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Rushiraj D Rathva
Ph.D. Scholar, Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India

NA Patel
Assistant Research Scientist, Main Vegetable Research Station, Anand Agricultural University, Anand, Gujarat, India

Pinakkumar Patel
Ph.D. Scholar, Department of Genetics and Plant Breeding, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Dantiwada, Gujarat, India

Baraskar Swapnil
Ph.D. Scholar, Department of Genetics and Plant Breeding, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, India

Rutvik J Joshi
Ph.D. Scholar, Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India

Corresponding Author:
Rutvik J Joshi
Ph.D. Scholar, Department of Genetics and Plant Breeding, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India

Heterosis analysis of F_1 hybrids for green fruit yield and its component traits in chilli (*Capsicum annuum* L.)

Rushiraj D Rathva, NA Patel, Pinakkumar Patel, Baraskar Swapnil and Rutvik J Joshi

Abstract
The present investigation was designed in order to estimate heterosis for fruit yield and its component traits in chilli. The experimental material comprised of 7 lines and 6 testers and their 42 hybrids developed using line x tester mating design which were evaluated in randomized block design with three replications. The experiment was conducted at Main Vegetable Research Station, Anand Agricultural University, Anand during *kharif-rabi* 2020-21. The standard heterosis for all the characters showed that none of the hybrids displayed consistent standard heterosis for all the characters under study. For green fruit yield per plant, the range of heterosis varied from -46.77% to 49.09%. Three crosses *viz.*, ACCMS I × GAVC 112, ACGMS 3 × ACS 18-08, ACGMS 3 × ACS 13 24 showed positive standard heterosis for green fruit yield per plant (kg). Indirect selection for traits like fruit weight, fruit length, fruit girth and number of fruits per plant could be done to obtain higher fruit yield through heterosis. The current investigation reveals good scope for commercial exploitation of heterosis in chilli.

Keywords: Heterosis, line × tester, chilli, fruit girth, pungency, yield

Introduction
Chilli (*Capsicum annuum* L.) is an important vegetable cum spice crop, grown in almost all parts of the world *i.e.* tropical and sub-tropical regions and native of Mexico. The genus *Capsicum* includes 30 species, five of which are cultivated *viz*., *C. annuum* L., *C. frutescens* L., *C. chinense* Jacq, *C. pubescens* R. & P. and *C. baccatum* L. (Ince *et al*., 2010) [5].
Studying flower structure is very important in order to develop a breeding strategy needed for improvement of any crop. Chilli is typical *Solanaceous* crop having white flowers which are actinomorphic, pedicellate, bisexual and hypogynous. Gynoecium is bicarpellate, syncarpous and ovary is either bilocular or tetralocular with ovules having exile placentation. Androecium having 5 stamen units which is epipetalous in nature. Calyx and corolla having 5 sepals and 5 petals, respectively. Chilli is classified as often cross-pollinated crop though natural cross-pollination occurs to the extent of 7-60% (Aiyadurai, 1966) [1].
C. annuum L. has wide variability in terms of fruit size, shape, colour, growth habit, yielding ability and capsaicinoids content of the fruit etc. Despite presence of such variability and importance of the crop as spice, medicinal and culinary use, the current breeding programmes do not suffice the need for ever growing demands of the crop. It comprises numerous chemicals including steam-volatile oils, fatty oils, capsaicinoids, carotenoids, vitamins, proteins, fibres and mineral elements (Bosland and Votava, 2000) [2]. Chillies are low in sodium and cholesterol free, rich in vitamin A, vitamin C, vitamin E and a good source of potassium and folic acid (Gopalan *et al*., 2004) [4].
Chilli offers much scope for improvement through heterosis breeding. The required goals of improving productivity in quickest time can be achieved through heterosis breeding which is feasible in this crop (Joshi and Singh, 1980) [15].

