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IMPROVING FRUIT TRAITS IN CHILLI PEPPER THROUGH HETEROSIS BREEDING

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SUMMARY

The present investigation was conducted at Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University, Ludhiana, India. The experimental material comprising of 28 F_1 hybrids (made in a half-diallel fashion excluding reciprocals), eight parental lines and four checks were transplanted in a randomized complete block design with three replications. The σ^2SCA:σ^2GCA (specific combining ability and general combining ability) ratio suggested that non-additive gene effects had greater role in controlling the inheritance of days to flowering, plant height, fruit length, fruit width, pericarp thickness, total fruit yield, early yield, number of seeds fruit^{-1}, and 100 seed weight. The line SD 463 was found best general combiner for early and total yield. The graphical analysis (Wr/Vr) showed that most of the traits exhibiting partial dominance and over dominance. The cross combination SD 463 × PP 403 was found superior in terms of *per se* performance, specific combining ability and heterosis over standard checks. Significant and desirable heterosis over better parent and standard checks were recorded for almost all the traits. The present study indicated the preponderance of non-additive gene action involved in the inheritance of studied traits. The presence of parallelism between *per se* performance, SCA and heterosis suggests the possibility of direct exploitation of these hybrids at commercial level.

Key words: *Capsicum annuum* L., general combining ability, heterosis breeding, specific combining ability

Key findings: The cross combination SD 463 × PP 403 have been identified as promising hybrid for early and total yield with other fruit traits. This hybrid has the potential to be exploited at the commercial level.

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INTRODUCTION

Among the five cultivated species of the genus *Capsicum*, *Capsicum annuum* L. is most widely cultivated for its pungent (hot pepper) and non-pungent (sweet pepper) fruits throughout the world. Chilli forms an indispensable adjunct in every home of tropical world as it provides a spicy taste, pungency and adds appealing colour to the food preparation. Its fruit contains a broad variety of antioxidant vitamins especially vitamin A and C, capsaicin, which determine the great variability of the fruit's smell, flavour, taste and consequently consumer preference (Bhattacharya *et al*., 2010; Bhutia *et al*., 2015). India is the largest producer of chillies in the world, an estimated cultivated area of about 0.792 million hectare and producing about 1.376 million tonnes of dry chilli pepper (FAO, 2013), but till the yield potential of chilli in India is low due to lack of high yielding, varieties/hybrids. However, despite continuous efforts at various levels the chilli productivity did not gain momentum. Genetics of economic traits is of paramount importance for evolving superior varieties of crop plants. The breeder of any crop plant must take into consideration many factors such as, yield, disease resistance, growth habit, agronomic adaptability and resistance to lodging, and so on. Major factors namely, earliness, quality, size, uniformity, and suitability for packaging and transportation also have to be taken into account. These above characters are generally complex in nature and are in turn influenced by many different physio-biochemical mechanisms. Since, they are quantitative in nature, and influenced by environment. Therefore, direct selection for these characters is neither suggestible nor feasible.

One of the most important method to improve the yield and quality is heterosis breeding. Heterosis has been exploited in large number of vegetable crops including chillies and it offers much scope of improvement in respect of yield and other quality traits through heterosis breeding (Singh *et al*., 2012; Chaudhary *et al*., 2013), which can further be utilized for the development of desirable recombinants. The expression of heterosis may be due to factors such as heterozygosity, allelic interaction *viz*., dominance or overdominance, non-allelic interaction or epistasis and maternal interactions. The F_1 hybrids offer several advantages like earliness, high yield, better quality, uniformity, wider adaptability and also help in development of dominant genes for resistance to diseases and pests (Riggs, 1988). The diallel analysis (Griffing, 1956) also enables the breeder to provide the behaviour of a cross in further generations by making use of F_1 itself. Diallel cross approach being quick and efficient to estimate the combining ability, mode of reproduction and components of variance was adopted to investigate yield and quality characters. Combining ability analysis described by Sprague and Tatum (1942) is an important tool for the selection of desirable parents together with the information regarding nature and magnitude of gene effects controlling quantitative traits (Basbag *et al*., 2007). Significant general combining ability (GCA) and specific combining ability (SCA) effects provide information to determine the efficacy of breeding for improvements in given traits and they can be used to identify the lines to be served as parents in a breeding program for improvement (Hasanuzzaman *et al*., 2012). In addition, this technique enables the breeder to combine desirable genes that are found in two or more genotypes. Gene action helps in selection of appropriate breeding procedures for improvement of various traits thereby necessitating breeders to initiate a judicious breeding programme in chilli pepper. Therefore combining ability and gene action analysis have been the most important and efficient tool in selecting the desirable parents for a hybridization, selection of breeding procedure and estimation of genetic parameters (Adarsh and Kumari, 2015). Keeping these facts in view, the present research work was planned and executed to study the combining ability and heterotic cross combinations in respect of fruit traits following diallel mating design.

MATERIAL AND METHODS

Generation of crosses

Twenty eight cross combinations were generated using 8 parental lines namely, MS 341, SL 461, DL 161, SL 462, SD 463, PP 402, PP 403, VR 521 following half-diallel mating design. For that purpose, true selfed seeds of eight lines (selected based on *per se* performance, Table 1) were sown in well-prepared nursery bed of 25 cm height and 1.0 m wide having loamy sand soil. Seeds, after treatment with Captan (2–3 g kg^{-1} of seed), were sown during the October 18, 2009 at a shallow depth of 5 cm. Seedlings were hardened by withholding water 5 days before transplanting. Seedlings were transplanted in the crossing block during the February 20, 2010 to obtain F_1s. Seedling growth during December and January months was very slow due to occurrence of low temperature that’s why

Table 1. Particulars of eight parents of chilli pepper evaluated in half-diallel for 10 fruit traits.

No	Parental line	Specific characters	Source
1.	MS 341	Genetic male sterile line, fruit light green, thick, small, high pungent	PAU, Ludhiana
2.	SL 461	Early, fruits dark green, prolific bearer	PAU, Ludhiana
3.	DL 161	Fruits light green, medium long	IIVR, Varanasi
4.	SL 462	Fruits dark green, prolific bearer	PAU, Ludhiana
5.	SD 463	Fruits dark green, long, cylindrical, prolific bearer	PAU, Ludhiana
6.	PP 402	Fruits dark green, long, cylindrical, prolific bearer	Pepsi, USA
7.	PP 403	Early, long green fruits	PAU, Ludhiana
8.	VR 521	Fruits dark green, medium long	USDA, USA

PAU: Punjab Agricultural University, Ludhiana, Punjab, India; IIVR: Indian Institute of Vegetable Research, Varanasi, India; Pepsi: Pepsi Foods Pvt. Ltd., USA; USDA: United States Department of Agriculture, Washington, DC, USA

transplanting was done in the month of February. Parents were crossed in half-diallel fashion excluding reciprocals and hybrid seeds were collected for the next year evaluation.

Field evaluation

The experimental material consisting of 28 F_1 hybrids along with 8 parents and four standard checks (CH-1, CH-3, Rudra, and Soldier), were grown in randomized complete block design in three replications for evaluation purpose during 2010–2011 at the Vegetable Research Farm, Punjab Agricultural University, Ludhiana, Punjab, India, which is situated at 30°54 North latitude, 70°45 East longitude and at a mean altitude of 247 m above sea level. The check hybrids, CH-1 and CH-3 were released by Punjab Agricultural University, Ludhiana, Punjab, India for commercial cultivation whereas, the hybrids Rudra and Soldier were from Nunhems Seeds Private Limited, India. The experimental materials were sown in well prepared nursery beds on October 21, 2010. The transplanting was done in the field on February 23, 2011. In each replication, there were ten plants in a row for each entry. Cultural practices, such as fertilization, irrigation, and weeds, diseases and insect-pests control were performed whenever they were thought necessary, as per the package of practices for cultivation of vegetables recommendations of the Punjab Agricultural University (Anonymous, 2010). The mean monthly agro-meteorological observations were recorded during the crop season (Figure 1).

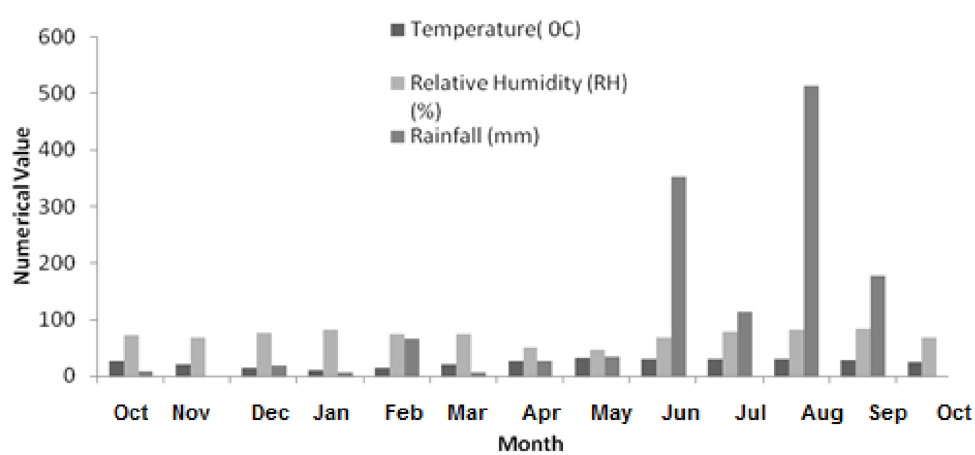


Figure 1. Climatic conditions from October 2010 to October 2011.

