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RESEARCH ARTICLE

Assessment of combining ability and heterosis in bottle gourd (*Lagenaria siceraria* L.) for yield and attributes character through line x tester design

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Abstract

General and specific combining ability variance and their effects were studied for thirteen characters in line × tester mating design in bottle gourd. Based on overall per se performance and among the parents, Narendra Dharidar, Punjab Long, and parents Narendra Rashmi were identified as good specific combiners for a maximum of 5 to 6 attributes, including yield for other contributing traits, suggesting that these parents may be used in the hybridization program aimed at the development of superior genotypes/varieties in bottle gourd. Tester Arka Bahar and Narendra Madhuri were considered to be good general combiners for 6 to 8 characters. These parents must be utilized in a suitable breeding programme *visa-vis* selection breeding for improvement productivity of yield and per unit area in bottle gourd. Based on overall results and per se performance, the F_1 hybrids, *i.e.* Pusa Sandesh × Kashi Ganga, IC-321747 × Narendra Madhuri, and NDBG-132 × Narendra Madhuri emerged to be the good specific combiners for maximum traits, including yield, which may be utilized for obtaining transgressive segregants in the next generation. Out of sixty-four cross combinations, only seventeen hybrids revealed superiority over better parents for yield. The seventeen cross combinations that showed more than 24% heterobeltiosis over better parents include: IC-498541×Narendra Madhuri, IC-592210×Arka bahar, Pusa Sandesh×Narendra Madhuri, NDBG-132×Pusa Naveen, Narendra Rashmi×Kashi Ganga, IC-321412×Pusa Naveen, Narendra Rashmi×Arka bahar, Narendra Rashmi×Pusa Naveen, Narendra Dharidar×Narendra Madhuri, Pusa Sandesh×Kashi Ganga, NDBG-132×Arka bahar, NDBG-132×Narendra Madhuri, Punjab long×Narendra Madhuri, Narendra Jyothi×Narendra Madhuri, IC-592210×Arka bahar, IC-338119×Arka bahar and IC- 498541×Kashi Ganga. This suggests that there is a great possibility to produce higher yielding varieties/genotypes.

Keywords

combining ability; heterosis; hybrid; superior; yield

Introduction

Bottle gourd fruits have various shapes including lengthy and curved necks, and long, straight necks. Fruit morphologies include round, oblate, pyriform, cavate, and cylindrical shapes; fruit color is dark green; as well as

other traits like variance in the height of the plant and the number of leaves, are all examples of the reported genetic diversity in different regions (1-3). The bottle gourd is valued for its medicinal and nutritional benefits. In each 100 g of fruit, there are major amounts of dietary fiber, vitamins B and C, calcium (20 mg), phosphorus (10 mg), iron (0.7 mg), and protein (0.2 g). The fruit also has a high moisture content (96.1 g), protein (0.2 g), and carbohydrates (2.5 g) (2, 3). Phenylalanine, lysine, and arginine are only some of the required amino acids and phytochemicals found in fruits. Essential nutrients, including zinc, nitrogen, manganese, and copper, are rich in the leaves (4, 5). Because it is monoecious, it is a crop that is heavily cross-pollinated and has a wide genetic diversity. In western Uttar Pradesh, the area under high-yielding types is very small. Therefore, it is important to develop better varieties and have a major yield advantage. Because bottle gourds are important as food and vegetable crops, improvements to them are very important. To obtain better performance, it's necessary to increase the yield with superior characteristics. The main characteristic studied to increase bottle gourd production through the collection of advantages of heterosis is yield. Therefore, it is essential to understand the parents' genetic nature better. With the objective of identifying the parents and performing the hybridization program to produce better hybrids, combining ability analysis is helpful (6, 7). A determination has been made to evaluate the parent's and crosses' general as well as specific combining ability (SCA) impacts on bottle gourds in the present study. The significance of this study is to increase the production of bottle gourd by estimating combining ability and heterosis that may be useful in a breeding improvement program for yield and quality characteristics (8). The purpose of this investigation is to examine the best hybrids and parents for use in the production of this crop that will enhance sustainable farming and feed the developing demand. The present study aims to evaluate the combining ability and heterosis in bottle gourd for yield and different yield contributing traits using line × tester design. The study will therefore produce superior parents and hybrids that could be used for breeding to increase production together with the desirable bottle gourd characteristics (9).

