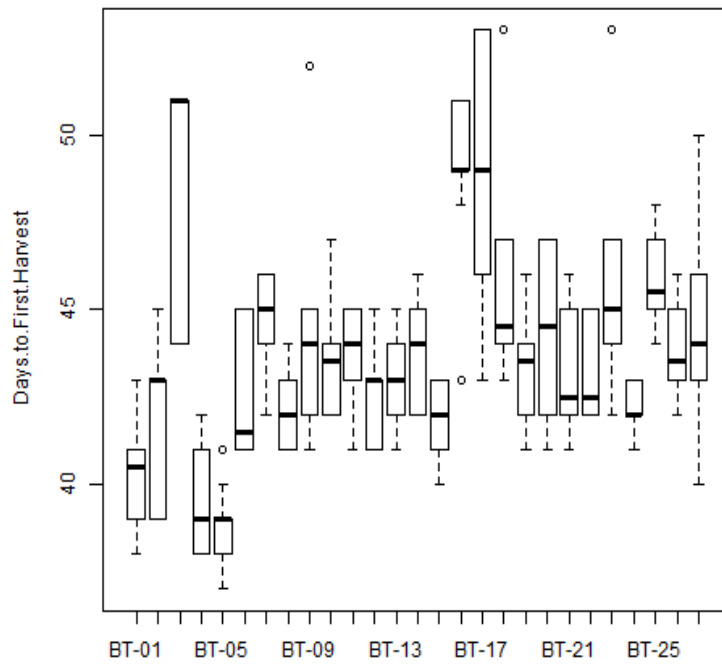


Figure 4.1.1.2c Box plots showing the distribution of data of days to first harvest

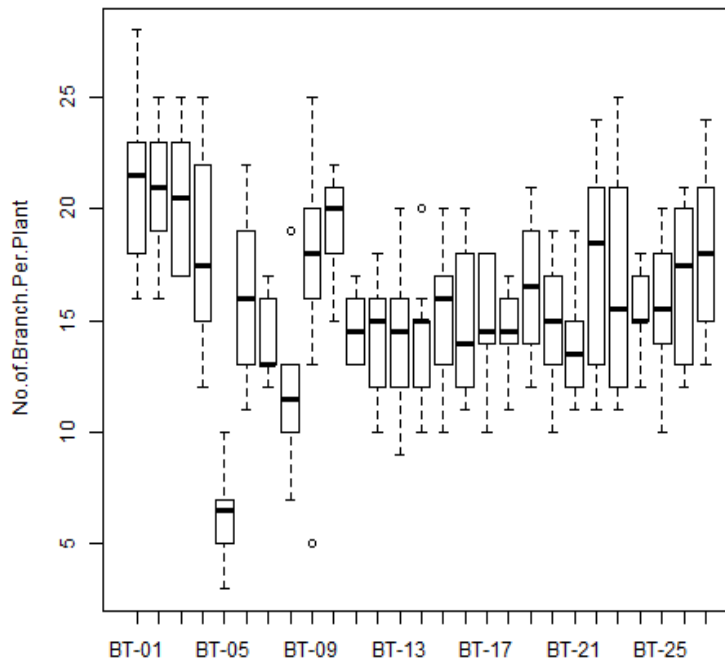


Figure 4.1.1.2d Box plots showing the distribution of data of number of branches per plant

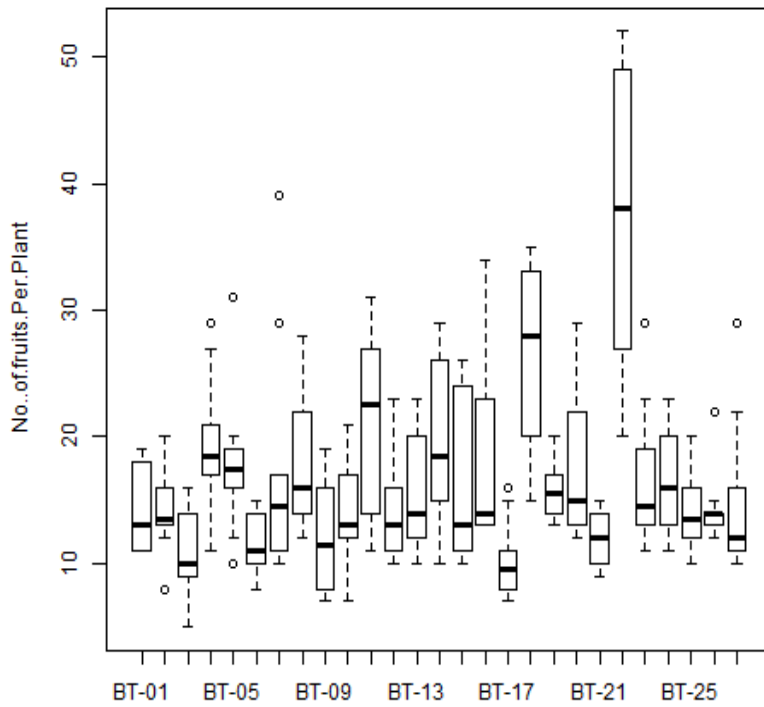


Figure 4.1.1.2e Box plots showing the distribution of data of number of fruits per plant

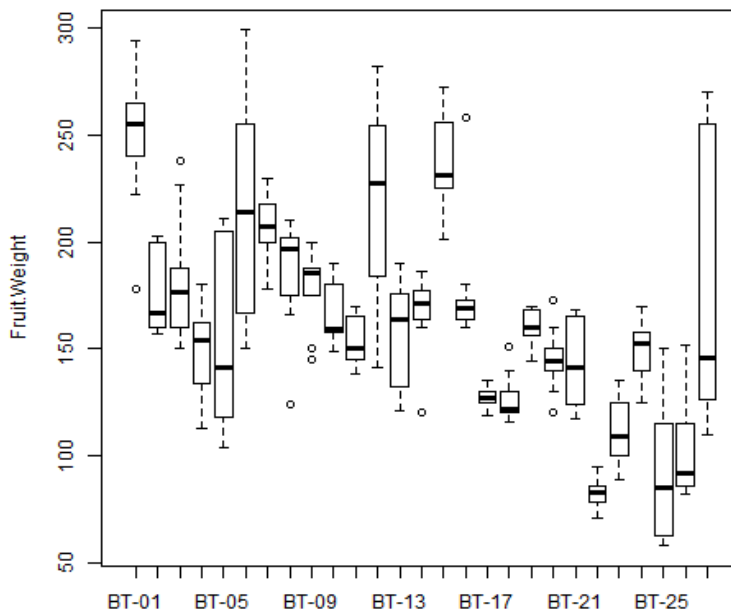


Figure 4.1.1.2f Box plots showing the distribution of data of single fruit weight

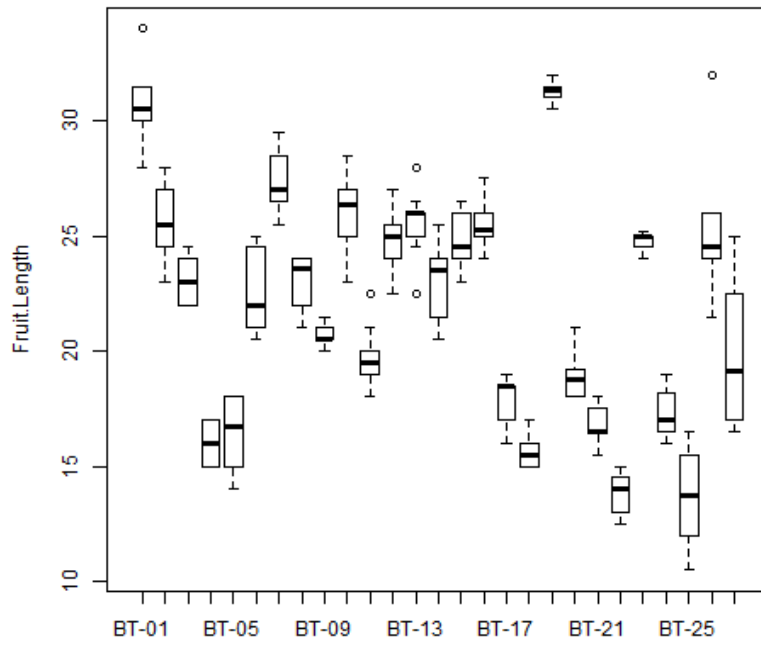


Figure 4.1.1.2g Box plots showing the distribution of data of fruit length

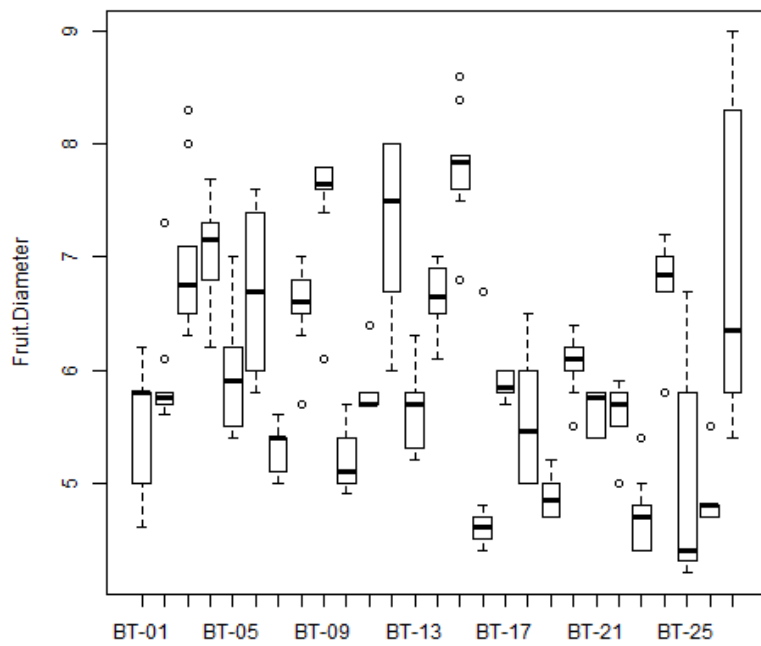


Figure 4.1.1.2h Box plots showing the distribution of data of fruit diameter

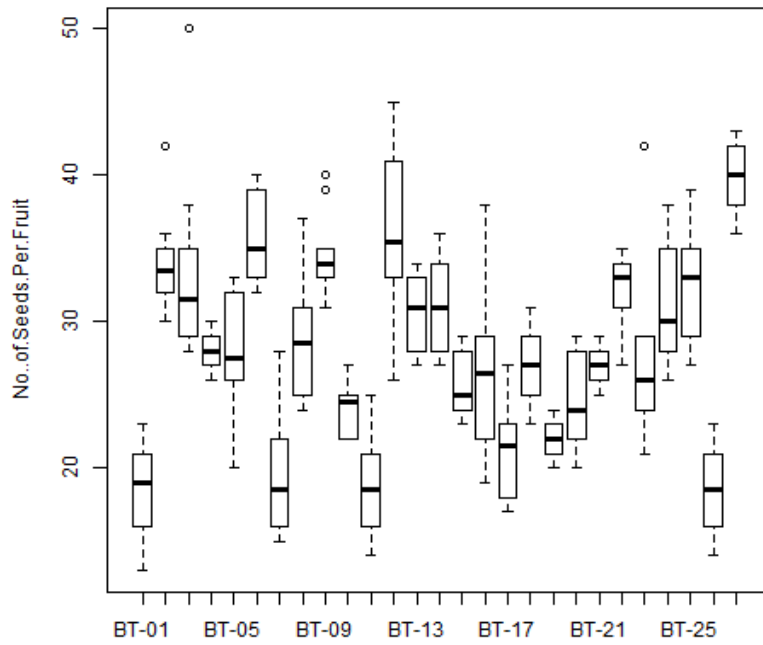


Figure 4.1.1.2i Box plots showing the distribution of data of number of seeds per fruit

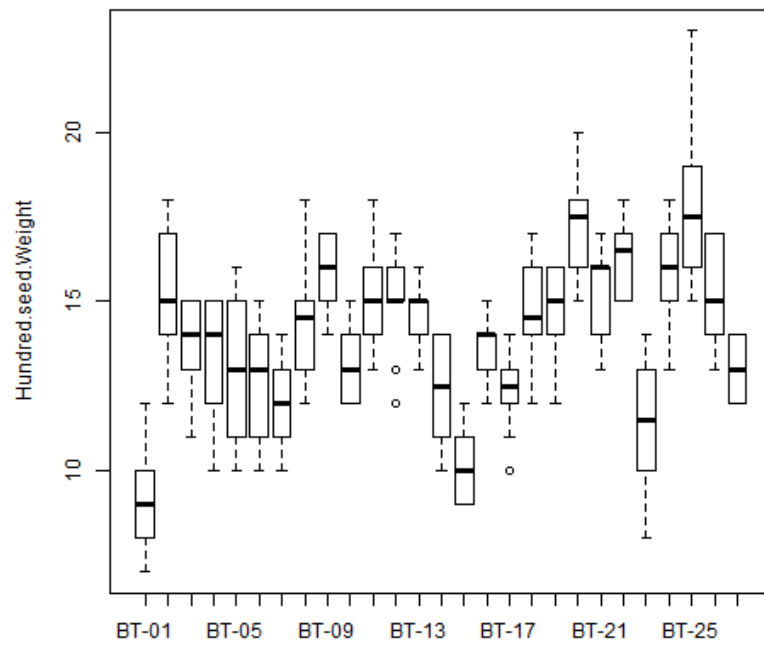


Figure 4.1.1.2j Box plots showing the distribution of data of 100-seed weight

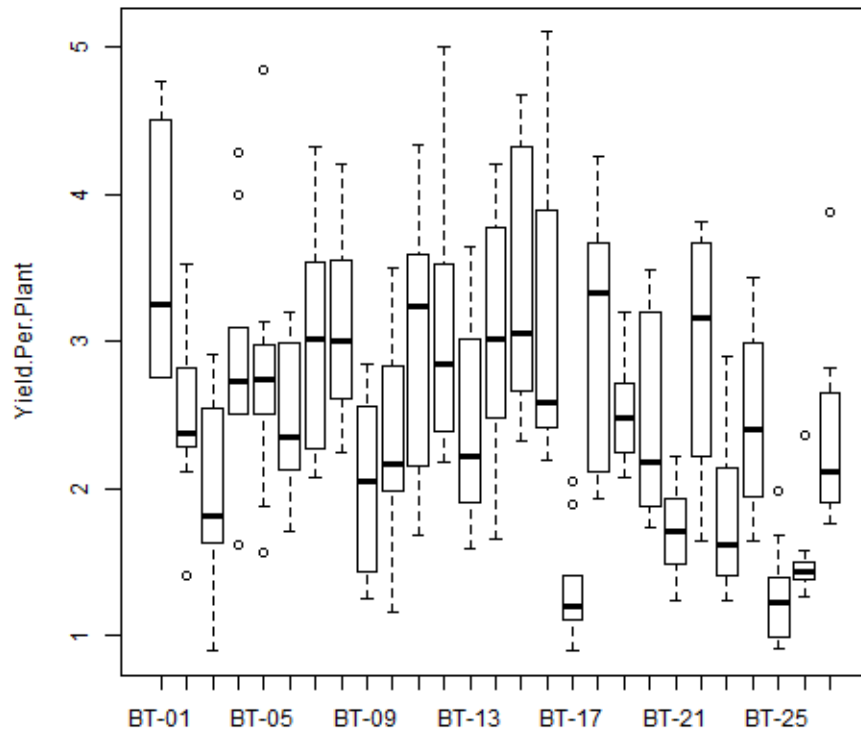


Figure 4.1.1.2k Box plots showing the distribution of data of yield per plant

Single fruit weight

The highest average single fruit weight was recorded in BT-1 (251.17 g) followed by BT-15 (236 g), BT-12 (219.70 g), BT-6 (213.36 g), BT-7 (207.80 g), BT-08 (187.20g) and BT-09 (179.20g). It can be utilized in hybridization for high yielding variety (Table 4.1.1.2).

Fruit length

Maximum fruit length was observed in BT-19 (31.24 cm) followed by BT-01 (30.40 cm), BT-07 (27.37 cm), BT-10 (26.13 cm), BT-26 (25.87 cm), BT-02 (25.70) and BT-13 (25.47 cm). It can be utilized in hybridization for long type, high yielding variety.

Fruit diameter

Maximum mean for fruit diameter showed in BT-15 (7.8 cm) followed by BT-09 (7.51 cm), BT-12 (7.31 cm), BT-03 (7.03 cm), BT-04 (7.00cm), BT-27 (6.91cm) and BT-24 (6.81 cm). This character could be utilized for bulky type, high yielding variety.

Number of fruits per plant

Yield is the ultimate goal for any crop production. The inbred line BT-22 produced the highest number of fruits per plant (37.20) followed by BT-18 (26.13), BT-11 (21.73), BT-04 (19.70), BT-14 (19.37), BT-16 (18.67) and BT-08 (18.10). These inbred lines could be used for high yielding variety.

Number of seeds per fruit

The BT-01 produced the lowest number of seeds per fruit (17.73) followed by BT-26, BT-11, BT-07, BT-19 and BT-27 produced the highest number of seeds per fruit (39.90) followed by BT-12 (35.90), BT-06 (35.50), BT-09 (34.50), BT-02 (33.93), BT-03 (33.23) and BT-25 (33.02). Number of seeds per fruit should be less to make it more acceptable to the consumer.

100-seed weight

Maximum mean of 100 seed weight showed in BT-25 (18.03g) followed by BT-20 (17.13g), BT-22 (16.40g), BT-24 (15.80 g), BT-21 (15.43g), BT-26 (15.30g) and BT-11 (15.30g). It can be utilized in hybridization for high yielding variety.

Yield

Yield is the most important trait and the ultimate goal for any crop production. The highest yield per plant was 3.69 kg in BT-1 followed by BT-15 (3.37 kg), BT-07 (3.23 kg), BT-12 (3.12 kg), BT-08 (3.01 kg) and BT-18 (3.01 kg). These inbred lines can be used in hybridization program for the development of high yielding hybrid varieties.

Morphological variability and genetic advance

Genotypic and phenotypic coefficient of variation are simple measure of variability, these measures are commonly used for the assessment of variability. The relative value of coefficient of variation gives an idea about the magnitude of variability present in a genetic population. Thus, the component of variation such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were computed. The phenotypic coefficient of variation was higher than the corresponding genotypic coefficient of variation indicating the influence of environment in the expression of the character under study. Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are categorized as low (less than 10%), moderate (10-20%) and high (more than 20%) as suggested by Sivasubramanian and Madhavamenon (1973). Heritability was measured using the formula given by Singh and Chaudhary, (1985) and the percentage was categorized as low (0-30%), moderate (30-60%) and high (60% and above) as given by Robinson *et al*, (1949). Genetic advance in percentage of mean was calculated by the formula given by Johnson *et al*, (1955), and the values were categorized as low (0-10%), moderate (10-20%) and high (20% and above) as given by him.

Mean sum of square due to genotypes, co-efficient of variation, range, genotypic and phenotypic coefficient of variation, heritability in broad sense and genetic advance in percentage of means for each character has been presented in the Table 4.1.1.3. The results presented in the table are discussed character wise.

Days to first female flower opening

From the average performance, it was revealed that days to first female flower opening ranged from 28.23 to 37.27 days with the mean value 31.51 days. The GCV and PCV were 7.35 and 7.53 respectively. The h^2_b was 75.26 % and the GA was 14.76 % (Table 4.1.1.3). Minimum difference between GCV and PCV were recorded for days to first female flower opening.

Maurya *et al.* (2018) in bitter gourd noticed almost the same result. Bimal (2008) also observed almost similar findings for days to first female flower opening ranged from 33.89 to 66.89 days and the mean being 55.07 days. The CV, GCV, PCV, h^2 (b), GA were 7.67%, 44.07, 60.25, 73.15 and 74.78 for this character respectively in bitter gourd. Pathak *et al.* (2014) explained that low GCV and PCV were observed in bitter gourd for days to first female flower opening (4.03% and 5.63%, respectively). Vahab (1989) found the PCV was low for days to first female flower opening (3.38) in bitter gourd.

Number of node at first female flower appeared

From the average performance, it was observed that number of node at first female flower appearance ranged from 16.30 to 28.42 and mean was 22.83. The GCV, PCV, h^2b and GAM were 14.10, 14.31, 68.32 % and 28.62 %, respectively (Table 4.1.1.3). Similar finding was found by Bimal (2008) in bitter gourd that the lowest node for first female flower appeared 10.45 whereas on later node 29.67 with the mean value of 20.29 and CV 18.33%. Maurya *et al.* (2018) observed medium GCV, PCV, high heritability and high genetic advance in bitter gourd. The genotypic and phenotypic co-efficient of variation for this trait were 39.22 and 73.30, respectively. The broad sense heritability and GA were 53.51% and 110.69%, respectively. Vahab (1989) found low PCV for node to first female flower formation (8.18) in bitter gourd. Prasad and Singh (1989) noticed high h^2 for female flower node number in ridge gourd. Joseph (1978) recorded 15.11 to 23.44 nodes for female flower initiation in snake gourd. Sureshbabu (1989) observed the lowest GCV and the highest h^2 (93%) for this trait in pumpkin.

Days to first harvest

Days to first edible fruit harvest ranged from 38.80 to 49.23 days with the mean value 43.77 days. The GCV, PCV, h^2b and GAM were 5.76, 5.84, 64.20 % and 11.72, respectively (Table 4.1.1.3). Difference of GCV and PCV were minimum which indicates less effect of environment for the expression of this character. Maurya *et al.* (2018) observed similar findings as GCV and GA were for days to first harvest (7% and 11.35%, respectively and heritability was high (61.07) in bitter gourd. Bimal (2008) explained that low GCV and PCV were observed for days to first harvest (1.98% and 3.20%, respectively and heritability was high (61.73) in bitter gourd. Banik (2003) reported that low GCV and PCV with high heritability and low genetic advance in bitter gourd.