Experimental data

Data were recorded from randomly selected five plants leaving a border plant at each corner. Observations were recorded in each replication on following traits:

*Days to flowering***:** To determine days to flowering, the number of days taken from date of transplanting to date of first flower opening was counted on five randomly selected plants and average worked out.

Plant height (cm): The plant height was measured in centimeters from ground level to the highest bud tip of five randomly selected plants in each parents/hybrids and the mean value was worked out. The measurement was done at the time of maturity.

Fruit length (cm): The length of red ripe fruits was measured in centimeters from the base of fruit to its tip on 10 randomly taken fruits from the third picking and the average was taken as fruit length.

Fruit weight (g): The weight of 10 randomly taken fruits from third picking was measured on the electronic balance and average fruit weight was worked out.

Fruit width (cm): The width of fruit was recorded at the middle portion of the fruit with the help of a 'Vernier caliper' on the same 10 fruits used for measurement of fruit length and average width was calculated.

Pericarp thickness (mm): The thickness of pericarp was measured in millimeters at the middle portion of the fruit with the help of a 'Vernier caliper' on the same 10 fruits used for measurement of fruit length and average pericarp thickness was calculated.

Early yield (g plant^{-1}): The yield obtained from the first two pickings was taken as early yield which is profitable as the produce gets more prices in the market. It was calculated by adding the weight of fresh red ripe fruits from first two pickings and dividing by five as the picking was done from randomly selected five plants leaving two border plants in each row.

Total yield (g plant^{-1}): It was calculated by adding the weight of fresh red ripe fruits from each picking and dividing by five (number of randomly selected plants from which picking was done).

Number of seeds fruit^{-1}: The total numbers of seeds extracted manually from 10 randomly taken fruits from third picking were counted and average number of seeds fruit^{-1} was worked out.

100 seed weight (mg): Hand-extracted seeds were counted and weighed through electronic balance.

Statistical analysis

The data was subjected to diallel analysis as per the method suggested by Griffing (1956). Component of variation was estimated as per the method given by Hayman (1954). The data collected were subjected to heterosis and combining ability analysis using statistical software WINDOSTAT developed by INDOSTAT services Ltd. Hyderabad, India.

RESULTS AND DISCUSSION

Estimation of combining ability effects

Analysis of variance for experimental design for various characters has revealed that the mean squares due to genotypes were highly significant for all the characters indicating considerable amount of variation in the material selected for study (Table 2). Analysis of variance for combining ability for different characters showed that the mean squares due to GCA and SCA were highly significant for all the characters (Table 2). This indicated that both additive and non-additive gene effects were involved in the inheritance of these traits. The σ^2SCA:σ^2GCA ratio suggested that non-additive gene effects had greater role in controlling the inheritance of days to flowering, plant height, fruit length, fruit width, pericarp thickness, total fruit yield, early yield, number of seeds fruit^{-1}, and 100 seed weight except for fruit weight where the ratio was less than unity indicating the predominance of additive gene effects.

The estimates of general combining ability (GCA) effects of parents and specific combining ability (SCA) effects of hybrids for different characters under study are presented in Tables 3 and 4, respectively. The estimates of general combining ability for days to flowering

Table 2. Analysis of variance for experimental design and combining ability of different characters.

Source	Replication (d.f.=2)	Genotypes (d.f.=35)	Error (d.f.=70)	GCA (d.f.=7)	SCA (d.f.=28)	Error (d.f.=70)	Components of genetic variance		
							σ^2GCA	σ^2SCA	σ^2SCA/σ^2GCA
Days to flowering	105.03**	77.00**	4.14	33.52**	23.70**	1.38	3.21	22.32	6.95
Plant height (cm)	0.75	359.66**	4.82	332.65**	66.69**	1.60	33.11	65.08	1.97
Fruit length (cm)	0.01	2.46**	0.07	2.66**	0.35**	0.02	0.26	0.33	1.27
Fruit width (cm)	0.02**	0.04**	0.00	0.04**	0.005**	.001	0.004	0.003	1.33
Fruit weight (g)	0.22	1.75**	0.08	2.31**	0.14**	0.02	0.23	0.12	0.52
Pericarp thickness (mm)	0.02	0.07**	0.01	0.03**	0.02**	0.003	0.003	0.02	6.67
Early yield (g plant-^{1})	171.78	43734.68**	767.52	21372.19**	12879.82**	255.83	2111.63	12623.99	5.98
Total fruit yield (g plant^{-1})	166.21	86147.12**	519.13	39556.57**	36023.95**	149.28	3503.26	26920.19	7.68
Number of seeds fruit^{-1}	0.52	471.87**	0.74	167.88**	154.64**	0.24	16.76	154.40	9.21
100-seed weight (mg)	1341.22	97633.46**	1174.43	44547.38**	29543.78**	391.47	4258.05	29546.16	6.94

** significant at 1% level

Table 3. General combining ability effects of parents for different characters in half-diallel cross of chilli pepper.

Parents	Days to flowerin g	Plant height (cm)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Pericarp thickness (mm)	Early yield (g plant^{-1})	Total fruit yield (g plant^{-1})	Number of seeds fruit^{-1}	100- seed weight (mg)
MS 341	-1.43**	5.40**	-0.87**	-0.00	-0.08	0.00	-7.82	37.35**	6.38**	123.83**
SL 461	1.01**	-7.34**	0.92**	0.07**	0.90**	-0.01	30.43**	-18.84**	3.09**	-30.75**
DL 161	-1.70**	-7.47**	-0.22**	-0.10**	-0.57**	-0.00	41.28**	40.41**	4.42**	9.43
SL 462	-1.36**	4.22**	-0.18**	-0.08**	-0.35**	-0.07**	-53.23**	-46.32**	-2.68**	-82.89**
SD 463	0.98**	4.49**	0.42**	0.04**	0.47	0.09**	74.18**	109.68**	-3.66**	34.18**
PP 402	3.41**	5.87**	0.01	0.09**	0.03	0.06**	-31.36**	-49.53**	-1.49**	-71.22**
PP 403	0.71*	-0.49	-0.15**	0.01	-0.02	-0.00	0.87	-4.86	-1.22**	23.68**
VR 521	-1.63**	-4.67**	0.07	-0.03**	-0.03**	-0.07**	-54.33**	-67.89**	-4.87**	-6.25
CD at 5%	0.69	0.75	0.09	0.02	0.10	0.03	9.43	7.20	0.29	11.67
CD at 1%	0.92	0.99	0.12	0.03	0.12	0.05	12.52	9.57	0.39	15.49

*,** significant at 5% and 1% level, respectively

Table 4. Specific combining ability effects of the hybrids for different characters.