Material and Methods
The investigation was carried out at Main Vegetable Research Station, Anand Agricultural University, Anand during *kharif-rabi* 2019-2020. The experimental material comprised of 7 lines and 6 testers (Table 1) and their 42 hybrids developed using line x tester mating design along with one standard hybrid check. Out of seven lines of chilli, two were cytoplasmic male sterile lines and remaining were govern by genetic male sterility system. The complete set of fifty six genotypes were evaluated in Randomized Complete Block Design with three replications during *kharif-rabi* 2020-21.

Seedlings were transplanted in each plot in one row of ten dibbles with a distance of 60 cm between rows and 60 cm between plants.
Five plants will be randomly selected from each experiment unit in all the replications except the border plants and those will be used for recording the observation like days to flowering initiation, plant height, primary branches per plant, fruit per plant, fruit length (cm), fruit girth (cm), fruit weight (g), Seeds per fruit, test weight (g), Green fruit yield per plant (g), Capsaicin content (mg/g) and ascorbic acid content (mg/g). Where, the character days to initiation of flowering was taken based on plot basis. Calculation of standard heterosis was done using formula given by Meredith and Bridge, 1972 [14].

Table 1: List of genotypes and their source

Genotypes	Source
Lines (Females)	
CCA 4759, ACCMS 1, ACGMS 1, ACGMS 2, ACGMS 3, ACGMS 4, ACGMS 5	MVRS, AAU, Anand
Testers (Males)	
GAVC 112, ACS 08-09, ACS 13-03, ACS 13-24, ACS 18-02, ACS 18-08	MVRS, AAU, Anand
Standard Check Hybrid	
GAVCH-1	MVRS, AAU, Anand

Results and Discussion

The analysis of variance showed that mean sum of squares (Table 2) due to genotypes were highly significant for green fruit yield and 11 other traits under study. This implies that for every characters at least one genotype was significantly differing from all other genotypes. Variances of parents were found highly significant for all the characters except primary branches per plant which implying that at least one parent for each characters were significantly deferring from others. The mean sum of squares due to parents vs hybrids were highly significant for all the characters except for fruit girth under study indicating possibility of significant amount of heterosis in the present investigation. Mean squares due to check us hybrids were significant for the characters *viz.*, days to initiation of flowering, plant height, seeds per fruit, capsaicin content and ascorbic acid content which suggested the presence of significant standard heterosis.

Table 2: Analysis of variance (mean squares) and variance components for various characters in chilli

Sr. No.	Source of variation	df	Days to initiation of flowering	Plant height	Primary branches per plant	Fruits per plant	Fruit length
1.	Replications	2	1.34	33.55	0.53*	587.06	2.75
2.	Genotypes	55	45.92**	174.66**	0.33**	5846.03**	6.04**
	a) Parents	12	35.63**	109.09*	0.12	4225.29**	22.41**
	i) Females	6	17.43**	79.41	0.16	1663.82**	3.26*
	ii) Males	5	49.39**	58.39	0.08	1658.03**	4.67**
	iii) Females *vs.* Males	1	76.07**	540.70**	0.07	32430.35**	5.00*
	b) Hybrids	41	49.00**	176.50**	0.37**	11303.35**	6.64**
	c) Parents *vs* Hybrids	1	80.44**	622.50**	1.32**	55379.16**	11.57**
3.	Check *vs* Hybrids	1	12.67*	516.54**	0.33	252.40	0.05
4.	Error	110	2.12	58.24	0.12	192.86	1.36
5.	Total	167	16.54	96.29	0.20	2059.40	2.92

