DEVELOPMENT OF F_1 HYBRIDS IN CHILLI (*Capsicum annuum* L.) FOR COMMERCIAL CULTIVATION

by

MOPIDEVI M NAGARAJU

(2013 - 12 - 119)

DEPARTMENT OF OLERICULTURE

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

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THESIS

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requirements for the degree of

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DEPARTMENT OF OLERICULTURE
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KERALA, INDIA

2015

DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT OF F_1 HYBRIDS IN CHILLI (*Capsicum annuum* L.) FOR COMMERCIAL CULTIVATION"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani, **Mopidevi M Nagaraju**

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CERTIFICATE

Certified that this thesis entitled **"DEVELOPMENT OF F_1 HYBRIDS IN CHILLI (*Capsicum annuum* L.) FOR COMMERCIAL CULTIVATION"** is a record of research work done independently by Mr. Mopidevi M Nagaraju under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellayani,
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We, the undersigned members of the advisory committee of Mr. Mopidevi M Nagaraju, a candidate for the degree of **Master of Science in Horticulture** with major in Olericulture, agree that the thesis entitled **"DEVELOPMENT OF F_1 HYBRIDS IN CHILLI (*Capsicum annuum* L.) FOR COMMERCIAL CULTIVATION"** may be submitted by Mr. Mopidevi M Nagaraju, in partial fulfilment of the requirement for the degree.

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LIST OF ABBREVIATIONS

%	-	per cent
&	-	and
µg	-	Microgram
σ^2A	-	Additive variance
σ^2D	-	Dominant variance
ANOVA	-	Analysis of variance
ASTA	-	American Spice Trade Association
a.m.	-	Anti meridian
BP	-	Better parent
CD (0.05)	-	Critical difference at 5 % level
cm	-	centimeter
DAT	-	Days after transplanting
d.f	-	Degrees of freedom
et al.	-	and co-workers/co-authors
F_1	-	First filial generation
g	-	gram
GCA	-	General combining ability
ha	-	hectare

HB	-	Heterobeltiosis
i.e.	-	that is
kg	-	kilogram
KAU	-	Kerala Agricultural University
mm	-	Milli meters
MP	-	Mid parent
NBPGR	-	National Bureau of Plant Genetic Resources
RH	-	Relative heterosis
SCA	-	Specific combining ability
SE	-	Standard error
S.E.D	-	Standard error difference
S.E.M	-	Standard error mean
SH	-	Standard heterosis
sp.	-	Species
t	-	tonne
viz.	-	namely

INTRODUCTION

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) is one of the most important commercially grown spice cum vegetable in the tropics. It belongs to the family Solanaceae and has a chromosome number of 2n = 24. The genus *Capsicum* includes 30 species, five of which are cultivated, *C. annuum* L., *C. frutescens, C. chinense, C. pubescens and C. baccatum* (Bosland and Votava, 2000). *C. annuum* is most widely cultivated in India. *C. frutescens* and *C. chinense* are grown in specific regions especially in North Eastern part of India and Karnataka and Kerala.

India is the largest producer, consumer and exporter of chilli in the world. In India chilli is grown in an area of 7.75 lakh ha with a production of 14.92 lakh tonnes. The major producers are Andhra Pradesh (49 %), Karnataka (15 %), Orissa (8 %), Maharashtra (6 %), West Bengal (5 %), Rajasthan (4 %) and Tamil Nadu (3 %). In Kerala, cultivation of chilli is limited to an area of 1340 ha with an annual production of 1290 tonnes (NHB, 2014).

The quality in chilli is determined by pungency level, oleoresin, fruit colour, fruit size, pericarp thickness, external glossiness and ascorbic acid content (Dhall, 2008). Dry matter content of red chilli fruit is an important quality character for the dry powder and dry fruit purpose, which are the major export items of chilli.

Many cultivars have been developed in chilli but the level of production and productivity has not increased considerably. Thus there is an urgent need of improvement of the crop for yield as well as for quality which may be accomplished by exploitation of hybrid vigour through heterosis breeding. Now a days hybrids have become very popular in many crops as they give an opportunity to utilize the synergistic effect of a genetic combination. This is more so in protected cultivation and precision farming.