Crosses	Days to flowering	Plant height (cm)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Pericarp thickness (mm)	Early yield (g plant^{-1})	Total fruit yield (g plant^{-1})	No of seeds fruit^{-1}	100- seed weight (mg)
MS 341× SL 461	0.39	5.55**	0.21	0.11**	0.79**	0.04	157.82**	131.07**	29.86**	-40.70*
× DL 161	3.09**	14.18**	0.10	0.04	-0.01	0.09**	2.51	36.28**	13.60**	207.46**
× SL 462	-2.58**	-8.79**	-0.39**	-0.61**	-0.36**	-0.15**	-70.85**	-105.53**	2.29**	7.77
× SD 463	2.76**	7.46**	0.36**	0.07**	0.39**	0.18**	-31.92*	-109.03**	0.93*	-97.59**
× PP 402	-2.01*	2.62*	0.49**	0.09**	0.48**	0.13**	181.14**	350.99**	-6.50**	-13.13
× PP 403	-4.31**	3.60**	-0.35**	-0.05**	-0.31*	0.05	-16.53	-6.12	-11.91**	461.47**
× VR 521	-4.31**	-1.62	0.33*	0.03	-0.04	0.02	-56.59**	101.52**	-16.59**	-108.71**
SL 461 × DL 161	0.66	3.65**	0.63**	0.09**	0.32*	0.23**	189.42**	255.14**	12.15**	-73.59**
× SL 462	-8.68**	0.75	-0.09	-0.00	-0.04	0.05	-34.23**	-59.97**	1.04*	-17.64
× SD 463	1.66	-5.47**	0.12	0.00	-0.02	-0.16**	-98.43**	-157.20**	-11.12**	-246.63**
× PP 402	-0.11	-5.38**	0.52**	-0.03	0.41**	-0.04	-69.65**	-138.39**	-18.82**	128.96**
× PP 403	0.59	1.00	-0.91**	-0.03	-0.29*	-0.01	-57.53**	-60.03**	-6.56**	-89.30**
× VR 521	-3.08**	5.98**	0.71**	-0.07**	0.03	0.09**	2.26	171.24**	-12.57**	-85.82**
DL 161 × SL 462	-8.31**	11.17**	-0.08	-0.06*	-0.09	-0.18**	52.51**	48.75**	-0.95*	-25.52
× SD 463	-10.98**	2.26*	1.13**	-0.10**	-0.02	-0.05	41.26**	63.08**	-6.44**	-169.81**
× PP 402	-3.74**	9.22**	-0.21	-0.01	-0.31**	-0.06	65.27**	82.26**	9.66**	-47.34**
× PP 403	2.96**	-2.57*	-0.32*	-0.05**	0.15	-0.25**	111.57**	95.29**	-5.75**	143.42**
× VR 521	5.62**	-13.39**	-0.82**	0.03	0.03	-0.07	-106.39**	-81.32**	-3.76**	-35.65*
SL 462× SD 463	0.69	-3.88**	0.12	-0.04	-0.19	-0.06	64.56**	164.95**	-10.62**	61.21**
× PP 402	-2.41*	5.34**	-0.45**	0.06	-0.04	0.20**	-71.99**	49.82**	10.75**	-7.89
× PP 403	2.29*	0.56	0.40**	0.01	-0.28*	-0.14**	-35.96**	-48.66**	12.94**	-6.94
× VR 521	2.29*	8.20**	1.14**	0.12**	0.40**	-0.01	86.81**	159.01**	-4.40**	-57.40**
SD 463 × PP 402	0.26	5.53**	0.32*	0.03	0.61**	0.19**	-45.45**	17.72	18.06**	-87.49**
× PP 403	3.29**	8.54**	-0.30*	-0.05**	0.56**	-0.15**	262.63**	378.95**	-1.35**	291.45**
× VR 521	-3.04**	9.39**	-1.04**	0.04	-0.45**	-0.06	-57.44**	-79.52**	8.90**	115.52**
PP 402 × PP 403	-3.14**	-6.02**	-0.29*	-0.05**	-0.33*	0.13*	-75.33**	-64.54**	2.68**	-230.58**
× VR 521	5.52**	-8.18**	-0.23	0.05	0.06	-0.03	209.98**	-62.12**	14.54**	285.99**
PP 403 × VR 521	-6.11**	6.23**	0.84**	0.02	0.29	-0.09**	-11.22	31.95**	18.06**	-199.65**
CD 5%	1.85	1.99	0.25	0.05	0.25	0.09	25.16	19.22	0.78	31.12
CD 1%	2.45	2.65	0.33	0.07	0.33	0.12	33.41	25.52	1.04	41.33

*,** significant at 5% and 1% level, respectively.

revealed that the parents DL 161, VR 521, MS 341, and SL 462 exhibited significant and negative GCA effects. Thus these lines were considered as good general combiners for days to flowering. In contrast, the lines PP 402, SL 461, SD 463, and PP 403 showed positive significant GCA effects and thus were adjudged as poor combiner for early flowering. The genotype SD 463 was the best general combiner for early and total yield. Moreover this parent also showed desirable GCA effects for plant height, fruit length, pericarp thickness, and 100 seed weight. A perusal of the general combining ability estimates showed that the line SL 461 was good general combiners for fruit weight. The genotypes MS 341, DL 161, and SL 461 were good general combiners for number of seeds fruit^{-1}, due to highly significant and positive GCA effects. Prasath and Ponnuswami (2008) recorded ByadagiKaddi and MDU Y as the good general combiners for early flowering, plant height, fruit length, fruit width and number of seed fruit^{-1}. Grajales *et al*. (2009) reported landrace Puebla to be good general combiners for pericarp thickness.

The SCA, effects for days to flowering were significant and negative in thirteen crosses. Top three hybrids based on SCA were DL 161 × SD 463 followed by SL 461 × SL 462, and DL 161 × SL 462. Out of 28 crosses, 11 crosses exhibited significant and positive SCA effects for fruit length and thus were adjudged as good specific combiners. Top five hybrids based on SCA were SL 462 × VR 521, DL 161 × SD 463, PP 403 × VR 521, SL 461 × DL 161, and SL 461 × PP 402. In case of fruit width, SCA effects were significant and positive in five crosses viz., SL 462 × VR 521, MS 341 × SL 461, MS 341 × PP 402, SL 461 × DL 161, and MS 341 × SD 463. To fruit weight top five hybrids based on SCA were MS 341 × SL 461, SD 463 × PP 402, SD 463 × PP 403, MS 341 × PP 402, and SL 461 × PP 402. Out of twenty eight crosses, eleven crosses exhibited significantly positive SCA effects and were, therefore, good specific combiners for early yield. Two cross combinations SL 461 × DL 161, and DL 161 × SD 463 displayed significant and positive SCA effects. Moreover, these crosses involved both the parents with significant and positive GCA values. There is ample scope of obtaining the transgressive segregant lines with high yield from the crosses.

Out of twenty eight crosses, fifteen crosses exhibited significantly positive SCA effects and were therefore good specific combiners for total fruit yield. The SCA effects among the crosses were ranged from 31.95 (PP 403 × VR 521) to 378.95 (SD 463 × PP 403). Top five hybrids based on SCA were SD 463 × PP 403, MS 341 × PP 402, SL 461 × DL 161, SL 461 × VR 521, and SL 462 × SD 463. The cross combinations MS 341 × DL 161, and DL 161 × SD 463 involved both the parents with positive and significant GCA effect. The other crosses showing significant and positive SCA effects have either one parent with significant and desirable GCA values or both the parents with non-significant GCA effects. It was also observed that six crosses showing high SCA for total fruit yield also exhibited significant and positive SCA effects for fruit weight indicating predominant role of this component trait in increasing fruit yield. For number of seeds fruit^{-1}, both positive as well as negative SCA effects were significant. Out of twenty-eight crosses, fourteen crosses showed significant and positive SCA effects. The cross combinations MS 341 × SL 461, MS 341 × DL 161, and SL 461 × DL 161 showed highly significant and positive SCA effects. These crosses have both the parents with significant and positive GCA effects and are therefore, potential source material to derive true breeding lines with desired number of seeds fruit^{-1} from the segregating populations. Prasath and Ponnuswami (2008) also reported negative and significant SCA effects for earliness; significant positive SCA effects for plant height; fruit length; fruit width; fruit weight; fruit yield; and seed number among different crosses. Grajales *et al*. (2009) reported the positive SCA value for pericarp thickness and fruit yield. Our results were also in consonance with the finding of Payakhapaab *et al*. (2012) who reported the significant specific combining ability effect for fruit weight plant^{-1}, yield, number of fruits plant^{-1}, fruit weight, fruit width, fruit length, and pericarp thickness.

Estimation of genetic components of variation

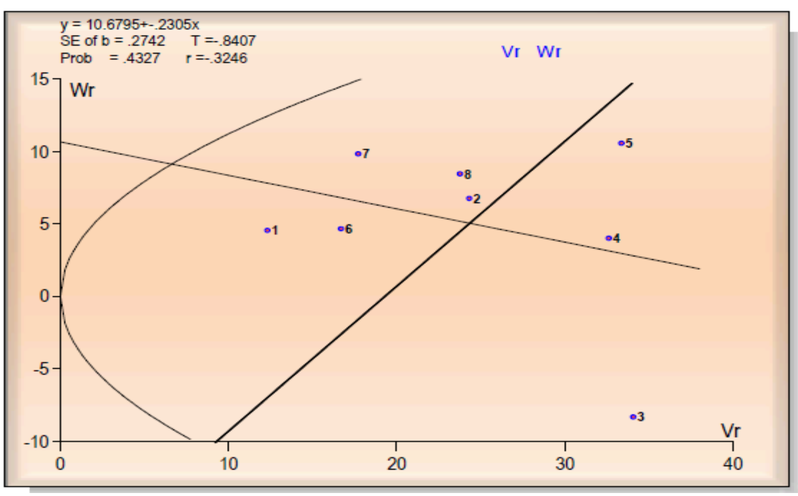
The estimates of components of variation revealed that both additive (D) and non-additive (H_1 and H_2) were important for most of the characters studied (Table 5). This is in harmony with the results of the combining ability analysis. However, the magnitude of non-additive components was more than additive components for most of the traits. For all the traits under study, t^2 was non-significant which indicated the absence of non-allelic interactions.

Table 5. Estimates and ratios of components of genetic variance for different characters.