Materials and Methods

Basic material, i.e., sixteen parental lines of bottle gourd viz., Narendra Jyothi, Narendra Rashmi, Pusa Sandesh, Vallabh Saral, Pusa Santusti, IC-321412, IC- 338119, IC-592210, IC-321460, IC-321747, NDBG-132, IC-398510, Pusa Samridhi, Pant Louki-1, Narendra Dharidar, and Punjab long, and four testers, namely, Kashi Ganga, Arka Bahar, Narendra Madhuri, and Pusa Naveen were procured from IIVR, IIHR, NDUAT and IARI, respectively for the present investigation. The parental material was grown at the Horticultural Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, during the Zaid season 2019-2020. All possible crosses were also made in a line × tester fashion to generate 64 cross combinations, and a total of sixty-four hybrids were evaluated during Zaid season of 2020. Seeds of each parental line and cross were planted in two rows, with a row length of 5.0 m, a row-to-row spacing of 1.0 meter, and a plant-to-plant distance of 45 cm. The observations were recorded on thirteen characters, viz., days to 1st flower initiation, days to 50% flower, days to 1st fruit set, vine length, number of leaves, number of primary branches, fruit length, fruit girth, average fruit weight, days to 1st fruit harvest, number of fruits per plant, duration of crops and yield. Analysis of genetic components of variance will be done as given by (10). The sources of parental lines, tester, and characters is shown in Table 1.

Results

Analysis of variance for the experiment with fifty-five treatments for thirteen characters, i.e., days to 1st flower initiation, days to 50% flower, days to 1st fruit set, vine length, number of leaves, number of primary branches, fruit length, fruit girth, average fruit weight, days to 1st fruit harvest, number of fruits per plant, duration of crop, and yield, was carried out for testing the significance of variance among the treatments for each character through the 'F' test (Table 2). The mean square due to lines × testers was non-significant for days to 1st flower initiation and days to 50% flowering, significant for vine length, and highly significant for the characters. The highly significant results (lines) from the analysis of variance were shown. For days to first flower initiation, days to 50% flowering, days to first fruit set, vine length (cm), number of leaves, number of primary branches, length of fruit (cm), the girth of fruit (cm), the average weight of fruit (g), days to 1st fruit harvest, number of fruits per plant, duration of crop, and yield q/ha, whereas testers expressed significant values of days to first flower initiation, days to 50% flowering, days to first fruit set, vine length (cm), number of leaves, number of primary branches, length of fruit (cm), the girth of fruit (cm), average fruit weight (g), days to first fruit harvest, number of fruit per plant, duration of crop, yield q/hac. However, the mean square due to line × testers was highly significant for days to first fruit set, vine length (cm), number of leaves, number of primary branches, fruit length (cm), the girth of fruit (cm), average fruit weight, days to first fruit harvest, number of fruit per plant, duration of crop, yield q/ha, reported that the expression of these characteristics was affected by both additive and non-additive gene. Previous reports have indicated a similar pattern of both additive and non-additive genes (11, 12). Supplementary Table 1 demonstrates the parents' general combining ability (GCA) effects obtained from the line × tester analysis. IC-321747, followed by IC498541, IC-338119, IC-321460, IC-592210, IC-321412, and Pusa Sandesh, Pusa Santusti, Vallabh Saral, and tester Arka Bahar, Narendra Madhuri for days to 1st flower Initiation, days to 50% flowering, and days to first fruit set. The lines Narendra Dharidar, NDBG-132, Punjab long, IC-592210, Vallabh saral, Pusa Samridhi, Pusa Sandesh, and tester Narendra Madhuri, Pusa Naveen had significant positive GCA values for vine length (cm) this was also reported by many scientists (13). Among lines, IC-321460, Pant louki-1, IC- 498541,

Table 1. Source of parental lines, tester, and characters.

