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Elucidation of heterosis and inbreeding depression for fruit yield and its component traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]

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Abstract
An investigation was conducted with nine diverse parents to develop thirty-six F_1's and F_2's by using half-diallel mating design to estimate heterosis and inbreeding depression for fruit yield and its components in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. The analysis of variance revealed highly significant differences among parents, F_1's and F_2's for all the characters studied. High heterosis for fruit yield per plant was reflected through high heterosis for number of fruits per plant, fruit length, fruit girth and average fruit weight in most of crosses. High magnitude of heterobeltiosis for fruit yield per plant was recorded in the cross, Arka Bahar x Santosh followed by Punjab Long x Santosh, Punjab Long x NDBG-15, Punjab Long x JBOGL-01-42 and Punjab Long x JBGL-43. The highest standard heterosis for fruit yield per plant was registered by the cross Arka Bahar x Santosh followed by Punjab Long x Santosh, Punjab Long x NDBG-15, NDBG-15 x Santosh and Punjab Long x JBGL-43. Two crosses *viz.*, JBOGL-01-42 x PBOG-88 and Aruna x Santosh exhibited significant and lowest inbreeding depression for fruit yield per plant. The crosses with high heterotic values for fruit yield per plant and its important attributes also showed high inbreeding depression. The cross combinations, Arka Bahar x Santosh and Punjab Long x Santosh were the most promising cross combinations for fruit yield per plant, on the basis of their high heterobeltiosis and standard heterosis in both F_1 and F_2 generations and thus, can be utilized effectively in the breeding programme.

Keywords: Heterosis, inbreeding depression, half-diallel mating design, bottle gourd

Introduction
Bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] also known as *Calabash*, is one of the most important vegetable grown in tropical and subtropical parts of the world which belongs to the family Cucurbitaceae with somatic chromosome number 2n = 22 (Bose and Som, 1986) [6]. Tropical Africa is the primary gene centre of origin in bottle gourd (Whitaker, 1971; Chakravarty, 1982 and Heiser, 1979) [24, 7, 13] which is the only species that has been used worldwide since prehistoric times. India is considered as a secondary centre of diversity of bottle gourd and it exhibits a wide range of variability with respect to its morphological traits, maturity period and fruit yield.

In India, current production level of vegetables is over 189.46 million tonnes from an area of 10.32 million hectares with productivity of 18.40 t/ha. Out of these, area and production of bottle gourd was 1.57 million hectares and 26.83 million tons, respectively (Anonymous, 2020a) [2]. In Gujarat, vegetable production level is about 132 lakh metric tonnes with an area of 6.5 lakhs hectares and productivity of 20.22 metric t/ha (Anonymous, 2020b) [3].

Heterosis breeding has been recognized as a practical tool in providing the plant breeders a means of increasing fruit yield and other economic traits. The hybrid vigour is the superiority of the hybrids over parents should be manifested in terms of high productivity, uniformity, improved quality, built in resistance, environmental adaptations and earliness. Therefore, for the development of effective heterosis breeding programme in bottle gourd, there is a need to elucidate the genetic nature and magnitude of quantitative inherited traits and estimated prepotency of parents in hybrid combinations. In bottle gourd, due to its monoecious nature, large flower size, easy pollination, high proportion of fruit set of pollinated pistillate flowers, large number of seeds per fruit and low seed rate required per unit area, bottle gourd is highly amenable for heterosis breeding programme (Singh, 2004) [20].

Besides heterosis studies, inbreeding depression is also important in deciding breeding methodology to be employed for crop improvement. The inbreeding depression results due to fixation of unfavorable recessive genes in F_2. Inbreeding depression studies also help to select which F_1 to be used as parents in mating design. It also reveals deleterious recessive alleles, which can then be eliminated through assortative mating. Hence, the present investigation was undertaken to study the best heterotic combinations for the exploitation of heterosis and to study inbreeding depression in bottle gourd.

Materials and Methods

The present investigtion was conducted with nine diverse parents *viz.*, Pusa Naveen, Arka Bahar, Aruna, Punjab Long, NDBG-15, Santosh, JBOGL-01-42, JBGL-43 and PBOG-88 to develop thirty-six F_1's during *Summer* 2019 and F_2's during *Kharif* 2019 at Vegetable Research Station, Junagadh Agricultural University, Junagadh. The final evaluation trial comprised of parents along with F_1's, F_2's and standard check (GABGH-1) in Randomized Block Design (RBD) with two replications during *Summer* 2020 at the Instructional Farm, College of Agriculture, Junagadh Agricultural University, Junagadh. The parents, F_1's and F_2's were grown in plot with spacing 2.0 m x 1.0 m. Each replication was consisted of 82 genotypes. Each plot of parents and F_1's was consisted of a single row of 10 plants, while F_2 was consisted of three rows of 10 plants for each genotype. The recommended package of practices and necessary plant protection measures were undertaken to raise a good crop. Observations were recorded on five competitive plants excluding border ones and was selected randomly from each single row plot of each parents and F_1's as well as 20 competitive plants of F_2's were selected in each replication for fruit yield per plant and its components *viz.*, number of nodes on main vine, vine length (m), number of fruits per plant, fruit length (cm), fruit girth (cm), average fruit weight (g) and total soluble solids (˚Brix).

The analysis of variance was performed to test the significance of difference among the genotypes for the characters studied as suggested by Panse and Sukhatme (1985) [18]. Magnitude of heterobeltiosis and standard heterosis was calculated as the deviation of F_1 from the better parent and standard check, respectively (Fonseca and Patterson, 1968) [10]. The inbreeding depression was calculated from the deviation between F_1 and its corresponding F_2 for each character separately (Allard 1960) [1].

Results and Discussion

The analysis of variance revealed (Table 1) highly significant differences among the genotypes for all the characters studied. This indicated that experimental material used in the present study had sufficient variability for different characters. Further partitioning of genotypic variance into parents, F_1's and F_2's also revealed that mean squares due to parents, F_1's and F_2's were also significant for all the characters. Likewise, mean squares due to parents *vs.* F_1's and parents *vs.* F_2's were significant for the studied characters. This indicated that among parents as a group, F_1's as a group and F_2's as a group showed significant differences and average heterosis existed for the characters studied. Similar findings were reported by Janaranjani *et al.* (2016) [14], Khot *et al.* (2018) [16], Jayanth *et al.* (2019) [15] and Balat *et al.* (2020) [4] for fruit yield and its component traits in bottle gourd.