Characters	D	H_1	H_2	F	E	$(H1/D)^{0.5}$	$H_2/4H1$	$(4DH_1)^{0.5} + F / (4DH_1)^{0.5} - F$	h^2/H_2	r	t^2	B
Days to flowering	10.25	83.38*	77.70*	1.40	2.31	2.85	0.23	1.05	0.95	-0.33	0.82	-0.23
Plant height (cm)	138.55*	248.77*	220.31*	30.18	1.57	1.34	0.22	1.17	1.12	0.95	7.76	067*
Fruit length (cm)	0.94*	1.43*	1.27*	-0.02	0.02	1.23	0.22	0.98	0.29	0.74	0.11	0.67*
Fruit width (cm)	0.02*	0.03*	0.01*	0.02*	0.001*	1.11	0.13	1.98	0.005	0.85	0.42	0.97*
Fruit weight (g)	0.57*	0.59*	0.45*	-0.31	0.02	1.01	0.19	0.57	0.51	0.87	3.51	0.60
Pericarp thickness (mm)	0.02*	0.11*	0.06*	0.04*	0.003	2.19	0.15	2.92	-0.007	0.08	0.14	0.07
Early yield (g plant^{-1})	6331.42*	50080.14*	45726.71*	798.56	255.83	2.81	0.22	1.05	0.60	0.61	1.81	0.39
Total fruit yield (g plant^{-1})	10384.12	97314.52*	92350.09*	-591.69	169.77	3.06	0.24	0.98	1.16	0.43	0.87	0.31
Number of seeds fruit^{-1}	88.63*	634.05*	583.00*	67.77	0.24	2.67	0.23	1.33	0.20	0.90	5.72	0.59*
100 seeds weight (mg)	15139.11	133118.80*	108472.10*	17292.80	393.00	2.97	0.20	1.48	0.04	0.63	71.65	0.11

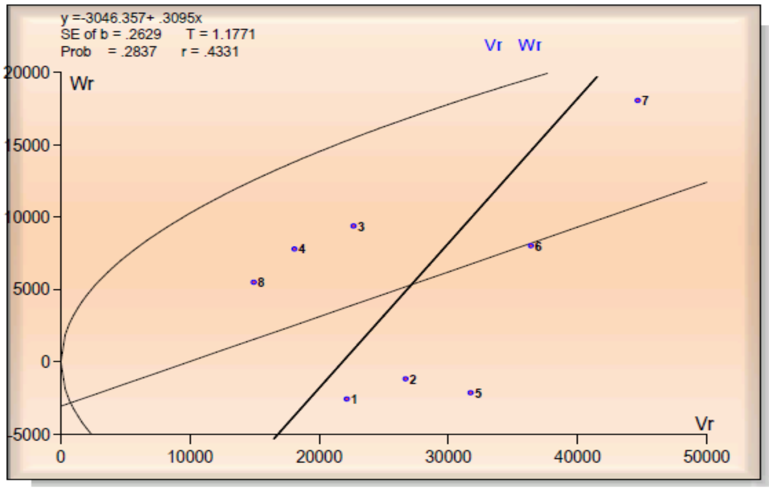
* significant at 1% level

The regression of Wr/Vr of unit slope differed from unity, which indicated the presence of epistasis in expression of plant height, fruit length, fruit width, fruit weight and number of seeds fruit^{-1} while, the regression of Wr on Vr did not differ from unity, thus confirmed the absence of epistasis in the expression of other traits. The correlation (r) of Wr + Vr with parents (Yr) was positive for all traits showing that recessive genes contributing towards the high mean performance of all these traits except in days to flowering in which weak correlation indicated that dominant and recessive genes equally influenced this trait (the Wr/Vr graph for days to flowering and total yield plant^{-1} is presented in Figures 2 and 3, respectively).



Where, 1- MS 341, 2- SL 461, 3- DL 161, 4- SL 462, 5- SD 463, 6- PP 402, 7- PP 403, 8- VR 521.

Figure 2. Wr/Vr graph for days to flowering.



Where, 1- MS 341, 2- SL 461, 3- DL 161, 4- SL 462, 5- SD 463, 6- PP 402, 7- PP 403, 8- VR 521.

Figure 3. Wr/Vr graph for total fruit yield plant^{-1} (g).

The significance of D, H_1 and H_2 in plant height, fruit length, fruit width, fruit weight, pericarp thickness, early yield and number of seeds fruit^{-1} indicated that both additive and non-additive variances were important for the manifestation of these traits but the relative value of dominance variance was higher than the additive one, which was further confirmed by the degree of dominance, indicating the presence of over dominance. However, for days to flowering, total fruit yield and 100-seed weight; the significance of H_1 and H_2 indicated that non-additive component of variances were important for these traits. Moreover, the degree of dominance was more than unity for these traits, which clearly indicated the existence of over dominance. The positive F value of all the traits under study suggested more frequency of dominant genes in the parents than recessive ones, which was asymmetrically distributed as shown by the ratio of H_2:$4H_1$ while the negative F value for fruit length, fruit weight and total fruit yield suggested more frequency of recessive genes in the parents than dominant ones. The non-significant value of E for all the traits under study indicated that environment did not play any role in the expression of these traits except fruit width where significant value of E indicated the role of environment in this trait (fruit width). The ratio of increaser and decreaser alleles H_2:$4H_1$ were less than 0.25 for all characters under study, which showed asymmetrical distribution of alleles in the parents. Moreover, the proportion of dominant and recessive genes in the parents as depicted by the formula $(4DH_1)^{0.5}$ + F/$(4DH_1)^{0.5}$ - F) also suggested the excess of dominant genes than recessive ones in the parents in all the traits (value more than one) except for fruit length, fruit weight, and total fruit yield in which the ratio (less than one) suggested the excess of recessive genes than dominant ones in the parents. The value of h^2/H_2 less than unity for all traits indicated that one major gene group regulates the expression of these traits except for plant height and total fruit yield where one minor gene group regulates the expression of these traits. Marame *et al*. (2009) reported that non-additive effects were predominant for total fruit yield. Marame *et al*. (2008) reported that the ratio H_2:$4H_1$ was not equal to 0.25 for fruit weight indicating the existence of over dominance for this trait and also reported positive F value for plant height, fruit length, and fruit weight indicating more frequency of dominant genes.

Estimation of heterosis over better parent and checks

The results pertaining to mean performance of parental lines, checks, and per cent heterosis of F_1 hybrids over better parent and standard check hybrids, CH-1, CH-3, Rudra, and Soldier are reported in the Tables 6 and 7. Days to flowering was considered important indicators for earliness in any crop. The range of mean performance was observed for days to flowering for parents and hybrids were 37.00 to 54.00 and 32.67 to 51.67, respectively. Among F_1's, minimum days to flowering was taken by the DL 161 × SD 463 followed by DL 161 × SL 462. The magnitude of heterosis ranged from -34.00 to 0.72% over better parent, and -25.76 to 17.42%; -11.71 to 39.64%; -25.20 to 18.31%; -27.94 to 13.97% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. The cross combinations DL 461 × SL 462, DL 161 × SD 463, and SL 461 × SL 462 showed significant negative heterosis for days to flowering. Significant negative heterosis for days to flowering was also reported by Shankarnag and Madalageri (2006); Farag and Khalil (2007). Fruit length and fruit width are closely related productivity traits, which also determine consumer acceptability. Parents SL 461 (7.40 cm) and SD 463 (6.64 cm) exhibited highest fruit length, while PP 403 (1.20 cm) and PP 402 (1.15 cm) observed maximum fruit width. The fruit length and width of F_1's varied from 4.73 cm (MS 341 × SL 462) to 7.86 cm (SL 461 × VR 521) and 0.80 cm (DL 161 × SL 462) to 1.20 cm (MS 341 × SL 461), respectively. For fruit length, the cross combinations SL 461 × VR 521, SL 461 × SD 463, and SL 461 × PP 402 exhibited significant and positive heterosis over better parent, and standard checks, CH-1; CH-3; Rudra; and Soldier. The magnitude of heterosis ranged from -24.29 to 26.05% over better parent and -14.56 to 41.88%; -20.22 to 32.47%; -33.52 to 10.39%; -22.06 to 29.42% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively for fruit length. Shankarnag and Madalageri (2006); Grajales *et al*. (2009); Perez *et al*. (2009); Chaudhary *et al*. (2013) also reported that hybrids generally show positive heterosis for fruit length. For fruit width, the crosses MS 341 × SL 461, MS 341 × PP 402, and SD 463 × PP 402 were highly heterotic over CH-3, Rudra, and Soldier. Fruit weight directly contributed towards the total yield and has key role in acceptance of produce by the consumer. Among the parents, SL 461 (4.13 g) was found to have highest fruit weight followed by SD 463 (3.44 g), whereas range of F_1 hybrids from 1.95 - 4.56 g. The F_1 hybrids MS 341 × SL 461 (4.56 g), SL 461 × SD 463 (4.29 g), and SL 461 × PP 402 (4.28 g) obtained maximum fruit weight that was higher than the other hybrids, parents and standard checks. The range of heterosis, from -25.12 to 31.81% over better parent, whereas, -29.64 to 64.70%; -27.72 to 69.18%; -50.09 to 16.84%; -21.72 to 83.24% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. The best heterotic combinations for fruit weight were MS 341 × SL 461 over better parents and standard checks followed by SL 461 × SD 463, and SL 461 × PP 402. A thick pericarp is important for green chilli and medium thickness is more suitable for dry chilli production as it takes lesser time for drying. The pericarp thickness among parents ranged from 0.86 (MS 341) to 1.27 mm (SD 463). Among F_1's, the maximum pericarp thickness was observed in DL 161 × SD 463 (1.67 mm) followed by SD 463 × PP 402 (1.38 mm). Out of 28 hybrids, only one hybrid showed significant positive heterobeltiosis over better parent 35.16% (MS 341 × PP 402). Best heterotic hybrids were SD 463 × PP 402 over all checks followed by MS 341 × SD 463, and SL 461 × DL 161. The magnitude of heterosis for pericarp thickness ranged from -38.03 to 35.16% over better parent, while, -33.05 to 19.25%; -19.38 to 43.60%; -24.10 to 35.18%; -16.49 to 48.75% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. For early yield, the magnitude of heterosis ranged from -29.83 to 153.63% over better parent, whereas, -51.17 to 100.31%; -70.91 to 22.26%; -50.16 to 104.42%; -45.51 to 123.52% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. The best heterotic hybrids over better parent were PP 402 × VR 521 followed by MS 341 × PP 402, and DL 161 × PP 403. The combination SD 463 × PP 403 was heterotic over CH-1; Rudra, and Soldier followed by SL 461 × DL 161, and MS 341 × SL 461. Total fruit yield plant^{-1} is one of the most important traits, which deserves highest consideration in any crop breeding programme. The total fruit yield of F_1's varied from 337.33 g