Sr. No.	Source of variation	df	Fruit girth	Fruit weight	Seeds per fruit	Test weight	Green fruit yield per plant	Capsaicin content	Ascorbic acid content
1.	Replications	2	0.04	0.17	20.34*	0.01	3636.24	0.001	0.001
2.	Genotypes	55	0.28**	1.66**	1276.91**	3.11**	125782.78**	1.46**	0.15**
	(a) Parents	12	0.38**	1.07**	1438.80**	2.04**	57905.06**	0.14**	0.24**
	(i) Females	6	0.60**	0.35	338.90**	1.12**	33872.52**	0.18**	0.03**
	(ii) Males	5	0.18	1.32**	682.62**	2.98**	78983.22**	0.09**	0.43**
	(iii) Females *vs* Males	1	0.04	4.12**	1246.27**	2.88**	96709.50**	0.09**	0.50**
	(b) Hybrids	41	0.26**	1.58**	2821.82**	2.77**	120068.20**	1.90**	0.13**
	(c) Parents *vs* Hybrids	1	0.26	12.63**	1114.09**	32.84**	1289254.00**	0.09**	0.17**
3.	Check *vs* Hybrids	1	0.05	0.71	28.10*	0.01	439.80	0.37**	0.01**
4.	Error	110	0.10	0.21	6.39	0.02	10960.88	0.001	0.001
5.	Total	167	0.16	0.69	424.99	1.04	48604.86	0.48	0.05

Days to initiation of flowering

For days to initiation of flowering, the parent which flowered earlier was considered to be better parent and the heterotic effect was calculated accordingly. Hence, heterotic effect in negative direction was considered desirable for this trait. The value of heterosis over standard check hybrid ranged from -26.45% to 20.69%. There were 33 significant crosses, out of which, 24 were negative direction. These results are in close agreement with Patel (2020) [10].

Plant height

Higher plant height results in higher biomass which translates into higher fruit yield. Hence, heterosis is desirable in positive direction for plant height. Standard heterosis for plant height varied from -3.35% (ACGMS 2 × GAVC 112) to 47.63% (ACCMS 1 × ACS 18-8). Twenty six crosses were found positive significant. This result is in close agreement with Siddappa *et al.* (2017) [11].

Primary branches per plant

Primary branches per plant is one of the important yield contributing trait and hence, positive heterosis is desirable for this trait. Standard heterosis had minimum and maximum value of -26.32% (ACCMS I × GAVC 112) and 12.37% (ACGMS 1 × ACS 18-8), respectively. None of the crosses were found to be significantly positive for standard heterosis. This result is in concurrence with Siddappa *et al.* (2017) [11] and Daware *et al.* (2019) [3].

Fruits per plant

Higher fruits per plant is directly proportional to green fruit yield and thus higher number of fruits per translated into higher green fruit yield per plant. Therefore, positive heterosis is desirable for this character. The range for fruits per plant according to standard heterosis was in between -44.86% (CCA 4759 × GAVC 112) and 88.20% (ACCMS 1 × GAVC 112). Out of 42 hybrids developed, only 13 crosses exhibited significant and positive useful heterosis. Vijeth *et al.* (2012) [13] was close agreement with result.

Fruit length

Longer fruits have good market/consumer preference, while, it also adds to green fruit yield and thus it is desirable in positive direction. Standard heterosis for fruit length varied from -24.20% (ACGMS 5 × ACS 08-09) to 32.72% (ACCMS 1 × ACS 13-03). Nine crosses were found to be heterotic over standard check out of which, 07 were positive for standard heterosis. This result is in close concurrence with Manikandan *et al.* (2020) [8].

Fruit girth

Thicker fruits accommodates more seeds per fruit and hence gains more weight as well as shelf life. Thus, fruit girth is desirable in positive direction. Values of standard heterosis varies from -14.00% (ACGMS 1 × GAVC 112) to 16.81% (CCA 4759 × ACS 18-08). Only 4 crosses exhibited significant and positive heterosis over standard check hybrid. Navhale *et al.* (2015) [9] as well as Kaur *et al.* (2017) [7] were close agreement for standard heterosis.