Lines	Source	Characters
Narendra Jyothi	NDUA&T Kumarganj Faizabad (U.P)	Fruit is long slender and attractive and early maturity.
NDBG-132	NDUA&T Kumarganj Faizabad (U.P)	Fruits are long slender shape; it is an early variety.
Narendra Rashmi	NDUA&T Kumarganj Faizabad (U.P)	Fruit is long bottle shape and early maturity.
Pusa Sandesh	IARI New Delhi	Vines medium to long fruits are attractive green, round, deep oblate, medium size.
Vallabh Saral	SVPUA& T Meerut (U.P)	Early high-yielding and small fruit size
Pusa Samridhi	IARI New Delhi	Fruits are long without a neck.
Pusa Santusti	IARI New Delhi	Pear shaped fruits and set fruits under low temperature as well as high temperature.
Narendra Dharidar	NDUA&T Kumarganj Faizabad (U.P)	Fruits are long bottle shapes with stripes.
IC-321412	NBPGR, New Delhi	High yield, medium fruit size, good quality.
IC-338119	NBPGR, New Delhi	Vigorous growth, and long fruit.
IC-592210	NBPGR, New Delhi	High-yielding, and large fruit size.
IC-371747	NBPGR, New Delhi	Dwarf plant, good and yield.
IC-321460	NBPGR, New Delhi	High yield potential, medium fruit size, good fruit quality
IC-498541	NBPGR, New Delhi	Vigorous plant growth, and long fruit.
Punjab long	Punjab Agriculture University	Long fruit, and high yield.
Pant Louki-1	G.B.U.A & T, Pant Nagar	It has long fruit, light green colour.
Tester		
Narendra Madhuri	NDUA&T Kumarganj Faizabad (U.P)	Fruit is attractive with a round shape, it produces highly palatable cooked vegetables.
Arka Bahar	IIHR Bengaluru	Fruits are medium long, and straight without crookneck. Light green shining fruit.
Pusa Naveen	IARI New Delhi	It is free from crook necked fruits. Its fruits are cylindrical and straight.
Kashi Ganga	IIVR Varanasi	Fruits are light green, length 30 cm, diameter 7 cm.

IC- 592210, Pusa Samridhi, and tester Narendra Madhuri, showed maximum positive significant GCA effect for the number of leaves. The values of GCA exhibited positive and significant effects for the lines Narendra Jyothi, NDBG-132, Pusa Sandesh, IC338119, Pant louki-, Narendra Dharidar, Punjab long, and tester Kashi Ganga for the number of primary branches. The fruit length (cm) is an important trait in bottle gourd, contributes greatly towards positive significant GCA for Narendra Rashmi, NDBG-132, Narendra Dharidar, Narendra Jyothi, IC- 592210, IC- 321412, IC-498541 and tester Pusa Naveen, Kashi Ganga, and Arka Bahar. The line Pusa Sandesh, Punjab long, Pusa Santusti, Narendra Rashmi, and tester Narendra Madhuri, Arka Bahar was the best combiner for fruit girth (cm). The most positive, and significant GCA effects were found in the following lines: Narendra Dharidar, IC-321747, Pusa Sandesh, IC-321460, Pusa Santusti, and tester viz., Pusa Naveen, and Kashi Ganga, which were the best combiner for average fruit weight (cm). Similar reports were registered by (14, 15). The maximum positive and significant GCA effect was observed in lines IC-321747, IC-338119, IC-321460, IC-321412, IC-498541, Vallabh Saral, IC-592210, Pusa Santusti, and tester Arka Bahar for days to the first fruit harvest. Positive and highly significant GCA effects were seen among the parents for line NDBG-132, Narendra Dharidar, Narendra Jyothi, Pusa Sandesh, Narendra Rashmi, Punjab long, Pusa Samridhi, and tester Arka Bahar, Narendra Madhuri, for the number of fruits per plant. The positive significant lines are IC-321747, Narendra Rashmi, IC-321412, and tester Kashi Ganga, Narendra Madhuri, which are the best combinations for the duration of the crop. The line NDBG-132, Narendra Jyothi, Pusa Sandesh, Narendra Dharidar, Narendra Rashmi, Punjab long, Pusa Samridhi, and tester Arka Bahar and Narendra Madhuri were identified because of the good and highly significant GCA positive effects as a good combination for yield q/ha. These results are in conformity with (16).

Estimate of SCA (Specific Combining Ability)

Supplementary Table 2 shows SCA effects and overall cross performance. Out of sixty-four cross combinations, to confirm whether the crosses selected based on SCA effects were the highest performance ones, the best fourteen crosses were chosen which represented the top combiners for yield performance. The selection parameters for SCA and desirable significant specific combining effects were the same. The following is an analysis of the character-wise findings of SCA effects (17). The hybrids with a significant positive value of SCA effects were selected as desirable, there were 36 crosses with a significant positive value, and seven of those crosses showed significant positive SCA effects, including days to 1st flower initiation. Pusa Sandesh × Kashi Ganga, followed by Pusa Santusti × Pusa Naveen, Narendra Dharidar × Arka Bahar, IC-321412 × Kashi Ganga, IC592210 × Narendara Madhuri, IC- 321460 × Kashi Ganga, NDBG-132 × Narendra Madhuri. The hybrid from the cross NDBG-132 × Narendra Madhuri, IC-321412 × Pusa Naveen, Narendra Jyothi × Pusa Naveen, Vallabh saral × Pusa Naveen, IC- 592210 × Narendra Madhuri, IC-321460 × Kashi Ganga, Narendra Rashmi × Arka Bahar had significant, desirable, positive SCA effects for days to 50% flowering (18). Hybrids from the crosses Punjab long ×