Table 1: Analysis of variance for the experimental design for different characters in bottle gourd

Source	d. f.	Mean square								
		Number of nodes on main vine	Vine length (m)	Number of picking	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Fruit yield (kg/plant)	Total soluble solids (˚Brix)
Replications	1	0.565	0.520	0.024	0.557	0.235	0.989	1416.893	1.099	0.047
Genotypes	80	61.181**	0.839**	5.146**	6.096**	14.712**	5.994**	48293.681**	9.842**	0.919**
Parents	8	33.933**	0.697**	1.625**	4.165**	10.436**	4.759**	9625.748**	1.339**	0.281**
F_1's crosses	35	46.430**	0.498**	3.382**	3.721**	12.001**	3.181**	40757.564**	3.631**	0.683**
P *vs.* F_1's	1	536.556**	6.930**	34.225**	39.933**	146.229**	42.456**	709363.748**	167.294**	0.663**
F_2's crosses	35	63.656**	0.994**	6.428**	8.535**	14.426**	6.573**	46370.442**	13.490**	1.204**
P *vs.* F_2's	1	76.849**	1.405**	3.600**	3.230**	46.764**	0.379	329532.634**	48.988**	0.390**
Error	80	3.745	0.165	0.149	0.592	0.761	0.296	1535.197	0.521	0.019

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

Number of nodes on main vine

A perusal of data for number of nodes on main vine (Table 2) revealed that out of 36 hybrids, 15 hybrids exhibited significant and positive heterobeltiosis. The maximum heterobeltiosis in the positive direction was recorded by Pusa Naveen x Arka Bahar (18.07%) followed by Arka Bahar x JBGL-43 (17.36%), Punjab Long x JBOGL-01-42 (16.67%) and Pusa Naveen x PBOG-88 (13.00%). Estimates of standard heterosis varied from 5.42 per cent (Pusa Naveen x JBGL-43) to 39.25 per cent (Pusa Naveen x Arka Bahar). Out of 36 crosses, 34 crosses recorded significant standard heterosis in positive direction (except Punjab Long x JBGL-43 and Pusa Naveen x JBGL-43). Yadav and Kumar (2012a) [25] in bottle gourd reported significant and positive heterosis for number of nodes on main vine.

In F_2, seventeen crosses showed significant and positive inbreeding depression of which the highest inbreeding depression was recorded by Pusa Naveen x Arka Bahar (24.23%) followed by Pusa Naveen x NDBG-15 (20.58%), Aruna x NDBG-15 (15.72%) and Pusa Naveen x Santosh (15.08%). On the other hand, significant and negative inbreeding depression were recorded by Santosh x JBOGL-01-42 (-9.29%), JBOGL-01-42 x PBOG-88 (-5.98%), Arka Bahar x Santosh (-4.49%) and Punjab Long x JBOGL-01-42 (-2.07%). Significant and high inbreeding depression was reported in bottle gourd by Pandey *et al.* (2004) [17] and Yadav and Kumar (2012b) [26] for number of nodes on main vine.

Vine length (m)

Heterosis over the better parent for vine length (Table 2) ranged from -12.27 per cent (Pusa Naveen x JBGL-43) to 17.60 per cent (Aruna x Punjab Long). Significant and positive values of heterobeltiosis were noted for two crosses *viz.*, Aruna x Punjab Long (17.60%) and Pusa Naveen x Arka Bahar (16.55%). Standard heterosis varied between 5.73 per cent (Pusa Naveen x JBGL-43) and 40.46 per cent (Pusa Naveen x Arka Bahar). Out of 36 hybrids, 20 hybrids exhibited significant and positive standard heterosis. Maximum, significant and positive standard heterosis was recorded by the cross Pusa Naveen x Arka Bahar (40.46%) followed by Aruna x Punjab Long (39.60%), Arka Bahar x Aruna (38.93%) and Pusa Naveen x Aruna (38.17%). The results were in harmony with findings of Gayakwaed *et al.* (2016) [11], Khot *et al.* (2018) [16], Jayanth *et al.* (2019) [15] and Balat *et al.* (2020) [4].

Significant inbreeding depression was noted in 11 F_2's, of which ten and one F_2's had positive and negative values, respectively. The inbreeding depression ranged from -16.67 per cent (JBOGL-01-42 x PBOG-88) to 28.07 per cent (Aruna x NDBG-15). High inbreeding depression was reported in Aruna x NDBG-15 (28.07%) followed by Pusa Naveen x Arka Bahar (25.88%), JBOGL-01-42 x JBGL-43 (20.14%) and Aruna x Punjab Long (20.10%), while lowest inbreeding depression was reported in JBOGL-01-42 x PBOG-88 (-16.67%). Dhumal *et al.* (2019) [8] reported similar results for high inbreeding depression in ridge gourd.

Table 2: Estimation of heterosis over better parent (BP) and standard check (SC) and inbreeding depression (ID) in per cent for number of nodes on main vine and vine length (m)