(SL 461 × PP 402) to 1027.87 g (SD 463 × PP 403), whereas that of parents from 287.93 g (VR 521) to 623.98 g (SD 463). The hybrid SD 463 × PP 403 showed highest heterosis over standard checks CH-1; CH-3; Rudra; and Soldier followed by MS 341 × PP 402, and SL 461 × DL 161, ranging from -23.44 to 110.62% over better parent, while, -39.87 to 83.21%; -55.09 to 36.84%; -40.00 to 82.82%; -39.41 to 84.63% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. Heterosis over better parent for fruit yield plant^{-1} was also reported by Shankarnag and Madalageri (2006); Farag and Khalil (2007); Sitaresmi *et al*. (2010). Heterosis up to 51% over better parent has been reported by Grajales *et al.* (2009). Chaudhary *et al*. (2013) also observed up to 239% heterosis in chilli pepper. Number of seeds fruit^{-1} should be less to make it more acceptable to the consumer. On the other hand, if the fruits contain less seeds, it will lead to soft fruits with poor shelf life and transportability. Pungency will also affect adversely. Thus the preference for less or more seeds in the fruits depends upon the purpose for which fruits are to be consumed. Moreover both traders and consumers require more seeds. Among the parental genotypes, the maximum seeds fruit^{-1} was found in SL 461 (45.20), while the minimum was recorded in PP 402 (17.87). Among the F_1 hybrids, the maximum seeds were observed in MS 341 × SL 461 (75.33), whereas the minimum was in DL 161 × PP 403 (3.47). Heterosis for both positive and negative nature was exhibited by the hybrids with regard to number of seeds fruit^{-1}, ranging from -58.41 to 82.64% over better parent, while, -49.46 to 102.51%; -44.81 to 121.14%; 118.60 to 775.97%; -22.31 to 211.29% over standard checks, CH-1; CH-3; Rudra; Soilder, respectively. The cross combination PP 402 × VR 521 recorded highest positive heterosis over better parent followed by SL 462 × PP 402, and MS 341 × SL 461. The cross combination MS 341 × SL 461 followed by MS 341 × DL 161, and SL 461 × DL 161 were heterotic over standard checks. Similarly, cross combination MS 341 × PP 403 had maximum 100 seed weight and it showed desirable heterosis over better parent and standard checks followed by SD 463 × PP 403, and MS 341 × DL 161. Shankarnag and Madalageri (2006); Grajales *et al*. (2009); Hasanuzzaman *et al*. (2013) reported positive heterosis for number of seeds fruit^{-1}.

Table 6. Performance of parental lines and checks for important fruit traits in chilli pepper.

Character	MS 341	SL 461	DL 161	SL 462	SD 463	PP 402	PP 403	VR 521	CH-1	CH-3	Rudra	Soldier	Grand Mean
Days to flowering	45.00	50.67	46.33	50.00	49.00	54.00	48.00	42.67	44.00	37.00	43.66	45.33	46.31
Plant height (cm)	64.27	47.27	37.80	66.73	62.03	75.13	58.33	52.33	68.60	79.23	83.66	63.33	63.23
Fruit length (cm)	4.05	7.40	5.52	5.49	6.64	5.99	6.34	5.71	5.54	5.93	7.12	6.07	5.98
Fruit width (cm)	0.88	1.14	0.87	0.90	1.13	1.15	1.20	0.86	1.11	1.04	1.01	0.92	1.02
Fruit weight (g)	2.31	4.13	1.78	2.56	3.44	2.56	3.00	2.01	2.76	2.69	3.90	2.48	2.80
Pericarp thickness(mm)	0.86	0.91	1.17	1.05	1.27	0.91	1.25	0.97	1.16	0.96	1.02	0.93	1.04
Early yield (g plant^{-1})	217.50	331.94	220.40	214.05	396.67	156.22	228.83	173.57	326.29	534.58	319.72	292.41	284.35
Total fruit yield (g plant^{-1})	419.20	435.47	375.17	347.28	623.98	327.17	370.97	287.93	561.03	751.16	562.23	556.73	468.19
Number of seeds fruit^{-1}	42.93	45.20	35.60	25.13	29.53	17.87	29.53	24.20	46.13	35.73	54.40	32.26	34.88
100 seed weight (mg)	460.26	473.25	325.97	321.89	433.37	296.34	142.76	238.65	383.01	432.89	184.93	246.43	328.31

Table 7. Mean performance and percent heterosis of F_1 hybrids over better parent (BP), standard checks (CH-1, CH-3, Rudra, Soldier).

Cross	Days to flowering						Plant height (cm)					
		Percentage increase / decrease over						Percentage increase / decrease over				
	Mean	BP	CH-1	CH-3	Rudra	Soldier	Mean	BP	CH-1	CH-3	Rudra	Soldier
MS 341 × SL 461	44.33	-12.50**	0.76	19.82**	1.52	-2.20	68.60	6.73**	0.00	-13.42**	-18.01**	8.32**
× DL 161	44.33	-4.32	0.76	19.82**	1.52	-2.20	77.10	19.96**	123.39**	-2.69*	-7.85**	21.74**
× SL 462	39.00	-22.00**	-11.36**	5.41	-10.69**	-13.96**	65.80	1.39	-4.08**	-16.95**	-21.36**	3.90*
× SD 463	46.67	-4.76	6.06	26.13**	6.86	2.95	82.33	28.10**	20.02**	3.92**	-1.60	30.01**
× PP 402	44.33	-17.90**	0.76	19.82**	1.52	-2.20	78.87	4.97**	14.97**	-0.46	-5.74**	24.53**
× PP 403	39.33	-18.06**	-10.61**	6.31	-9.93*	-13.23**	73.50	14.36	7.14**	-7.23**	-12.15**	16.06**
× VR 521	37.00	-17.78**	-15.91**	0.00	-15.27**	-18.38**	64.10	-0.26	-6.56**	-19.10**	-23.39**	1.22
SL 461 × DL 161	44.33	-12.50**	0.76	19.82**	1.52	-2.20	53.83	13.87**	-21.53**	-32.05**	-35.66**	-15.00**
× SL 462	35.33	-30.26**	-19.70**	-4.50	-19.07**	-22.05**	62.60	-6.18**	-8.75**	-20.99**	-25.18**	-1.15
× SD 463	48.00	-5.26	9.09*	29.73**	9.92*	5.89	56.67	-8.64**	-17.40**	-28.48**	-32.27**	-10.52**
× PP 402	48.67	-9.88**	10.61**	31.53**	11.44**	7.36	58.13	-22.62**	-15.26**	-26.63**	-30.52**	-8.21**
× PP 403	46.67	-7.89*	6.06	26.13**	6.87	2.95	58.17	-0.27	-15.21**	-26.59**	-30.48**	-8.15**
× VR 521	40.67	-19.74**	-7.58	9.91*	-6.87	-10.29**	58.97	12.68**	-14.04**	-25.58**	-29.52**	-6.89**
DL 161 × SL 462	33.00	-34.00**	-25.00**	-10.81*	-24.43**	-27.20**	72.90	9.24**	6.27**	-7.99**	-12.87**	15.11**
× SD 463	32.67	-33.33**	-25.76**	-11.71*	-25.20**	-27.94**	64.27	3.61*	-6.32**	-18.89**	-23.19**	1.48
× PP 402	42.33	-21.60**	-3.79	14.41**	-3.06	-6.61	72.60	3.36*	5.83**	-8.37**	-13.23**	14.64**
× PP 403	46.33	-3.47	5.30	25.23**	6.10	2.21	54.47	-6.61**	-20.60**	-31.25**	-34.90**	-14.00**
× VR 521	46.67	0.72	6.06	26.13**	6.86	2.95	39.47	-24.57**	-42.47**	-50.19**	-52.83**	-37.68**
SL 462 × SD 463	44.67	-10.67**	1.52	20.72**	2.28	-1.46	69.80	4.60**	1.75	-11.90**	-16.58**	10.22**
× PP 402	44.00	-18.52**	0.00	18.92**	0.76	-2.93	80.40	7.01**	17.20**	1.48	-3.91**	26.95**
× PP 403	46.00	-8.00*	4.55	24.32**	5.34	1.48	69.27	3.80*	0.97	-12.58**	-17.21**	9.37**
× VR 521	43.67	-12.67**	-0.76	18.02**	-0.01	-3.67	72.73	8.99**	6.03**	-8.20**	-13.07**	14.85**
SD 463 × PP 402	49.00	-9.26**	11.36**	32.43**	12.21**	8.10*	80.87	7.64**	17.88**	2.07	-3.35**	27.69**
× PP 403	49.33	0.68	12.12**	33.33**	12.97**	8.83*	77.53	24.98**	13.02**	-2.14	-7.33**	22.43**
× VR 521	40.67	-17.01**	-7.58	9.91*	-6.88	-10.29**	74.20	19.61**	8.16**	-6.35**	-11.32**	17.16**
PP 402 × PP 403	45.33	-16.05**	3.03	22.52**	3.81	0.00	64.33	-14.37**	-6.22**	-18.80**	-23.11**	1.58
× VR 521	51.67	-4.32**	17.42**	39.64**	18.31**	13.97**	58.00	-22.80**	-15.45**	-26.80**	-30.68**	-8.42**
PP 403 × VR 521	37.33	-22.22**	-15.15**	0.90	-14.51**	-17.64**	66.07	13.26**	-3.69*	-16.61**	-21.04**	4.32
CD 5%	3.31			3.41			3.57			3.68		
CD1%	4.40			4.40			4.74			4.74		