Table 2. Analysis of variance for L× T analysis.

	d.f.	Days to 1st flower Initiation	Days to 50% flower	Days to 1st fruit set	Vine Length (cm)	Number of leaf	Number of primary branch	Fruit Length (cm)
REPLICATION	2	0.01	1.28	1.69	0.20	1.25	0.07	0.01
CROSS	63	47.45**	43.61**	57.24**	1342.8**	80.44**	2.71**	125.09**
LINE(combing ability)	15	165.35**	152.60**	177.63**	4158.7**	117.72**	5.78**	201.61**
TEST combing ability)	3	144.66**	105.23**	173.49**	4368.4**	886.83**	6.32**	1421.28**
L×T combing ability)	45	1.67	3.17	9.36**	202.4*	14.26**	1.45**	13.17**
ERROR	126	1.18	2.32	2.32	107.9	4.33	0.04	0.60

	d.f	Fruit girth (cm)	Average fruit weight (gm)	Days to 1st fruit harvest	Number of fruit per plant	Duration of crop	Yield q/hac
REPLICATION	2	0.30	1546.9**	0.69	1.41	9.38	51.03
CROSS	63	35.13**	21256.8**	58.77**	15.39**	22.40**	1820.75**
LINE combing ability)	15	119.79**	65236.1**	148.01**	52.53**	58.66**	6255.13**
TEST combing ability)	3	61.46**	44752.4**	89.42**	11.20**	24.61**	1339.09**
L×T combing ability)	45	5.16**	5030.6**	26.98**	3.29**	10.16**	374.74**
ERROR	126	0.30	710.8	3.08	0.46	10.42	52.73

Significant at 5 % probability level, and ** Significant at 1 % probability level.

Pusa Naveen, Pusa Sandesh × Kashi Ganga, Narendra Dharidar × Pusa Naveen, Narendra Dharidar × Arka Bahar, IC-321460 × Kashi Ganga, Punjab long × Narendra Madhuri, Narendra × Arka Bahar had the highest positive and significant value of SCA effect for days to first fruit set. The hybrid from the most promising crosses which exhibited high positive and significant SCA effects for vine length was Punjab long × Pusa Naveen, NDBG-132 × Narendra Madhuri, IC- 321412 × Arka, IC-338119 × Narendra Madhuri, IC338119 × Arka Bahar. The top high significant and positive SCA effects were observed in crosses IC-592210 × Kashi Ganga, NDBG-132 × Pusa Naveen, Pant Louki-1 × Kashi Ganga, IC-321460 × Kashi Ganga, NDBG-132 × Kashi Ganga, IC- 321747 × Narendra Madhuri, Vallabh saral × Narendra Madhuri, IC-592210 × Arka Bahar for number of leaves. The hybrids from the crosses IC-592210 × Kashi Ganga, Pant louki-1 × Arka Bahar, Vallabh Saral × Pusa Neveen, IC-498541 × Pusa Naveen and Pusa Sandesh × Kashi Ganga had significant positive effects for the number of primary branches. The highest positive and significant SCA effects were recorded for IC-338119 × Kashi Ganga, IC-338119 × Narendra Madhuri, IC-338119 × Pusa Naveen, Narendra Dharidar × Pusa Naveen, IC321747 × Kashi Ganga for fruit length (cm). The SCA effects for fruit girth (cm) ranged from IC-592210 × Narendra Madhuri to Pusa Sandesh × Pusa Naveen. The crosses with negatively significant SCA effects for fruit girth were considered desirable as they were flowering in nature (19). The top positive and significant values of SCA effect for average fruit weight were obtained by the crosses namely, IC-321747 × Narendra Madhuri, IC-338119 × Narendra Madhuri, IC592210 × Kashi Ganga, IC- 498541 × Arka Bahar, Pusa Samridhi × Arka Bahar, Narendra Dharidar × Pusa Naveen, Pusa Santusti × Arka Bahar. The hybrids from the crosses IC- 592210 × Arka Bahar, IC- 498541 × Narendra Madhuri, Punjab long × Pusa Naveen, IC- 498541 × Pusa Naveen, IC- 592210 × Kashi Ganga, Narendra Dharidar × Arka Bahar had significant, desirable, positive SCA effects for days to 1st fruit harvest. Hybrids from the crosses Pusa Sandesh × Kashi Ganga, IC-338119 × Pusa Naveen, Narendra Rashmi × Pusa Naveen, Narendra Dharidar × Kashi Ganga, and Vallabh Saral × Pusa Naveen had positive SCA effects for number of fruits per plant. The top crosses positive values include Pusa Sandesh × Kashi Ganga, NDBG -132 × Narendra Madhuri, Narendra Rashmi × Pusa Naveen, IC- 498541 × Pusa Naveen, Narendra Dharidar × Arka Bahar, and Punjab long × Arka Bahar for the duration of the crop. The top valuable crosses which showed high positive and significant SCA effects for yield q/ha were Pusa Sandesh × Kashi Ganga, IC-338119 × Pusa Naveen, Narendra Dharidar × Narendra Rashmi, IC-321747 × Arka Bahar, Narendra Rashmi × Pusa Naveen, Punjab long × Narendra Madhuri, NDBG-132 × Narendra Madhuri, IC-321747 × Narendra Madhuri and IC-321747 × Pusa Naveen had negative significant SCA effects. The mean performance of crosses could not properly reflect SCA effects, and high SCA effects do not always mean that particular combinations do very well. High SCA effects of hybrids may not have a more significant mean performance (20). Observed that higher heterosis percentages were not typically signified by the SCA effects of hybrids. Hybrids should be selected depending on both combining ability and average performance. Based on the study's findings, the best cross combination identified for performance, GCA, SCA, and standard heterosis is NDBG 132 × Narendra Madhuri. This cross exhibited the best overall performance and significant positive SCA effects, making it a strong candidate for yield improvement. Pusa Sandesh × Kashi Ganga, notable for high SCA effects and positive heterosis, indicates its potential for enhanced traits.