Sr. No.	Crosses	Number of nodes on main vine			Vine length (m)		
		BP	SC	ID	BP	SC	ID
1	Pusa Naveen x Arka Bahar	18.07**	39.25**	24.23**	16.55*	40.46**	25.88**
2	Pusa Naveen x Aruna	7.26*	29.72**	1.67	14.65	38.17**	0.35
3	Pusa Naveen x Punjab Long	4.99	23.83**	-0.26	-2.93	16.98	-2.94
4	Pusa Naveen x NDBG-15	8.40**	27.85**	20.58**	-1.50	18.70	8.84
5	Pusa Naveen x Santosh	6.66*	25.79**	15.08**	9.90	32.44**	17.58**
6	Pusa Naveen x JBOGL-01-42	3.65	22.24**	-0.08	4.99	26.53**	0.23
7	Pusa Naveen x JBGL-43	-10.62**	5.42	0.71	-12.27	5.73	1.17
8	Pusa Naveen x PBOG-88	13.00**	33.27**	-0.35	11.16	33.97	0.36
9	Arka Bahar x Aruna	8.66**	31.40**	9.07**	15.56	38.93**	17.45**
10	Arka Bahar x Punjab Long	4.79	18.50**	5.99*	0.56	20.90*	5.45
11	Arka Bahar x NDBG-15	-3.64	8.97*	11.02**	-11.83	6.01	10.26
12	Arka Bahar x Santosh	13.22**	28.04**	-4.49	-0.40	19.75*	-9.64
13	Arka Bahar x JBOGL-01-42	10.74**	25.23**	12.69**	4.21	25.29**	9.22
14	Arka Bahar x JBGL-43	17.36**	32.71**	-0.85	12.86	35.69**	-0.07
15	Arka Bahar x PBOG-88	6.61*	20.56**	-0.08	-1.59	18.32	-0.40
16	Aruna x Punjab Long	12.98**	36.64**	11.15**	17.60*	39.60**	20.10**
17	Aruna x NDBG-15	12.83**	36.45**	15.72**	12.54	33.59**	28.07**
18	Aruna x Santosh	-3.40	16.82**	0.28	6.11	25.95**	-4.70
19	Aruna x JBOGL-01-42	1.85	23.18**	14.26**	5.63	25.38**	12.40*
20	Aruna x JBGL-43	3.25	24.86**	12.65**	-0.16	18.51	4.35
21	Aruna x PBOG-88	-2.78	17.57**	3.90	-1.13	17.37	1.06
22	Punjab Long x NDBG-15	1.54	11.21**	6.64*	4.66	15.84	6.92
23	Punjab Long x Santosh	1.84	14.02**	-0.04	8.79	20.42*	0.16
24	Punjab Long x JBOGL-01-42	16.67**	24.30**	-2.07	3.43	20.99*	-11.36
25	Punjab Long x JBGL-43	7.10	7.10	3.14	11.21	23.09*	7.05
26	Punjab Long x PBOG-88	4.28	9.35*	8.38*	1.98	12.88	15.72*
27	NDBG-15 x Santosh	0.33	12.34**	5.91	10.02	8.97	6.39
28	NDBG-15 x JBOGL-01-42	8.87**	19.25**	-0.08	3.43	20.99*	-2.76
29	NDBG-15 x JBGL-43	4.61	14.58**	13.50**	17.15	16.03	14.64*
30	NDBG-15 x PBOG-88	5.97	16.07**	-0.56	5.19	10.21	-0.78
31	Santosh x JBOGL-01-42	0.67	12.71**	-9.29**	5.71	23.66*	-12.11
32	Santosh x JBGL-43	5.84	18.50**	12.07**	12.09	8.78	7.81
33	Santosh x PBOG-88	4.67	17.20**	9.09**	12.20	17.56	15.50*
34	JBOGL-01-42 x JBGL-43	5.61	12.52**	7.35*	3.26	20.80*	20.14**
35	JBOGL-01-42 x PBOG-88	8.60*	15.70**	-5.98	-1.63	15.08	-16.67*
36	JBGL-43 x PBOG-88	3.74	8.79*	4.47	12.20	17.56	10.71
	S.Em. ±	1.409		1.368	0.357		0.287
	CD at 5%	4.013		3.851	1.017		0.810

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

Number of fruits per plant

In respect of number of fruits per plant (Table 3), eight cross combinations had significant and positive heterobeltiosis, whereas only cross *i.e.* Santosh x JBOGL-01-42 (-25.89%) expressed significant and negative heterobeltiosis. The highest heterobeltiotic cross was Arka Bahar x JBOGL-01-42 (41.77%) followed by Arka Bahar x Aruna (26.58%), Punjab Long x JBOGL-01-42 (26.00%) and Aruna x PBOG-88 (21.95%) possessed significant and positive heterobeltiosis values. Significant and positive standard heterosis was also observed in eleven crosses. The maximum, significant and positive standard heterosis was reported by Pusa Naveen x Santosh (40.86%) followed by Arka Bahar x Santosh and Punjab Long x Santosh (31.18%), Santosh x PBOG-88 (25.81%) and NDBG-15 x PBOG-88 (24.73%). The maximum, significant and negative standard heterosis was observed in cross Aruna x Punjab Long (-12.90%). Similar results in desired direction was reported by Gayakwaed *et al.* (2016) [11] and Balat *et al.* (2020) [4].

Among F_2's, sixteen cross combinations recorded significant and positive inbreeding depression. Maximum inbreeding depression was recorded in Punjab Long x NDBG-15 (42.98%) followed by Pusa Naveen x Arka Bahar (39.45%) and Santosh x PBOG-88 (37.18%), whereas minimum inbreeding depression was observed in the cross *i.e.* Pusa Naveen x Punjab Long (-12.78%) followed by JBOGL-01-42 x PBOG-88 (-12.36%) and Arka Bahar x PBOG-88 (-12.24%). Significant and high inbreeding depression was observed by Pandey *et al.* (2004) [17] and Yadav and Kumar (2012b) [26].

Fruit length (cm)

Out of 36 crosses, sixteen crosses exhibited significant and positive values for heterobeltiosis for fruit length (Table 3). Heterosis over better parent varied from -2.35 per cent (Pusa Naveen x PBOG-88) to 25.50 per cent (Santosh x JBOGL-01-42). The desirable hybrid was closely followed by Santosh x JBGL-43 (20.58%), Arka Bahar x Santosh (18.55%) and NDBG-15 x Santosh (16.35%). With regards to standard heterosis, twenty crosses exhibited significant and positive standard heterosis. The standard heterosis varied from -3.99 per cent (NDBG-15 x JBGL-43) to 26.06 per cent (Santosh x JBOGL-01-42). This was followed by Punjab Long x NDBG-15 (25.65%), Pusa Naveen x Punjab Long (23.42%) and Punjab Long x JBOGL-01-42 (22.58%). Similar findings for fruit length were observed by Pandey *et al.* (2004) [17] and Ghughe *et al.* (2016) [12].