Number of branches per plant

Significant variation was observed with respect to number of branches per plant which ranged from 6.43 to 21.13 and mean was 15.76. The GCV, PCV, h^2_b and GAM were 18.02, 18.26, 78.14 % and 36.62%, respectively (Table 4.1.1.3). Bimal (2008) reported that primary branches per plant varied from 5.75 to 10.33, the mean value was 7.45, the genotypic and phenotypic CV were medium and heritability h^2_b was high in bitter gourd. Mangal *et al.* (1981) also noted high h^2 for branches per vine in bitter gourd.

Single fruit weight

The average fruit weight of the 27 genotypes ranged from 82.8 to 251.2 g. The mean value, GCV, PCV were 163.2, 25.02 and 25.02, respectively. The $h^2_{(b)}$ was 85.08 % for this trait with high GA 51.52% (Table 4.1.1.3) which is an indicative of greater proportion of additive genetic variance and consequence a high genetic gain from selection. Jat *et al.* (2014) observed similar type findings in cucumber. Pathak *et al.*, (2014) explained that high GCV and PCV were recorded in bitter gourd for average fruit weight (31.73% and 32.26%, respectively) and high heritability with high GA was observed for fruit weight (96.74% and 64.29%, respectively) which is in the close conformity with in the present's results.

Fruit length

Fruit length ranges from 13.60cm to 31.24cm. The mean value was 21.86. The GCV and PCV for this character were 22.17 and 22.19 respectively. The $h^2_{(b)}$ was 90.98 % and GA being 45.64 (Table 4.1.1.3) Pathak *et al.*, (2014) explained that the GCV and PCV were recorded for fruit length (24.05% and 25.18%, respectively) and high heritability with high GA was observed in bitter gourd (91.25% and 47.33%, respectively) which was in the close conformity with the present findings. They also observed minimum difference between GCV and PCV. Bimal (2008) observed that the GCV and PCV for the character were high (58.04 and 85.78) respectively. The trait had high heritability h^2_b (67.67 %) and genetic advance being 151.58 % in bitter gourd.

Fruit diameter

Fruit diameter ranges from 4.70 cm and 7.80 cm respectively. The mean value was 6.02 cm. The GCV and PCV for this character were 14.80 and 14.94 respectively. The h^2_b was 77.32 % and GA being 30.19% (Table 4.1.1.3). Banik (2003) found the GCV and PCV of 18.09 and 18.82,

respectively and GA 36.04% in bitter gourd. Jat *et al.* (2014) observed similar type findings (GCV and PCV for this character were 15.01 and 15.60, respectively, h^2_b was 92.51% and GA was 29.73%) in cucumber. Banik (2003) found the GCV and PCV of 16.19 and 16.43, respectively in snake gourd. Uddin (2008) also found the GCV and PCV were 14.60 and 14.68, respectively. The h^2_b was 98.90% with the genetic advance 29.90% in cucumber which is close conformity with the present study.

Number of fruits per plant

Number of fruits per plant ranges from 10.30 to 37.2 and the mean value was 16.69. The GCV, PCV were 32.16 and 32.33 respectively. The h^2_b was 90.64% and genetic advance was 65.89 for this trait (Table 4.1.1.3). Sahoo and Singh (2020) observed the similar type results in cucumber that high GCV, PCV (30.90% and 32.85%, respectively), heritability (88%) and GA (59.88%) for number of fruits per plant. Pathak *et al.* (2014) explained that high GCV and PCV were recorded for number of fruits per plant (37.61% and 39.92%, respectively) and high heritability (88.75%), high GA (72.99%) also found in bitter gourd which is similar to the study. Bimal (2008) also observed that the GCV, PCV, heritability and genetic advance (GA) for this character was high in bitter gourd which also similar to the present study.

Number of seeds per fruit

The seeds per fruit ranged from 17.73 to 39.90. The mean value was 28.02 (Table 4.1.1.3). The GCV and PCV were 21.23 and 21.30, respectively with high h^2_b 91.01 % and genetic advance 43.60% (Table 4.1.1.1). Wide range of variability considering number of seeds per fruit (46.47 to 646.33) along with high GA (51.64%) was reported by Rahman (2006) in pumpkin. It was also reported that the GCV and PCV value were 32.14 and 41.20, respectively. Bimal (2008) observed that the GCV and PCV were 21.82 and 25.18, respectively and the h^2_b was 86.66%, the genetic advance was 13.06% which is similar findings with the present study

100 -seed weight

Among the studied accessions, significant variations were noticed considering hundred seed weight. The 100-seed weight was ranged from 9.23 g to 18.03 g with mean value of 14.00. The GCV, PCV were 14.41 and 14.54, respectively with high h^2_b (73.38%) and genetic advance

(29.41%) (Table 4.1.1.3). Rahman (2006) also mentioned that significant variation was available considering 100 seed weight and obtained weight of hundred seeds ranged from 7.76 to 20.63g. He also recorded that the GCV, PCV were 16.41 and 17.91, respectively and h^2_b was 83.95%. Bimal (2008) observed that the highest 100 seed weight of 20.49 g and the lowest weight of 11.41 g were recorded. The mean value was 15.76g. The GCV and PCV were 10.93 and 20.04, respectively in bitter gourd which also supported the finding of the present study.

Fruit yield per plant

Considerably higher variation was recorded in case of yield per plant and varied from 1.32 to 3.69 kg with an average of 2.53 kg. The GCV and PCV were 24.82 and 25.02, respectively. The h^2_b was 88.32% and genetic advance was 50.73% for this trait (Table 4.1.1.3). Maurya *et al.* (2018) explained that the GCV and PCV were recorded for fruit length (21.6% and 22.8%, respectively) and high heritability with high GA was observed in bitter gourd (89.09% and 42%, respectively) which was in the close conformity with the present findings. Hossain *et al.* (2010) reported that the highest GCV for yield per plant (42.75%) in cucumber. Bimal (2008) reported the high heritability h^2_b (82.524%) for the trait in bitter gourd which is almost same reaction of present study. High GCV and high heritability indicated that the traits offer adequate scope for effective selection criteria for improvement and easily transferable if hybrid development is target in bitter gourd.

Bitter gourd being a highly cross-pollinated crop has much variation and therefore the present observation is quite rational as reported earlier by Maurya *et al.* (2018) in Bitter gourd, Uddin (2008) in cucumber and Bimal (2008) in bitter gourd.

Table 4.1.1.3 Estimates of different genetic parameters for different characters of 27 inbred lines of bitter gourd

Sl. No.	Characters	Range	Mean \pm SE	Coefficient of variation		Heritability in broad sense (% h^2_b)	GA in % of mean (GAM)
				GCV	PCV		
1	Days to first female flower opening	28.23-37.27	31.51 \pm 0.43	7.35	7.53	75.26	14.76
2	No. of node at first female flower appeared	16.30 -28.42	22.83 \pm 0.46	14.10	14.31	68.32	28.62
3	Days to first fruit harvest	38.80 -49.23	43.77 \pm 0.34	5.76	5.84	64.20	11.72
4	Number of branches per plant	6.43 -21.13	15.76 \pm 0.38	18.02	18.26	78.14	36.62
5	Single fruit weight (g)	82.8-251.2	163.2 \pm 0.77	25.02	25.02	85.08	51.52
6	Fruit length (cm)	13.60 -31.24	21.86 \pm 0.16	22.17	22.19	90.98	45.64
7	Fruit diameter (cm)	4.700 -7.800	6.018 \pm 0.10	14.80	14.94	77.32	30.19
8	Number of fruits per plant	10.30 - 37.2	23.69 \pm 0.45	32.16	32.33	90.64	65.89
9	Number of seeds per fruit	17.73 -39.90	28.02 \pm 0.39	21.23	21.30	91.01	43.60
10	100- seed weight (g)	9.23 - 18.03	14.00 \pm 0.22	14.41	14.54	73.38	29.41
11	Yield (kg/plant)	1.32 -3.69	2.53 \pm 0.06	24.82	25.02	88.32	50.73

GCV: Genotypic co-efficient of variation

h^2_b : Heritability in broad sense

PCV: Phenotypic co-efficient of variation

GA: Genetic Advance

The selection of genotypes to serve as parents is one of the most important steps in any crossing program for plant breeding. Selection of parents depends on specific objectives of the research program and their performance in F₁ generations. Potentiality of the parents must be evaluated before selecting parents. Various statistical analyses are available to select suitable parents. Experience of the breeder is one of the important factors in this matter. The study of genetic divergence through multivariate analysis is frequently applied in parent selection by researchers involved in breeding programs of several crops, leading to a reduction in the number of crosses (Guerra *et al.*, 1999). In breeding programs, the common approach of selecting parents on the basis of *per se* performance does not lead to fruitful results. Hence, potential parents need to be selected based on their genetic architecture and combining ability (Sundharaiya and Venkatesan 2007).

4.1.2 Selection of yield contributing traits based on trait association

4.1.2.1 Inter relationship among the yield contributing traits

Study of relationships between yield and yield components is very important in choosing suitable selection criteria for yield improvement in bitter gourd. It is a prerequisite to critically assess the interrelationship for yield and its contributing characters. Yield is the result of the expression and association of several plant growth components. The study of relationships among quantitative traits is important for assessing the feasibility of joint selection of two or more traits.

Estimates of correlation coefficients for all pairs of different characters were presented in Table 4.1.2.1. The present investigation revealed that genotypic correlation coefficient was higher in magnitude than respective phenotypic correlation coefficient for most of the characters which may be attributed to the masking effect of the environmental factors in revealing the true association. This is conformity with works on different cucurbits by Singh (2014) in bitter gourd and Durga *et al.* (2017) in bitter gourd.

Correlation studies provide information about the nature and magnitude of various associations among the traits. It measures the mutual association between two variables but not permit to depict the cause-and-effect relationship of traits contributing directly or indirectly towards the economic yield.

Association of component characters revealed positive and significant correlation of first female flower with node number at first female flower appeared; first harvest and 100 seed weight, node number with first harvest; branch per plant; number of seeds per fruit and 100 seed weight. Branches per plant with fruit length, single fruit weight with fruit length; fruit diameter and yield per plant, fruit length with yield per plant, fruit diameter with yield per plant, fruit per plant with yield per plant, number of seed per fruit with 100-seed weight (Table 4.1.2.1).

Analysis of correlation

Phenotypic and genotypic correlation coefficients between yield and yield contributing components of bitter gourd are presented in Table 4.1.2.1 and 4.1.2.2. In most of the cases, it was observed that the magnitude of genotypic correlations were higher than the corresponding phenotypic correlations coefficients between various pairs of characters in the present study. Higher genotypic correlation co-efficient than their phenotypic correlation co-efficient between various pairs of characters have also been observed by Uddin (2008) in cucumber, Masud (1995), Islam *et al.*, (2009) in bitter gourd. Such high genotypic correlation coefficient between yield and yield related traits indicated presence of genetic relation between them but environmental effects reduced the values at phenotypic level. On the other hand, fruit per plant with yield per plant had higher phenotypic correlation co-efficient than corresponding genotypic correlation co-efficient indicating remarkable environmental influence on the association of these characters.

Days to first female flower opening

The results revealed that days to first female flowering had positive significant correlation with node number at first female flower, days to first harvest and hundred seed weight at genotypic level (Table 4.1.2.1). This finding is conformity with Jatav *et al.* (2016) in bitter gourd. This character had significant negative correlation with single fruit weight, fruit length, number of fruits per plant and yield per plant. Jatav *et al.* (2016) also found significant negative correlation of first female flower with yield per plant in bitter gourd. Islam *et al.*, (2009) in bitter gourd, Prasad *et al.*, (1993), Uddin (2008) in cucumber and Durga *et al.*, (2017) in bitter gourd found significant negative correlation of this trait with number of fruits per plant which supported the present findings for this trait.

Number of node at first female flower appeared

Node at which first female flower appears had significant positive correlation at genotypic level with days to first harvest, number of branches per plant, number of seeds per fruit and 100 seed weight. Similar findings were found by Jatav *et al.*, (2016) in bitter gourd that node number had significant positive correlation at genotypic level with number of days to first harvest. However, it exhibited negative significant correlation at genotypic levels with single fruit weight and yield per plant.

Days to first harvest

This trait was positively correlated with branches per plant and 100 seed weight at genotypic level. Jatav *et al.* (2016) in bitter gourd found positive correlation with 100 seed weight for this trait. It had also significant negative correlation with single fruit weight, fruit diameter and yield per plant at genotypic and phenotypic levels. Almost similar findings were found by Jatav *et al.* (2016) and Durga *et al.* (2017) in bitter gourd that days to first harvest had significant negative correlation at genotypic level with fruit diameter and yield per plant.

Number of branches per plant

Number of branches per plant had significant positive correlation with fruit length. These results are in consonance with the findings of Durga *et al.* (2017) in bitter gourd. The trait is negatively correlated with fruits per plant, 100 seed weight and yield per plant at genotypic level. On the other hand, single fruit weight, fruit diameter and number of seeds per fruit showed non-significant positive correlation at genotypic level with this trait (Table 4.1.2.1). Jatav *et al.* (2016) found in bitter gourd that significant negative correlation at genotypic levels with number of seeds per fruit for this trait.

Single fruit weight

Correlation coefficient revealed that single fruit weight had highly significant and positive correlation with fruit length ($r_g=0.584^{**}$), fruit diameter ($r_g=0.481^{**}$), hundred seed weight ($r_g=0.580^{**}$ and yield per plant ($r_g=0.605^{**}$) at genotypic and phenotypic levels (Table 4.1.2.1 and 4.1.2.2). The result indicated that yield per plant will be increased with the single fruit weight. Almost similar findings were found by Durga *et al.* (2017) in bitter gourd for this trait. These results are in consonance with the findings of Jatav *et al.* (2016) in bitter gourd. This trait

had highly negative significant correlation with fruits per plant, days to first female flower open, number of node at first female flower open and days to first harvest but for number of seeds per fruit, it showed nonsignificant positive correlation with them both at phenotypic and genotypic levels. Similar finding was also recorded for number of fruits per plant by Jatav *et al.* (2016) in bitter gourd for this trait.

Fruit length

Fruit length was highly significant and positively correlated with single fruit weight and yield per plant at genotypic level (Table 4.1.2.1). Durga *et al.* (2017) found positive significant correlation for yield per plant with fruit length in bitter gourd which was similar to findings. Uddin (2008) found highly significant positive correlation with single fruit weight and yield per plant of this trait in cucumber at phenotypic and genotypic levels which were similar to the present findings. On the other hand, fruits per plant, number of seeds per fruit and 100 seed weight showed negative significant correlation with fruit length at genotypic and phenotypic levels. Jatav *et al.* (2016) found that significant positive correlation with fruit per plant and 100 seed weight for this trait in bitter gourd.

Fruit diameter

It was observed that fruit diameter had highly significant and positive correlation with number of seeds per fruit, single fruit weight and yield per plant at both phenotypic and genotypic levels (Table 4.1.2.1 and 4.1.2.2). This character had negative but nonsignificant correlation with fruits per plant and hundred seed weight at both phenotypic and genotypic levels. Significant positive correlation of this trait with single fruit weight was reported by Uddin (2008) in cucumber and similar findings were also found by Durga *et al.* (2017) in bitter gourd for this trait. Jatav *et al.* (2016) found nonsignificant negative correlation with hundred seed weight for this trait in bitter gourd.

Number of fruits per plant

Number of fruits per plant was highly significant and positively correlated with yield per plant both at phenotypic ($r_p=453^{**}$) and genotypic ($r_g=0.451^{**}$) levels (Table 4.1.2.1 and 4.1.2.2). It indicates that yield per plant will be increased with the number of fruits per plant. These results are in consonance with the findings of Durga *et al.* (2017) in bitter gourd (0.637^{**}), Jatav *et al.*

(2016) in bitter melon (0.590**), Aruah *et al.* (2012), Uddin (2008) in cucumber ($r_g=0.755^{**}$, $r_p=0.752^{**}$). On the other hand, this trait had negative significant correlation with days to first female flower opening ($r_g=-0.342^{**}$), single fruit weight ($r_g= -0.396^{**}$) and fruit length ($r_g= -0.361^{**}$). Similar finding was also reported by Jatav *et al.* (2016) for days to first female flower opening ($r_g= -0.470^{**}$) and single fruit weight ($r_g= -0.323^{**}$) in bitter melon for this trait.

But with 100 seed weight having nonsignificant and positive correlation both at phenotypic and genotypic levels and number of seeds per fruit showed nonsignificant negative correlation for this trait which is similar to Jatav *et al.* (2016) in bitter melon for this trait.

Number of seeds per fruit

Number of seeds per fruit had significant and positive correlation with 100 seed weight, number of node at which first female flower open and fruit diameter at both phenotypic and genotypic levels (Table 4.1.2.1 and 4.1.2.2). Jatav *et al.* (2016) found positive correlation with 100 seed weight at genotypic level. It had also significant and positive correlation with fruit diameter in bitter melon. This trait expressed nonsignificant and negative correlation with yield per plant, days to first fruit harvest and number of fruits per plant both at phenotypic and genotypic levels.

100-seed weight

Correlation coefficient revealed that 100-seed weight had highly significant and positive effect with yield per plant both at phenotypic and genotypic levels (Table 4.1.2.1 and 4.1.2.2). Jatav *et al.* (2016) found positive correlation with yield per plant in bitter melon both at phenotypic and genotypic levels. Days to first female flower open, node number at which female flower open, single fruit weight and number of seeds per fruit showed significant and positive correlation with 100-seed weight; but it had negative correlation with branches per plant, fruit length and fruit diameter.

4.1.2.1 Genotypic correlation coefficient among 11 characters in bitter gourd

Characters	Days to first female flower opening	No. of node at first female flower appeared	Days to first fruit harvest	Number of branches per plant	Single perfruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Number of seeds per fruit	100-seed weight (g)
Number of node	0.325**									
Days to first harvest	0.588**	0.516**								
Number of branches per plant	0.023	0.321**	0.098							
Single fruit weight (g)	-0.228*	-0.361**	-0.288**	0.112						
Fruit length (cm)	-0.243*	-0.179	-0.041	0.302**	0.584**					
Fruit diameter (cm)	0.153	-0.061	-0.250*	0.005	0.481**	-0.178				
Number of fruits per plant	-0.342**	0.190	-0.111	-0.104	-0.396**	-0.361**	-0.160			
Number of seeds per fruit	0.008	0.249*	-0.010	0.052	0.013	-0.335**	0.518**	-0.042		
100 seed weight (g)	0.377**	0.404**	0.137	-0.120	0.580**	-0.499**	-0.132	0.199	0.281*	
Yield/plant (kg)	-0.531**	-0.260*	-0.415**	-0.066	0.605**	0.266*	0.262*	0.451**	-0.091	0.405**

* $P \leq 5\%$ level, ** $P \leq 1\%$ level, respectively

4.1.2.2 Phenotypic correlation coefficient among 11 characters in bitter gourd

Characters	Days to first female flower opening	No. of node at first female flower appeared	Days to first fruit harvest	Number of branches per plant	Single fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Number of seeds per fruit	Number of 100-seed weight (g)
Number of node	0.317**									
Days to first fruit harvest	0.569**	0.509**								
Number of branches per plant	0.012	0.311**	0.092							
Single fruit weight (g)	-0.223*	-0.356**	-0.283*	0.112						
Fruit length (cm)	-0.237*	-0.177	-0.039	0.299**	0.584**					
Fruit diameter (cm)	0.142	-0.060	-0.240*	0.017	0.478**	-0.176				
Number of fruits per plant	-0.330**	0.186	-0.113	-0.100	-0.394**	-0.359**	-0.160			
Number of seed per fruit	0.009	0.243*	-0.009	0.057	0.014	-0.333**	0.517**	-0.043		
100 seed weight (g)	0.365**	0.394**	0.135	-0.119	0.574**	0.493**	-0.132	0.199	0.281*	
Yield/plant (kg)	-0.514**	-0.259*	-0.414**	-0.057	0.600**	0.264*	0.260*	0.453**	-0.089	0.399**

*P ≤ 5% level, ** P ≤ 1% level, respectively

In general, it was estimated that the magnitude of genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients between various pairs of characters in the present study. Higher genotypic correlation co-efficient than their phenotypic correlation co-efficient between various pairs of characters have also been observed cucumber by Singh *et al.* (2002), Singh *et al.* (2014); Jatav *et al.* (2016) and Durga *et al.* (2017) in bitter gourd. Such high genotypic correlation coefficient between yield and yield related traits indicated presence of strong inherent genotypic relationship between the characters studied but environmental effects reduced the values at phenotypic level. This can also be interpreted as a strong inherent genotypic relationship between the characters studied though their phenotypic expression was not impeded by environmental influence. The highest positive genotypic correlation (0.605**) was found between single fruit weight and yield per plant followed by Days to first female flower open and number of days to first harvest (0.588**) and single fruit weight and fruit length (0.584**). These results are close conformity with the findings of Durga *et al.* (2017) in bitter gourd.

Path analysis of yield and yield contributing traits

Upon the assessment of apparent relationship between yield and yield components, it was necessary to partition the direct and indirect effects of each character on yield to understand the nature of association at genotypic and phenotypic levels. In order to fulfill the requirement, the path coefficient analysis was computed and direct and indirect effects of different characters on yield per plant are presented in the Table 4.1.2.3 and Table 4.1.2.4.

The yield was considered as dependent (effect) on 11 independent (cause) variables. Path coefficient analysis was based on correlation using yield per plant as the dependent factor and 10 other quantitative characters viz., days to first female flower opening, number of node at first female flower open, days to first harvest, number of branches per plant, single fruit weight, fruit length, fruit diameter, number of fruits per plant, number of seeds per fruit and 100-seed weight as independent factor. Correlation coefficient of each independent quantitative character was partitioned into direct and indirect effects towards yield per plant. All the direct effects were less than one indicating that inflation due to multicollinearity was minimal (Gravois and Helms, 1992).