Heterosis

The mean superiority of F_1 hybrids over their respective better parents was used in the present study to measure the degree of heterosis. Heterosis may vary from high to

low based on the parents' mean. Depending on the mean of the significant parent, heterosis may be high or low. It is possible to produce a hybrid that performs effectively by itself yet has inferior heterosis compared to its parents. However, a cross with a high percentage of heterosis but lower performance overall is possible. It also means that selecting an ideal cross combination based on high heterosis may not always result in the combination with the best overall performance. After selecting a cross combination, the per se performance is the realized value given preference above the heterotic response, which is an estimate. The former has a larger percentage of heterosis. Following investigating each cross to determine if hybrid vigor over better parent and mid parent was present (Supplementary Table 3), none of the crosses showed vigor for any of the traits in the present study.

Days to first flower Initiation

The current study's heterosis over a superior parent ranged from (-1.31), Pusa Samridhi × Kashi Ganga to (15.86), IC-398510 × Kashi Ganga. As many as 14 crosses showed significantly better parent heterosis in the positive direction, while 43 crosses exhibited significant heterosis in the negative direction, and over the mid parent for this trait ranged from (-0.01) Narendra jyothi × Kashi Ganga to (18.33) IC-498541 × Kashi Ganga. Out of 64 crosses, 16 crosses showed a significant positive direction, while 18 crosses exhibited a significant negative direction. Among the crosses check parent for this trait ranged from (-0.40) Narendra Rashmi × Arka Bahar to (15.89) IC-321747 × Arka Bahar as many as 23 crosses showed significant check parent heterosis in the positive direction, while 19 crosses exhibited significance in the negative direction.

Days to 50 % flowering

For the days to 50 % flowering, significant negative heterosis was exhibited, ranging from (-0.06) Punjab Komal × Arka Bahar to IC-498541 × Arka Bahar (15.18). Sixteen crosses showed significant positive heterosis and 21 crosses showed significant negative heterosis compared to their better parents heterosis for this trait. The mid parent heterosis ranged from Pant louki-1 × Narendra Madhuri (-0.18) to IC-498541 × Arka Bahar (21.22). Three hybrids out of 64 showed negative significance and twenty-six crosses were positive and significant. The check parent heterosis ranged from NDBG-132 × Narendra Madhuri (-0.64) to IC-338119 × Arka Bahar (16.87) out of 64 crosses, 37 crosses showed significant positive, and 2 crosses showed negative and significant heterosis for this trait.