Significant and positive inbreeding depression was exhibited by sixteen crosses, while only one cross *i.e.* JBOGL-01-42 x PBOG-88 (-7.24%) exhibited significant and negative inbreeding depression. Minimum, significant inbreeding depression with positive values was observed in Arka Bahar x JBOGL-01-42 (5.69%), Santosh x JBGL-43 (5.80%) and Arka Bahar x Aruna (6.30%). Radharani *et al.* (2015) [19] reported significant inbreeding depression for fruit length in bitter gourd.

Table 3: Estimation of heterosis over better parent (BP) and standard check (SC) and inbreeding depression (ID) in per cent for number of fruits per plant and fruit length (cm)

Sr. No.	Crosses	Number of fruits per plant			Fruit length (cm)		
		BP	SC	ID	BP	SC	ID
1	Pusa Naveen x Arka Bahar	4.04	10.75	39.45**	1.63	5.44	8.03**
2	Pusa Naveen x Aruna	2.02	8.60	-7.92	4.40	8.31*	-1.19
3	Pusa Naveen x Punjab Long	-11.11	-5.38	-12.78	7.86**	23.42**	6.85**
4	Pusa Naveen x NDBG-15	10.00	18.28*	14.55*	5.50	9.46**	5.11
5	Pusa Naveen x Santosh	16.96**	40.86**	23.85**	5.24	9.19**	8.02**
6	Pusa Naveen x JBOGL-01-42	-10.10	-4.30	-2.25	13.55**	17.81**	4.75
7	Pusa Naveen x JBGL-43	10.10	17.20*	-7.59	-1.92	1.76	-3.12
8	Pusa Naveen x PBOG-88	16.16*	23.66**	-3.89	-2.35	1.32	0.53
9	Arka Bahar x Aruna	26.58**	7.53	32.25**	4.57	2.13	6.30*
10	Arka Bahar x Punjab Long	15.19	-2.15	20.31*	-0.89	13.42**	8.21**
11	Arka Bahar x NDBG-15	2.00	9.68	27.22**	9.58**	7.03*	7.63**
12	Arka Bahar x Santosh	8.93	31.18**	0.82	18.55**	15.78**	-1.75
13	Arka Bahar x JBOGL-01-42	41.77**	20.43**	33.04**	2.59	3.04	5.69*
14	Arka Bahar x JBGL-43	4.30	4.30	-3.90	0.14	-2.20	0.22
15	Arka Bahar x PBOG-88	21.95**	7.53	-12.24	7.75*	5.24	0.96
16	Aruna x Punjab Long	3.85	-12.90	18.42	-0.92	13.38**	14.58**
17	Aruna x NDBG-15	1.00	8.60	25.63**	4.73	-1.93	6.55*
18	Aruna x Santosh	-2.68	17.20*	-5.30	9.14*	0.51	-3.60
19	Aruna x JBOGL-01-42	11.54	-6.45	8.91	6.09	6.56*	7.39**
20	Aruna x JBGL-43	-5.38	-5.38	23.58*	7.41*	-2.57	6.75*
21	Aruna x PBOG-88	21.95**	7.53	17.75*	1.09	-3.18	5.15
22	Punjab Long x NDBG-15	-11.00	-4.30	42.98**	9.81**	25.65**	13.49**
23	Punjab Long x Santosh	8.93	31.18**	6.35	2.63	17.44**	0.99
24	Punjab Long x JBOGL-01-42	26.00**	1.61	-6.35	7.12*	22.58**	-0.50
25	Punjab Long x JBGL-43	5.38	5.38	13.78	0.77	15.31**	10.43**
26	Punjab Long x PBOG-88	12.20	-1.08	28.78**	0.59	15.11**	9.20**
27	NDBG-15 x Santosh	-4.46	15.05*	10.28	16.35**	8.96**	3.64
28	NDBG-15 x JBOGL-01-42	-6.00	1.08	-3.72	7.13*	7.60*	-0.31
29	NDBG-15 x JBGL-43	2.00	9.68	21.81**	2.53	-3.99	8.34**
30	NDBG-15 x PBOG-88	16.00*	24.73**	-1.94	4.23	-0.17	5.09
31	Santosh x JBOGL-01-42	-25.89**	-10.75	-11.14	25.50**	26.06**	-1.93
32	Santosh x JBGL-43	-6.25	12.90	24.05**	20.48**	10.95**	5.80*
33	Santosh x PBOG-88	4.46	25.81**	37.18**	11.01**	6.32	4.34
34	JBOGL-01-42 x JBGL-43	-3.23	-3.23	15.56	2.42	2.87	4.86
35	JBOGL-01-42 x PBOG-88	10.98	-2.15	-12.36	6.83*	7.30*	-7.24**
36	JBGL-43 x PBOG-88	-6.45	-6.45	25.86**	12.56**	7.81*	4.80
	S.Em. ±	0.482		0.544	0.691		0.617
	CD at 5%	1.374		1.532	1.969		1.736

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

Fruit girth (cm)

The extent of significant heterobeltiosis for fruit girth (Table 4) ranged from -9.31 per cent (Pusa Naveen x PBOG-88) to 15.72 per cent (NDBG-15 x Santosh). Fifteen crosses registered significant and positive heterobeltiosis. The desirable heterobeltiotic hybrid was followed by Santosh x JBOGL-01-42 (12.06%), Santosh x JBGL-43 (11.98%) and Aruna x PBOG-88 (11.72%). Seventeen crosses exhibited significant and positive values, while one cross *i.e.* Pusa Naveen x PBOG-88 (-5.72%) reported significant and negative standard heterosis. Estimates of standard heterosis ranged from -5.72 per cent (Pusa Naveen x PBOG-88) to 18.02 per cent (Punjab Long x JBGL-43). The desirable standard heterotic hybrid was followed by NDBBG-15 x

Santosh (15.62%), Punjab Long x NDBG-15 (15.12%) and Santosh x JBOGL-01-42 (14.99%). The results for fruit girth were in accordance with the findings of Pandey *et al.* (2004) [17] and Ghughe *et al.* (2016) [12].