Significant correlation coefficient between two characters does not always indicate presence of linkage between them. So, association of characters determined by correlation co-efficient

may not provide an exact picture of the relative importance of direct and indirect influence of each of the yield components towards yield. As a matter of fact, in order to find out a clear picture of the relationship between fruit yield and yield components, path analysis study was done at genotypic and phenotypic level. The residual effects of genotypic and phenotypic path analysis were 0.051 and 0.061; respectively revealed higher per cent of genetic variability in yield per plant was contributed by 11 characters which were studied. These residual effects towards yield in the present study might be due to many reasons such as other characters which were not studied, environmental factor and sampling errors in bitter gourd (Table 4.1.2.3 and 4.1.2.4).

Days to first female flower opening

From the results of path analysis, it was observed that days to first female flower opening had positive direct effect on yield at phenotypic (0.027) and genotypic (0.039) levels (Table 4.1.2.3 and 4.1.2.4). But very negligible negative indirect effect through node number, number of branches per plant, days to first harvest, number of fruits per plant, single fruit weight, fruit length, fruit diameter, number of seeds per fruit and 100-seed weight towards yield. Similar type findings were reported by Jatav *et al.* (2016) in bitter gourd.

Node number at first female flower opening

This trait recorded negligible negative direct effect on fruit yield per plant at genotypic (-0.013) and phenotypic (-0.02) levels. Several of the yield contributing characters such as days to first harvest, number of branches per plant, fruit length number of seeds per fruit and 100 seed weight showed negative indirect effects to yield per plant. The indirect effects through days to first female flower opening, fruit diameter and number of fruits per plant were positive on yield. Present findings were close to Jatav *et al.* (2016) and Kumar *et al.* (2018) in bitter gourd.

Days to first fruit harvest

Days to first fruit harvest showed low negative direct effects on fruit yield per plant at genotypic (-0.0801) and phenotypic (-0.069) levels. Maximum of the yield contributing characters showed negligible negative indirect effects to yield per plant. The indirect effects through days to first female flower opening, fruit diameter and number of seeds per fruit were positive on yield. But number of node at which female flower open, number of branches per

plant, single fruit weight, fruit length, number of fruits per plant and 100-seed weight showed negative indirect effects to yield per plant. Kumar *et al.* (2018) observed in bitter gourd which is similar to the findings of present studies.

Number of branches per plant

This trait showed low negative direct effect on fruit yield at genotypic (-0.081) and phenotypic (-0.068) levels. Four yield contributing characters viz. days to first female flower opening, single fruit weight, fruit length and hundred seed weight showed positive indirect effects to yield per plant. Remaining five characters viz. node number at which female flower open, days to first harvest, fruit diameter, number of fruits per plant and number of seeds per fruit showed negative indirect effect on yield. Similar type findings were reported by Jatav *et al.* (2016) in bitter gourd.

Single fruit weight

The results of the path analysis revealed that single fruit weight had the highest positive direct effect (0.932) on yield of bitter gourd followed by number of fruits per plant had the second highest (0.816) positive direct effect on fruit yield at genotypic level indicated that these characters are the major component of fruit yield in bitter gourd. This trait had also positive indirect effect with number of node at first female flower open, days to first harvest, fruit length and hundred seed weight towards yield at genotypic level. Remaining characters viz. days to first female flower open, number of branches per plant, fruit diameter, number of fruits per plant and number of seeds per fruit showed negative indirect effect on yield. Jatav *et al.* (2016) and Kumar *et al.* (2018) in bitter gourd showed the highest positive direct effect of single fruit weight on yield which is similar to the findings of present studies. Kallo and Sidhu (1982) in musk melon, Singh *et al.* (2002) in cucumber, Uddin (2008) in cucumber obtained similar results of present findings.

Fruit length

Path analysis revealed that fruit length had the positive direct effect (0.014) on fruit yield at genotypic level. Kumar *et al.* (2018) in bitter gourd showed the positive direct effect on fruit yield which was similar to the present study. On the other hand, node number, first harvest, single fruit weight, fruit diameter, number of seeds per fruit and hundred seed weight had positive indirect effect on yield at genotypic and phenotypic levels. Pathak *et al.* (2014) in

bitter gourd obtained almost similar results of present findings. Several of the yield contributing characters i.e.; days to first female flower opening, number of branches per plant and number of fruits per plant showed negative indirect effects to yield per plant. Jatav *et al.* (2016) reported that day to first female flower opening and number of branches per plant showed negative indirect effects to yield per plant in bitter gourd also similar with this study.

Fruit diameter

Fruit diameter had negligible negative indirect effects on fruit yield at genotypic level (-0.078) and phenotypic (-0.053) level. Several of the yield contributing characters i.e.; number of branches per plant, fruit length, number of fruits per plant and number of seeds per fruit showed negative indirect effects to yield per plant. On the other hand, days to first female flower opening, node number at which female flower open, days to first harvest, single fruit weight and 100 seed weight had positive indirect effect to yield at genotypic and phenotypic levels. Similar type findings were reported by Jatav *et al.* (2016) in bitter gourd showed that fruit diameter had negative direct effects on fruit yield at genotypic level.

Number of fruits per plant

It was revealed from the path analysis study that fruits per plant showed second highest positive direct effect to yield per plant at genotypic (0.816) and phenotypic (0.812) levels indicated that these characters are the major component of fruit yield in bitter gourd. Several yield contributing characters viz. days to first female flower opening, node number at which female flower open, single fruit weight, fruit length and 100-seed weight showed negative indirect effects to yield per plant. On the other hand, number of branches per plant, days to first harvest, fruit diameter and number of seeds per fruit had positive indirect effect to yield at genotypic level. Pathak *et al.* (2014) reported in bitter gourd that highly positive direct effect to yield at genotypic and phenotypic levels which was similar to the result of present findings. Uddin (2008) in cucumber, showed the high positive direct effect of fruit number on yield which are also similar to the findings of present studies.

Number of seeds per fruit

This trait showed negative direct effects on fruit yield per plant at genotypic (-0.010) and phenotypic (-0.015) levels. Similar type findings were reported by Jatav *et al.* (2016) in bitter gourd. Several yield contributing characters, days to first female flower opening, days to first

harvest and single fruit weight showed positive indirect effects on yield per plant. On the other hand, node number at which female flower open, number of branches per plant, fruit length, fruit diameter, number of fruits per plant, number of seeds per fruit and 100-seed weight showed negative indirect effects on yield per plant.

100 -seed weight

This trait was recorded as positive direct effects on fruit yield per plant at genotypic (0.026) and phenotypic (0.023) levels. Similar type findings were reported by Jatav *et al.* (2016) in bitter gourd. Several yield contributing characters, days to first female flower opening, branch per plant, fruit diameter and fruits per plant showed positive indirect effects on yield per plant. number of node at which female flower open, days to first harvest, single fruit weight, fruit length and number of seeds per fruit showed negative non significant effect on fruit yield.

Several general conclusions are found in these studies: (1) Correlations (both phenotypic and genotypic) between yield and its principal components, number of fruits per plant and weight per fruit, are generally significant and positive. (2) Single fruit weight normally presents the greatest direct effect on yield, followed by number of fruits per plant. (3) Fruit length and days to first female flower open are the variables that generally have the greatest direct positive effects in path analysis on yield.

In plant breeding, it is very difficult to have complete knowledge of all component traits of yield. The residual effect permits precise explanation about the pattern of interaction of other possible components of yield. In other words, residual effect measures the role of possible independent variables which were not included in the study of dependent variable. In the present study, the residual effect values were at genotypic (0.0051) and at phenotypic (0.061) levels, respectively. This clearly shows the importance of inclusion of some more characters for clear partition of the direct and indirect effects among the yield components. The path coefficient analysis was obtained for clear, understanding of association of the genotypic correlation coefficient of yield with contributing components. The genotypic correlation coefficient was partitioned into direct and indirect effects through path coefficient analysis of parents.

From the estimate of correlation coefficient and direct and indirect effect of fruit yield attributing traits, it is clear that fruit weight and number of fruits per plant are the vital traits

towards fruit yield. So, the estimate of correlation coefficient and direct and indirect effect of fruit yield attributing traits, it is clear that for bring out designed improvement towards fruit yield in future of bitter gourd, average fruit weight and number of fruits per plant can be used as direct selection parameters.

Based on the results of path analysis, the present study revealed that major emphasis should be laid on selection process with more number of fruits per plant and single fruit weight and there should be economic balance among these traits to get higher fruit yield kg per plant. However, it is better to select number of fruits per plant for yield improvement in bitter gourd, because, increase of fruit weight could not be done beyond certain level. Not only this, increase of fruit weight exceeding the certain level would decrease the customers' preference may cause low market demand in this country.

From the present study, it can be inferred that the characters viz. fruit number, fruit weight, fruit length, days to first female flower anthesis showed positive direct effect on yield. Therefore these characters should be considered for selection to improve yield. Similar observation and comment was found by Pathak *et al.* (2014) in bitter gourd.

Table 4.1.2.3 Phenotypic path analysis showing direct (bold) and indirect effects of traits on yield per plant in bitter gourd

Characters	Days to first female flower opening	Number of node at first female flower open	Days to first fruit harvest	Number of branches per plant	Single fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Number of seeds per fruit	100-seed weight (g)	Correlation With Yield per Plant (kg)
Days to first female flower opening	0.027	-0.008	-0.039	-0.001	-0.205	-0.005	-0.008	-0.265	-0.0001	-0.009	-0.514**
Number of node at first female flower open	0.009	-0.026	-0.035	-0.021	-0.321	-0.004	0.003	0.149	-0.004	-0.009	-0.259*
Days to first fruit harvest	0.015	-0.013	-0.069	-0.006	-0.260	-0.001	0.013	-0.080	0.0001	-0.003	-0.414**
Number of branches per plant	0.001	-0.008	-0.007	-0.068	0.098	0.006	-0.001	-0.082	-0.001	0.003	-0.057
Single fruit weight (g)	-0.006	0.009	0.020	-0.007	0.903	0.012	-0.025	-0.318	-0.0002	0.014	0.600**
Fruit length (cm)	-0.007	0.005	0.003	-0.020	0.527	0.020	0.009	-0.290	0.005	0.012	0.264*
Fruit diameter (cm)	0.004	0.001	0.017	-0.001	0.431	-0.004	-0.053	-0.131	-0.008	0.003	0.260*
Number of fruits per plant	-0.009	-0.005	0.007	0.007	-0.354	-0.007	0.009	0.812	0.001	-0.005	0.453**
Number of seeds per fruit	0.0001	-0.006	0.001	-0.003	0.012	-0.007	-0.027	-0.036	-0.016	-0.007	-0.089
100- seed weight (g)	0.010	-0.010	-0.009	0.008	-0.526	-0.010	0.007	0.162	-0.004	0.024	0.399**

Note: *P<0.05, **P<0.01, respectively; Residual effect: 0.061

Table 4.1.2.4 Genotypic path analysis showing direct (bold) and indirect effects of traits on yield per plant in bitter gourd

Characters	Days to first female flower opening	Number of node at first female flower appeared	Days to first fruit harvest	Number of branches per plant	Single fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Number of seeds per fruit	100 -seed weight (g)	Correlation With Yield per Plant (kg)
Days to first female flower opening	0.039	-0.004	-0.047	-0.002	-0.213	-0.003	-0.012	-0.279	-0.0001	-0.010	-0.531**
Number of node at female flower open	0.013	-0.013	-0.041	-0.026	-0.337	-0.002	0.005	0.155	-0.003	-0.011	-0.260*
Days to first fruit harvest	0.023	-0.007	-0.080	-0.008	-0.268	-0.001	0.019	-0.091	0.0001	-0.004	-0.415**
Number of branches per plant	0.001	-0.004	-0.008	-0.081	0.105	0.004	-0.0004	-0.085	-0.001	0.003	-0.066
Single fruit weight (g)	-0.009	0.005	0.023	-0.009	0.932	0.008	-0.038	-0.323	-0.0001	0.016	0.605**
Fruit length (cm)	-0.009	0.002	0.003	-0.024	0.544	0.014	0.014	-0.295	0.003	0.013	0.266*
Fruit diameter (cm)	0.006	0.001	0.020	-0.0004	0.449	-0.002	-0.078	-0.131	-0.005	0.004	0.262*
Number of fruits per plant	-0.013	-0.003	0.009	0.008	-0.369	-0.005	0.013	0.816	0.0004	-0.005	0.451**
Number of seeds per fruit	0.0003	-0.003	0.001	-0.004	0.012	-0.005	-0.040	-0.034	-0.010	-0.007	-0.091
100 -seed weight (g)	0.015	-0.005	-0.011	0.010	-0.549	-0.007	0.010	0.162	-0.003	0.026	0.405**

Note: *P<0.05, **P<0.01, respectively; Residual effects: 0.051

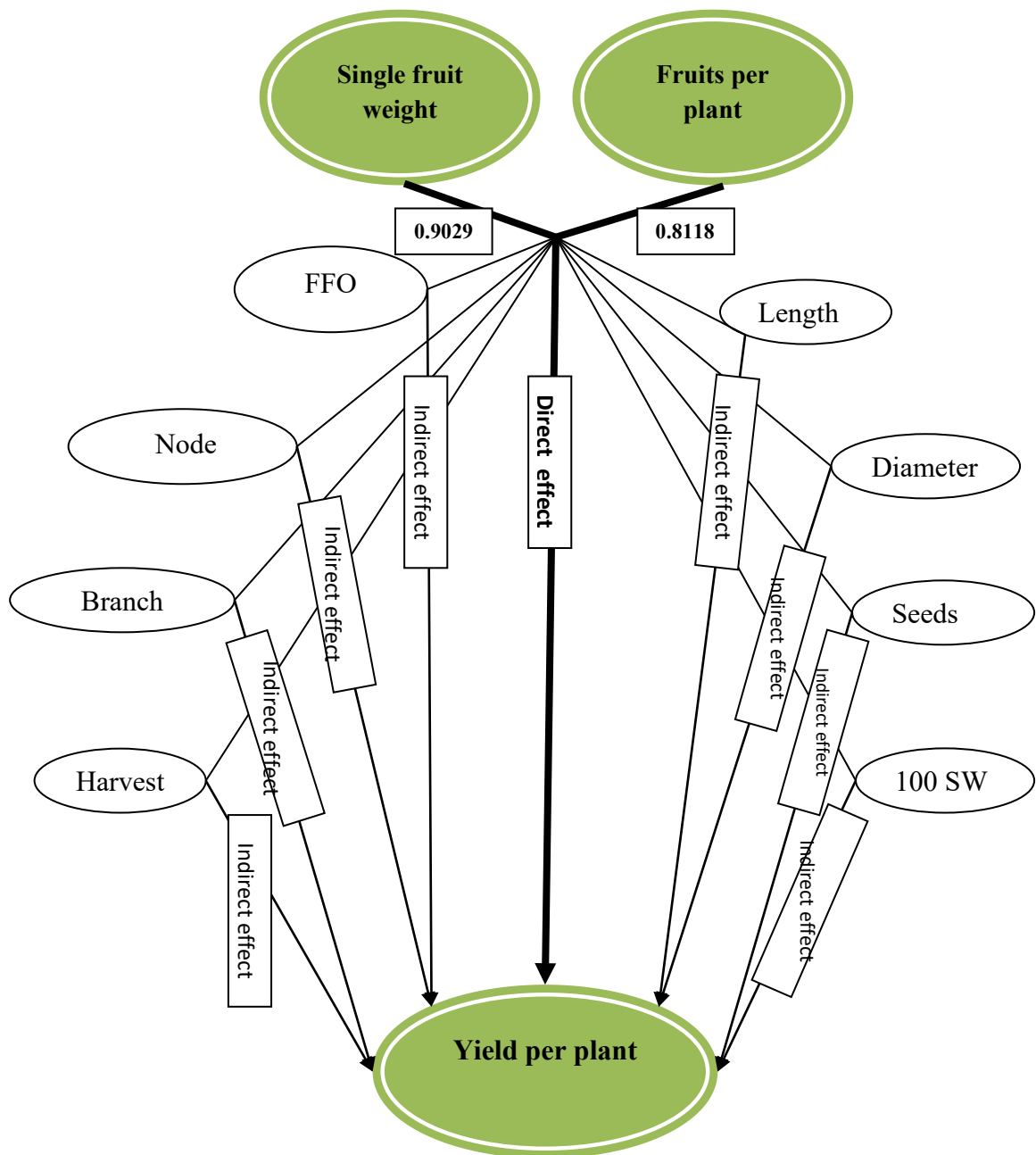


Figure 4.1.2.1 Showing phenotypic direct and indirect effect of single fruit weight & fruits per plant on yield per plant in Bitter gourd

Note: FFO=Days to first female flower open
 Branch=Number of branches
 Fruit per Plant=Number of fruits per plant
 Diameter=Fruit diameter
 100 SW=Hundred seed weight

Node=Number of node at female flower open
 Harvest=Days to 1st harvest
 Length= Fruit length
 Seeds= Number of seeds per fruit

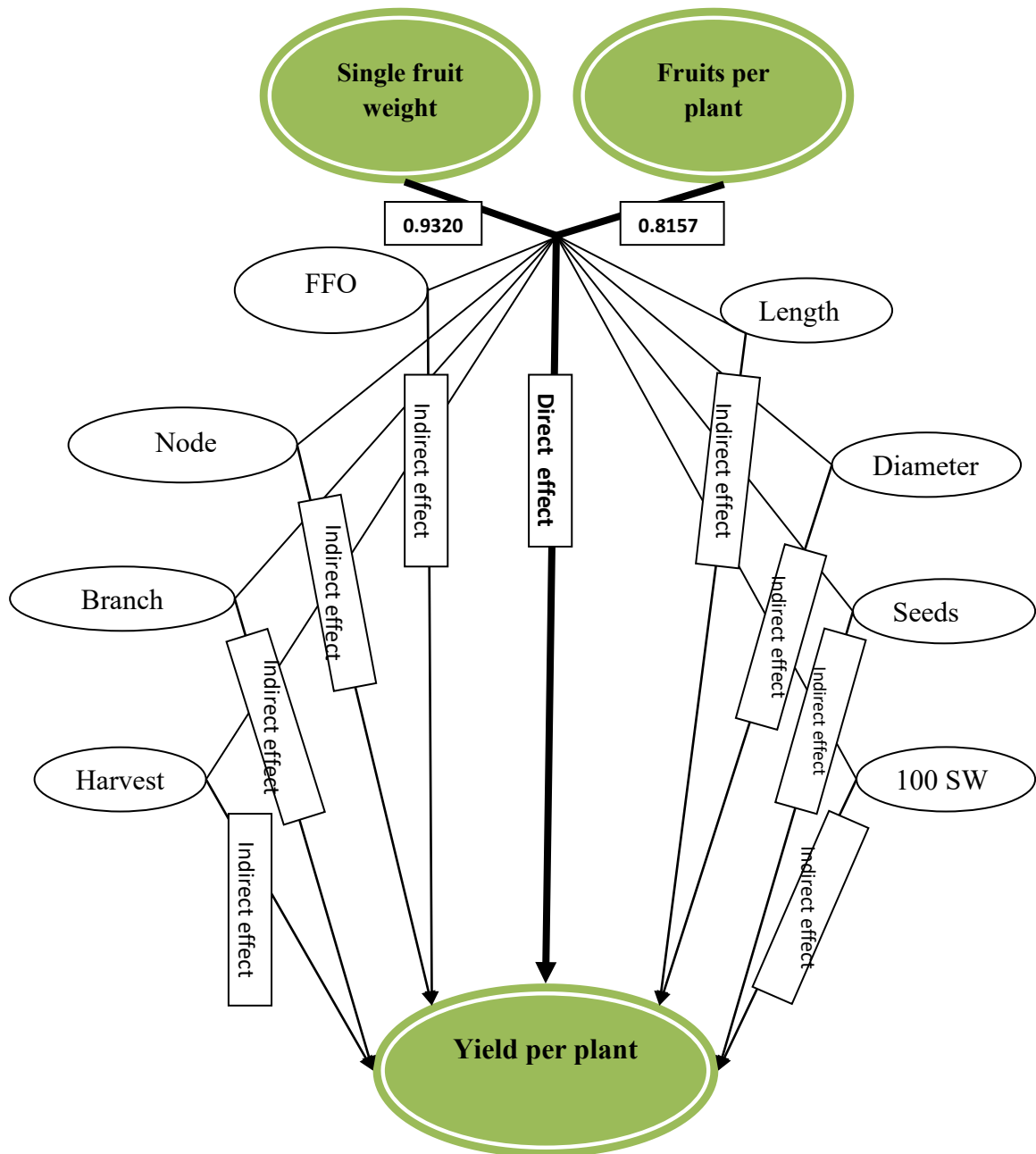


Figure 4.1.2.2 Showing genotypic direct and indirect effect of single fruit weight & fruits per plant on yield per plant in Bitter gourd

Note: FFO=Days to first female flower open
 Branch=Number of branches
 Fruit per Plant=Number of fruits per plant
 Diameter=Fruit diameter
 100 SW=Hundred seed weight

Node=Number of node at female flower open
 Harvest=Days to 1st harvest
 Length= Fruit length
 Seed= Number of seeds per fruit

Estimation of heritability

Heritability in the narrow sense is important to the plant breeder, because the effectiveness of selection depends on the additive portion of genetic variance in relation to total variance (Falconer, 1960). Parent offspring regression is a widely used estimator of heritability that is simple to compute and is unbiased even when selection of parents occurs (Falconer, 1981). This is the only method that has been proved unbiased in the presence of selection. It is important to realize that heritability is a property not only of a character but also of the population and the environment (Falconer and Mackay, 1996).

Since the value of heritability depends on the magnitude of all the components of variance, a change in any of those factors will affect it. Therefore, change of conditions of culture or management, such as plant date, density, number of replications and years, will affect environmental variance (Wricke and Weber, 1986; Falconer and Mackay, 1996).