Days to first fruit set

Negative heterosis is selected for this characteristic as it results in early harvesting as the minimum number of days required for fruit setting - better parent, midparent, and standard check. The better parent heterosis ranged from Narendra Dharidar × Narendra Madhuri (-17.79) to IC-498541 × Kashi Ganga (11.31). Out of 64 crosses, 41 crosses showed significant negative, and 10 crosses showed positive and significant. The mid-parent heterosis ranged from Narendra Jyothi × Narendra Madhuri (-0.01) to IC-498541 × Arka Bahar (17.40). Out of 64 crosses, 14 crosses showed significant positive, and 23 crosses showed significant and negative heterosis. The check parent heterosis ranged from Vallabh Saral × Arka Bahar (-0.05) to IC-321747 × Arka Bahar (10.14). 14 crosses out of 27 showed negative significance, and 12 crosses were positive and significant.

Vine length

The range of variation for vine length was observed among the better parents from Punjab long × Kashi Ganga (-5.53) to NDBG-132 × Narendra Madhuri (29.20). As many as 37 crosses showed positive significance and one cross-significant negative heterosis for this trait. A wide range of mid-parents was also displayed in the crosses. It varied from IC-338119 × Pusa Naveen (4.04) to NDBG-132 × Narendra Madhuri (31.43). 64 crosses exhibited significant positive heterosis. Similar to this, standard heterosis through the check Pusa Naveen varied widely, from IC-321412 × Kashi Ganga (5.37) to Punjab long × Pusa Naveen (35.96). Out of 64 crosses, sixty-four crosses exhibited significant positive standard heterosis.

Number of leaves

The better parent heterosis among the crosses ranged from Punjab long × Pusa Naveen (-4.26) to IC321460 × Narendra Madhuri (25.61). Out of 64 crosses, 12 crosses showed significant negative heterosis and 32 crosses showed significant positive heterosis compared to the better parent. The mid-parent heterosis for this trait ranged from Vallabh Saral × Arka Bahar (-5.70) to IC321460 × Narendra Madhuri (29.26). Two crosses out of 64 crosses showed negative significance and 35 crosses had positive significant mid-parent heterosis. The standard heterosis ranged from Pusa Santusti × Arka Bahar (-4.26) to IC-321460 × Narendra Madhuri (16.69). 10 crosses out of 64 crosses showed significant negative and 23 crosses positive significant standard heterosis for this trait.

Number of primary branches

In the present study, out of 26 crosses that displayed significant positive and 22 crosses that were negative, significant heterosis, the better parent ranged from IC- 321412 × Pusa Naveen (-5.04) to Narendra Jyothi × Kashi Ganga (40.27). For this trait, average heterosis ranged from IC321460 × Narendra Madhuri (-4.06) to Narendra Jyothi × Kashi Ganga (44.97). Out of 64 crosses, 32 crosses were significantly positive and 14 crosses were negative, indicating significant heterosis over mid-parent. Standard heterosis over check ranged from Vallabh Saral × Kashi Ganga (-5.04) to Narendra Jyothi × Kashi Ganga (47.48). 39 crosses recorded significant positive and 13 crosses were significant negative heterosis over the check (Supplementary Table 4).

Fruit length (cm)

The better parent heterosis for this trait varied from Punjab long × Pusa Naveen (-3.79) to Pusa Sandesh × Pusa Naveen (17.03). 19 crosses, out of 64 exhibited significant positives, and 25 crosses were negative, significantly better parent heterosis. The extent of mid-parent ranged from IC-338119 × Pusa Naveen (-3.65) to Pusa Sandesh × Pusa Naveen (43.73) for this trait. 35 crosses were positive sig-

nificant, and 6 crosses were negative significant mid-parent heterosis. The heterosis over check parent ranged from Narendra Dharidar × Pusa Naveen (-0.41) to Pusa Sandesh × Pusa Naveen (86.19). A significant positive standard heterosis was observed for 53 crosses out of 64 for this trait (Supplementary Table 5).

Average fruit weight (g)

The better parent heterosis for average fruit weight ranged from Narendra Rashmi × Narendra Madhuri (-4.05) to Pusa Sandesh × Arka Bahar (15.76) 29 crosses, out of 64 exhibited significant positive and 6 crosses negative significant heterosis. The mid parent ranged from IC-592210 × Arka Bahar (-4.89) to Narendra Dharidar × Pusa Naveen (18.79) 45 crosses were positively significant and only 1 cross was negatively significant. The standard heterosis for this trait ranged from Pusa Samridhi × Narendra Madhuri (-3.89) to IC-321747 × Narendra Madhuri (28.23) with 40 crosses being positive significant and 3 crosses being negative significant (Supplementary Table 5).