Significant inbreeding depression in positive and negative direction was recorded by twenty-two and two crosses, respectively. The lowest, significant and negative inbreeding depression was recorded by Punjab Long x Santosh (-10.50%) and Punjab Long x JBOGL-01-42 (-5.84%), whereas, Pusa Naveen x Santosh (6.06%) registered minimum but positive inbreeding depression for this trait. Dhumal *et al.* (2019) [8] recorded similar results for high inbreeding depression in ridge gourd for fruit girth.

Average fruit weight (g)

Out of 36 cross combinations, 30 crosses indicated significant and positive heterobeltiosis for average fruit weight (Table 4). Estimates for heterobeltiosis varied between -0.42 per cent (Arka Bahar x JBOGL-01-42) and 79.09 per cent (Santosh x JBOGL-01-42). The highest heterotic hybrid was followed by NDBG-15 x Santosh (63.31%), Santosh x JBGL-43(48.26%) and Punjab Long x NDBG-15 (47.42%). Twenty-three crosses registered significant and positive values. Standard heterosis varied between -6.79 per cent (NDBG-15 x JBGL-43) and 62.84 per cent (Santosh x JBOGL-01-42). This was followed by Punjab Long x NDBG-15 (55.72%), Punjab Long x JBOGL-01-42 (42.86%) and Punjab Long x JBGL-43 (38.05%). This result was in confirmation with Sirohi and Rana (2007) [23], Singh *et al.* (2012) [22], Gayakwaed *et al.* (2016) [11] and Ghughe *et al.* (2016) [12].

In F_2 generation, seventeen and three crosses exhibited significant and positive as well as negative inbreeding depression, respectively. Minimum and significant inbreeding depression was observed in cross Arka Bahar x JBGL-43 (11.38%) followed by Arka Bahar x Aruna (12.24%), Aruna x NDBG-15 (13.12%) and Pusa Naveen x Arka Bahar (14.82%). On the other hand, minimum, significant and negative inbreeding depression was exhibited by the cross JBOGL-01-42 x PBOG-88 (-14.42%) followed by Aruna x Santosh (-13.92%). Radharani *et al.* (2015) [19] reported significant and high inbreeding depression for average fruit weight in bitter gourd.

Table 4: Estimation of heterosis over better parent (BP) and standard check (SC) and inbreeding depression (ID) in per cent for fruit girth (cm) and average fruit weight (g)

Sr. No.	Crosses	Fruit girth (cm)			Average fruit weight (g)		
		BP	SC	ID	BP	SC	ID
1	Pusa Naveen x Arka Bahar	0.82	4.82*	12.22**	16.15**	10.43*	14.82**
2	Pusa Naveen x Aruna	1.43	5.45*	1.86	29.38**	18.51**	-1.00
3	Pusa Naveen x Punjab Long	2.13	9.86**	4.06	23.22**	30.16**	2.43
4	Pusa Naveen x NDBG-15	-5.89*	-2.16	-3.31	24.28**	13.84**	3.16
5	Pusa Naveen x Santosh	-2.81	1.04	6.06*	2.01	-6.56	-3.64
6	Pusa Naveen x JBOGL-01-42	0.95	4.95*	3.71	39.30**	27.60**	6.91
7	Pusa Naveen x JBGL-43	-4.37	-0.59	-0.81	11.76*	2.37	-6.93
8	Pusa Naveen x PBOG-88	-9.31**	-5.72*	2.24	4.44	-4.33	1.32
9	Arka Bahar x Aruna	7.53**	3.51	11.52**	10.32	4.89	12.24**
10	Arka Bahar x Punjab Long	-0.21	7.34**	10.29**	19.65**	26.39**	15.99**
11	Arka Bahar x NDBG-15	8.33**	4.73	12.33**	23.11**	17.05**	18.96**
12	Arka Bahar x Santosh	9.50**	9.41**	-1.11	37.77**	30.99**	-1.20
13	Arka Bahar x JBOGL-01-42	6.05*	8.82**	9.06**	-0.42	-5.32	-0.21
14	Arka Bahar x JBGL-43	6.12*	3.06	10.48**	11.26*	5.78	11.38*
15	Arka Bahar x PBOG-88	8.46**	4.41	4.14	20.79**	14.84**	2.04
16	Aruna x Punjab Long	-6.49**	0.59	11.77**	11.50*	17.78**	23.30**
17	Aruna x NDBG-15	2.84	-0.59	11.93**	16.57**	-5.19	13.12*
18	Aruna x Santosh	7.61**	7.52**	11.22**	15.37*	-6.17	-13.92**
19	Aruna x JBOGL-01-42	1.89	4.55	10.31**	28.28**	16.65**	18.74**
20	Aruna x JBGL-43	10.70**	7.52**	16.39**	21.95**	4.54	19.86**
21	Aruna x PBOG-88	11.72**	0.81	13.39**	14.63	-0.41	16.66**
22	Punjab Long x NDBG-15	7.03**	15.12**	8.89**	47.42**	55.72**	21.63**
23	Punjab Long x Santosh	-1.97	5.45*	-10.50**	22.99**	29.92**	-7.76*
24	Punjab Long x JBOGL-01-42	3.89	11.75**	-5.84**	35.24**	42.86**	-0.85
25	Punjab Long x JBGL-43	9.73**	18.02**	19.07**	30.69**	38.05**	22.98**
26	Punjab Long x PBOG-88	3.47	11.30**	8.07**	23.43**	30.38**	16.02**
27	NDBG-15 x Santosh	15.72**	15.62**	15.41**	63.31**	29.63**	18.35**
28	NDBG-15 x JBOGL-01-42	-2.89	-0.36	-4.52	28.03**	16.42**	-2.68
29	NDBG-15 x JBGL-43	0.51	-2.39	8.83**	8.74	-6.79	16.14**
30	NDBG-15 x PBOG-88	3.68	0.23	2.36	12.66*	-2.13	2.75
31	Santosh x JBOGL-01-42	12.06**	14.99**	-2.58	79.09**	62.84**	-0.84
32	Santosh x JBGL-43	11.98**	11.88**	11.93**	48.26**	27.09**	15.05**
33	Santosh x PBOG-88	3.24	3.15	9.69**	7.47	-6.64	-2.96
34	JBOGL-01-42 x JBGL-43	-1.45	1.13	7.10**	23.26**	12.08*	15.86**
35	JBOGL-01-42 x PBOG-88	6.23**	9.00**	3.65	21.92**	10.86*	-14.42**
36	JBGL-43 x PBOG-88	4.40	1.40	7.90**	34.53**	16.88**	8.07
	S.Em. ±	0.383		0.384	28.733		27.705
	CD at 5%	1.092		1.083	81.843		77.974