(cont'd)

Table 7. Mean performance and percent heterosis of F_1 hybrids over better parent (BP), standard checks (CH-1, CH-3, Rudra, Soldier).

Cross	Fruit length (cm)						Fruit width (cm)					
		Percentage increase / decrease over						Percentage increase / decrease over				
	Mean	BP	CH-1	CH-3	Rudra	Soldier	Mean	BP	CH-1	CH-3	Rudra	Soldier
MS 341 × SL 461	6.42	-13.29**	15.82**	8.15*	-9.88**	5.65	1.20	5.87	7.76	15.34**	18.36**	29.86**
× DL 161	5.17	-6.28	-6.62	-12.81**	-27.34**	-14.82**	0.97	9.81	-13.13**	-7.03	-4.59	4.68
× SL 462	4.73	-13.73**	-14.56**	-20.22**	-33.52**	-22.06**	0.94	4.43	-15.52**	-9.58*	-7.21	1.80
× SD 463	6.07	-8.63*	9.51*	2.25	-14.79**	-0.11	1.13	0.059	1.49	8.63	11.48*	22.30**
× PP 402	5.79	-3.34	4.57	-2.36	-18.63**	-4.61	1.19	3.47	6.87	14.38**	17.38**	28.78**
× PP 403	4.80	-24.29**	-13.36**	-19.10**	-32.58**	-20.97**	0.99	-17.50**	-11.34**	-5.11	-2.62	6.83
× VR 521	5.70	-0.18	2.83	-3.99	-19.99**	-6.20	1.03	16.23**	-8.06	-1.60	0.98	10.79
SL 461 × DL 161	7.49	1.26	35.26**	26.29**	5.24	23.38**	1.09	-3.81	-2.09	4.79	7.54	17.99**
× SL 462	6.82	-7.88*	23.04**	14.89**	-4.26	12.24**	1.02	-10.56*	-8.96*	-2.56	0.00	9.71
× SD 463	7.61	2.84	37.36**	28.26**	6.88*	25.30**	1.14	0.29	2.09	9.27	12.13*	23.02**
× PP 402	7.61	2.79	37.30**	28.20**	6.84*	25.25**	1.15	-0.58	2.69	9.90*	12.79**	23.74**
× PP 403	6.02	-18.60**	8.72*	1.52	-15.40**	-0.82	1.08	-10.28*	-3.58	3.19	5.90	16.19**
× VR 521	7.86	6.22*	41.88*	32.47**	10.39**	29.42**	0.99	-12.61**	-11.04*	-4.79	-2.30	7.19
DL 161 × SL 462	5.69	3.02	2.65	-4.16	-20.13**	-6.37	0.80	-11.44*	-28.36**	-23.32**	-21.31**	-13.67**
× SD 463	7.49	12.85**	35.26**	26.29**	5.24	23.38**	0.87	-23.08**	-22.39**	-16.93**	-14.75**	-6.47
× PP 402	5.75	-4.12	3.73	-3.15	-19.29**	-5.38	1.00	-13.29**	-10.45*	-4.15	-1.64	7.91
× PP 403	5.48	-13.56**	-1.08	-7.64	-23.03**	-9.77**	0.89	-25.83**	-20.30**	-14.70**	-12.46**	-3.96
× VR 521	5.19	-9.10*	-6.26	-12.47**	-27.06**	-14.49**	0.93	7.69	-16.42**	-10.54*	-8.20	0.72
SL 462 × SD 463	6.52	-1.81	17.69**	9.89*	-8.43**	7.35	0.95	-15.68**	-14.93**	-8.95	-6.56	2.52
× PP 402	5.55	-7.45	0.12	-6.52	-22.10**	-8.67*	1.04	-9.54*	-6.57	0.00	2.62	12.59*
× PP 403	6.25	-1.47	12.76**	5.28	-12.27**	2.85	0.88	-26.67**	-21.19**	-15.65**	-13.44**	-5.04
× VR 521	7.19	26.05**	29.84**	21.24**	1.03	18.44**	1.05	15.87**	-6.27	0.32	2.95	12.95*
SD 463 × PP 402	6.91	4.12	24.79**	16.52**	-2.90	13.83**	1.18	2.02	5.37	12.78**	15.74**	26.98**
× PP 403	6.13	-7.63*	10.71**	3.37	-13.86**	0.99	1.03	-14.17**	-7.76	-1.28	1.31	11.15*
× VR 521	5.61	-15.51**	1.26	-5.45	-21.21**	-7.63*	1.07	-4.73	-3.88	2.88	5.57	15.83**
PP 402 × PP 403	5.74	-9.52**	3.55	-3.31	-19.43**	-5.54	1.08	-10.28*	-3.58	3.19	5.90	16.19**
× VR 521	6.27	4.56	13.12**	5.62	-11.99**	3.18	1.13	-2.31	0.90	7.99	10.82*	21.58**
PP 403 × VR 521	6.93	9.25*	25.03**	16.74**	-2.72	14.05**	1.03	-13.89**	-7.46	-0.96	1.64	11.51*
CD 5%	0.44			0.46			0.94			0.10		
CD1%	0.59			0.59			0.12			0.12		

(cont'd)

Table 7. Mean performance and percent heterosis of F_1 hybrids over better parent (BP), standard checks (CH-1, CH-3, Rudra, Soldier).

Cross	Fruit weight (g)						Pericarp thickness (mm)					
		Percentage increase / decrease over						Percentage increase / decrease over				
	Mean	BP	CH-1	CH-3	Rudra	Soldier	Mean	BP	CH-1	CH-3	Rudra	Soldier
MS 341 × SL 461	4.56	10.24	64.70**	69.18**	16.84**	83.24**	1.06	16.48	-8.62	10.03	3.58	13.98
× DL 161	2.29	-1.15	-17.35*	-15.10	-41.37**	-8.04	1.13	-3.70	-2.87	16.96	10.10	21.15*
× SL 462	2.16	-15.52	-21.93**	-19.80*	-44.62**	-13.14	0.82	-21.97**	-29.60**	-15.22	-20.20*	-12.19
× SD 463	3.72	8.24	34.46**	38.12**	-4.62	49.60**	1.31	3.16	12.53	35.64**	27.69**	40.50**
× PP 402	3.37	31.81**	21.81*	25.12**	-13.59*	35.52**	1.23	35.16**	6.03	27.68**	20.20*	32.26**
× PP 403	2.53	-15.65*	-8.43	-5.94	-35.04**	1.88	1.08	-13.56*	-6.61	12.46	5.86	16.49
× VR 521	2.44	5.62	-11.69	-9.28	-37.35**	-1.74	0.99	2.07	-14.94*	2.42	-3.58	6.09
SL 461 × DL 161	3.59	-13.06*	29.88**	33.42**	-7.86	44.50**	1.24	6.27	7.18	29.07**	21.50**	33.69**
× SL 462	3.45	-16.45**	24.82**	28.22**	-11.45**	38.87**	1.01	-3.82	-13.22	4.50	-1.63	8.24
× SD 463	4.29	3.79	55.06**	59.28**	10.00	72.52**	0.95	-25.00**	-18.10*	-1.38	-7.17	2.15
× PP 402	4.28	3.63	54.82**	59.03**	9.83	72.25**	1.05	15.38	-9.48	9.00	2.61	12.90
× PP 403	3.53	-14.60*	27.59**	31.06**	-9.49	41.96**	1.00	-20.21**	-13.79	3.81	-2.28	7.53
× VR 521	3.49	-15.56**	26.14**	29.58**	-10.51	40.35**	1.04	7.24	-10.63	7.61	1.30	11.47
DL 161 × SL 462	1.95	-23.86**	-29.64**	-27.72**	-50.09**	-21.72*	0.78	-33.33	-32.76**	-19.38*	-23.78**	-16.13
× SD 463	2.83	-17.75**	2.17	4.95	-27.52**	13.67	1.67	-15.26*	-7.47	11.42	4.89	15.41
× PP 402	2.10	-17.99	-24.22**	-22.15*	-46.24**	-15.68	1.04	-11.11	-10.34	7.96	1.63	11.83
× PP 403	2.51	-16.54*	-9.40	-6.93	-35.73**	0.80	0.78	-38.03**	-33.05**	-19.38*	-24.10**	-16.49
× VR 521	2.02	0.50	-26.87**	-24.88**	-48.12**	-18.63	0.89	-23.65**	-22.99**	-7.27	-12.70	-3.94
SL 462 × SD 463	2.87	-16.39*	3.86	6.68	-26.32**	15.55	1.00	-21.32**	-14.08	3.46	-2.61	7.17
× PP 402	2.59	1.17	-6.51	-3.96	-33.68**	4.02	1.23	17.52*	6.03	27.68**	20.20*	32.26**
× PP 403	2.30	-23.42**	-16.87	-14.60	-41.03**	-7.51	0.82	-34.84**	-29.60**	-15.22	-20.20*	-12.19
× VR 521	2.61	2.09	-5.66	-3.09	-33.08**	4.96	0.88	-15.92	-24.14**	-8.65	-14.01	-5.38
SD 463 × PP 402	4.05	17.85**	46.39**	50.37**	3.85	62.87**	1.38	9.21	19.25**	43.60**	35.18**	48.75**
× PP 403	3.95	14.84*	42.65**	46.53**	1.20	58.71**	0.97	-23.42**	-16.38*	0.69	-5.21	4.30
× VR 521	2.57	-25.12**	-6.99	-4.46	-34.02**	3.49	0.99	-21.84**	-14.66*	2.77	-3.26	6.45
PP 402 × PP 403	2.62	-12.65	-5.18	-2.60	-32.72**	5.50	1.23	-1.86	6.03	27.68**	20.20*	32.26**
× VR 521	2.64	3.39	-4.46	-1.86	-32.22**	6.30	0.99	2.76	-14.37	3.11	-2.93	6.81
PP 403 × VR 521	2.82	-5.99	2.05	4.83	-27.61**	13.54	0.86	-31.12**	-25.57**	-10.38	-15.64	-7.17
CD 5%	0.46			0.47			0.16			0.17		
CD1%	0.61			0.61			0.22			0.22		