Days to first fruit harvest

Days to 1st fruit harvest is an estimate of earliness as early harvesting results and increases the plant's flowering and fruiting season. Therefore, heterosis in the opposite direction is selected for this characteristic. The range of better parent heterosis is for 64 crosses varied from IC-498541 × Arka Bahar (-23.92) to Narendra Jyothi × Narendra Madhuri (6.46) 42 crosses out of 64 exhibited significant negative better parent heterosis. A wide range of mid-parent heterosis is also given in the crosses. It varies from IC498541 × Arka Bahar (-14.94) to Narendra Jyothi × Kashi Ganga (7.60). 5 crosses were negative significant and 21 crosses, out of 64 exhibited positive significant mid-parent heterosis. Similar to this, standard heterosis all over the check Pusa Naveen varied widely, from Punjab long × Kashi Ganga (-5.28) to IC-321747 × Arka Bahar (26.89). Out of 64 crosses, 56 crosses were positive significantly, and only crosses had negative significant standard heterosis (Supplementary Table 6).

Number of fruits per plant

The better parent heterosis of the number of fruits per plant varied from Punjab long × Pusa Naveen (-4.95) to Pusa Santusti × Arka Bahar (24.00). 41 crosses were positive significant, and 6 crosses were negative significant, better parent heterosis. The mid-parent ranged from IC338119 × Kashi Ganga (-7.81) to IC-321460 × Arka Bahar (33.57). Among 64 crosses, 59 crosses were positively significant and only one cross was negative significant heterosis over the mid parent. The standard heterosis ranged from IC-321747 × Pusa Naveen (-5.53) to Pusa Sandesh × Kashi Ganga (39.41). 58 crosses were positively significant and only one cross was negatively significant (Supplementary Table 6).

Duration of crop

For this characteristic, the better parent heterosis varied from IC-321412 × Arka Bahar (-3.82) to IC338119 × Arka Bahar (-6.99), 8 crosses exhibited significant negativeheterosis over the better parent. The heterosis over mid-parent for this trait ranged from Narendra Dharidar × Kashi Ganga (- 3.64) to Narendra Rashmi × Pusa Naveen (14.01), 16 crosses positive significant and Three crosses negative significant heterosis. The heterosis over check variety (Standard heterosis) for this trait 64 crosses reported significant positive standard heterosis (Supplementary Table 6).

Yield (q/ha)

The better parent heterosis for average fruit yield (q/ha) ranged from IC-498541 × Pusa Naveen (-8.00) to Narendra Dharidar × Narendra Madhuri (46.78). 53 crosses were positively significant, and two crosses were negatively significant for better parent heterosis. The mid-parent heterosis highest ranged Narendra Dharidar × Kashi Ganga (59.42) for this trait. 61 crosses were positive for significant mid-parent heterosis. The heterosis over check variety (Pusa Naveen) was observed from IC-338119 × Kashi Ganga (-4.97) to Pusa Sandesh × Kashi Ganga (35.65). The significant standard heterosis was observed for 56 crosses of positive significance and 3 crosses of negative significance (Supplementary Table 6).

Discussion

The GCA estimates of the sixteen lines and four testers for the thirteen traits are given in Supplementary Table 1. Agronomic factors such as flowering capacity, fruit result and related traits, and seed yield and related traits were found to vary in bottle gourds, a morphologically different crop. Work was centered on GCA estimates of sixteen lines and four testers for thirteen traits in bottle gourds, a crop characterized by morphological variation. The traits involved features such as whether the plant is male or female and the type of fruit and seed that is produced. Altogether, these agronomic factors differed markedly across the lines under investigation. By comparing the genotypes it was revealed that Narendra Jyothi was the best general combiner for the number of leaves, fruit length, the number of fruits per plant, and overall yield (q/ha). Narendra Rashmi also came out as a strong general combiner for fruit length, girth, number of fruits, crop duration, and, yield. Pusa Sandesh exhibited GCA for primary branch numbers, fruit girth, average fruit weight, and yield and Vallabh Saral was early flowering followed by the vine length. Out of them, Pusa Santusti had higher GCA for traits such as early flowering, fruit girth, and average fruit weight. This work further indicated that the non-additive gene effects relate significantly to SCA, with the genes originating from the parents being positively additive for SCA effects (21). Of the hybrids, Pusa Sandesh × Kashi Ganga, Pusa Santusti × Pusa Naveen, and IC-321412 × Kashi Ganga showed positive GCA estimates for early flowering. Likewise, for 50% flowering, the cross Punjab Komal × Narendra Madhuri and IC-321460 × Kashi Ganga revealed a positive estimate of SCA. SCA effect of the highest size was clear among combinations like- IC-338119 × Kashi Ganga, IC-321747 × Kashi Ganga, and Narendra Rashmi × Kashi Ganga in terms of fruit length. Among the eleven hybrids, there were positive significant SCA effects in terms of yield per hectare; Pusa