Heritability estimates in early generations provide basic information for designing an efficient and effective breeding strategy. Heritability is greatly influenced by the breeding population, i.e., the selection for a trait, hence by the gene frequencies concerned. Primitive landraces, unselected, generally show high additive variance, hence high heritability. On the contrary, advance breeding materials that have undergone considerable selection show low additive variance, hence low heritability. The heritability estimate cannot be generalized to a crop since it is highly specific and valid for the material involved in the experiment and for the environment of experimentation. It is important that environments are generally uncontrolled and diverse genetic materials are used in plant breeding. Selection of a trait should fairly be easy if heritability of that trait is very high. This is because there would be a close correspondence between genotype and phenotype due to a relatively smaller contribution of environment to the phenotype. Nevertheless, for a trait with low heritability, selection may be considerably difficult or virtually impractical due to the masking effect of the environment on the genotypic effects (Singh, 1990). The heritability in broad sense was found to be high for the majority of the characters of bitter melon which indicated less environmental effect and the additive gene action. Low narrow sense of heritability coupled with higher degree of non-additive gene action in yield and its components suggested that heterosis breeding might be advantageous for obtaining higher gains in bitter melon.

Table 4.1.2.5 Estimates of heritability for different characters in bitter gourd

Characters	Broad sense heritability (h^2_b)
Days to first female flower opening	77.51
No. of node at first female flower appeared	70.12
Days to first fruit harvest	66.63
Number of branches per plant	79.35
Single Fruit weight	86.72
Fruit length	93.21
Fruit diameter	79.15
Number of fruits per plant	93.52
Number of seeds per fruit	92.21
100 seed weight (g)	74.83
Yield (kg/plant)	89.23

Maurya *et al.* (2018) were reported high heritability values for days to first female flowering, number of node at first female flower open, fruit length, number of fruits per plant, single fruit weight and fruit yield in bitter gourd.

The high heritability values (90%) were observed for number of seeds per fruit, fruit length and number of fruits per plant which corroborated the findings of Yadav *et al.*, (2012) in cucumber. Similar findings were reported by Tyagi *et al.* (2018) and Maurya *et al.* (2018) in bitter gourd. Higher heritability values 90% were observed for yield per vine, node number of first female flower, fruit diameter and seed weight was also reported by Kichenaradjoui and Shakila (2017) in ash gourd. In the present study, all the traits expressed high heritability. The results in the experiment revealed higher heritability estimates for all the characters that indicates less influence of environment and is governed by additive gene effects. Similar results were also reported by Sahoo and Singh (2020) in cucumber.

4.2 Experiment II: Selection of parents based on genetic background utilizing Line x Tester analysis

4.2.1 Analysis of Variance (ANOVA)

All genotypes were showed differences with respect to the traits used in the experiment (Table 4.2.1.1& Table 4.2.1.2). There was a significant variation among lines, testers and hybrids, hence it is possible to calculate the general combining abilities in the population. Line × tester technique is useful in deciding the relative ability of lines to produce desirable hybrid combinations. It also provides information on genetic components and enables the breeders to choose appropriate breeding methods for hybrid variety development programs (Singh and Kumar, 2004).

The analysis of variance (Table 4.2.1.1 & Table 4.2.1.2) showed highly significant differences among genotypes, parent, parent vs. crosses, crosses, lines and lines x testers for all the traits studied and further indicates the presence of sufficient diversity among the lines and testers. Parental lines recorded higher significant variance for all the characters (Table 4.2.1.1).In pooled analysis of variance, the significant differences for testers were observed for all the traits except first female flower opening, node number, first harvest, hundred seed weight and yield per plant, while variance due to interaction effect (line x tester) was highly significant for all the characters (Table 4.2.1.2). The results are in conformity with earlier findings (Sundharaiya and Venkatesan 2007), (Singh and Kumar, 2004).

Table 4.2.1.1 ANOVA for combining ability of 11 different characters

Parameters	df	First female flower open	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Seeds per fruit	100-seed weight (g)	Yield per plant (kg)
Replications	2	0.33	0.63	0.11	0.084	0.14	0.42	0.012	5.09	0.34	0.51*	5.71
genotypes	76	17.20**	26.39**	21.22**	17.96**	4068.89**	43.82**	2.84**	1.29**	173.52**	20.35**	3.38**
Parents	26	15.35**	31.25**	19.46**	24.21**	4995.53**	70.50**	2.39**	8.67**	106.07**	12.13**	1.20**
Parents vs Crosses	1	40.04**	34.20**	338.47**	4.34**	762.92**	33.94**	93.65**	4.13**	6823.97**	113.02**	1.36**
Crosses	49	17.18**	23.65**	15.67**	14.93**	3644.67**	29.86**	1.23**	6.89**	73.59**	22.82**	1.83**
Error	152	0.20	0.22	0.21	0.13	0.28	0.15	0.013	2.38	0.24	0.12	8.16

*Significant at 5% **Significant at 1%

Table 4.2.1.2 ANOVA based on Line x Tester analysis for 11 different characters

Parameters	df	First female flower open	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit Length (cm)	Fruit Diameter (cm)	Fruits per plant	Seeds per fruit	100-seed weight (g)	Yield per plant (kg)
Lines	24	22.85*	39.37**	19.69**	20.27**	5.19**	49.05**	1.48**	98.43**	110.89**	35.34**	2.44**
Testers	1	6.78	4.77	3.47	83.63**	3.43**	105.22**	19.03**	259.17**	502.01**	2.40	2.46
Lines x Testers	24	11.95**	8.71**	12.17**	6.72**	8.18**	7.54**	0.24**	31.54**	18.44**	11.15**	1.20**
Error	152	0.20	0.22	0.21	0.13	2.78	0.15	0.01	0.24	0.24	0.12	0.01

*Significant at 5% **Significant at 1%

Table 4.2.1.3 GCA and mean value of lines and testers of bitter gourd

Inbred lines	First female flower open	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Seeds per fruit	100- seed weight (g)	Yield/ plant (kg)
BT-1	-2.78**	-5.75**	-1.13	-2.57**	56.51**	7.48**	-0.59	-7.78**	-5.43**	-4.47**	-0.21
	28.23	17.10	40.20	21.13	251.17	30.40	5.55	14.53	17.73	9.23	3.69
BT-2	-1.13	0.66	-0.54	-2.92**	-26.9**	-1.46**	-0.58	-4.07**	10.61**	-0.95	-1.13
	29.20	26.93	41.90	20.23	178.83	25.70	5.83	14.13	33.93	15.13	2.47
BT-3	1.79**	1.53**	1.74**	-0.54	8.77**	-1.57**	0.42	1.01	5.17**	-0.93	0.39
	34.67	25.40	48.27	18.83	175.60	23.13	7.03	10.93	33.23	13.57	1.93
BT-4	1.44*	2.05**	0.90	-1.47**	17.94**	-1.76**	0.72	1.87**	4.54**	-1.58**	0.91
	32.03	23.47	39.37	18.37	147.80	15.95	7.00	19.70	28.23	13.23	2.86
BT-5	-0.13	1.89**	-0.39	-0.78	-16.62**	-3.72**	0.21	2.54**	5.39**	-2.45**	0.29
	28.67	16.30	38.80	6.43	156.73	16.43	5.95	17.87	27.90	13.03	2.78
BT-6	-1.39*	-2.16**	-1.92**	1.39*	35.71**	0.39	0.54	-3.67**	4.72**	-0.91	0.28
	29.72	20.07	42.47	16.10	213.33	22.45	6.70	11.50	35.50	12.70	2.45
BT-7	1.95**	0.83	0.79	-1.47**	5.54**	1.72**	-0.55	-0.61	-1.75**	-3.03**	0.17
	31.40	18.15	44.70	14.10	207.80	27.37	5.30	17.63	19.00	12.18	3.23
BT-8	-1.24	-4.58**	-1.71**	-1.68**	-32.29**	-2.68**	-0.453	3.70**	2.96**	1.23	-0.17
	30.90	19.23	42.10	11.80	187.20	23.09	6.55	18.10	29.20	14.40	3.10
BT-9	3.17**	1.99**	2.52**	3.18**	3.93**	-0.76	0.31	-1.23	-0.93	1.29	0.01
	36.57	22.24	44.53	17.10	179.20	20.65	7.51	11.90	34.50	15.70	2.05
BT-11	0.71	0.68	0.69	-0.88	-25.96**	-2.86**	-0.34	6.77**	-6.44**	-3.82**	-0.59
	31.90	22.60	43.90	14.63	152.10	19.60	5.79	21.73	18.87	15.30	2.99
BT-12	3.41**	1.64**	3.25**	-0.22	-7.79**	1.62**	-0.23	-1.80**	-0.55	0.69	-0.36
	31.60	27.70	42.57	14.40	219.70	24.78	7.31	14.30	35.90	15.00	3.12
BT-13	-0.09	1.77**	-0.46	1.56**	23.78**	3.59**	0.12	1.59**	0.76	-3.13**	0.94
	29.90	22.28	43.00	14.30	158.40	25.47	5.67	15.50	30.60	14.63	2.42
BT-14	-0.44	-2.79**	-0.76	0.85	41.32**	2.53**	0.60	0.14	-1.86**	-1.23	1.16
	32.90	19.92	43.90	14.43	164.87	23.00	6.61	19.37	31.10	12.43	3.01
BT-15	-1.59**	-4.76**	-1.08	3.42**	56.97**	2.05**	0.74	-2.07**	-0.69	3.32**	0.99
	28.63	21.11	42.03	15.40	236.87	24.75	7.80	15.97	25.50	10.07	3.37

N.B: The upper row indicates the GCA and lower row indicates the mean value for the selected characters against each of the inbred lines

Table 4.2.1.3 GCA and mean value of lines and testers of bitter gourd (continued)

BT-16	-1.69**	-0.72	-1.77**	0.27	-3.82**	-0.03	0.14	-2.27**	4.13**	3.72**	-0.34
	32.67	26.63	49.10	14.90	176.27	25.47	4.79	18.67	26.72	13.80	3.08
BT-17	2.36**	2.06**	1.93**	-1.38*	14.89**	-0.72	0.79	2.03**	-3.85**	-0.31	0.90
	37.27	28.07	49.23	14.90	127.73	18.07	5.88	10.30	21.53	12.43	1.32
BT-18	2.04**	4.07**	2.17**	1.91**	15.31**	-0.26	0.48	-2.08**	-5.09**	4.48**	0.06
	29.67	25.07	46.63	14.50	126.70	15.69	5.57	26.13	26.90	14.69	3.01
BT-19	-0.48	2.71**	0.33	2.93**	2.43**	4.70**	-0.72	-4.39**	-2.39**	2.61**	-0.56
	30.70	25.13	43.10	16.30	160.03	31.24	4.86	15.80	21.90	14.50	2.52
BT-20	0.69	-0.29	1.83**	-0.43	11.01**	0.14	0.01	-5.19**	-1.92**	2.77**	-0.53
	34.37	24.19	44.37	14.77	145.10	18.89	6.07	17.80	24.58	17.13	2.44
BT-21	1.83**	1.48**	1.41**	-0.22	-1.89**	-2.85**	0.01	-2.87**	-3.38**	0.38	-0.43
	32.03	23.07	43.13	13.90	147.90	16.83	5.62	11.93	26.87	15.43	1.72
BT-22	-2.29**	0.77	-2.16**	1.88**	-45.69**	-4.07**	-0.14	11.89**	0.24	2.74**	0.39
	29.60	28.42	43.20	17.63	82.80	13.92	5.63	37.20	32.30	16.40	2.93
BT-23	-4.61**	-3.82**	-4.26**	1.73**	-41.08**	0.69	-0.60	1.96**	-3.69**	-1.43**	-0.81
	28.80	22.82	45.40	16.27	111.87	24.78	4.70	16.57	27.33	11.33	1.81
BT-24	0.21	-0.38	0.93	-2.67**	-35.93**	-4.19**	0.01	0.89	-1.27	0.19	-0.69
	32.13	21.09	42.30	15.63	150.37	17.27	6.81	16.17	31.77	15.80	2.48
BT-25	-1.27	0.49	-2.44**	-1.32*	-15.25**	-0.71	-0.04	1.96**	5.35**	1.41*	0.05
	33.50	22.87	45.60	15.37	94.93	13.60	4.93	13.97	33.02	18.03	1.33
BT-26	-0.46	0.65	0.11	-0.57	-40.78**	2.75**	-0.85	1.66**	-4.63**	-0.58	-0.71
	31.70	20.64	43.70	16.93	106.13	25.87	4.91	14.30	18.44	15.30	1.51
Testers											
BT-10	-0.21	0.18	-0.15	0.75	-15.12**	0.84	-0.36	1.31*	-1.83**	-0.13	-0.13
	32.17	23.00	43.63	19.17	167.30	26.13	5.20	13.83	24.03	13.33	2.25
BT-27	0.21	-0.18	0.15	-0.75	15.12**	-0.84	0.36	-1.32*	1.83**	0.13	0.13
	29.97	22.93	44.70	18.10	178.90	19.72	6.91	14.90	39.90	13.13	2.67
CD of Line and Tester											
Lines	0.36	0.38	0.36	0.29	0.42	0.32	0.09	0.39	0.39	0.28	0.07
Tester	0.10	0.10	0.10	0.08	0.11	0.04	0.03	0.11	0.11	0.08	0.02

N.B: The upper row indicates the GCA and lower row indicates the mean value for the selected characters against each of the inbred lines

4.2.2 Selection of parents based on combined GCA and mean ranking

Ranking of inbred lines on the basis of GCA

BT-1 possessed the highest rank for fruit length followed by BT-19 and BT-12; it also stood second rank for average fruit weight on the basis of general combining ability (Table 4.2.2.1). BT-12 showed the highest ranking for first female flower opening followed by BT-9 and BT-17. BT-18 possessed the highest ranked for node number followed by BT-19 and BT-17, it also stood highest ranked for hundred seed weight. BT-12 showed the highest ranked for first fresh fruit harvest followed by BT-9 and BT-18. BT-15 possessed the highest ranked for number of branches per plant and average fruit weight, it also stood second ranked for fruit diameter and yield per plant. Rest of the characters showed moderate values. BT-22 showed the highest ranked for number of fruits per plant followed by BT-11 and BT-8. BT-2 stood the highest ranked for number of seeds per fruit followed by BT-5 and BT-25. BT-18 possessed the highest ranked for hundred weight followed by BT-16 and BT-15. But it also produced the highest 100 seed weight which was due to bigger size of seed. So, commercial farmers would disagree with this genotype for less covering their land. BT-14 showed the highest ranked for yield per plant followed by BT-15, BT-13 and BT-4 (Table 4.2.2.1).

Ranking of inbred lines on the basis of mean values

Yield is the ultimate goal for any crop production. The highest yield was in BT-1 genotypes followed by BT-15 and BT-7 (Table 4.2.2.2). The single fruit weight possessed the highest weight in BT-1 followed by BT-15, BT-12, BT-6 and BT-7, respectively. It also scored the highest in first female flower opening followed by BT-15, BT-05 and BT-23. Number of seeds per fruit, 100-seed weight and number of branches per plant possessed ranking one in BT-01. Number of seeds per fruit should be less to make it more acceptable to the consumer. BT-05 showed the highest ranked for node number at which first female flower appeared followed by BT-01, BT-07 and BT-08, respectively. BT-05 possessed the highest ranked for the character first harvest followed by BT-04, BT-01 and BT-02. The genotypes BT-19 showed the highest ranked for fruit length followed by BT-01, BT-07 and BT-26, respectively. Fruit diameter possessed the highest rank in BT-23 followed by BT-16, BT-19 and BT-26. The highest fruit per plant was in BT-22 genotypes followed by BT-18, BT-11 and BT-04, respectively (Table 4.2.2.2).

Combined ranking of inbred lines based on GCA and mean performance

In case of parent selection, the highest and the lowest GCA have been considered to know the gene action. Parents were considered on the basis of maximum and minimum GCA ranking for making hybridization program. Parent selection is an important step in any breeding program. The highest mean value also has been considered in the case of parent selection. The genotypes with high mean value can directly be used as parents in hybridization (Resmi and Sreelathakumary, 2017).

In the present study, out of 27, seven different parental lines were selected on the basis of combining ability using line x tester method (The experimental field view showed in Figure 4.2.2.2) and mean value of inbred lines (Table 4.2.1.3) and finally total ranking of inbred lines (Table 4.2.2.3). To select homozygous parents from the inbred lines ranking was done on the basis of general combining ability utilizing line x tester analysis and mean performance. Parents having the highest mark were given lowest rank (Table 4.2.2.3). From 27 inbred lines, seven parents were selected based on lowest ranking value (Hasanuzzaman, 2010) and Azad (2014). Ranking helped in selection of parent from different inbred lines. The dissimilarity/ variability among the seven selected parents were quite high and fruit morphotypes of selected parents are shown in Figure 4.2.2.1. BT-1, BT-7 was selected due to the highest ranking for GCA (203 and 144, respectively) within the inbred lines. BT-18, BT-13 was selected due to the lowest ranking for GCA (90 and 104, respectively) within 27 inbred lines (Table 4.2.2.1). Higher mean values were also considered for selecting the parental lines (Table 4.2.2.2). Finally, BT-1, BT-4, BT-7, BT-13, BT-15, BT-18 & BT-19 were selected on the basis of ranking value for 7×7 diallel crossing program (Table 4.2.2.3 and Figure 4.2.2.1). The salient features of the selected seven parents are represented in Table 4.2.2.4. BT-1 was green, long with smooth spine. BT-4 was light green, fatty with more spines. BT-7 was very light green, long with smooth spine. BT-13 was green, medium long and sharp spine. BT-15 was shiny green, medium long, fatty with more spines. BT-18 was green, fatty and blunted spine. BT-19 was light green, slender and long shaped (Figure 4.2.2.1). So, utilizing this genetic architecture and potentiality of the selected seven parents could be evaluated by combining ability to obtain the desirable recombinant.

Table 4.2.2.1 Ranking of inbred lines on the basis of general combining ability (GCA) in bitter gourd

Genotypes	First female flower open	Node number	First harvest	Branches per plant	Average fruit weight(g)	Fruit length(cm)	Fruit diameter(cm)	Fruits per plant	Seeds per fruit	100 seed weight(g)	Yield per plant (kg)	Total ranking number
BT-01	24	25	19	22	2	1	22	24	24	25	15	203
BT-02	17	15	16	24	20	17	21	21	1	17	25	194
BT-03	7	9	6	14	10	18	7	10	4	16	7	108
BT-04	8	4	9	20	6	19	3	7	6	20	4	106
BT-05	13	6	14	16	18	23	9	4	2	21	8	134
BT-06	20	20	22	8	4	10	5	20	5	15	9	138
BT-07	5	11	10	20	11	7	20	13	15	22	10	144
BT-08	18	23	20	21	21	20	19	3	8	9	14	176
BT-09	2	5	2	2	12	16	8	14	13	8	13	95
BT-11	9	14	11	17	19	22	18	2	25	24	21	182
BT-12	1	8	1	11	16	8	17	15	11	10	17	115
BT-13	12	7	15	7	5	3	11	9	9	23	3	104
BT-14	14	21	17	9	3	5	4	12	16	18	1	120
BT-15	21	24	18	1	1	6	2	16	12	3	2	106
BT-16	22	13	21	10	15	12	10	18	7	2	16	146
BT-17	3	3	4	19	8	15	1	5	21	13	5	97
BT-18	4	1	3	4	7	13	6	17	23	1	11	90
BT-19	16	2	12	3	13	2	24	22	18	6	20	138
BT-20	10	18	5	13	9	11	13	23	17	4	19	142
BT-21	6	10	7	12	14	21	14	19	19	11	18	151
BT-22	23	12	23	5	25	24	16	1	10	5	6	150
BT-23	25	22	25	6	24	9	23	6	20	19	24	203
BT-24	11	19	8	23	22	25	12	11	14	12	22	179
BT-25	19	17	24	18	17	14	15	6	3	7	12	152
BT-26	15	16	13	15	23	4	25	8	22	14	23	178

*The highest number indicate the lowest ranking

Table 4.2.2.2 Ranking of inbred lines on the basis of mean value for yield and yield contributing characters in bitter gourd

Genotypes	First female flower open	Node number	First harvest	Branches per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruits per plant	Seeds per fruit	100 seed weight (g)	Yield per plant (kg)	Total ranking number
BT-01	1	2	3	1	1	2	7	16	1	1	1	36
BT-02	5	22	4	2	8	5	13	18	22	16	15	130
BT-03	22	20	22	3	10	9	22	23	21	9	20	181
BT-04	16	16	2	4	18	20	21	4	14	8	11	134
BT-05	3	1	1	23	14	19	15	8	13	7	12	116
BT-06	8	6	8	10	4	12	19	22	24	6	16	135
BT-07	12	3	18	20	5	3	6	10	4	4	3	88
BT-08	11	4	6	22	6	10	17	7	15	11	5	114
BT-09	23	10	17	6	7	13	24	21	23	19	19	182
BT-11	15	12	15	18	15	14	12	3	3	17	9	133
BT-12	13	23	9	18	3	7	23	17	25	15	4	157
BT-13	9	11	10	19	13	6	11	15	16	13	18	141
BT-14	19	5	15	17	11	11	18	5	17	5	8	131
BT-15	2	9	5	12	2	8	25	13	8	2	2	88
BT-16	18	21	23	14	9	6	2	6	9	10	6	124
BT-17	24	24	24	14	20	16	14	24	5	5	25	195
BT-18	7	18	21	16	21	21	8	2	11	14	7	146
BT-19	10	19	11	8	12	1	3	14	6	12	13	109
BT-20	21	17	16	15	19	15	16	9	7	22	17	174
BT-21	16	15	12	21	17	18	9	20	10	18	22	178
BT-22	6	25	13	5	25	22	10	1	19	21	10	157
BT-23	4	13	19	9	22	7	1	11	12	3	21	122
BT-24	17	8	7	11	16	17	20	12	18	20	14	160
BT-25	20	14	20	13	24	23	5	19	20	23	24	205
BT-26	14	7	14	7	23	4	4	17	2	17	23	132

*The highest number indicate the lowest ranking

Table 4.2.2.3 Ranking of inbred lines on the basis of GCA and mean value in bitter gourd

Inbred lines	Ranked based on GCA	Ranked based on mean performance	Total number	Combined ranking
BT-01	203	36	239	4
BT-02	194	130	324	21
BT-03	108	181	289	14
BT-04	106	134	240	5
BT-05	134	116	250	8
BT-06	138	135	173	12
BT-07	144	88	232	2
BT-08	176	114	290	15
BT-09	95	182	277	13
BT-11	182	133	315	19
BT-12	115	157	272	11
BT-13	104	141	245	6
BT-14	120	131	251	9
BT-15	106	88	194	1
BT-16	146	124	270	10
BT-17	97	195	292	16
BT-18	90	146	236	3
BT-19	138	109	247	7
BT-20	142	174	316	20
BT-21	151	178	329	23
BT-22	150	157	307	17
BT-23	203	122	325	22
BT-24	179	160	339	24
BT-25	152	205	357	24
BT-26	178	132	210	18

*The highest number indicates the lowest ranking

Table 4.2.2.4 Mean performance for eleven characters of selected seven inbred lines in bitter gourd

Genotype	First female flower opening	Node number	First harvest	Branch per plant	Average fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit / plant	Seeds/ fruit	100 seed weight(g)	Yield per plant (kg)
BT-01	28.23	17.10	40.20	21.13	251.17	30.40	5.55	14.53	17.73	9.23	3.69
BT-04	32.03	23.47	39.37	18.37	147.80	15.95	7.00	19.70	28.23	13.23	2.86
BT-07	31.40	18.15	44.70	14.10	207.80	27.37	5.30	17.63	19.00	12.18	3.23
BT-13	29.90	22.28	43.00	14.30	158.40	25.47	5.67	15.50	30.60	14.63	2.42
BT-15	28.63	21.11	42.03	15.40	236.87	24.75	7.80	15.97	25.50	10.07	3.37
BT-18	29.67	25.07	46.63	14.50	126.70	15.69	5.57	26.13	26.90	14.69	3.01
BT-19	30.70	25.13	43.10	16.30	160.03	31.24	4.86	15.80	21.90	14.50	2.52



Figure 4.2.2.1 Fruit morphotypes of selected seven parental lines



Figure 4.2.2.2 Experimental field view of bitter gourd

4.3 Experiment III: Genetic analysis of the selected parents based on diallel analysis

The diallel analysis helps to obtain information on the genetic systems governing the inheritance of attributes to be improved, and hence may help in predicting the performance in subsequent generations by assessing the potential of different crosses. The diallel cross is defined as all possible crosses among a group of parents. Plant breeders use diallel analysis as an aid in selection and to investigate genetic properties of parents and their crosses. A diallel analysis can provide useful information regarding the genetic control of a quantitative trait. It provides information on average performance of individual lines in crosses known as general combining ability (GCA). It also gives information about the performance of crosses relative to the average performance of parents involved in the cross known as specific combining ability (SCA). Significant GCA and SCA effects provide information to help determine the efficacy of breeding for improvements in given traits and they can be used to identify lines to serve as parents in a breeding program for trait improvement (Kearsey and Pooni, 1996). The following parents are used for combining ability in this study: BT-01, BT-04, BT-07, BT-13, BT-15, BT-18 and BT-19.