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

Fruit yield (kg/plant)

Perusal of the data for fruit yield per plant (Table 5) revealed that out of 36 cross combinations, thirty-three crosses showed significant and positive heterosis over the better parent. The positive values varied between 15.14 per cent (Aruna x Santosh) and 79.59 per cent (Arka Bahar x Santosh). The highest heterotic hybrid was closely followed by Punjab Long x Santosh (78.22%), Punjab Long x NDBG-15 (74.88%), Punjab Long x JBOGL-01-42 (70.54%) and Punajb Long x JBGL-43 (69.90%). As regards to standard heterosis, twenty-three crosses showed significant and positive values. The estimates of standard heterosis ranged from -1.22 per cent (Aruna x JBGL-43) to 71.51 per cent (Arka Bahar x Santosh). The desirable hybrid was followed by Punjab Long x Santosh (70.19%), Punjab Long x NDBG-15 (49.01%), NDBG-15 x Santosh (48.85%) and Punjab Long x JBGL-43 (45.44%). The results of heterosis for fruit yield per plant was in harmony with findings of Janaranjani *et al.* (2016) [14], Doloi *et al.* (2018) [9], Khot *et al.* (2018) [16], Singh and Mamta (2018) [21], Jayanth *et al.* (2019) [15] and Balat *et al.* (2020) [4].

Twenty-one F_2 cross combinations revealed significant and positive inbreeding depression, whereas two F_2's observed significant and negative inbreeding depression. Minimum, significant and negative inbreeding depression was registered by the cross JBOGL-01-42 x PBOG-88 (-29.11%) followed by Aruna x Santosh (-19.52%), whereas minimum, significant and positive inbreeding depression was reported by Pusa Naveen x NDBG-15 (17.34%) followed by Pusa Naveen x Santosh (21.14%) and Aruna x NDBG-15 (23.22%). Significant and high inbreeding depression was observed in bottle gourd by Pandey *et al.* (2004) [17] and Yadav and Kumar (2012b) [26]; Radharani *et al.* (2015) [19] in bitter gourd; Bhardwaj *et al.* (2009) [5] in sponge gourd and Dhumal *et al.* (2019) [8] in ridge gourd for fruit yield per plant.

Total soluble solids (˚Brix)

Heterobeltiosis for total soluble solids ranged (Table 5) between -39.57 per cent (Arka Bahar x Punjab Long) and 9.89 per cent (Santosh x PBOG-88). Ninteen crosses exhibited significant and negative values and only one cross *i.e.* Santosh x PBOG-88 (9.89%) showed significant and positive heterobeltiosis. Ninteen and six crosses recorded significant and positive as well as significant and negative standard heterosis, respectively. The standard heterosis varied from -23.53 per cent (Arka Bahar x Punjab Long) to 39.06 per cent (Santosh x PBOG-88). The desirable hybrid was closely followed by JBGL-43 x PBOG-88 (31.52%), Pusa Naveen x Arka Bahar (30.92%), NDBG-15 x Santosh (29.26%) and NDBG-15 x JBGL-43 (28.81%). Doloi *et al.* (2018) [9] in bottle gourd observed similar results.

In F_2 generation, sixteen and one cross exhibited significant but negative and positive inbreeding depression, respectively. Lowest inbreeding depression with significant and negative values was observed in NDBG-15 x JBOGL-01-42 (-43.47%) followed by Arka Bahar x JBOGL-01-42 (-36.96%), Punjab Long x JBOGL-01-42 (-33.93%) and Santosh x JBGL-43 (-27.95%). Maximum inbreeding depression in positive direction was observed in cross Santosh x JBOGL-01-42 (24.44%). This result was in confirmation with the results of Doloi *et al.* (2018) [9] in bottle gourd.

A comparative assessment of ten best heterobeltiotic crosses for fruit yield per plant along with their heterobeltiotic effects for yield components is presented in Table 6. The cross combination, Arka Bahar x Santosh recorded the highest heterobeltiosis (79.59%) with highest mean fruit yield per plant (12.89 kg) followed by Punjab Long x Santosh (78.22%), Punjab Long x NDBG-15 (74.88%), Punjab Long x JBOGL-01-42 (70.54%), Punjab Long x JBGL-43 (69.90%), Aruna x JBOGL-01-42 (60.00%), NDBG-15 x Santosh (55.87%), Arka Bahar x PBOG-88 (52.87%), Santosh x JBOGL-01-42 (52.18%) and Punjab Long x PBOG-88 (51.16%) with acceptable mean fruit yield per plant. The top performing F_1 hybrids over the better parent (Table 6) for fruit yield per plant also showed significant and positive heterobeltiosis for all the ten crosses for average fruit weight; followed by seven crosses for fruit girth; six crosses for fruit length; three crosses for number of nodes and two crosses for number of fruits per plant. While correlating heterobeltiosis of fruit yield with other traits (Table 6), it was observed that significant and positive association of heterobeltiosis of fruit yield was observed with fruit girth and average fruit weight.

Likewise, Table 7 showed the comparative assessment of ten best standard heterotic crosses for fruit yield per plant along with their standard heterotic effects for yield components. The cross combination, Arka Bahar x Santosh recorded the highest standard heterosis (71.51%) with highest mean fruit yield per plant (12.89 kg) followed by Punjab Long x Santosh (70.19%), Punjab Long x NDBG-15 (49.01%), NDBG-15 x Santosh (48.85%), Punjab Long x JBGL-43 (45.44%), Santosh x JBOGL-01-42 (45.33%), Punjab Long x JBOGL-01-42 (45.31%), Santosh x JBGL-43 (43.52%), Pusa Naveen x NDBG-15 (34.66%) and Pusa Naveen x Santosh (31.66%) with acceptable mean fruit yield per plant.