Fruit weight

Fruit weight is very important green fruit yield contributing character as it directly adds to green fruit yield per plant. Thus, significant positive heterosis is desirable for this character. Values for heterosis over standard check varied from -27.91% (ACGMS 1 x C S 08-09) to 11.78% (ACCMS 1 GAVC 112). Out of 42 crosses, 18 crosses were significant for over standard check and among them, only 1 cross was positive for fruit weight.

Seeds per fruit

More number of seeds are desirable per fruit as it increases weight and capsaicin content and indirectly hardens fruit which increases shelf life. Thus, significant and positive heterosis is desirable. Standard heterosis ranged from -45.11% (ACGMS 1 × ACS 08-09) to 57.64% (ACCMS 1 x GAVC 112), 37 hybrids had exhibited significant heterosis out of which 16 were positive. None of the authors were found similar result.

Test weight

Test weight is also desirable in positive direction because more weight of seeds, more will be the weight of fruits and capsaicin content is found higher in seeds. Standard heterosis ranged from 41.14% (ACGMS 1 × ACS 08-09) to 35.47% (ACCMS 1 × GAVC 112), 35 crosses were significant for standard heterosis out of which, 17 were positive. Tembhurne and Rao (2012) [12] result was close agreement for economic heterosis.

Green fruit yield per plant

Green fruit yield per plant is one of the major important trait and hence, positive heterosis is desirable for this trait. Heterosis over standard check lies from -46.77% (ACGMS 1 × ACS 08-09) to 49.09% (ACCMS I × GAVC 112). Total 21 crosses were significant out of which, 09 were positive. None of the authors were found similar result.

Capsaicin content

In chilli, capsaicin is an important quality trait, which determines the pungency of the produce. In case of green fruits, consumers prefer high and moderate pungent chillies. Looking to high demand of pungent chilli in market, significant and positive heterosis is desirable for this character. Standard heterosis ranged from -51.58% (ACCMS 1 × ACS 1303) to 309.14% (CCA 4759 × GAVC 112). Total 38 crosses were significant for economic heterosis out of which, 21 were significant positive for capsaicin content. This result is close concurrence with Patel (2020) [10].

Ascorbic acid content

In case of green fruits, and positive heterosis is desirable for this character. Standard heterosis ranged from 41.47% (CCA 4759 × ACS 13-24) to 190.27% (ACGMS 4 × ACS 18-02). Out of 42 crosses, 24 were significant for economic heterosis again 16 were significant positive for ascorbic acid content. Above result is contrasting and different for all authors reported in the review of literature.

The magnitude of heterosis found in present study stressed the importance of using genetically divergent parents in hybridization programme. Apart from these hybrids, there are some F_1 hybrids not showing significant heterosis but were still better than the superior parents. Further, maximum heterosis observed in F_1 hybrids was not expressed by the best performing parents, but at least one poor or average performing parent was involved in these significantly high heterotic F_1 hybrids.