4.3.1 Analysis of variance (ANOVA) for combining ability

The analysis of variance for diallel analysis revealed that significant differences for all the characters among genotypes and hybrids (Table 4.3.1.1) hence selection will be effective in improving the traits. ANOVA for combining ability showed that GCA variances were significant for all the traits except number of branches per plant, first harvest and number of seeds per fruit. Significant SCA variances were also observed for all the characters studied. Hence these characters may be improved through hybridization (heterosis) indicating predominance of non-additive gene effects. The significant variances due to GCA indicate the additive gene action, while that for SCA indicates the non-additive gene action.

Therefore, in the present investigation both additive and non-additive gene actions were found to influence the performance of the hybrids. Additive gene action was found for all characters except number of branches per plant, first harvest and number of seeds per fruit for which only non-additive gene actions were predominant. Mean square of reciprocal effect of three characters (days to first female flower open, number of node at first female flower open and days to first harvest) were higher than the SCA, which indicated the existence of reciprocal effects in bitter gourd. The non-additive effects played a more important role than

additive effects. Mean square of reciprocal is less than GCA in all of the eleven characters indicating the major contribution of nuclear genes effect.

In ribbed gourd, Latif (1993) found significant variances due to GCA for number of fruits per plant, fruit length, fruit breath and yield per plant and also observed significant variances due to SCA for all yield and yield contributing characters.

The variances due to general combining ability (GCA) were greater than those of specific combining ability (SCA) for most of the traits studied (Table 4.3.1.1.) indicating the additive genetic variance in the inheritance of these traits, i.e., mostly the additive gene actions were responsible for the expression of these characters. Non additive gene actions were also found in days to first harvest and number of seeds per fruit. Vegad *et al.* (2011) noted that variance due to GCA and SCA were highly significant for all the characters except SCA for days to first male and female flower opening. They also explained that both additive and non-additive genetic variance were present for inheritance of fruit yield and its components. The ratio of GCA: SCA was greater than unity for most of the traits indicating the importance of additive genetic variance in the inheritance of the traits studied. These findings were very close to the present study.

Almost similar type findings were also reported by Naliyadhara *et al.* (2010) and Vegad *et al.* (2011). Singh *et al.* (2013) explained that fruit length and fruit breadth showed significance differences between GCA and SCA variances which indicated additive gene action. Naliyadhara *et al.* (2010) estimated that the variance of SCA were higher than GCA for almost all the traits which indicated the predominance of non-additive gene action for most of the characters in sponge gourd.

The magnitudes of GCA and SCA effects are indicative of the relative important once of additive and non-additive gene action in the inheritance of a trait (Griffing, 1956b; Kornegay and Temple, 1986). According to a large GCA: SCA variance ratio suggests importance of additive gene effects, while a low ratio signifies presence of dominant and/or epistatic gene effects (Griffing, 1956a, Kornegay and Temple 1986).

A close correspondence was observed between *per se* performance and combining ability effects for the attributes studied. Dhillon and Sharma (1987) observed in a study at Ludhiana, India with two characters viz. days to marketable maturity and days to anthesis of the first female flower in 10 *Cucurbita pepo* inbred and their 45 F₁ revealed highly significant SCA

and GCA variances for both traits. Banik (2003) studied the nature of combining ability of parents and crosses in a 6x6 diallel cross of snake gourd and reported that significant mean sum of squares due to GCA and SCA for all the characters indicated both additive as well as non-additive type of gene actions. She concluded that both additive and dominant genetic components were important for yield and yield components in snake gourd. She also observed the highest significant SCA variances for first male and female flower opening, average fruit weight, yield per plant, number of fruits per plant and 100-seed weight.

Laxuman (2005) reported that the analysis of combining variance revealed that both GCA and SCA variances were significant for 15 of the 16 characters in bitter gourd. Such results indicated the importance of both additivity and non-additivity in the inheritance of these 15 characters in bitter gourd.

The results of the present investigation have similarity with the findings of Singh *et al.* (2013), Bimal (2008) in bitter gourd.

Table 4.3.1.1 Analysis of variance (ANOVA) for combining ability of yield and yield components of bitter gourd

Source of variation	Df	Characters (Mean sum of square)										
		First female flower open	Number of node	Number of branches per plant	First harvest	Number of fruits per plant	Single fruit weight	Fruit length	Fruit diameter	Number of seeds per fruit	100-seed weight	Yield per plant
Block	2	0.02	0.01	1.88**	0.17	0.20	0.38	0.01	0.03	0.23	0.34*	0.01
Crosses	48	15.96 **	23.63**	19.98**	18.38**	108.70**	4042.50**	72.37**	1.51**	53.49**	6.60**	3.34**
GCA	6	15.88 *	20.88**	10.14ns	9.84ns	157.67**	6133.42**	163.58**	2.88**	25.65ns	7.30**	2.10*
SCA	21	2.62 **	5.71**	8.32**	4.63**	23.06**	690.84**	5.24**	0.25**	26.65**	1.78**	1.03**
Reciprocal	21	5.00 **	6.33**	4.01**	5.36**	14.71**	636.76**	3.16**	0.08**	8.00**	1.17**	0.92**
Error	96	0.05	0.05	0.03	0.07	0.05	0.05	0.03	0.01	0.04	0.03	0.00
GCA: SCA		6.06	3.66	1.22	1.77	6.84	8.88	31.22	11.52	1.20	4.10	2.03
Rec: GCA		0.31	0.30	0.40	0.54	0.09	0.10	0.02	0.03	0.31	0.16	0.44

*P<0.05, **P<0.01, respectively

4.3.2 Estimation of GCA and SCA effects of the parents

General combining ability is the average performance of a line in hybrid combinations, while SCA is used to designate deviations of certain crosses from expectations based on the average performance of the lines involved (Sprague and Tatum, 1942). Genetically, GCA is primarily associated with genes, which are additive in their effects, whereas SCA is attributed to the non-additive genetic portion of the total genetic effects (Rojas and Sprague, 1952). Additive effects are the predictable portion of the genetic effects and are therefore useful to plant breeders. Diallel cross designs are frequently used in plant breeding research to obtain information on general combining ability (GCA) and specific combining ability (SCA).

So, the choice of appropriate parental material for crossing is the first and foremost step in the development of new crop cultivars. Knowledge on the effects of general combining ability (GCA) and specific combining ability (SCA) is useful in the selection of parental genotypes. General and specific combining ability effects are important indicators of the potential value of inbred lines in hybrid combinations.

In combining ability analysis, parents were categorized into (i) good combiners for highest GCA effects (ii) Poor combiners for lowest value of GCA effects, (iii) average combiners for those having moderate GCA effects between highest and lowest values. Similarly, on the basis of SCA effects, specific combiners (crosses) were also defined into same group for different plant characters.

4.3.2.1 General combining ability (GCA) effects of the parents

The estimation of general combining ability (GCA) effects of seven parental inbred lines in F1 generations are presented in Table 4.3.2.1. In the present study, parents were classified as good, average and poor combiner based on their GCA effects according to Acharya *et al.* (2019) in bitter melon. Parents with desirable and significant GCA effects were considered as good combiners, while parents exhibiting nonsignificant estimates were classified as average combiners. Parents showing significant undesirable GCA effects were classified as poor combiners. A good combiner for any economic character need not be a good combiner for all other characters. Therefore, the magnitude and direction of the significant effects of GCA for the seven parents provides meaningful comparison and would give clue to the future breeding program for crop improvement. Character-wise interpretations of GCA effects are given below.

Days to first female flower open

For days to first female flowering, negative estimates of general combining ability (GCA) effects were considered desirable, since these were preferable for earliness of the parents (Table 4.3.2.1). Because it indicates the general capacity of early parent to transmit its behavior to progeny in cross combination with other parents. The estimates of GCA effects ranged from -0.95 in BT-01 to 2.20 in BT-04 for female flower opening. Total five parents (BT-01, BT-07, BT-13, BT-15 and BT-18) had significant negative GCA effects for days to female flower opening. Out of these parental lines, BT-01 had the highest negative estimates and considered as the best general combiner for this trait among all the genotypes followed by BT-15, B-13, BT-18 and BT-07. Therefore, this parent might be used in the breeding program for developing early flowering, i.e., early fruiting varieties. The rest two parents (BT-04 and BT-19) showed nonsignificant positive GCA effect which is not desirable for this trait. Uddin (2008) reported in cucumber (*Cucumis sativus* L.) considering GCA effects the parent F8 (CS0102) was the best for early female flower opening. The present findings are in conformity with Bhatt *et al.* (2017) in bitter melon where it was revealed that the parental genotype BT-01 were desirable for negative GCA effects and the best general combiner for days to first female flowering in bitter melon.

Number of node at first female flower opening

For number of node at which first female flower opening traits of parents with negative values were considered as favorable as well as good combiner. Among seven parents, three parents namely BT-07, BT-01 and BT-13 showed negative GCA estimates and they were considered as good general combiners. BT-07 had the highest GCA effect (-1.79) followed by BT-01(-1.09) for node number. Verma *et al.* (2013) reported that the line NDBT-13 was good combiner for node number (significantly negative GCA effects) in bitter melon which is conformity with this study. Bhatt *et al.* (2017) also reported similar type findings in bitter melon. Three parents (BT-04, BT-18 and BT-19) showed nonsignificant positive and BT-15 showed significant positive GCA effect which is not desirable for this trait.

Number of branches per plant

Out of seven parental lines five lines *viz.*, BT-1, BT-04, BT-15, BT-18 and BT-19 showed positive GCA effects in favorable direction for number of branches per plant as considered as desirable trait as combiner. Parents BT-07 and BT-13 showed negative significant GCA

effect which is not favorable for this trait. Acharya *et al.* (2019) reported that IC-68237 was considered good general combiner (positive) for number of primary branches in bitter gourd.

Days to first fruit harvest

Days to first harvest is the most important character in bitter gourd for earliness. Parents BT-15, BT-18, BT-07, BT-19 and BT-BT-13 showed favorable significant negative GCA effects for days to first fruit harvest. But BT-01 and BT-04 showed positive GCA effect which is not desired for this trait. Parents BT-15 had the highly significant GCA effect (-0.06) followed by BT-18 (-0.06), BT-07, BT-19 and BT-13. This indicates that parent BT-15 was the best general combiner for earliness for fruit harvest followed by parent BT-18 and BT-07 (Table 4.3.2.1). The present result is consonance with the reports of Bhatt *et al.* (2017) in bitter gourd. Verma *et al.* (2013) also reported significant negative GCA effect for this trait in bitter gourd.

Number of fruits per plant

Out of seven parental lines, BT-18 (7.15), and BT-19 (0.48)) expressed positive GCA effects. Hence these parental lines appeared as good general combiners. Eventually, these parents can be used sequentially in breeding program for developing varieties bearing more number of fruits per plant. Whereas, BT-01, BT-13, BT-15 and BT-07 exhibited negative and significant GCA effects (Table 4.3.2.1) were the poor combiners for this trait. Punjab-14 was found good general combiner for fruits per plant reported by Bhatt *et al.* (2017) in bitter gourd.

Single fruit weight (g)

Among the parental lines, BT-15 was good general combiner having positive GCA effect followed by BT-01 (17.1), BT-07 (14.38) and BT-19 (6.57) (Table 4.3.2.1). Whereas, BT-04, BT-13 and BT-18 exhibited negative and significant GCA effects (Table 4.3.2.1) were the poor combiners for this trait. Hence, BT-15 was the good general combiner to use in crossing to improve the average single fruit weight. Bhatt. *et al.* (2017) reported also similar type findings in bitter gourd. Bimal (2008) observed almost similar findings for this trait in bitter gourd.

Table 4.3.2.1 General combining ability (GCA) effects and mean performance for yield and yield components of parental lines in Bitter gourd

Parents	Value	First female flower open	Number of node	Number of branches per plant	First harvest	Number of fruits per plant	Single fruit weight	Fruit length	Fruit diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-01	GCA	-0.95**	-1.09**	0.25	0.54	-3.14**	17.11	2.89	-0.44**	-1.90**	-1.28**	-0.21**
	Mean	28.23	17.10	21.13	40.20	14.53	251.17	30.40	5.55	17.73	9.23	3.69
BT-04	GCA	2.20	0.66	0.58	0.13	-0.16**	-30.84**	-5.41**	0.47	0.31	0.34	-0.60**
	Mean	31.70	23.47	18.37	39.37	19.70	147.80	15.95	7.00	28.23	13.23	2.86
BT-07	GCA	-0.08**	-1.79**	-1.26**	-0.18**	-1.35**	14.38	1.73	-0.45**	-1.35**	-0.41**	0.05*
	Mean	31.40	18.15	14.10	44.70	17.40	207.80	27.37	5.30	19.00	12.18	3.23
BT-13	GCA	-0.63**	-0.41**	-1.20**	-0.86**	-1.58**	-5.16**	0.18	-0.01**	1.59	0.16	-0.27**
	Mean	29.90	22.28	14.30	43.00	15.50	158.40	25.47	5.67	30.60	14.63	2.42
BT-15	GCA	-0.63**	0.01*	0.51	-0.06**	-1.40**	22.48	0.29	0.70	0.62	0.01**	0.21
	Mean	28.63	21.04	15.40	42.03	15.97	236.93	24.75	7.80	25.50	10.07	3.37
BT-18	GCA	-0.33**	0.82	0.66	-0.06**	7.15	-24.55**	-3.68**	0.09	0.83	1.08	0.55
	Mean	29.63	25.07	14.50	46.30	26.13	126.83	15.69	5.57	26.90	14.69	3.01
BT-19	GCA	0.42	1.80	0.46	-0.20**	0.48	6.57	3.99	-0.36**	-0.10**	0.11	0.27
	Mean	30.70	25.23	16.30	43.10	15.80	160.03	31.24	4.86	21.90	14.50	2.52
S.E(gi)		0.056	0.056	0.044	0.063	0.055	0.057	0.041	0.019	0.052	0.041	0.009
CD (gi) at 5%		0.111	0.110	0.087	0.125	0.109	0.113	0.081	0.038	0.103	0.081	0.018
at 1%		0.147	2.446	1.936	0.165	0.144	0.150	0.108	0.050	0.137	0.108	0.024

*P<0.05, **P<0.01, respectively

Fruit length (cm)

Fruit length is directly associated with weight of fruit. Among the seven parents, BT-19 showed the highest positive GCA effect indicating that it was the best general combiner among the all-parental lines followed by BT-01, BT-07 and BT-18. It had the highest mean value also (Table: 4.3.2.1). It can be used in hybridization program to improve the length of fruit. The rest three parents viz. BT-04 and BT-19 showed significant negative GCA effect; therefore, they were poor combiners for this trait. The present result is similar to the reports of Singh *et al.* in bitter gourd, Bhatt *et al.* (2017) in bitter gourd also reported positive and negative GCA effect.

Fruit Diameter (cm)

The parent BT-15 had the highest positive GCA effect (0.70) followed by BT-04 (0.47) and BT-18 (0.09) (Table: 4.3.2.1). Other parents showed negative significant GCA effects for this trait. Hence, BT-15, BT-04 and BT-18 were the good general combiners to use in crossing to improve this trait. Bhatt.*et al.* (2017) in bitter gourd and Sing *et al.* (2013) in bitter gourd reported almost similar results which supported to present study.

Number of seeds per fruit

The highest positive GCA effects illustrated in BT-13 (1.59) followed by BT-18 (0.83) and BT-15(0.62) (Table: 4.3.2.1). So, these parents can be used as good general combiners to improve this trait. This character is needed for seed production. But to develop less seeded bitter gourd, the parents BT-01 (-1.90), BT-07 (-1.35) and BT-19 (-0.10) were the good general combiners that showed negative significant GCA effects for this trait. General consumers choose this trait for fresh fruit. Bimal (2008) in bitter gourd found almost similar findings for this character.

100-seed weight

The parent BT-15 (0.01) expressed the highest significant and positive GCA effects for this character (Table: 4.3.2.1). This trait effects on single fruit weight and ultimately on fruit yield per plant. Four parents (BT-18, BT-04, BT-13 and BT-19) showed positive GCA effects and rest of two (BT-01 and BT-07) showed negative significant GCA effects. Similar findings were also reported by Acharya *et al.* (2019) in bitter gourd.

Fruit yield per plant

The range of the estimates of GCA effects varied from -0.60 in BT-13 to 0.55 in BT-18. Out of seven parental lines, BT-07 expressed significant positive GCA effects. It means that this line was good and the best general combiner (Table: 4.3.2.1). Therefore, this parental line (BT-07) followed by BT-18, BT-19 and BT-15 can be used in breeding program for exploiting additive genes with yield. Such positive association among the parental performance and significant positive GCA effects in bitter gourd were reported by Singh *et al.* (2013) and Bhatt *et al.* (2017).

Information regarding GCA effect of the parent is of prime importance as it helps in successful prediction of genetic potentiality of crosses. In the present study, although significant GCA was observed in all the traits but no parent was found having significant GCA in all the traits studied. But considering most of the characters, BT-07 was the best general combiner under study followed by BT-15, BT-18 and BT-19. In majority of the cases, good general combiners showed better mean performance indicating that the parents may be selected based on GCA and mean performance. The parent with good GCA for a character also exhibits well *per se* performance. Similar results for some characters were reported by Singh *et al.* (2013) in bitter gourd for the parent HABG-30.

4.3.2.2 Specific combining ability (SCA) effects of the crosses

Specific combining ability is a performance of a parent under consideration, in a specific cross. It is due to dominance genetic variance and all the three types of gene interactions (additive x additive, additive x dominance and additive x epistasis). It also helped in identification and hence selection of the best crosses combinations. 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 21 crosses in F1 generation for 11 characters studied are presented in Table 4.3.2.2. There were a good number of crosses having significant and positive SCA effects. The SCA effects in negative direction was considered favorable for traits like as, days to first female flower opening, node number to first female flower anthesis and days to first

fruit harvest. The parents are BT-01, BT-04, BT-07, BT-13, BT-15, BT-18 and BT-19. The character-wise interpretation of SCA effects are given below:

Days to first female flower opening

Considering all the parameters studied for combining ability analysis, negative significant SCA effect is only preferable for first female flowering, node number and first harvest to calculate earliness. Out of 21 F₁s, nine showed significant and negative SCA effects for days to first female flowering (Table: 4.3.2.2) indicated good specific combiners. Among these hybrids BT-07 X BT-15 (-1.75) was the best specific combiner followed by BT-13 X BT-18 (-1.54), BT-01 X BT-19 (-1.27), BT-07 X BT-13 (-0.95) and BT-13 X BT-15 (-0.69) were found as the top four specific combiners respectively. Hence the cross combination, BT-07 X BT-15 provided opportunity for promoting early flowering for female in this crop. The results are in conformity with the finding of Bhatt *et al.* (2017) in bitter gourd.