Out of ten heterotic crosses over standard check, four crosses *viz.*, Arka Bahar x Santosh, Punjab Long x Santosh, NDBG-15 x Santosh and Punjab Long x JBGL-43 hold significant and positive standard heterosis for number of fruits per plant, fruit length and fruit girth as well as average fruit weight (except number of nodes and number of fruits per plant in cross Punjab Long x JBGL-43). Likewise, the crosses Punjab Long x NDBG-15, Santosh x JBOGL-01-42, Punjab Long x JBOGL-01-42 and Santosh x JBGL-43 had also significant and positive standard heterosis for number of nodes, fruit length, fruit girth and average fruit weight. Similarly, the rest of two crosses *i.e.* Pusa Naveen x NDBG-15 and Pusa Naveen x Santosh, had significant and positive standard heterosis for number of nodes, number of fruits per plant and fruit length. When comparing relationship of fruit yield per plant over other component traits for standard heterosis, significant and positive correlation of standard heterosis of fruit yield (Table 7) was reported with number of fruits per plant, fruit length, fruit girth and average fruit weight indicated that these four traits are most contributing traits for heterosis for fruit yield.

To know the relationship between different statistical parameters used in the present investigation (Table 8), the correlation coefficients had been worked out. *Per se* performance of crosses was compared with heterobeltiosis revealed significant and positive correlation between both the parameters for fruit yield and its component traits. Further, *per se* performance of crosses was also compared with inbreeding depression revealed significant and negative association between both the parameters for all the characters under studied which means that increase in *per se* performance of one character will lead to decrease in inbreeding depression of that character and *vice versa*. There was also significant and positive correlation between heterobeltiosis and standard heterosis for fruit yield and its component traits.

Table 5: Estimation of heterosis over better parent (BP) and standard check (SC) and inbreeding depression (ID) in per cent for fruit yield (kg/plant) and total soluble solids (˚Brix)

Sr. No.	Crosses	Fruit yield (kg/plant)			Total Soluble Solids (˚Brix)		
		BP	SC	ID	BP	SC	ID
1	Pusa Naveen x Arka Bahar	25.55**	22.13*	48.41**	3.46	30.92**	-4.03
2	Pusa Naveen x Aruna	32.02**	28.43**	-9.69	-18.28**	1.81	-2.96
3	Pusa Naveen x Punjab Long	25.96**	22.53**	-10.53	-31.23**	-14.33**	-5.63
4	Pusa Naveen x NDBG-15	38.43**	34.66**	17.34*	-14.77**	6.18	-2.13
5	Pusa Naveen x Santosh	35.34**	31.66**	21.14**	-23.72**	-3.47	-8.59*
6	Pusa Naveen x JBOGL-01-42	25.69**	22.27*	5.23	-16.95**	3.47	0.73
7	Pusa Naveen x JBGL-43	23.24**	19.88*	-15.23	-11.16**	12.82**	3.88
8	Pusa Naveen x PBOG-88	21.58*	18.27*	-8.33	2.16	28.36**	-18.80**
9	Arka Bahar x Aruna	39.67**	12.82	40.62**	-14.30**	8.45*	-27.68**
10	Arka Bahar x Punjab Long	45.11**	23.64**	33.12**	-39.57**	-23.53**	-13.81*
11	Arka Bahar x NDBG-15	50.98**	28.05**	41.16**	-2.38	23.53**	2.08
12	Arka Bahar x Santosh	79.59**	71.51**	-0.36	-37.78**	-21.27**	3.07
13	Arka Bahar x JBOGL-01-42	40.76**	13.70	32.78**	-20.02**	1.21	-36.96**
14	Arka Bahar x JBGL-43	28.50**	10.00	8.42	-0.83	25.94**	-1.56
15	Arka Bahar x PBOG-88	52.87**	23.48**	-9.75	-0.60	25.79**	-4.32
16	Aruna x Punjab Long	20.36*	2.55	37.65**	-24.77**	-14.33**	-24.82**
17	Aruna x NDBG-15	21.30*	2.87	35.58**	-14.44**	-2.56	-24.61**
18	Aruna x Santosh	15.14	9.95	-19.52*	0.60	27.30**	-6.28
19	Aruna x JBOGL-01-42	60.00**	9.25	26.13*	-9.80**	2.71	-1.76
20	Aruna x JBGL-43	15.39	-1.22	38.62**	-0.24	26.70**	-24.29**
21	Aruna x PBOG-88	39.55**	6.95	31.30**	-3.24	21.57**	-1.12
22	Punjab Long x NDBG-15	74.88**	49.01**	55.41**	-25.36**	-22.78**	-0.20
23	Punjab Long x Santosh	78.22**	70.19**	-0.96	-0.48	25.94**	-0.96
24	Punjab Long x JBOGL-01-42	70.54**	45.31**	-7.34	-11.55**	0.45	-33.93**
25	Punjab Long x JBGL-43	69.90**	45.44**	33.81**	0.59	27.75**	-25.74**
26	Punjab Long x PBOG-88	51.16**	28.80**	40.08**	-22.57**	-2.71	-26.67**
27	NDBG-15 x Santosh	55.87**	48.85**	26.42**	2.15	29.26**	-4.08
28	NDBG-15 x JBOGL-01-42	39.07**	17.95*	-5.95	-19.65**	-8.75*	-43.47**
29	NDBG-15 x JBGL-43	19.48	2.27	34.75**	1.43	28.81**	-7.85*
30	NDBG-15 x PBOG-88	43.71**	21.88*	0.70	-0.24	25.34**	-3.85
31	Santosh x JBOGL-01-42	52.18**	45.33**	-11.99	-15.14**	7.39	24.44**
32	Santosh x JBGL-43	50.29**	43.52**	35.74**	-1.43	25.19**	-27.95**
33	Santosh x PBOG-88	22.82*	17.29*	35.17**	9.89**	39.06**	-17.57**
34	JBOGL-01-42 x JBGL-43	26.49**	8.28	28.73**	-5.94*	19.46**	-11.11**
35	JBOGL-01-42 x PBOG-88	40.82**	7.93	-29.11**	-15.73**	5.88	3.13
36	JBGL-43 x PBOG-88	27.42**	9.08	31.63**	3.56	31.52**	-3.44
	S.Em. ±	0.459		0.510	0.090		0.098
	CD at 5%	1.308		1.437	0.256		0.277