The yield potential of chilli in India is low due to poor yielding varieties and high incidence of pests and diseases. One of the methods to improve the yield and quality is heterosis breeding. The importance of heterosis breeding has been recognized widely in many vegetable crops. Heterosis signifies increased or decreased vigour of the F_1 hybrids over the parents. The expression of heterosis may be due to factors such as heterozygosity, allelic interaction *viz.*, dominance or over dominance, non-allelic interaction or epistasis and maternal interactions. Developed countries like USA, Canada, Japan, Korea, Israel *etc.*, are producing hybrids in almost all vegetables. But, India is lagging much behind in this aspect. The F_1 hybrids offer several advantages like earliness, high yield, improved quality, uniformity, wider adaptability and also help in deployment of dominant genes for resistance to diseases and pests (Riggs, 1988).

In breeding programme of high yielding varieties of crop plants, the breeder often deals with problem of selecting the desirable parents. Combining ability is one of the important aspects for selecting desirable parents and cross combinations to be used in formulation of systematic breeding programme. Diallel design gives better control over the experimental material and thereby provides more precise information in various parameters obtained from this design.

The varieties now available in KAU are released for vegetable purpose. A hybrid possessing higher yield, better quality and vegetable cum powdering property will be an important contribution to farmers to cultivate them in the open field in protected cultivation and precision farming.

Hence, the present study was undertaken with the following objectives.

1. To develop superior dual purpose chilli F_1 hybrids with medium pungency, deep red colour, high dry matter and vitamin C content.
2. To estimate the magnitude of heterosis for fruit yield and its components and quality characters.
3. To estimate the general and specific combining ability effects of parents and crosses, respectively.
4. To identify the good general combiners and specific combiners for use in future breeding programme.
5. To study the nature and magnitude of gene actions.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The objective of chilli breeding is generally to improve the plant production and its quality, pest and disease resistance, improving some horticultural traits, as well as to improve the ability against the environmental stress condition. Biometrical techniques – diallel analysis is one of the methods commonly used for the evaluation and selection of parents for hybridization. The parents are chosen on the basis of the measurement of heterosis and combining ability and the breeding procedure is decided on the basis of gene action involved in the expression of various quantitative characters. In this section an attempt has been made to review the up-to-date literature with respect to these aspects as follows.

Keeping in view the objectives of the present investigation relevant literature is reviewed and presented in the following headings.

2.1 HETEROSIS

The term heterosis is now widely used, which refers to the phenomena in which the F_1 hybrid obtained by crossing the two genetically dissimilar homozygous individuals, shows increased or decreased vigour over the parental values. Shull (1908) referred this phenomenon as the stimulus of heterozygosis. The expression of heterosis may be due to factors such as heterozygosity, allelic interaction such as dominance or over-dominance, non-allelic interaction or epistasis and maternal interactions. The degree of heterosis depends upon the number of heterozygous alleles. Higher the number of heterozygous alleles, more is the heterosis expected (East and Hayes, 1912).

Exploitation of hybrid vigour to increase the yield has become an important technique in vegetable breeding. But the conventional hand emasculation and pollination method used for hybrid seed production in chilli is highly uneconomical as it is a labours process. Early flowering is generally an indication of early yield which is most preferred by the growers to fetch the high market prices prevailing in the early cropping season and also to reduce the risk of crop maintenance in late season. Even though India ranks first in area and production of chilli, its productivity is very low as compared to foreign countries like Japan (3.6 t/ha) and Korea (2.0 t/ha.). One of the options to achieve quantum jump in yield is heterosis. Heterosis breeding provides an opportunity in productivity, earliness and yield attributing characters.

Heterosis is a result of certain type of gene effects *viz.*, additive, dominance and epistasis (additive x additive, additive x dominance, dominance x dominance) of these additive type of gene effects contribute to additive genetic variance. Therefore, higher the contribution of additive type of gene effect to the manifestation of heterosis, greater would be the retention of vigour in subsequent segregating generations (Lal *et al.*, 1973).

The first report on heterosis in chilli came from Deshpande (1933) who observed it for earliness, plant height, fruit girth, fruits per plant and yield per plant. A considerable degree of heterosis has been documented in chilli for various characters. Heterosis reported for different characters by various workers are presented in Table 1.