Node number

Estimates of specific combining ability for earliness in respect of node number at which first female flower appeared were significantly negative and favorable in thirteen hybrids. The crosses BT-07 X BT-18 (-2.92) exhibited the highest significant negative SCA effect followed by BT-04 X BT-19 (-2.45), BT-1 X BT-15 (-2.04), BT-04 X BT-13 (-2.04), BT-15 X BT-18 (-1.17) and BT-01 X BT-04 (-1.15) were found as the top five specific combiners (Table 4.3.1.3). Similar results were reported by Sundaram (2008) and Verma *et al.* (2013) in bitter gourd.

Number of branches per plant

The favorable SCA effects were manifested in twelve hybrids for number of branches per plant. The cross BT-18 X BT-19 (3.03) exhibited the highly positive significant SCA effects followed by BT-04 X BT-18 (2.87), BT-04 X BT-15 (2.87) and BT-13 X BT-15 (2.60) (Table 4.3.2.2). Similar findings were also found by Bimal (2008) in bitter gourd.

Days to first fruit harvest

The desirable negative SCA effects for earliness were observed in thirteen cross combinations (Table 4.3.2.2). The best five promising crosses in order of significance performance for earliness for fruit harvest were BT-07 x BT-15 (-1.72), BT-01 x BT-13 (-

1.59), BT-15 x BT-18 (-1.09), BT-01 x BT-18 (-0.98) and BT-18 x BT-19 (-0.84) respectively. The significant and positive sca effects for lateness were also observed in six hybrids with maximum value for BT-01 x BT-04 (2.47). The results are in conformity with the finding of Bhatt *et al.* (2017) in bitter gourd.

Number of fruits per plant

The highest significant and positive SCA effects were expressed by the combination BT-18 x BT-19 (8.64) followed by BT-13 x BT-18 (4.40), BT-04 x BT-07 (4.38), BT-07 x BT-19 (2.08) and BT-01 x BT-15 (1.56). Total nine combinations showed significant and negative SCA effects. On the other hand, four combinations showed nonsignificant values for this parameter. Hence the cross-combination BT-18 x BT-19 was the best specific combiner to increase number of fruits per plant. But BT-13 x BT-18, BT-04 x BT-07, BT-07 x BT-19 and BT-01 x BT-15 were the good combinations for number of fruits per plant (Table 4.3.2.2). Singh *et al.* (2013) reported that HABG-23 x HABG-34 was the best (positive significant) specific combiner for number of fruits per plant in bitter gourd followed by HABG-28 x HABG-31 and HABG-24 x HABG-30 which were consonance to the present study.

Table 4.3.2.2 Specific combining ability (SCA) effects for yield and yield components of different crosses in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-01X BT-04	-0.35*	-1.15**	0.57**	2.47**	2.37*	-24.48**	-1.69**	0.07	-1.47**	-0.54**	-0.05*
BT-01X BT-07	0.12	-0.40**	0.06	1.43**	-2.14*	-2.40**	-0.05	0.16**	-0.22	0.45**	-0.43**
BT-01X BT-13	-0.47**	1.02**	-1.77**	-1.59**	1.79	-12.21**	-1.33**	-0.03	-0.23	-1.04**	0.41**
BT-01X BT-15	0.37**	0.85**	-0.31*	2.31**	1.56**	-11.89**	0.14	-0.20**	0.59**	0.42**	0.13**
BT-01X BT-18	1.77**	1.28**	-0.96**	-0.98**	-1.19**	-15.67**	-1.77**	-0.20**	-1.97**	1.22**	-0.70**
BT-01X BT-19	-1.27**	-1.00**	0.24*	0.1	-1.27**	28.36**	3.16**	0.24**	-0.76**	0.92**	0.31**
BT-04X BT-07	1.73**	0.60**	-0.06	-0.21	4.38**	-23.10**	-2.11**	-0.09*	-2.02**	-0.12	0.20**
BT-04X BT-13	1.23**	-2.04**	-1.77**	-0.23	-1.89**	27.44**	0.39**	0.50**	-3.57**	1.27**	0.187**
BT-04X BT-15	0.63**	1.84**	2.87**	1.66**	-0.17	-4.54**	0.58**	-0.33**	-4.04**	0.88**	-0.03
BT-04X BT-18	-0.27*	0.93**	2.87**	0.37*	-0.92**	15.04**	2.13**	0.13**	2.97**	-0.62**	0.17**
BT-04X BT-19	0.03	-2.45**	-1.04**	-0.29	-1.85**	-21.19**	-2.99**	0.12**	-2.00**	-0.19	-0.75**
BT-07X BT-13	-0.95**	-0.78**	1.82**	-1.12**	-0.30*	-7.53**	0.003	-0.16**	0.01	-0.44**	-0.23**
BT-07X BT-15	-1.75**	-0.16	-1.45**	-1.72**	-0.08	18.88**	0.94**	0.09*	-1.61**	0.26**	0.48**
BT-07X BT-18	-0.25	-2.92**	0.80**	-0.21	-2.13**	4.21**	-0.81**	0.10*	0.67**	0.58**	-0.05*
BT-07X BT-19	-0.15	1.80**	1.30**	-0.37*	2.08**	9.56**	1.20**	0.16**	-1.04**	-0.51**	0.70**
BT-13X BT-15	-0.69**	-2.04**	2.60**	-0.34*	0.15	8.07**	-0.43**	0.28**	-0.18	0.46**	0.20**
BT-13X BT-18	-1.54**	-0.70**	1.30**	0.57**	4.40**	-3.75**	0.19	0.40**	-4.38**	-0.87**	0.56**
BT-13X BT-19	1.56**	1.32**	-0.40**	0.85**	-0.88**	-2.07**	-0.84**	-0.22**	-1.58**	-0.48**	-0.30**
BT-15X BT-18	0.95**	-1.17**	0.43**	-1.09**	1.32**	-19.03**	-0.65**	0.15**	-3.67**	1.17**	0.04*
BT-15X BT-19	0.91**	-0.45**	0.58**	-0.1	0.39**	-4.81**	-1.66**	0.06	2.14**	-0.02	0.02
BT-18X BT-19	-0.64**	-0.96**	3.03**	-0.84**	8.64**	21.92**	0.94**	0.51**	-1.38**	-0.77**	1.85**
SE (Sij)	0.14	0.14	0.11	0.16	0.14	0.14	0.10	0.05	0.13	0.10	0.03
CD 5%	0.28	0.27	0.21	0.31	0.27	0.28	0.20	0.09	0.26	0.20	0.05
CD 1%	0.36	0.36	0.28	0.41	0.36	0.37	0.27	0.13	0.34	0.27	0.07

P<0.05, **P<0.01 respectively

Single fruit weight

Out of 21 cross combinations BT-01 X BT-19 (28.36) showed the highest significant and positive SCA effect for single fruit weight followed by BT-04 X BT-13, BT-18 X BT-19, BT-07 X BT-15 and BT-04 X BT-18. They could be termed as good specific combiners as they had higher SCA values for average fruit weight. The cross-combination BT-01 X BT-04 (-24.48) had the highest significant and negative SCA effect followed by BT-04 X BT-07, BT-04 X BT-19 and BT-15 X BT-18 (Table 4.3.1.3). Thus BT-01 X BT-19 was considered as the best specific cross combination for increase fruit weight but BT-04 X BT-13, BT-18 X BT-19, BT-07 X BT-15 and BT-04 X BT-18 were the good combinations for average single fruit weight. Singh *et al.* (2013) found that HABG-24 X HABG-34 was the best (positive significant) specific combiner for single fruit weight in bitter gourd. Similar results were reported by Acharya *et al.* (2019) in bitter gourd.

Fruit length

The highest significant and positive SCA effect for this trait was revealed by the cross BT-01 X BT-19 (3.16) followed by BT-04 X BT-18 (2.13), BT-07 X BT-19 (1.20) BT-07 X BT-15 (0.94) and BT-18 X BT-19 (0.94). The cross BT-04 X BT-19 showed the highest significant and negative SCA effect (-2.99) followed by BT-04 X BT-07, BT-01 X BT-18 and BT-01 X BT-04. Other combinations showed nonsignificant effects for this trait (Table 4.3.2.2). Similar results were observed by Verma *et al.* (2013), Singh *et al.* (2013) and Bhatt *et al.* (2017) in bitter gourd.

Fruit diameter

Out of 21 reciprocal F1's, only 12 revealed significant and positive SCA effects for this trait. The cross-combination BT-18 X BT-19 (0.51) exhibited the highest significant positive SCA effect followed by BT-04 X BT-13, BT-01 X BT-19, BT-07 X BT-19 and BT-01 X BT-07. The cross-combination BT-04 X BT-15 (-0.33) showed the highest significant and negative sca effect followed by BT-13 X BT-19, BT-01 X BT-15 and BT-01 X BT-18. Only three combinations showed nonsignificant effect. Hence, the cross-combination BT-18 X BT-19 was the best specific combination to get widest fruit in this crop (Table 4.3.2.2). Verma *et al.* (2013) and Bhatt *et al.* (2017) reported several crosses with the highest significant positive SCA effects for fruit diameter in bitter gourd.

Number of seeds per fruit

The cross-combination BT-04 X BT-18 (2.97) provided maximum value of the parameter followed by BT-15 X BT-19, BT-07 X BT-18 and BT-01 X BT-15. On the other hand, the cross BT-13 X BT-18 (-4.38) showed the highest negative significant value followed by BT-04 X BT-15, BT-15 X BT-18 and BT-04 X BT-15 (Table 4.3.1.3). Hence, the cross with high significant and positive SCA effect, such as BT-04 X BT-18, BT-15 X BT-19, BT-07 X BT-18 and BT-01 X BT-15 were considered as the good specific combiners for more seeded fruit development. But BT-13 X BT-18, BT-04 X BT-15, BT-15 X BT-18 and BT-04 X BT-15 were considered as the good specific combiners for less seeded fruit development. Acharya *et al.* (2019) reported P7 X P5 showed the highest negative significant (-3.08) and P3 X P2 the highest positive significant (5.29) in bitter gourd.

100-seed weight

Out of 21 F₁s, ten crosses had significant positive SCA effects for this trait. The cross BT-04 X BT-13, (1.27) showed the highest significant and positive effect followed by BT-01 X BT-18, BT-15 X BT-18, BT-01 X BT-19 and BT-04 X BT-13 (Table 4.3.1.3). On the other hand, BT-01 X BT-13 (-1.04) expressed the highest significant and negative SCA effect followed by BT-13 X BT-18, BT-18 X BT-19 and BT-04 X BT-18. Thus, the crosses BT-04 X BT-13, BT-01 X BT-18, BT-15 X BT-18, BT-01 X BT-19 and BT-04 X BT-13 were the good specific combinations for developing fruits which contain more weight of seed. Bimal (2008) reported that P1 X P2 showed the highest negative significant (-1.65) and P4 X P6 the highest positive significant (1.61) for this trait in bitter gourd.

Fruit yield per plant

Among the cross combinations, 12 hybrids showed significant and positive SCA effects of which BT-18 X BT-19 (1.85) provided maximum effect for the parameter fruit yield per plant (Table: 4.3.2.2) followed by BT-07 X BT-19, BT-13 X BT-18, BT-07 X BT-15, BT-01 X BT-13 and BT-04 X BT-07. Total seven crosses showed significant and negative SCA effects for this trait. Rest of the cross combinations expressed nonsignificant and positive/negative SCA effects. Thus BT-18 X BT-19 was the best specific combination due to the highest positive SCA effects. There were several crosses that showed higher SCA values (BT-07 X BT-19, BT-13 X BT-18, BT-07 X BT-15, BT-01 X BT-13 and BT-04 X BT-07, respectively) considering yield per plant indicating the possibilities of exploiting these crosses in the

development of commercial hybrid variety. Similar type findings were also reported by Bhatt *et al.* (2017) in bitter gourd in which Punjab-14 x Arka Harit was the best specific combination due to the highest positive SCA effects (0.13).

None of the hybrids indicated significant positive specific combining ability (SCA) effects for all the characters (Table: 4.3.2.2). Sharma *et al.*, (2001) and Bimal (2008) also observed similar results in case of cucumber and bitter gourd, respectively.

Bimal (2008) reported in bitter gourd that the SCA effects of the cross combination P1 X P2 was superior for average single fruit weight, fruit yield, fruit length, flesh thickness and 100-seed weight. The cross P3 X P5 was best for days to first male and female flower open, number of fruits per plant, single fruit weight and yield per plant. He also reported that P2 X P4 may be selected for the number of fruits per plant and yield per plant.

The SCA effects (S_{ij}) signify the role of non-additive gene action in character expression. It denotes the higher specific combining ability leading to the highest performance of some specific cross combination. That is why, it relates to a particular cross. For instance, the crosses BT-18 X BT-19, BT-07 X BT-19, BT-13 X BT-18, BT-07 X BT-15, BT-01 X BT-13 and BT-01 X BT-19 manifest the highest S_{ij} for yield per plant in positive direction (Table 4.3.1.3). It follows that the best cross performance was exhibited by BT-19 when crossed with BT-18, BT-07 and BT-01. When this is viewed vis-a-vis their GCA effects, it marks that BT-01, BT-04 and BT-13 manifested negative but significant GCA for the character of yield per plant (Table 4.3.1.2); while BT-18, BT-15 and BT-19 positive but BT-07 were significantly positive. This spins off a couple of important inferences.

On the basis of line X tester and diallel analysis, selected seven parents are classified into three categories e.g., High (H^+), Medium (M^+) and Low (L^+) GCA. It was observed that BT-18, BT-15, BT-07 showed high GCA, BT-19, BT-13 showed medium GCA and BT-01, BT-04 showed low GCA. High SCA effects may arise not only in crosses involving H^+ X H^+ combinations (e.g., BT-07 X BT-15), but also in those involving H^+ X M^+ (e.g., BT-18 X BT-19 and BT-07 X BT-19). Even L^+ X M^+ cross combinations (e.g., BT-01 X BT-13) or L^+ X H^+ crosses (e.g., BT-04 X BT-07) can also lead to high SCA values. Thus, in practice some of the poor combiners should also be accommodated in hybridization program.

Reciprocal SCA effect

The estimates of reciprocal SCA effects (R_{ij}) of 21 crosses and their standard errors for different comparisons were studied for eleven different traits and the results have been presented in Table 4.3.2.3. The reciprocal effects in negative direction was considered favorable for traits like as, days to first female flower opening, node number to first female flower opening and days to first fruit harvest. Character wise reciprocal effect has been discussed in the following manner.

Days to first female flower opening

The highest significant and negative reciprocal effect was exhibited by the cross BT-07 X BT-01 (-3.70) followed by BT-18 X BT-07, BT-13 X BT-07 and BT-04 X BT-01 for days to female flower opening (Table: 4.3.1.4). Such results indicated that these crosses performed heterotic effects for early flowering which was desirable, because they provide opportunity for promoting early flowering in this crop. Bimal (2008) also noticed that negative significant reciprocal effect in the cross $P_5 \times P_4$ (-4.92) in bitter melon which was very close to present study.

Node number at which first female flower appeared

The reciprocal SCA estimates were favorable negative in eleven hybrids. The top four value of negative reciprocal effects were recorded by the crosses BT-18 X BT-07 (- 3.90) followed BT-19 X BT-13, BT-15 X BT-01 and BT-13 X BT-07 (Table 4.3.2.3). Bimal (2008) also reported that in the cross $P_5 \times P_4$ showed significant and negative reciprocal value (-3.92**).

Number of branches per plant

The favorable significant reciprocal effects were manifested in four hybrids for number of branches per plant. The reciprocal cross BT-19 X BT-13 (1.95) exhibited the highly significant reciprocal effects followed by BT-07 X BT-01, BT-19 X BT-18 and BT-04 X BT-01 (Table 4.3.2.3). But fourteen combinations showed negatively significant for reciprocal effects of number for branches per plant. Similar type results were found by Bimal (2008) in bitter melon

Days to first fruit harvest

The negative reciprocal effects for earliness were observed in thirteen reciprocal cross combinations (Table 4.3.2.3). The best three promising crosses in order of performance for earliness for fruit harvest were BT-18 X BT-07 (-5.00), BT-19 X BT-13 (-4.15), BT-19 X BT-07 (-2.60) and BT-18 X BT-13 (-2.50) respectively. The significant and positive reciprocal effects for lateness were also observed in four hybrids with maximum value for BT-18 X BT-15 (2.85). Bimal (2008) also reported that two crosses for first fruit harvest significant negative reciprocal effects for these characters.

Number of fruits per plant

For fruits per plant the significant values of positive reciprocal effects were manifested in five hybrids (Table 4.3.2.3). The hybrid BT-19 X BT-13 (4.85), BT-19 X BT-04 (1.50), BT-18 X BT-01 (-1.05) and BT-07 X BT-01 (-0.80) were identified as four top specific combiners for higher number of fruits per plant. The results are conformity with the findings of Bimal (2008) in bitter gourd.

Single fruit weight

Among the 21 reciprocal cross combinations, the values of SCA effects revealed that nine crosses exhibited positive and favorable effects (Table 4.3.1.4). On the other hand, eleven crosses showed negative estimates of reciprocal effects. Cross BT-07 X BT-01 (41.75) was identified as top specific combiners for heavier fruit weight followed by BT-18 X BT-07, BT-19 X BT-15, BT-04 X BT-01 and BT-19 X BT-18 respectively were the specific combinations for lighter fruit weight. Similar findings were also reported by Bimal (2008) in bitter gourd.

Table 4.3.2.3 Estimation of SCA for reciprocal effects for yield and yield components of different crosses in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-04* BT-01	-1.30**	-0.80**	0.30**	1.00**	-0.60**	21.85**	1.38**	0.11*	1.08**	0.28**	-0.38**
BT-07* BT-01	-3.70**	1.50**	0.85**	-0.15	0.80**	41.75**	1.75**	0.40**	0.80**	-0.56**	0.81**
BT-07* BT-04	-0.55**	1.45**	-0.85**	0.3	-1.00**	-5.00**	-0.95**	0.12**	-0.57**	0.60**	-0.26**
BT-13* BT-01	1.65**	1.10**	-0.70**	0.15	-2.40**	-27.30**	-1.43**	-0.13**	4.17**	0.48**	-1.22**
BT-13* BT-04	1.03**	-1.04**	-0.77**	-0.33	-1.24**	21.44**	0.29**	0.60**	-0.57**	-0.43**	0.10**
BT-13* BT-07	-1.85**	-2.00**	-1.20**	-0.80**	-2.90**	6.45**	3.45**	-0.54**	-1.69**	0.07	-0.40**
BT-15* BT-01	-0.30*	-3.05*	-0.35**	0.15	-3.55**	-5.05**	-0.20*	-0.01	-2.30**	-0.32**	-0.83**
BT-15* BT-04	1.00**	-1.10**	-1.75**	2.40**	-3.00**	-12.05**	-0.80**	0.01	-0.42**	-1.82**	-0.76**
BT-15* BT-07	0.05	-1.15**	-1.00**	-1.80**	-2.40**	-27.30**	-0.40**	-0.31**	-2.05**	-0.53**	0.15**
BT-15* BT-13	-0.45**	-0.65**	-2.50**	-1.90**	-2.50**	-15.55**	-1.23**	0.17**	-1.47**	0.59**	-0.80**
BT-18* BT-01	1.50**	2.80**	-1.25**	-0.15	1.05**	0.65**	0.18	0.14**	-0.52**	-0.27**	-0.20**
BT-18* BT-04	-1.20**	0.2	-1.75**	-2.50**	-2.30**	-15.40**	-0.38**	-0.30**	-4.50**	-0.47**	-0.75**
BT-18* BT-07	-2.15**	-3.90**	-3.20**	-5.00**	-2.50**	29.60**	1.98**	0.13**	3.11**	0.09	0.33**
BT-18* BT-13	-0.1	-1.90**	-1.45**	-2.50**	-0.40**	-16.90**	-1.18**	0.07	-2.37**	-1.75**	-0.60**
BT-18* BT-15	3.40**	0.65**	-0.90**	2.85**	-6.70**	-3.25**	-0.50**	0.02	-0.68**	-0.85**	-1.15**
BT-19* BT-01	0.90**	-0.90**	-1.05**	-0.40*	-4.10**	-6.10**	-0.42**	-0.11*	0.24	1.44**	-1.06**
BT-19* BT-04	0.75**	0.2	-0.80**	0.40*	1.50**	1.10**	0.53**	0.09*	-1.80**	-0.04	0.22**
BT-19* BT-07	2.10**	0.50**	0.1	-2.60**	-1.03**	7.93**	1.25**	-0.01	1.04**	-0.03	-0.03
BT-19* BT-13	1.25**	-3.80**	1.95**	-4.15**	4.85**	-10.70**	0.50**	-0.12**	-2.47**	-0.05	0.65**
BT-19* BT-15	-1.20**	-1.15**	-1.45**	-1.00**	-1.70**	26.90**	1.75**	0.20**	1.65**	0.95**	0.22**
BT-19* BT-18	-0.85**	0.05	0.65**	-1.55**	0.70**	12.10**	0.18	0.24**	0.27*	0.05	0.11**
SE (Rij)	0.16	0.16	0.12	0.18	0.16	0.16	0.12	0.05	0.15	0.12	0.03
CD 5%	0.32	0.32	0.25	0.36	0.31	0.33	0.23	0.11	0.30	0.23	0.06
CD 1%	0.42	0.42	0.33	0.47	0.41	0.43	0.31	0.14	0.39	0.31	0.07

*P<0.05, **P<0.01 respectively

Fruit length and diameter

Out of 21 F₁, eight cross combinations for fruit length and nine crosses for fruit diameter showed significant and positive reciprocal effects (Table 4.3.1.4). BT-13 X BT-07 (3.45) is the highest significant and positive reciprocal effects followed by BT-18 X BT-07, BT-07 X BT-01, BT-19 X BT-15, BT-07 X BT-01 for fruit length and BT-07 X BT-01 (0.40) is the highest significant and positive reciprocal effects followed by BT-19 X BT-18, BT-19 X BT-15, BT-15 X BT-13, BT-15 X BT-01 for fruit diameter, indicated the effect of gene(s) of cytoplasm. Bimal (2008) in bitter gourd also noted the significant and positive reciprocal effects for these characters.