(cont'd)

Table 7. Mean performance and percent heterosis of F_1 hybrids over better parent (BP), standard checks (CH-1, CH-3, Rudra, Soldier).

Cross	Early yield (g plant^{-1})						Total fruit yield (g plant^{-1})					
		Percentage increase / decrease over						Percentage increase / decrease over				
	Mean	BP	CH-1	CH-3	Rudra	Soldier	Mean	BP	CH-1	CH-3	Rudra	Soldier
MS 341 × SL 461	496.35	49.53**	52.12**	-7.15	55.25**	69.74**	693.67	59.29**	23.64**	-7.65**	22.38**	24.60**
× DL 161	351.90	59.66**	7.85	-34.17**	10.06	20.34*	658.13	57.00**	17.31**	-12.38**	17.06**	18.21**
× SL 462	184.03	-15.39	-43.60**	-65.58**	-42.44**	-37.06**	429.60	2.48	-23.43**	-42.81**	-23.59**	-22.84**
× SD 463	350.37	-11.67	7.38	-34.46**	9.59	19.82*	582.10	-6.71*	3.75	-22.51**	3.53	4.56
× PP 402	457.89	110.53**	40.33**	-14.35**	43.22**	56.59**	882.90	110.62**	57.37**	17.54**	57.04**	58.59**
× PP 403	292.44	27.80**	-10.38	-45.30**	-8.53	0.01	510.47	36.08**	1.68	-24.06**	1.46	2.47
× VR 521	199.19	-9.34	-39.57**	-63.11**	-38.32**	-32.56**	615.07	46.72**	9.63**	-18.12**	9.40**	10.48**
SL 461 × DL 161	577.04	73.84**	76.85**	7.94	80.48**	97.34**	820.80	88.48**	46.30**	9.27**	45.99**	47.43**
× SL 462	258.89	-22.01**	-20.66**	-51.57**	-19.03**	-11.46	418.97	-3.79	-25.32**	-44.22**	-25.48**	-24.75**
× SD 463	322.09	-18.80**	-1.29	-39.75**	-0.74	10.15	477.73	-23.44**	-14.85**	-36.40**	-15.03**	-14.19**
× PP 402	337.33	-22.54**	-39.87**	-55.09**	-23.27**	-16.10*	337.33	-22.54**	-39.87**	-55.09**	-40.00**	-39.41**
× PP 403	460.37	5.72	-17.94**	-38.71**	-9.40	-0.93	460.37	5.72	-17.94**	-38.71**	-18.12**	-17.31**
× VR 521	628.60	44.35**	12.04**	-16.32**	-7.96	0.64	628.60	44.35**	12.04**	-16.32**	11.80**	12.91**
DL 161 × SL 462	586.93	56.45**	4.62	-21.86**	11.50	21.91**	586.93	56.45**	4.62	-21.86**	4.39	5.42
× SD 463	472.63	19.15**	44.85**	-11.59**	47.83**	61.63**	757.27	21.36**	34.98**	0.81	34.69**	36.02**
× PP 402	391.11	77.45**	19.86**	-26.84**	22.33**	33.75**	617.23	64.52**	10.02**	-17.83**	9.78**	10.87**
× PP 403	469.63	105.23**	43.93**	-12.15**	46.89**	60.61**	674.93	79.90**	20.30**	-10.15**	20.05**	21.23**
× VR 521	196.48	-10.85	-39.78**	-63.25**	-38.55**	-32.81**	435.29	16.02**	-22.41**	-42.05**	-22.58**	-21.81**
SL 462 × SD 463	401.43	1.20	23.03**	-24.91**	25.56**	37.28**	772.41	23.79**	37.68**	2.83	37.38**	38.74**
× PP 402	159.34	-25.56*	-51.17**	-70.91**	-50.16**	-45.51**	498.07	43.42**	-11.22**	-33.69**	-11.41**	-10.54**
× PP 403	227.59	-0.54	-30.25**	-52.43**	-28.82**	-22.17**	444.27	19.76**	-20.81**	-40.86**	-20.98**	-20.20**
× VR 521	295.18	37.91**	-9.53	-44.78**	-7.67	0.95	588.90	69.57**	4.97	-21.60**	4.74	5.78
SD 463 × PP 402	313.29	-21.02**	-3.98	-41.39**	-2.01	7.14	621.97	-0.32	10.86**	-17.20**	10.62**	11.72**
× PP 403	653.58	64.77**	100.31**	22.26**	104.42**	123.52**	1027.87	64.73**	83.21**	36.84**	82.82**	84.63**
× VR 521	278.33	-29.83**	-14.70*	-47.93**	-12.94	-4.81	506.37	-18.85**	-9.74**	-32.59**	-9.94**	-9.05**
PP 402 × PP 403	210.10	-8.19	35.61**	-60.70**	-34.29**	-28.15**	425.17	14.61**	-24.22**	-43.40**	-24.38**	-23.63**
× VR 521	440.22	153.63**	34.92**	-17.65**	-37.69**	50.55**	364.55	11.43**	-35.02**	-51.47**	-35.16**	-34.52**
PP 403 × VR 521	261.24	9.79	-23.00**	-53.00**	-21.42**	-14.08	503.30	35.67**	-10.29**	-33.00**	-10.48**	-9.60**
CD 5%	45.10			46.41			34.45			38.17		
CD1%	59.89			59.89			45.76			49.26		

(cont'd)

Table 7. Mean performance and percent heterosis of F_1 hybrids over better parent (BP), standard checks (CH-1, CH-3, Rudra, Soldier).