Table 3: Magnitude of standard heterosis for various characters in chilli

Sr. No.	Hybrids	Days to initiation of flowering	Plant height	Primary branches per plant	Fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Seeds per fruit	Test weight (g)	Green fruit yield per plant (g)	Capsaicin content (mg/g)	Ascorbic acid content (mg/g)
1.	1F × 1M	-17.24**	11.31	-17.63*	-44.86**	-13.13	-4.76	-25.58**	-42.05**	-27.39**	-39.56**	309.14**	61.16**
2.	1F × 2M	20.69**	5.74	-7.11	66.07**	17.17	15.68*	5.38	26.24**	26.92**	34.87**	196.25**	31.35**
3.	1F × 3M	16.09**	36.70**	-10.53	-38.49**	15.82	9.24	-25.32**	-37.66**	-2.29**	-38.36**	183.70**	0.00
4.	1F × 4M	10.34**	9.35	5.26	38.69**	-13.86	0.00	-0.26	20.99**	18.01**	33.33**	177.49**	-41.47**
5.	1F × 5M	10.34*	37.83**	-13.95	-11.75	21.30*	0.00	-15.92**	-17.07**	-14.70**	-19.69	218.87**	0.00
6.	1F × 6M	10.34*	21.55**	-22.89**	-16.45*	-11.79	16.81*	-21.97**	-32.50**	-26.98**	-33.00**	189.21**	-4.32
7.	2F × 1M	14.93*	34.54**	-26.32**	88.20**	-14.48	10.08	11.78*	57.64**	35.47**	49.09**	229.78**	-2.33
8.	2F × 2M	-2.31	34.32**	-8.68	-14.05	8.58	3.64	-18.91**	-28.58*	-24.99**	-26.00**	247.06**	-2.33
9.	2F × 3M	-6.90	44.12**	3.42	-12.00	32.68**	5.60	-14.22**	-15.04**	-12.07**	-14.68	-51.58**	-31.89**
10.	2F × 4M	-6.90	39.61**	-1.84	9.45	-13.86	-3.92	-9.10	5.56*	9.79**	4.20	-16.41**	0.00
11.	2F × 5M	2.31	24.01*	-12.37	8.37	26.47**	14.85*	3.52	3.53	1.45	2.56	-4.69*	-2.33
12.	2F × 6M	6.90	47.63**	7.11	-3.43	12.00	6.44	-0.26	-2.35	0.21	-0.74	-33.18**	30.81**
13.	3F × 1M	10.34*	10.86	3.42	-16.06	3.72	-14.00	-19.22**	-29.99**	-24.02**	-31.31**	-40.21**	0.00
14.	3F × 2M	-24.14**	25.18*	-1.84	-43.09**	27.92**	0.00	-27.91**	-45.11**	-41.14**	-46.77**	-38.69**	-36.76**
15.	3F × 3M	-13.79**	34.42**	-12.37	35.36**	30.30**	4.48	-1.04	14.96**	-18.28**	30.68**	-48.77**	-35.14**
16.	3F × 4M	-9.21*	20.67*	7.11	-1.96	-8.27	-2.80	-12.67*	-14.09**	-8.01**	-14.27	-5.39**	-2.70
17.	3F × 5M	-17.24**	23.39*	5.26	-12.09	-14.48	-9.52	-19.84**	-31.40**	-23.95**	-31.51**	-10.08**	2.16
18.	3F × 6M	-10.34*	31.98*	12.37	11.95	0.62	-1.12	-7.49	9.40**	9.11**	8.53	-29.66**	-29.19**
19.	4F × 1M	-11.48**	-3.35	7.11	30.27**	7.86	12.04	-1.97	13.79**	15.53**	13.15	-45.72**	2.33
20.	4F × 2M	2.31	21.50*	-7.11	8.77	-14.17	0.00	-8.53	5.64*	12.01**	7.55	9.85**	-4.65
21.	4F × 3M	-12.66**	23.13*	-10.53	56.08**	-15.20	-3.92	7.13	28.67**	28.78**	39.59**	0.82	61.70**
22.	4F × 4M	6.90	24.40*	-8.68	3.77	12.72	7.28	2.59	0.55	5.53**	0.38	-9.38**	28.11**
23.	4F × 5M	-10.34*	14.27	-17.63*	-15.42	-13.86	-8.40	-16.79**	-20.44**	-15.11**	-21.13	-2.35	-6.49
24.	4F × 6M	-16.10**	17.49	-12.37	-6.32	-14.17	12.04	-1.55	-5.71*	-1.72	-1.03	-5.88*	-31.89**
25.	5F × 1M	16.10**	11.03	7.11	-5.58	0.31	4.48	-0.78	-4.93*	0.62	-0.87	51.23**	9.30*