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

Table 6: Comparative study of ten most heterobeltiotic crosses for fruit yield per plant with their heterobeltiotic effects for yield components in bottle gourd

Sr. No.	Crosses	Mean fruit yield (kg/ plant)	Per cent heterosis over better parent (Heterobeltiosis)							
			Fruit yield (kg/plant)	Number of nodes on main vine	Vine length (m)	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Total soluble solids (˚Brix)
1	Arka Bahar x Santosh	12.89	79.59**	13.22**	-0.40	8.93	18.55**	9.50**	37.77**	-37.78**
2	Punjab Long x Santosh	12.79	78.22**	1.84	8.79	8.93	2.63	-1.97	22.99**	-0.48
3	Punjab Long x NDBG-15	11.20	74.88**	1.54	4.66	-11.00	9.81**	7.03**	47.42**	-25.36**
4	Punjab Long x JBOGL-01-42	10.92	70.54**	16.67**	3.43	26.00**	7.12*	3.89	35.24**	-11.55**
5	Punjab Long x JBGL-43	10.93	69.90**	7.10	11.21	5.38	0.77	9.73**	30.69**	0.59
6	Aruna x JBOGL-01-42	8.21	60.00**	1.85	5.63	11.54	6.09	6.12*	28.28**	-9.80**
7	NDBG-15 x Santosh	11.18	55.87**	0.33	10.02	-4.46	16.35**	15.72**	63.31**	2.15
8	Arka Bahar x PBOG-88	9.28	52.87**	6.61*	-1.59	21.95**	7.75*	8.46**	20.79**	-0.60
9	Santosh x JBOGL-01-42	10.92	52.18**	0.67	5.71	-25.89**	25.50**	12.06**	79.09**	-15.14**
10	Punjab Long x PBOG-88	9.68	51.16**	4.28	1.98	12.20	0.59	3.47	23.43**	-22.57**
Correlation of H (Heterobeltiosis) of fruit yield with other traits (n=36)				-0.007	-0.189	0.150	0.285	0.357*	0.484**	-0.216

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

Table 7: Comparative study of ten most standard heterotic crosses for fruit yield per plant with their standard heterotic effects for yield components in bottle gourd

Sr. No.	Crosses	Mean fruit yield (kg/ plant)	Per cent heterosis over standard check (Standard heterosis)							
			Fruit yield (kg/plant)	Number of nodes on main vine	Vine length (m)	Number of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Total soluble solids (˚Brix)
1	Arka Bahar x Santosh	12.89	71.51**	28.04**	19.75*	31.18**	15.78**	9.41**	30.99**	-21.27**
2	Punjab Long x Santosh	12.79	70.19**	14.02**	20.42*	31.18**	17.44**	5.45*	29.92**	25.94**
3	Punjab Long x NDBG-15	11.20	49.01**	11.21**	15.84	-4.30	25.65**	15.12**	55.72**	-22.78**
4	NDBG-15 x Santosh	11.18	48.85**	12.34**	8.97	15.05*	8.96**	15.62**	29.63**	29.26**
5	Punjab Long x JBGL-43	10.93	45.44**	7.10	23.09*	5.38	15.31**	18.02**	38.05**	27.75**
6	Santosh x JBOGL-01-42	10.92	45.33**	12.71**	23.66*	-10.75	26.06**	14.99**	62.84**	7.39
7	Punjab Long x JBOGL-01-42	10.92	45.31**	24.30**	20.99*	1.61	22.58**	11.75**	42.86**	0.45
8	Santosh x JBGL-43	10.78	43.52**	18.50**	8.78	12.90	10.95**	11.88**	27.09**	25.19**
9	Pusa Naveen x NDBG-15	10.12	34.66**	27.85**	18.70	18.28*	9.46**	-2.16	13.84**	6.18
10	Pusa Naveen x Santosh	9.89	31.66**	25.79**	32.44**	40.86**	9.19**	1.04	-6.56	-3.47
Correlation of SH (Standard Heterosis) of fruit yield with other traits (n=36)				-0.228	-0.246	0.360*	0.679**	0.546**	0.670**	-0.176

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

Table 8: Correlation coefficient between *per se* performance and heterobeltiosis, *per se* performance and inbreeding depression and heterobeltiosis and standard heterosis for various characters in bottle gourd

Sr. No.	Characters	*per se* performance and heterobeltiosis	*per se* performance and inbreeding depression	Heterobeltiosis and standard heterosis
1	Number of nodes on main vine	0.743**	-0.650**	0.743**
2	Vine length (m)	0.636**	-0.788**	0.636**
3	Number of fruits per plant	0.414*	-0.809**	0.414*
4	Fruit length (cm)	0.421**	-0.497**	0.421**
5	Fruit girth (cm)	0.681**	-0.768**	0.681**
6	Average fruit weight (g)	0.827**	-0.492**	0.827**
7	Fruit yield (kg/plant)	0.809**	-0.899**	0.809**
8	Total soluble solids (˚Brix)	0.969**	-0.556**	0.969**

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

Conclusion

The highest heterobeltiosis for fruit yield per plant was recorded in the cross, Arka Bahar x Santosh followed by Punjab Long x Santosh, Punjab Long x NDBG-15, Punjab Long x JBOGL-01-42 and Punjab Long x JBGL-43. Whereas, the highest standard heterosis for fruit yield per plant was registered by the cross Arka Bahar x Santosh followed by Punjab Long x Santosh, Punjab Long x NDBG-15, NDBG-15 x Santosh and Punjab Long x JBGL-43. High heterosis for fruit yield per plant was reflected through high heterosis in number of fruits per plant, fruit length, fruit girth and average fruit weight in most of the crosses. Two crosses *viz.*, JBOGL-01-42 x PBOG-88 and Aruna x Santosh exhibited significant and lowest inbreeding depression for fruit yield per plant. Such crosses could be exploited in future breeding programmes for development of varieties with increased fruit yield by taking specific trials in bottle gourd.

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