Cross	Number of Seeds Fruit^{-1}						100-Seed weight (mg)					
		Percentage increase / decrease over						Percentage increase / decrease over				
	Mean	BP	CH-1	CH-3	Rudra	Soldier	Mean	BP	CH-1	CH-3	Rudra	Soldier
MS 341 × SL 461	75.33	66.67**	102.51**	121.14**	775.97**	211.29**	571.78	17.23**	23.56**	9.32	155.91**	92.04**
× DL 161	60.40	40.68**	62.37**	77.30**	602.33**	149.59**	584.64	30.26**	98.84**	75.93**	311.83**	209.05**
× SL 462	42.00	-2.17	12.90**	23.29**	388.37**	73.55**	278.37	2.03	22.60**	8.48	153.92**	90.55**
× SD 463	39.67	-7.61**	6.63**	16.44**	361.24**	63.91**	555.65	-13.38**	25.66**	11.18	160.26**	95.30**
× PP 402	34.40	-19.88**	-7.53**	0.98	300.00**	42.15**	264.17	0.02	20.19**	6.34	148.94**	86.81**
× PP 403	29.27	-31.83**	-21.33**	-14.09**	240.321**	20.94**	427.50	123.76**	168.88**	137.90**	456.89**	317.91**
× VR 521	20.93	-51.24**	-43.73**	-38.58**	143.41**	-13.50**	451.22	-6.63	12.20	-0.73	132.38**	74.39**
SL 461 × DL 161	55.67	23.16**	49.64**	63.41**	547.29**	130.03**	761.60	-44.25**	-14.89	-24.70**	76.27**	32.28**
× SL 462	37.47	-17.11**	0.72	9.98**	335.66**	54.82**	469.58	-49.37**	-24.42**	-33.13**	56.54**	17.47
× SD 463	24.33	-46.17**	-34.59**	-28.57**	182.95**	0.55	481.29	-68.93**	-53.61**	-58.96**	-3.93	-27.90*
× PP 402	18.80	-58.41**	-49.46**	-44.81**	118.60**	-22.31**	460.36	-21.67**	16.93*	3.46	142.18**	81.74**
× PP 403	31.33	-30.68**	-15.77**	-8.02**	264.34**	29.48**	1029.8	-43.25**	-15.28*	-25.04**	75.48**	31.68**
× VR 521	21.67	-52.06**	-41.76**	-36.40**	151.94**	-10.47**	429.74	-47.87**	-22.18**	-31.15**	61.17**	20.95
DL 161 × SL 462	36.80	3.37	-1.08	8.01**	327.91**	52.07**	289.49	-44.94**	15.96*	-25.64**	74.06**	30.62**
× SD 463	30.33	-14.79**	-18.46**	-10.96**	252.71**	25.34**	177.67	-49.60**	-23.07**	-31.93**	59.34**	19.58
× PP 402	48.60	36.52**	30.65**	42.66**	465.12**	100.83**	447.86	-46.68**	-81.61*	-27.99**	68.58**	26.51*
× PP 403	3.47	-5.99**	-10.04**	-1.76	289.15**	38.29**	324.51	-47.22**	-19.44**	-28.72**	66.86**	25.22*
× VR 521	31.80	-10.67**	-14.52**	-6.65**	269.77**	31.40**	298.05	-33.57**	1.41	-10.28	110.03**	57.61**
SL 462 × SD 463	19.07	-35.44**	-48.75**	-44.03**	121.71**	-21.21**	294.67	-22.01**	13.15	0.11	134.34**	75.86**
× PP 402	42.60	69.50**	14.52**	25.05**	395.35**	76.03**	311.75	-7.01	-32.41**	-40.20**	39.98*	5.05
× PP 403	45.07	52.60**	21.15**	32.29**	424.03**	86.23**	308.57	-17.03*	-7.40	-18.07**	91.79**	43.93**
× VR 521	24.07	-4.24	-35.30**	-29.35**	179.84**	-0.55	388.41	39.20**	-28.38**	-36.63**	48.34**	11.32
SD 463 × PP 402	48.93	65.69**	31.54**	43.63**	468.99**	102.20**	258.87	-46.67**	-22.63**	-31.54**	60.25**	20.25
× PP 403	29.80	0.90	-19.89**	-12.52**	246.51**	23.14**	354.68	38.70**	101.21**	78.03**	316.74**	212.74**
× VR 521	36.40	23.25**	-2.15	6.85**	323.26**	50.41**	274.33	1.56	47.33**	30.36**	205.15**	129.00**
PP 402 × PP 403	36.00	21.90**	-3.23	5.68**	318.60**	48.76**	770.68	-66.60**	-62.73**	-67.02**	-22.80	-42.07**
× VR 521	44.20	82.64**	18.82**	29.75**	413.95**	82.64**	564.32	39.49**	64.32**	45.39**	240.34**	155.41**
PP 403 × VR 521	48.00	62.53**	29.03**	40.90**	458.14**	98.35**	629.40	-47.11**	-37.69**	-44.87**	29.05	-3.16
CD 5%	1.40			1.44			55.79			57.41		
CD1%	1.86			1.86			74.09			74.09		

CONCLUSION

Parents SD 463 was the best general combiner for early and total yield combined with several other yield traits followed by SL 461, PP 402, and MS 341. The best heterotic combinations in the desirable direction over the better standard check were DL 461 × SL 462 for days to flowering, SL 461 × VR 521 for fruit length, MS 341 × SL 461 for fruit width, fruit weight, and number of seeds fruit^{-1}, SD 463 × PP 402 for pericarp thickness, SD 463 × PP 403 for early yield, total fruit yield, and 100 seed weight. In these investigations, the results indicated the preponderance of non-additive gene action in the inheritance of fruit traits, suggesting the occurrence of hybrid vigour. The parallelism of *per se* performance, SCA, and heterosis suggests the possibility of direct exploitation of these hybrids at commercial level.

REFERENCES

Adarsh MN, Kumari P (2015). Combining ability and gene action studies for important horticultural traits in chilli, *Capsicum annuum* L. *Int. J. Farm Sci*. 5(1): 251-262.

Anonymous (2010). Chilli. In: *Package of practices for cultivation of vegetables*. Punjab Agricultural University, Ludhiana. pp. 41-43.

Basbag S, Ekinci R, Gencer O (2007). Combining ability and heterosis for earliness characters in line × tester population of *Gossypium hirsutum* L. *Hereditas* 144: 185-190.

Bhattacharya A, Chattopadhyay A, Mazumdar D, Chakravarty A, Pal S (2010). Antioxidant constituents and enzyme activities in chilli peppers. *Int. J. Veg. Sci*. 16(3): 201-211.

Bhutia ND, Seth T, Shende VD, Dutta S, Chattopadhyay A (2015). Estimation of Heterosis, dominance effect and genetic control of fresh fruit yield, quality and leaf curl disease severity traits of chilli pepper (*Capsicum annuum* L.). *Scientia Horticulturae* 182: 47-55.

Chaudhary A, Kumar R, Solankey SS (2013). Estimation of heterosis for yield and quality components in chilli (*Capsicum annuum* L.). *Afr. J. Biotechnol*. 12(47): 6605-6610.

FAO (2013). *Production quantities of chillies and peppers, dry by country*. Food and Agriculture Organization of the United Nations. www.faostat.fao.org, Accessed November 22, 2016.

Farag ST, Khalil RM (2007). Combining ability, heterosis and some genetic parameters in pepper hybrids. *Egyptian J. Plant Breed*. 11: 243-258.

Grajales PM, Hernandez GVA, Lomeli PA, Castellanos SJ (2009). Combining ability and heterosis for fruit yield and quality in manzano hot pepper (*Capsicum pubescens* R and P) Landraces. *Rev. Chapingo Ser. Hortic*. 15(1): 103-109.

Griffing B (1956). Concept of general and specific combining ability in relation to diallel cross systems. *Aust. J. Biol. Sci*. 9: 463-493.

Hasanuzzaman M, Hakim MA, Fersdous J, Islam MM, Rahman L (2012). Combining ability and heritability analysis for yield and yield contributing characters in chilli (*Capsicum annuum*) landraces. *Plant Omics J*. 5(4): 337-344.

Hasanuzzaman M, Hakim MA, Hanafi MM, Shukor-Juraimi A, Islam MM, Shamsuddin AKM (2013). Study of heterosis in Bangladeshi chilli (*Capsicum annuum* L.) landraces. *Agrociencia* 47: 683-690.

Hayman BI (1954). The theory and analysis of diallel crosses. *Genetics* 39(6): 789-809.

Marame F, Desalegne L, Singh H, Fininsa C, Sigvald R (2008). Genetic components and heritability of yield and yield related traits in hot pepper. *Res. J. Agric. Biol. Sci*. 4(6): 803-809.

Marame F, Dessalegne L, Fininsa C, Sigvald R (2009). Heterosis and heritability in crosses among Asian and Ethiopian parents of hot pepper genotypes. *Euphytica* 168(2): 235-247.

Payakhapaab S, Boonyakiat D, Nikornpun M (2012). Evaluation of heterosis and combining ability of yield components in chillies. *J. Agric. Sci*. 4(11): 154-161.

Perez GM, Gonzalez HVA, Pena LA, Sahagun CJ (2009). Combining ability and heterosis for fruit yield and quality in Manzano hot pepper (*Capsicum pubescens* R & P) landraces. *Rev. Chapingo Ser. Hort*. 15: 47-55.

Prasath D, Ponnuswami V (2008). Heterosis and combining ability for morphological, yield and quality characters in paprika type chilli hybrids. *Indian J. Hort*. 65(4): 441-445.

Riggs TJ (1988). Breeding F_1 hybrid varieties of vegetables. *J. Hort. Sci*. 63(3): 362-369.

Shankarnag B, Madalageri MB (2006). Studies on heterosis in male sterile based hybrids in chilli (*Capsicum annum* L.). *Int. J. Agric. Res*. 2(2): 327-329.

Singh DK, Tewari P, Jain SK (2012). Heterosis studies for growth, flowering and yield of chilli (*Capsicum annuum* L.). *Pantnagar J. Res*. 10(1): 61-65.

Sitaresmi T, Sujiprihati S, Syukur M (2010). Combining ability of several introduced and local chilli pepper (*Capsicum annuum* L.) genotypes and heterosis of the offsprings. *J. Agron. Indonesia* 38: 212-217.

Sprague GF, Tatum LM (1942). General versus specific combining ability in single crosses of corn. *J. Am. Soc. Agron*. 34: 923-932.