Fruit yield and other traits

Considering the traits viz. yield per plant, number of seeds per fruit, 100-seed weight the reciprocal combination BT-13 X BT-01 showed highly significant and positive reciprocal effects for number of seeds per fruit, the cross BT-19 X BT-01 showed highly positive significant reciprocal effect for 100-seed weight. The cross BT-07 X BT-01 showed highly significant and positive reciprocal effect for yield per plant. So, considering the reciprocal effect of all characters studied, it may be concluded that characters having significant reciprocal effect indicated that the control of genes also present in cytoplasm. The significant and positive reciprocal differences for, fruit yield per plant, number of seeds per fruit and 100-seed weight were also reported by Bimal (2008) in bitter gourd.

The reciprocal effects (R_{ij}) are important because they can detect a desirable female (seed parent) base in hybridization program, particularly for producing commercial F₁ hybrids. In the present study, nearly all the crosses except BT-07 X BT-01, BT-19 X BT-13, BT-19 X BT-04, BT-19 X BT-15, BT-19 X BT-18, BT-18 X BT-07, BT-15 X BT-07 and BT-13 X BT-04 have shown negative (though significant) R_{ij} considering the character for yield per plant (Table 4.3.2.3). Thus BT-19, BT-18, BT-15, BT-07 and BT-13 were deployed as female parent.

From reciprocal SCA, it was revealed that 14 crosses with different characters showed maternal effect hence special attention should be given in case of parental selection for hybrid variety development.

4.4 Experiment IV: Evaluation of experimental hybrids through heterosis study

4.4.1 Estimation of heterosis

The magnitude of heterosis was calculated as percent increase or decrease of F₁ values over the mid parent (MP), better parent (BP) and standard (check) variety. The negative estimates of heterosis was considered desirable for traits such as days to first female flower opening, node number to first female flower opening and days to first fruit harvest. However, for rest of the characters, a positive estimate of heterosis was considered favorable. Heterosis were estimated and observed for individual crosses (i.e., 42 hybrids) in yield and yield contributing characters over mid parent, better parent (heterobeltiosis) and standard (check) variety. The findings have been presented in Table 4.4.1, 4.4.2 and 4.4.3, respectively. The performance of heterosis over mid parent, better parent (heterobeltiosis) and standard variety (Tia F₁ which is commercial popular variety in Bangladesh released by LTSL) are discussed character-wise in the following manner.

Days to first female flower opening

The range of significant heterosis for this character varied from -18.15 to 13.72% over better parent, -13.81 to 15.68% and -7.89 to 24.37% over mid parent and standard variety respectively. Out of 42 cross combinations 18 hybrids showed significant negative heterosis i.e., earliness in female flower opening over better parent. The highest and desirable heterosis over mid parent was observed in the cross BT-01 X BT-07 (-13.81%) followed by BT-07 X BT-13 (-12.56%), BT-07 X BT-18 (-9.89%) and BT-19 X BT-07 (-8.53%). The highest and desirable heterosis over better parent was observed in the cross BT-01 X BT-07 (-18.15%) followed by BT-07 X BT-13 (-12.65%), BT-07 X BT-18 (-12.42%), BT-15 X BT-07 (-11.46%) and BT-07 X BT-15 (-11.15%). The negative significant standard heterosis was found in only four crosses for days to female flower opening. It was ranged from -7.89% in BT-01 X BT-07 to -3.58% in BT-18 X BT-15. The hybrids BT-15 X BT-07, BT-18 X BT-15 and BT-01 X BT-07 showed significant negative heterosis over mid, better parental values and standard variety for female flower opening could be considered as the most promising for this trait among 42 hybrids. Similar results in better parent were also studied by Acharya (2019) and Kandasami (2015) in bitter melon. The highest (-18.15 %) negative heterosis over better parent for days to first female flower opening was recorded in the cross BT-01 X BT-07 followed by the crosses BT-07 X BT-13, BT-07 X BT-18, BT-15 X BT-07 and BT-07 X

BT-15, respectively. Hybrid BT-15 X BT-07 (-11.46) exhibited negative significant economic heterosis for days to anthesis of first female flower opening.

Acharya *et al.* (2019) reported that only two crosses viz., HABG-24 X HABG-30 and HABG-29 X HABG-30 showed significant negative heterobeltosis for days to 50 % flowering in bitter gourd. Negative heterosis is desirable for having early genotypes. So, these crosses may be considered as the most promising for this trait.

Node number at first female flower appeared

In case of node number at which first female flower open, the range of heterosis in favorable direction varied from -3.15 to -44.00 and -2.84 to -42.65 over mid parent and standard/check variety, respectively. Maximum significant heterosis percentage (-42.65) was recorded in F₁ BT-07 X BT-18 whereas minimum percentage of heterosis (-2.84) was observed in hybrid BT-01 X BT-13 over standard/check variety in favorable direction (Table 4.4.5 and Table 4.4.6). Among 42 F₁'s, 31 F₁ showed heterosis in desirable direction over mid parent and 26 hybrids had significant heterosis in favorable direction over standard/check variety, respectively. BT-07 X BT-18 showed maximum negative heterosis (-44.00) over mid parent in desirable direction (Table 4.4.1). Heterobeltiosis over best parent for node number of first female flower was recorded in BT-07 X BT-18, BT-07 X BT-13 and BT-13 X BT-18 (Table 4.4.3). Maximum significant heterosis percentage (-51.73) was recorded in hybrid BT-07 X BT-18 whereas minimum percentage of heterosis (-5.45) was observed in the hybrid BT-01 X BT-18 over better parent. Hybrid BT-15 X BT-07 (-9.23), BT-18 X BT-15 (-24.60), BT-19 X BT-18 (14.80), BT-18 X BT-13 (-14.23) exhibited negative significant economic heterosis for node number of first female flower. Similar findings as negative significant economic heterosis for node number of first female flower were reported by Acharya (2019), Kandasami (2015), Talekar *et al.* (2013) and Bimal (2008) in bitter gourd.

Number of branches per plant

The extent of significant heterosis for number of branches per plant ranges from -8.00 to 58.25 over mid parent, while for standard/check variety heterosis ranges from -24.64 to 17.54. Among 42 F₁'s, 38 showed significant heterosis for primary branches per plant over standard variety. Highly significant positive heterosis for primary branches per plant (17.54) was expressed by BT-15 X BT-04 followed by BT-18 X BT-19(13.27) and BT-15 X BT-13(11.37) over standard/check variety Tia (Table 4.4.5 and Table 4.4.6). Hybrids BT-18 X BT-07(55.17), BT-15 X BT-13(52.60), BT-18 X BT-13 (46.90), BT-18 X BT-19 (46.63), BT-13X BT-07 (42.66) and BT-18 X BT-15(40.26) showed the highest heterobeltiosis over

better parents for primary branches per plant (Table 4.4.6 and Table 4.4.5). Hybrids BT-18 X BT-07 (55.17) and BT-15 X BT-13 (52.60) showed the highest heterobeltiosis over better parents for primary branches per plant. Comparable results were found by Talekar *et al.* (2013) in bitter gourd that the range of heterosis varied from -26.23 to 13.70 over better parents. Bimal (2008) also reported the highest positive significant heterosis was observed in $P_6 \times P_2$ (13.24**) followed by $P_5 \times P_1$ (9.67), $P_1 \times P_3$, (9.65**) and $P_2 \times P_1$ (5.92) for primary branches per plant in bitter gourd.

Days to first fruit harvest

In case of days to first fruit harvest, the range of heterosis in favorable direction varied from -1.54 to -16.26% and -2.08 to -11.81% over mid parent and standard/check variety, respectively. Maximum significant heterosis (-11.81%) was recorded in F1 BT-07 X BT-18 whereas minimum significant heterosis (-2.08%) was observed in hybrid BT-07 X BT-04 over standard variety. Among 42 hybrids, 15 & 19 crosses showed significant heterosis in favorable direction over mid parent and standard variety, respectively. BT-07 X BT-18 showed the maximum highly significant heterosis (-16.26) over mid parent (Table 4.4.1). Among the hybrids, 24 crosses showed significant heterosis in favorable direction over better parent. Maximum significant heterosis (-17.71%) was recorded in F1 BT-07 X BT-18 and minimum significant heterosis (-2.32%) was observed in hybrid BT-19 X BT-04 over better parent.

Similar finding was reported by Rao (2017) in bitter gourd that the significant desirable heterosis -6.78% (PA X S-54) was observed for days to first fruit harvest.

Table 4.4.1 Percent of heterosis over mid parent for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-01X BT-04	-0.22*	-13.72**	5.32**	13.11**	19.18**	-18.64**	-12.62**	6.11**	-32.56***	7.18**	1.14
BT-01X BT-07	-13.81**	2.7	7.85**	4.83**	0.84	8.72**	1.79*	12.96**	-19.31**	6.83**	16.02
BT-01X BT-13	2.87*	4.10*	-8.00**	-1.2	10.54**	-26.21**	-16.23**	4.25*	-12.58**	-3.13	-18.05**
BT-01X BT-15	1.29	-12.96**	5.11**	11.39**	0.98	-17.52**	-4.99**	-2.5	-32.92**	24.97**	-12.26**
BT-01X BT-18	11.64**	12.41**	-0.09	-0.81	26.89**	-17.35**	-10.17**	8.81**	-37.57**	16.97**	-3.58**
BT-01X BT-19	-0.23	-11.65**	1.51	3.00**	-8.35**	9.24**	6.10**	11.01**	-24.46**	21.57**	0.38
BT-04X BT-07	6.50**	-0.04	7.80**	2.06*	28.30**	-24.58**	-24.51**	5.85**	-41.31**	7.33**	4.82*
BT-04X BT-13	7.47**	-20.87**	2.24	1.74*	3.98*	11.10**	-11.87**	16.97**	-46.20**	4.59**	17.80**
BT-04X BT-15	11.05**	-4.29**	26.16**	15.48**	-3.55*	-20.10**	-12.78**	-1.35	-48.04**	8.50**	-16.20**
BT-04X BT-18	0.11	-7.28**	21.10**	-3.11**	12.15**	-10.50**	-0.43	9.02**	-37.96**	-2.77	7.67**
BT-04X BT-19	8.01**	-17.45**	5.58**	4.04**	23.38**	-12.74**	-18.63**	14.17**	-44.57**	-3.0	9.44**
BT-07X BT-13	-12.56**	-26.30**	16.20**	-9.01**	-3.95*	2.02**	7.70**	-3.19	-35.26**	-5.95**	4.38*
BT-07X BT-15	-7.05**	-14.27**	7.80**	-9.84**	0.1	-6.87**	-1.57*	-0.92	-41.12**	12.90**	4.73**
BT-07X BT-18	-9.89**	-44.00**	12.59**	-16.26**	6.13**	20.91**	3.59**	16.50**	-9.40**	8.47**	49.75**
BT-07X BT-19	4.99**	2.34	29.61**	-10.02**	33.13**	18.04**	6.64**	14.37**	-21.53**	-7.13**	67.11**
BT-13X BT-15	-4.67**	-22.45**	24.58**	-6.62**	5.51**	-4.64**	-12.78**	12.69**	-35.63**	16.98**	8.02**
BT-13X BT-18	-6.94**	-25.24**	27.78**	-8.85**	51.32**	-10.04**	-9.61**	24.77**	-54.19**	-19.15**	48.78**
BT-13X BT-19	0.33	-20.87**	30.07**	-10.57**	58.47**	5.08**	-5.13**	9.21**	-43.11**	-10.92**	68.07**
BT-15X BT-18	15.68**	-12.38**	32.44**	2.34**	5.94**	-15.17**	-8.25**	10.87**	-44.27**	18.37**	7.87**
BT-15X BT-19	0.45	-13.13**	21.14**	-2.51**	24.03**	15.78**	-1.95**	11.37**	-8.02**	16.31**	53.66**
BT-18X BT-19	-4.20**	-14.12**	55.19**	-8.50**	85.53**	35.74**	4.42**	33.12**	-29.88**	-6.05**	137.83**

Table 4.4.2 Reciprocal effect of heterosis over mid parent for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-04x BT-01	8.45**	-5.83**	2.28	18.14**	26.19**	-40.55**	-24.49**	2.76	-41.93**	2.2	-21.86**
BT-07x BT-01	11.01**	-14.33**	-1.8	5.54**	-9.19**	-27.66**	-10.33**	-1.78	-27.99**	17.26**	-30.48**
BT-07x BT-04	9.98**	-13.98**	18.28**	0.63	39.08**	-18.95**	-15.74**	1.95	-36.47**	-2.11	22.12**
BT-13x BT-01	-8.49**	-7.07**	-0.09	-1.92*	42.51**	0.45**	-6.03**	8.70**	-47.12**	-11.20**	61.83**
BT-13x BT-04	7.47**	-20.87**	2.24	1.74*	3.98*	11.10**	-11.87**	16.97**	-46.20**	10.72**	17.80**
BT-13x BT-07	-0.49	-6.51**	43.66**	-5.36**	31.31**	-5.02**	-18.42**	16.32**	-21.65**	-6.92**	32.92**
BT-15x BT-01	3.40**	19.03**	8.94**	10.66**	47.54**	-13.38**	-3.54**	-2.35	-11.64**	31.68**	34.62**
BT-15x BT-04	4.42**	5.60**	46.89**	3.69**	30.09**	-7.57**	-4.91**	-1.49	-44.89**	39.74**	32.38**
BT-15x BT-07	-7.38**	-2.53	21.36**	-1.54*	28.87**	17.69**	1.5	8.40**	-22.70**	22.46**	70.47**
BT-15x BT-13	-1.59	-16.45**	58.25**	2.31**	37.29**	11.10**	-3.02**	7.65**	-25.13**	7.50**	63.70**
BT-18x BT-01	1.27	-14.15**	13.94**	-0.12	16.56**	-18.04**	-11.69**	3.78*	-32.92**	21.40**	8.25**
BT-18x BT-04	7.93**	-8.93**	42.39**	8.56**	32.22**	11.93**	4.31**	18.41**	-5.32**	3.94*	58.78**
BT-18x BT-07	4.21**	-7.91**	57.34**	5.71**	29.10**	-14.47**	-14.76**	11.90**	-36.82**	7.13**	28.81**
BT-18x BT-13	-6.27**	-9.19**	47.92**	2.35**	55.16**	13.66**	1.81	22.46**	-37.74**	4.77**	92.69**
BT-18x BT-15	-7.67**	-18.02**	44.48**	-10.57**	69.60**	-11.59**	-3.31**	10.42**	-39.11**	32.02**	79.92**
BT-19x BT-01	-6.33**	-3.15*	12.73**	4.92**	45.71**	15.18**	8.79**	15.43**	-26.92**	-2.61	68.44**
BT-19x BT-04	3.21**	-19.10**	14.81**	2.10*	6.48**	-14.17**	-23.08**	11.13**	-30.19**	-2.4	-7.06**
BT-19x BT-07	-8.53**	-2.27	28.29**	1.82*	45.58**	9.42**	-1.89*	14.57**	-31.74**	-6.68**	69.20**
BT-19x BT-13	8.58**	11.12**	4.58**	8.71**	-3.51*	18.52**	-8.62*	13.77**	-24.30**	-10.21**	15.42**
BT-19x BT-15	8.54**	-3.19*	39.43**	2.19*	45.44**	-11.33**	-14.45**	5.21**	-21.94**	0.81	38.15**
BT-19x BT-18	1.44	-14.51**	46.75**	-1.57*	78.86**	18.87**	2.93**	24.10**	-32.09**	-6.76**	130.24**

Table 4.4.3 Percent of heterosis over better parent for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-01X BT-04	-5.68**	-25.43**	-1.58	11.94**	3.55**	-35.38**	-33.39**	-4.86**	-45.10**	-9.02**	-10.32**
BT-01X BT-07	-18.15**	-0.28	-10.09**	-0.45	-7.47**	-0.66**	-3.29**	10.38**	-22.00**	-6.10**	8.72**
BT-01X BT-13	0.76	-8.00**	-22.87**	-4.42**	7.10**	-39.84**	-23.03**	3.17**	-30.96**	-21.00**	-32.15**
BT-01X BT-15	0.58	-21.11**	-9.15**	8.96**	-3.55	-19.85**	-13.82**	-16.54**	-43.14**	19.80**	-16.10**
BT-01X BT-18	9.00**	-5.45**	-15.77**	-7.34**	-1.28	-37.81**	-31.91**	8.68**	-48.20**	-4.74**	-12.49**
BT-01X BT-19	-4.23**	-25.89**	-10.09**	-0.46	-12.03**	-10.58**	4.67**	4.08*	-31.64**	-0.51	-15.64**
BT-04X BT-07	5.99**	-11.36**	-4.72**	-4.03**	20.81**	-35.47**	-40.26**	-7.00**	-50.91**	3.07	-1.22
BT-04X BT-13	4.42**	-22.87**	-9.07**	-2.56**	-7.11**	7.39**	-28.34**	5.86**	-48.28**	-0.41	8.84**
BT-04X BT-15	5.68**	-9.23**	15.97**	11.82**	-12.69**	-35.13**	-28.28**	-6.41**	-50.55**	-4.48*	-22.60**
BT-04X BT-18	-3.15**	-10.24**	8.35**	-10.37**	-1.66	-16.85**	-1.25	-2.14	-39.42**	-7.58**	4.90*
BT-04X BT-19	6.31**	-20.34**	-0.36	-0.46	11.17**	-16.08**	-38.54**	-3.29	-50.79**	-7.24**	2.89
BT-07X BT-13	-14.65**	-33.13**	15.38**	-10.74**	-9.20**	-10.11**	3.96**	-6.35**	-47.53**	-13.83**	-8.65**
BT-07X BT-15	-11.15**	-20.16**	3.25*	-12.53**	-4.02*	-12.59**	-6.27**	-16.79**	-48.63**	3.09	2.51
BT-07X BT-18	-12.42**	-51.73**	11.03**	-17.71**	-11.61**	-2.65**	-18.51**	13.71**	-22.70**	-0.77	44.72**
BT-07X BT-19	3.82**	-12.02**	20.86**	-11.63**	27.01**	4.48**	0.03	9.62**	-26.73**	-14.55**	48.64**
BT-13X BT-15	-6.69**	-24.61**	20.13**	-7.67**	3.97*	-20.44**	-14.01**	-2.69*	-40.99**	-1.28	-7.18**
BT-13X BT-18	-7.36**	-29.39**	26.90**	-12.10**	20.54**	-19.00**	-26.96**	23.63**	-56.96**	-19.29**	34.23**
BT-13X BT-19	-0.98	-25.50**	22.09**	-10.67**	56.96**	4.54**	-13.89**	1.41	-51.20**	-11.32**	64.99**
BT-15X BT-18	13.72**	-19.41**	28.57**	-2.38**	-14.67**	-34.88**	-25.05**	-5.00**	-45.72**	-0.25	2.12
BT-15X BT-19	-2.93**	-20.34**	17.79**	-3.71**	23.38**	-3.01**	-12.13**	-9.62**	-14.51**	-1.47	34.14**
BT-18X BT-19	-5.86**	-14.40**	46.63**	-11.66**	48.85**	21.66**	-21.57**	24.67**	-36.39**	-6.65**	118.21**

Table 4.4.4 Reciprocal effect of heterosis over better parent for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-04x BT-01	2.52*	-18.61**	-4.42**	16.92**	9.64**	-52.78**	-42.43**	-7.86**	-52.73**	-13.25**	-30.71**
BT-07x BT-01	5.41**	-16.80**	-18.14**	0.22	-16.67**	-33.91**	-14.80**	-4.02*	-30.39**	3.06	-34.86**
BT-07x BT-04	9.46**	-23.72**	4.54**	-5.37**	30.96**	-30.65**	-33.31**	-10.43**	-46.86**	-5.99**	15.09**
BT-13x BT-01	-11.04**	-17.88**	-16.25**	-5.12**	38.06**	-18.10**	-13.65**	7.58**	-58.24**	-27.59**	33.98**
BT-13x BT-04	4.42**	-22.87**	-9.07**	-2.56**	-7.11**	7.39**	-28.34**	5.86**	-48.28**	5.42**	8.84**
BT-13x BT-07	-2.87**	-15.18**	42.66**	-7.16**	24.14**	-16.31**	-21.25**	12.52**	-36.50**	-14.72**	16.33**
BT-15x BT-01	2.68*	7.88**	-5.84**	8.25**	40.92**	-15.83**	-12.50**	-16.41*	-25.10**	26.23**	28.74**
BT-15x BT-04	-0.63	0.14	35.03**	0.4	17.77**	-24.96**	-21.82**	-6.54**	-47.56**	23.02**	22.28**
BT-15x BT-07	-11.46**	-9.23**	16.23**	-4.47**	23.56**	10.45**	-3.35**	-8.97**	-32.55**	11.82**	66.86**
BT-15x BT-13	-3.68**	-18.77**	52.60**	1.16	35.28**	-7.32**	-4.38**	-7.05**	-31.37**	-9.27**	40.67**
BT-18x BT-01	-1.12	-27.79**	-3.94**	-6.70**	-9.31**	-38.33**	-33.06**	3.65	-44.35**	-1.13	-1.75
BT-18x BT-04	4.42**	-11.84**	27.40**	0.43	15.94**	3.99**	3.45*	6.29**	-7.56**	-1.2	54.70**
BT-18x BT-07	1.27	-20.61**	55.17**	3.89**	7.53**	-31.14**	-32.95**	9.22**	-46.10**	-2	24.48**
BT-18x BT-13	-6.69**	-14.23**	46.90**	-1.3	23.60**	2.34**	-17.74**	21.34**	-41.50**	4.58**	73.84**
BT-18* BT-15	-9.22**	-24.60**	40.26**	-14.69**	36.61**	-32.13**	-21.01**	-5.38**	-40.69**	11.26**	70.32**
BT-19x BT-01	-10.10**	-18.76**	-0.16	1.39	39.87**	-5.72**	7.33**	8.22**	-33.88**	-20.30**	41.56**
BT-19x BT-04	1.58	-21.93**	8.35**	-2.32**	-4.06*	-17.45**	-41.90**	-5.86**	-38.02**	-6.67**	-12.62**
BT-19x BT-07	-9.55**	-15.98**	19.63**	0	38.89**	-3.16**	-7.97**	9.81**	-36.26**	-14.14**	50.50**
BT-19x BT-13	7.17**	4.62**	-1.84	8.58**	-4.43	17.91**	-17.06**	5.64**	-35.07**	-10.62**	13.31**
BT-19x BT-15	4.89**	-11.23**	35.58**	0.93	44.68**	-25.72**	-23.34**	-14.62**	-27.45**	-14.60**	20.60**
BT-19x BT-18	-0.33	-14.80**	38.65**	-4.97**	43.49**	6.54**	-22.70**	16.23**	-38.40**	-7.35**	111.24**