26.	5F × 2M	13.79**	24.90*	-3.42	-22.72**	-2.07	5.60	-20.42**	-31.71**	-24.43**	-31.98**	-16.41**	32.56**
27.	5F × 3M	-21.83**	40.44**	-13.95	36.05**	-12.41	-13.17	-0.78	18.33**	20.23**	33.06**	-3.52	123.78**
28.	5F × 4M	-17.24**	28.74**	-8.68	66.12**	2.38	-14.01	10.19	34.77**	32.09**	43.59**	-5.86*	-37.84**
29.	5F × 5M	20.69**	11.98	-10.53	56.47**	-14.17	1.68	5.16	22.71**	20.29**	33.91**	89.57**	-4.32
30.	5F × 6M	-18.38**	24.06**	-13.95	73.46**	-5.89	10.08	11.12	37.44**	32.51**	45.20**	59.79**	157.30**
31.	6F × 1M	-17.24**	6.08	-17.63*	-44.66**	-22.75*	7.28	-25.01**	-33.98**	-26.71**	-35.57**	17.65**	-2.70
32.	6F × 2M	-9.21*	46.10**	-17.63*	-0.68	-3.52	14.01	1.66	0.24	2.48	0.03	-28.14**	-4.86
33.	6F × 3M	-4.59	25.88*	-7.11	26.84**	20.37*	6.44	-2.59	13.47**	12.69**	12.92	11.37**	31.35**
34..	6F × 4M	-16.10**	4.57	-1.84	20.03*	-14.17	12.04	-4.14	9.40**	11.74**	9.01	5.86*	60.08**
35.	6F × 5M	0.00	20.45*	-10.53	-18.31*	-3.52	-1.12	-17.83**	-21.38**	-16.71**	-24.45*	105.9**	190.27**
36.	6F × 6M	-23.00**	27.35**	-10.53	-11.70	-3.52	12.89	-19.53**	-24.35**	-22.09**	-25.82*	27.06**	29.73**
37.	7F × 1M	-20.69**	18.71	-17.63*	-9.60	21.30*	4.48	-11.63*	-12.69**	-6.15**	-13.42	2.35	28.11**
38.	7F × 2M	-13.79**	24.51*	-17.63*	0.73	-24.20*	4.48	-3.10	-7.20**	-2.55	-4.22	18.76**	-4.65
39.	7F × 3M	-24.14**	-0.39	-22.89**	6.81	-9.00	-1.96	-1.86	0.94	7.18**	2.14	35.67**	2.33
40.	7F × 4M	-24.14**	7.24	-15.79**	-25.52**	-11.79	4.48	-3.36	13.24**	-26.92**	12.03	18.05**	18.60**
41.	7F × 5M	-26.45**	8.08	-19.21**	-22.48**	-4.55	10.08	-19.27**	-22.39**	-20.08**	-24.90*	-9.38**	16.28**
42.	7F × 6M	-26.45**	11.53	-7.11	-10.87	-2.79	15.69*	-3.88	-9.55**	-3.58	-4.67	51.76**	-35.14**

Table 4: Promising top three hybrids for fruit yield per plant (kg) with standard heterosis and component traits showing desired heterosis

Sr. No.	Hybrids	Fruit yield per plant (kg)	Standard heterosis over check GAVCH-1	Useful and significant standard heterosis for component traits
1.	ACCMS 1 × GAVC 112	2.52	49.09**	Fruits per plant, Fruit weight (g), Seeds per fruit, Test weight, Capsaicin content (mg/g)
2.	ACGMS 3 × ACS- 13-24	2.49	43.59**	Fruits per plant, Seeds per fruit, Test weight, Capsaicin content (mg/g)
*- Significant at 5 per cent and **-Significant at 1 per cent				

Conclusion

Among all hybrids, the top two crosses *viz.*, ACCMS 1 × GAVC 112 and ACGMS 3 × ACS-13-24 (Table 4) exhibited high standard heterosis and per se performance as shown in table 3. Hence, these crosses could be exploited commercially to boost the fruit yield in chilli after thorough testing at different environments. These hybrids were exploited to get better transgressive segregants for different traits.

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