Sandesh × Kashi Ganga, Narendra Dharidar × Narendra Rashmi, etc. The importance of heterosis was also stressed with even positive heterosis identified in hybrids for such characteristics as flowering period, fruit length, and yield. The hybrids, IC-398510 × Kashi Ganga, and IC-321412 × Pusa Naveen manifested high and significantly positive heterosis for early flowering, Narendra Rashmi × Kashi Ganga and Pusa Sandesh × Narendra Madhuri for fruit length. Heterosis for primary branches was significant and observed in crosses Pusa Sandesh × Kashi Ganga and IC 592210 × Kashi Ganga. Regarding fruit girth, positive heterosis was reported in the cross Pusa Sandesh × Pusa Naveen and Pusa Santusti × Narendra Madhuri, and so on. In Narendra Rashmi × Kashi Ganga and Pusa Sandesh × Kashi Ganga hybrids, heterosis over the standard check was observed during the period of crop duration. Overall, 53 crosses showed positive heterosis for yield per hectare as Narendra Dharidar × Narendra Madhuri and Punjab Komal × Kashi Ganga hybrids. This work showed that the hybrids for bottle gourd had significant heterotic effects for earliness, fruit length, and yield. The maximum and minimum SCA effects coupled with heterosis in several hybrid combinations imply that the right selection of parent genotypes can help evolve high-yielding hybrids with desirable characters. This further justifies the need for GCA and SCA in the development of breeding strategies through the enhancement of yield and other desirable horticultural characters in the bottle gourd (22).

Conclusion

The study concludes with the conclusion that significant differences were found in the bottle gourd's general combining ability (GCA) and specific combining ability (SCA) for every parameter that was taken into consideration. This underlines the significance of additive and non-additive genetic processes in determining how specific traits develop. Its potential for early maturation was shown by the hybridization between NDBG-132 and Kashi Ganga, which showed enhanced negative better parent and mid-parent heterosis for characteristics related to early flowering and fruit harvest. The possibility of improving every characteristic in bottle gourds through heterosis breeding is shown by the observation that several different hybrid combinations also showed positive heterosis for yield. The study underlines how important it is to combine ability analysis with heterosis breeding when breeding F_1 hybrids for the commercial production of bottle gourds on a large scale. The study showed the significance of genetic effects by identifying significant variations in GCA and SCA for all characteristics. The hybridization of Kashi Ganga and NDBG-132 showed the potential for early maturation. The significance of combining ability analysis in breeding programs is shown by the positive heterosis for yield observed in several hybrids.

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Authors' contributions

RS & BS drafted the manuscript. SP, SS & MS participated in the sequence alignment. RS & MK participated in the design of the study and performed the statistical analysis. AK, MK & SKS conceived of the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

Supplementary data

Supplementary Table 1. General Combining Ability (GCA) effects for parents.

Supplementary Table 2. Specific Combining Ability (SCA) effects for hybrids morphological and yield.

Supplementary Table 3. Estimates of better parent, mid parent and standard check heterosis in 64 F_1 progenies (Day to 1st flower, 50% flower & fruit set).

Supplementary Table 4. Estimates of better parent, mid parent and standard check heterosis in 64 F_1 progenies. (Vine lendth, No. of leaf & primary branch)

Supplementary Table 5. Estimates of better parent, mid parent and standard check heterosis in 64 F_1 progenies. (Fruit length & fruit grith)

Supplementary Table 6 Estimates of better parent, mid parent and standard check heterosis in 64 F_1 progenies. (Days to 1st fruit harvest, No. of fruits/plant, Crop duration & Yield)

Supplementary Table 7. Classification of lines/tester for character based on GCA (good, average and poor)

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