Table 4.4.5 Percent of heterosis over check variety (Tia F₁) for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-01X BT-04	7.17**	-17.06**	-1.42	4.17**	-20.00**	-18.07**	-23.58**	4.23*	-3.73*	-11.41**	-34.40**
BT-01X BT-07	-7.89**	-14.22**	-9.95**	3.01**	-36.86**	25.95**	10.94**	-4.07*	-7.95**	-15.83**	-20.48**
BT-01X BT-13	7.17*	-2.84**	-22.75**	-4.86**	-34.90**	-23.73**	-11.70**	-8.45**	31.22**	-14.95**	-50.37**
BT-01X BT-15	3.23**	-21.33**	-9.00**	6.02**	-39.61**	1.62**	-1.13	1.88	-9.94**	-11.27**	-38.63**
BT-01X BT-18	15.77**	12.32**	-15.64**	-0.69	1.18	-21.15**	-21.89**	-5.32**	-13.46**	2.93	-35.99**
BT-01X BT-19	5.38	-11.37**	-9.95**	-0.69	-45.49**	13.38**	23.40**	-9.55**	-7.02**	6.15**	-38.30**
BT-04X BT-07	20.43**	-1.42	-17.06**	-0.69	-6.67**	-32.31**	-38.30**	1.88	-13.91**	0.36	-36.84**
BT-04X BT-13	18.64**	-14.22**	-20.85**	-3.01**	-28.24**	-14.13**	-31.13**	15.96**	-1.71	7.23**	-38.43**
BT-04X BT-15	20.07**	0.95	0.95	8.80**	-32.55**	-22.41**	-33.02**	14.24**	-13.29**	-7.00**	-48.33**
BT-04X BT-18	10.04	6.64**	-5.69**	-3.94**	0.78	-37.96**	-40.57**	7.20**	6.23**	-0.13	-37.44**
BT-04X BT-19	20.79**	-4.74**	-13.27**	-0.69	-14.12**	-32.21**	-27.55**	5.95**	-13.71**	-1.04	-41.79**
BT-07X BT-13	-3.94**	-29.38**	-21.80**	-7.64**	-38.04**	-5.70**	7.36**	-16.90**	-0.27	-7.22**	-41.60**
BT-07X BT-15	-0.15	-20.38**	-24.64**	-9.49**	-34.51**	4.54**	-3.21**	1.56	-18.63**	-7.59**	1.56**
BT-07X BT-18	-1.43	-42.65**	-23.70**	-11.81**	-9.41**	2.12**	-15.85**	-0.94	29.15**	7.23**	-7.48**
BT-07X BT-19	16.85**	5.21**	-6.64**	-8.56**	-13.33**	9.59**	17.92**	-9.08**	-0.33	-8.84**	-4.97**
BT-13X BT-15	0.36	-20.38**	-12.32**	-8.10**	-34.90**	-4.85**	-17.36**	18.78**	12.15**	6.29**	-38.03**
BT-13X BT-18	-0.72	-16.11**	-12.80**	-5.79**	23.53**	-35.23**	-29.81**	9.70**	-18.20**	-12.79**	-19.95**
BT-13X BT-19	8.96	-10.90**	-5.69**	-10.88**	-2.75*	-15.55**	1.51	-10.02**	-7.25**	-4.52**	-17.84**
BT-15X BT-18	20.79**	-4.27**	-6.16**	4.63**	-12.55**	-22.11**	-30.00**	15.96**	-9.32**	7.79**	-31.83**
BT-15X BT-19	6.81**	-4.74**	-9.00**	-3.94**	-22.75**	16.00**	3.58**	10.33**	35.40**	5.12**	-10.45**
BT-18X BT-19	3.58**	2.37	13.27**	-5.32**	52.55**	-1.72**	-7.55**	8.61**	6.27**	0.87	11.84**

Table 4.4.6 Reciprocal effect of heterosis over check variety (Tia F₁) for different yield contributing characters in bitter gourd

Crosses	First Female Flower Open	Number of Node	Number of Branches per plant	First Harvest	Number of fruits per plant	Single Fruit Weight	Fruit Length	Fruit Diameter	Number of seeds per fruit	100-seed weight	Yield per plant
BT-04X BT-01	16.49**	-9.48**	-4.27**	8.80**	-15.29**	-40.13**	-33.96**	0.94	-17.10**	-15.53**	-49.32**
BT-07X BT-01	18.64**	-28.44**	-18.01**	3.70**	-43.14**	-16.20**	-2.26*	-16.59**	-17.85**	-7.61**	-52.35**
BT-07X BT-04	24.37**	-15.17**	-9.00**	-2.08*	1.18	-27.26**	-31.13**	-1.88	-6.81	-8.47**	-26.42**
BT-13XBT-01	-4.66**	-13.27**	-16.11**	-5.56**	-16.08**	3.84**	-0.94	-4.54**	-20.62**	-22.03**	-2.01
BT-13X BT-04	18.64**	-14.22**	-20.85**	-3.01**	-28.24**	-14.13**	-31.13**	15.96**	-1.7	13.50**	-38.43**
BT-13X BT-07	9.32	-10.43**	-3.32**	-3.94**	-15.29**	-12.22**	-18.68**	-0.16	20.68**	-8.18**	-25.63**
BT-15X BT-01	5.38**	7.58**	-5.69**	5.32**	-11.76**	6.71**	0.38	2.03	18.63**	-6.51**	-5.83**
BT-15X BT-04	12.90**	11.37**	17.54**	-2.31**	-9.02**	-10.25**	-26.98**	14.08**	-8.03**	19.78**	-18.37**
BT-15XBT-07	-0.36*	-9.48**	-15.17**	-1.16*	-10.69**	32.10**	-0.19	11.11**	6.83**	0.24	12.40**
BT-15XBT-13	3.23**	-14.22**	11.37**	0.69	-15.29**	10.85**	-8.11**	13.46**	30.43**	-2.31	-6.09**
BT-18X BT-01	5.02**	-14.22**	-3.79**	0.13	-7.06**	-21.81**	-23.21**	-9.70**	-7.02**	6.83**	-28.13**
BT-18X BT-04	18.64**	4.74**	10.90**	7.64**	18.82**	-22.41**	-37.74**	16.43**	62.11**	6.76**	-7.74**
BT-18X BT-07	13.98**	-5.69**	6.64**	11.34**	10.20**	-27.76**	-30.75**	-4.85**	-9.94**	5.90**	-20.41**
BT-18X BT-13	0.21	1.9	0.95	5.79**	26.67**	-18.17**	-20.94**	7.67**	11.18**	13.01**	3.68**
BT-18X BT-15	-3.58**	-10.43**	2.37*	-8.56**	40.00**	-18.83**	-26.23**	15.49**	-0.91	20.22	10.71**
BT-19X BT-01	-1.08	-2.84	0.28	1.16	-13.33**	19.54**	26.53**	-5.95**	-10.05**	-14.97**	3.54**
BT-19X BT-04	15.41**	-6.64**	-5.69**	-2.55**	-25.88**	-33.32**	-31.51**	3.13	8.70**	-0.43	-50.57**
BT-19X BT-07	1.79	0.47	-7.58**	3.47**	-5.23**	1.58**	8.49**	-8.92**	-13.29**	-8.40**	-3.78**
BT-19X BT-13	17.92**	25.12**	-24.17**	8.33**	-40.78**	-4.75**	-2.23*	-6.26**	23.42**	-3.76*	-43.58**
BT-19X BT-15	15.41**	6.16**	4.74**	0.69	-9.41**	-11.16**	-9.62**	4.23*	14.91**	-8.89**	-19.49**
BT-19X BT-18	9.68**	1.90**	7.11**	1.85*	47.06**	-13.93**	-8.87**	1.25	2.92	0.11	10.98**

Number of fruits per plant

The F1 BT-18 X BT-19 indicated the highest (85.53%) positively significant heterosis over mid parent followed by BT-19 X BT-18 (78.86%), BT-18 X BT-15 (69.60%) for number of fruits per plant. On the other hand, the crosses BT-18 X BT-13 (55.16%) and BT-15 X BT-07 (28.87%) showed also better performance for this trait. Considering the heterosis over better parent, the highest positively significant heterobeltiotic effect was found 56.96% in BT-13 X BT-19 followed by 48.85% in BT-18 X BT-19 and 44.68% in BT-19 X BT-15. Several hybrids showed significantly positive heterosis effect over standard check variety (Tia F₁). The highest positive significant heterosis showed by the cross BT-18 X BT-19 (52.55%) followed by BT-19 X BT-18 (47.06%), BT-18 X BT-15 (40.00%) and BT-18 X BT-13 (26.67%). Therefore, the crosses BT-18 X BT-19, BT-19 X BT-18, BT-18 X BT-15 and BT-18 X BT-13 could be considered as the most promising for this trait among 42 hybrids.

Singh *et al.* (2013) found high heterosis (48.75%) over better parent for fruits per plant in bitter gourd. Kandasamy (2015) reported in bitter gourd. that the highest heterobeltiotic effect for number of fruits per plant was 38.10% and the lowest was 2.79%. Uddin (2008) reported the highest heterobeltiotic effect for number of fruits per plant in hybrid F6 X M3 (50%) followed by F3 X M3 (41.67%), F4 X M1 (31.37%), F8 X M1 (31.37%), F7 X M3 (29.17%) and F3 X M1 (25.49%) in cucumber (*Cucumis sativus* L). Rao *et al.* (2017) also reported the maximum significant desirable heterosis over standard check variety for number of fruits per plant as 97.52% (PA X S-2) in bitter gourd.

Single fruit weight

The range of significant heterosis percentage for this character varied from -27.66% to 35.74% over mid-parental values. The positive heterosis was varied from 2.02% to 35.74%. The highest positive significant heterosis was exhibited by the cross BT-18 X BT-19 (35.74%) followed by the crosses BT-07 X BT-18 (20.91%), BT-19 X BT-18 (18.87%), BT-19 X BT-13 (18.52%) and BT-07 X BT-19 (18.04%). The crosses of BT-15 X BT-07 (17.69%) and BT-18 X BT-13 (13.66%) also gave good results considering average fruit weight. The positive heterobeltiotic effect was ranged from 3.99% in BT-18 X BT-04 to 21.66% in BT-18 X BT-19. The highest significant positive heterosis over better parent showed 21.66% in BT-18 X BT-19 followed by 17.91% in BT-19 X BT-13 and 10.45% in BT-15 X BT-07. The highest significant positive heterosis showed 32.10% in BT-15 X BT-07 followed by 19.54% in BT-19 X BT-01 and 16.00% in BT-15 X BT-19 over check commercial variety (Tia F₁)

Similar trend of results was recorded by Singh *et al.* (2013) in bitter gourd, where he reported that four, out of 21 crosses showed highly positive heterosis over better parent for average fruit weight, and the estimated maximum heterosis was obtained in HABG-28 X HABG-29 (62.50%) followed by HABG-31 X HABG-34 (53.85%). Kandasamy (2015) reported the highest significant positive heterosis (49.44%) for better parent and 5.30% in the hybrid P3 X P2 over standard check for individual fruit weight of bitter gourd. Talekar *et al.*, (2013) found high heterosis (17.92%) over better parent for single fruit weight in bitter gourd.

Fruit length

Out of 42 cross combinations, only 09 hybrids exhibited significant positive heterosis for this trait. Significant positive heterosis in the F1 hybrids ranged from 1.79 % in BT-01 X BT-07 to 8.79% in BT-19 X BT-01. The highest heterosis was found 8.79% in BT-19 X BT-01 followed by 7.70% in BT-07 X BT-13, 6.64% in BT-07 X BT-19, 6.10% in BT-01 X BT-19 over mid parent. Highest heterobeltiotic effect was found 7.33% in BT-19 X BT-01 followed by 4.67% in BT-01 X BT-19, 3.45% in BT-18 X BT-04. The highest standard positive heterosis was found 26.53% in BT-19 X BT-01 followed by 23.40% in BT-01 X BT-19, 17.92% in BT-07 X BT-19 and 10.94% in BT-01 X BT-07. Most of the crosses showed negative significant heterosis over check commercial variety (Tia F₁).

Similar type findings are reported by Bimal (2008) that the significant desirable heterosis was observed for fruit length as 9.73% (P1 X P2) over better parent in bitter gourd. Singh *et al.* (2013) found that significant desirable heterosis 30.15% over better parent in bitter gourd and Rao *et al.* (2017) also reported that fourteen hybrid and PDM X S-2 showed the highest significant desirable positive heterosis (63.64%) over standard check variety in bitter gourd.

Kandasamy (2015) also reported the range of heterosis from 1.43% to 39.79% over better parent and maximum positive heterosis (22.10%) over check variety for fruit length in bitter gourd.

Fruit diameter

Total 33 cross out of 42 combinations showed positive heterosis over mid parent for this trait. It was ranged from 3.78% in BT-18 X BT-01 to 33.12% in BT-18 X BT-19. The highest positive heterosis was 33.12% in BT-18 X BT-19 followed by 24.77% in BT-13 X BT-18, 24.10% in BT-19 X BT-18, 22.46% in BT-18 X BT-13, 18.41% in BT-18 X BT-04, 16.97% in BT-13 X BT-04. The highest positive significant heterobeltiotic effect was found 24.67% in BT-18 X BT-19 followed by 23.63% in BT-13 X BT-18, 21.34% in BT-18 X BT-13,

13.71% in BT-07 X BT-18 and 12.52% in BT-13 X BT-07. The negative heterobeltiotic effect was ranged from -2.14% to -15.54%. Most of the crosses showed positive significant heterosis over check commercial variety (Tia F₁). It was ranged from 4.23% to 18.78%. The highest positive standard heterosis was 18.78% in BT-13 X BT-15 followed by 15.96% in BT-15 X BT-18, BT-04 X BT-13, BT-13 X BT-04 and 15.49% in BT-18 X BT-15. The crosses BT-15 X BT-07 and BT-18 X BT-19 also showed significant positive heterosis on standard variety.

Rao *et al.* (2017) also reported that the higher standard heterosis (48.07%) for fruit diameter was observed when PA and S-57 were used as one parent in bitter gourd. Acharya *et al.* (2019) observed that heterobeltiosis was 20.00% in P2 x P10 and 18.12% in P1 x P10 for fruit diameter in bitter gourd.

Number of seeds per fruit

The highest negative significant heterosis over better parent was -58.24% in BT-13 X BT-01 followed by -56.96% in BT-13 X BT-18, -52.73% in BT-04 X BT-01 and -51.20% in BT-13 X BT-19. The crosses BT-18 X BT-13, BT-18 X BT-15, BT-19 X BT-18, BT-18 X BT-19 and BT-15 X BT-07 also gave good results considering this trait while the negative significant heterosis was recorded over better parent value of bitter gourd. The range of significant heterosis percentage for this character varied from -5.32% to -54.19% over mid-parental values. The maximum crosses over standard check variety showed negative significant heterosis. The highest significant heterobeltiotic effect was found 62.11% in the cross BT-18 X BT-04. Considerable positive significant heterobeltiotic effect was found in hybrid combinations. On the other hand, 15 crosses out of 42 showed positively significant heterosis over standard check variety (Tia F₁). The highest significant positive standard heterotic effect was found 62.11% in the cross BT-18 X BT-04 followed by 35.40% in BT-15 X BT-19, 31.22% in BT-01 X BT-13 and 30.43% in BT-15 X BT-13. These crosses can be utilized in heterosis breeding program for the improvement of seed yield per fruit in bitter gourd. Acharya *et al.* (2019) reported as similar findings that the negative significant heterobeltiosis (%) for number of seeds per fruit were recorded in a hybrid viz., P2 X P9 (-4.08) in E1 and maximum heterosis were P2 X P6 (-17.54) in E2 in bitter gourd.

100-seed weight

Seeds contain larger food material preferably produce vigorous seedlings and have a chance for getting higher yield. However, the extent of heterosis over mid parent value ranged from -5.95% in cross BT-07 X BT-13 to 39.74% in hybrid BT-15 X BT-04. The significant positive heterosis was also followed by 32.02% in the cross BT-18 X BT-15 and 31.68% in BT-15 X BT-01, 24.97% in BT-01 X BT-15 and 22.46% in BT-15 X BT-07, while the highest heterobeltiotic positively significant effect was found 26.23% in the cross BT-15 X BT-01 followed by 23.02% in the cross BT-15 X BT-04, 19.80% in BT-01 X BT-15 and 11.82% in BT-15 X BT-07. On the other hand, most of the crosses showed (21 crosses out of 42) negatively significant heterosis and the highest was -15.83% over standard check variety (Tia F₁). The highest positively significant standard heterotic effect was found 19.78% in BT-15 X BT-04 followed by 13.50% in BT-15 X BT-04 and 13.01% in BT-18 X BT-13. Similar findings were recorded by Banik (2003). She observed that the positive significant heterosis ranged from 2.12 to 45.96 per cent over better parent in snake gourd for this trait. Bimal (2008) reported that the significant negative heterosis was observed for 100 seed weight - 29.16 (P5*P6) in bitter gourd which supported to the present study.

Fruit yield per plant

Yield is a complex character. It depends on so many characters, such as number of fruits per plant, fruit length, fruit diameter, weight per fruit, days to first female flower open, seed weight etc. However, around 75% of the crosses showed (32 crosses out of 42) positive significant heterosis over mid parent values for yield per plant indicating the possibilities of exploiting those crosses for hybrid variety development. The extent of heterosis over mid parent value ranged from -30.48% in cross BT-07 X BT-01 to 137.83% in hybrid BT-18 X BT-19. The significant positive heterosis was also observed 130.24% in the cross BT-19 X BT-18, 92.69% in BT-18 X BT-13, 79.92% in BT-18 X BT-15 and 70.47% in BT-15 X BT-07. The highest positive significant heterobeltiotic effect was found 118.21% in the cross BT-18 X BT-19 followed by 111.24% in BT-19 X BT-18, 73.84% in BT-18 X BT-13, 70.32% in BT-18 X BT-15 and 66.86% in BT-15 X BT-07. On the other hand, only six crosses out of 42 showed significant positive heterosis over check variety (Tia F₁). The highest significant positive standard heterotic effect was found (30.14%) in BT-18 X BT-19 followed by BT-19 X BT-18 (25.98%), BT-18 X BT-15 (13.71%) and BT-15 X BT-07 (12.40%). These crosses can be utilized in heterosis breeding program for the improvement of yield per plant in bitter gourd. Similar findings were recorded in bitter gourd by Singh *et al.* (2013) where 19 crosses

out of 21 showed positive significant heterosis over better parent for yield per plant. The extent of heterosis over better parent ranged from -16.90 % to 79.58 %. The better parent heterosis was observed to be as high as 85.71% (P5 X P3) for yield per plant in bitter gourd (Bimol, 2008). Laxuman *et al.* (2012) explained that the magnitude of heterosis over commercial check was very high for all the characters studied in bitter gourd. Talekar *et al.* (2013) reported both positive and negative heterosis for different qualitative and quantitative characters in F₁ hybrids of bitter gourd. They reported the range of heterosis were -58.96 to 51.14% over better parent and -55.65 to 73.79% over check variety for fruit yield per plant in bitter gourd. Similar type findings were reported by Akarya *et al.* (2019) that significant positive heterosis upto 62.92% over better parents in bitter gourd. Rao *et al.* (2017) reported the higher magnitude of heterosis (-4.19 to 36.38) over commercial check (Pusa Do Mousami) for yield per plant in bitter gourd.

Considering earliness, yield and yield contributing traits of the studied and compared to check variety (Tia F₁), the cross combinations, BT-15 X BT-07, BT-18 X BT-19 and BT-18 X BT-15 revealed significantly higher heterosis which led to conclude that these three combinations could be the most promising hybrids (F₁). During the present study, the cross combination of BT-15 X BT-07 is registered as the name of **HSTU-1** (Registration number: 1(27)/293/2020) (Figure 4.4.1) and BT-18 X BT-19 as **HSTU-2** (Registration number: 1(27)/294/2020) (Figure 4.4.2) from National Seed Board of Bangladesh.

The Salient features of HSTU-1

Sowing time: Kharif season
 Harvest : 42 days after transplanting
 Fruit length: 27 cm
 Fruit diameter: 7 cm
 Single fruit weight: 260 g
 Fruit color: Attractive green color
 Spine: Medium
 Fruits per plant: 22
 Fruit yield/plant: 5.6 kg
 Yield per Acre: 11.2 ton

The Salient features of HSTU-2

Sowing time: Kharif season
 Harvest : 41 days after transplanting
 Fruit length: 25 cm
 Fruit diameter: 6.8 cm
 Single fruit weight: 195 g
 Fruit color: Shiny green
 Spine: Medium
 Fruits per plant: 29
 Fruit yield/plant: 5.5
 Yield per plant: 11 ton



Figure 4.4.1 Fruit morphotypes of HSTU-1 hybrid variety



Figure 4.4.2 Fruit morphotypes of HSTU-2 hybrid variety