2.2 COMBINING ABILITY

Hybridization is the most potent technique for breaking yield barriers and evolving varieties having high yielding potential. Selection of suitable parents is one of the most important steps in hybridization programme. Selection of parents on the basis of phenotypic performance alone is not a sound procedure, since phenotypically superior lines may not lead to expected degree of heterosis. Therefore, selection of potential parents, based on genetic information and knowledge of their combining ability is very important. The combining ability concept was first proposed by Sprague and Tatum (1942) in corn. According to them, the general combining ability (*gca*) is the comparative ability of the line to combine with other lines. It is deviation of the mean performance of all the crosses involving a parent from overall mean. Specific combining ability (*sca*) was defined as the deviation in the performance of specific cross from the performance expected on the basis of general combining ability effects of parents involved in the crosses. A positive general combining ability (*gca*) indicates a parent that produces above average progeny, whereas parent with negative general combining ability (*gca*) effect produces progeny that performs below average of the population. Specific combining ability (*sca*) can be either negative or positive and *sca* always refers to specific cross and never to particular parent by itself.

The most commonly used designs for combining ability studies are diallel and line x tester (L x T) analysis. These designs are also useful in characterizing the nature and magnitude of gene action involved in controlling the quantitative traits.

The general and specific combining ability effects and variances obtained from a set of F_1s would enable a breeder to select desirable parents and crosses for each of the quantitative components separately. Sprague and Tatum (1942) from their results concluded that, the general combining ability was largely the result of additive gene action, while the specific combining ability due to dominance, epitasis and genotypic environment interaction.

The other approach to create variability is by recombination of genotypes and evaluating the recombinants in segregating generations for combining ability. In cross pollinated crops like maize, this principle is involved in breeding procedures like recurrent selection for general and specific combining ability. These procedures as such cannot be reproduced entirely in self and often cross-pollinated crops like cotton because of the difficulty of intermating the selected plants. However, the segregants selected for high combining ability can be selfed to fix the high combining ability of lines in segregating generations (Patil and Patil, 2003).

Summarizing the reports it can be stated that fruit length, fruit diameter, fruit weight, number of fruits and fruit yield showed predominance of GCA variance implying additive gene action. SCA variance and non-additive genetic control were also observed for number of primary branches in chilli. The yield is a complex character where a majority of workers have reported the predominance of SCA variance implying non-additive gene action.

The available literature pertaining to combining ability in chilli is presented in Table 2.

Table 1. Heterosis for different characters in chilli as reported by different authors

Number of hybrids studied	Range of heterosis (%) over			Authors
	Mid parent	Better parent	Standard check	
1. Plant height (cm)				
24 hybrids	-16.99 to 26.46	-26.17 to 25.09	-29.16 to 20.04	Patel *et al*. (2001)
21 hybrids	--	--	-17.33 to 55.10	Shankarnag *et al.* (2006)
30 hybrids	--	--	16.81 to 131.37	Prasath and Ponnuswami (2008)
40 hybrids	-12.92 to 39.07	-14.39 to 15.91	-28.99 to 4.63	Ganeshreddy et al. (2008)
66 hybrids	-40.8 to 25.65	-47.7 to 18.24	-63.07 to 7.29	Fekadu *et al.* (2009)
45 hybrids	--	-21.36 to 24.57	-24.70 to -3.98	Kamble *et al*. (2009)
50 hybrids	--	-25.52 to 70.36	-9.27 to 110.16	Patel *et al*. (2010)
9 hybrids	--	-19.92 to 8.74	-6.69 to 20.27	Payakhapaab *et al*. (2012)
28 hybrids	--	-22.68 to 7.75	-26.47 to 4.99	Patil *et al*. (2012)
51 hybrids	-30.85 to 48.31	-37.41 to 44.48	-31.98 to 31.08	Tembhurne and Rao (2012)
28 hybrids	--	-31.69 to 29.91	-20.99 to 39.71	Patel *et al*. (2014)
72 hybrids	-20.29 to 18.11	-24.70 to 15.94	-10.98 to 25.38	Kumar *et al*. (2014)
66 hybrids	--	-3.11 to 32.21	--	Singh *et al.* (2014)
10 hybrids	-28.92 to 15.74	-39.54 to -20.93	--	Bhutia *et al.* (2015)
2. Primary branches per plant				
24 hybrids	-20.22 to 28.14	-32.82 to 35.23	-28.43 to 31.70	Patel *et al.* (2001)
21 hybrids	--	--	-2.86 to 26.49	Shankarnag *et a.* (2006)
30 hybrids	--	--	-42.22 to 82.68	Prasath and Ponnuswami (2008)
40 hybrids	-14.29 to 55.13	-22.22 to 44.05	-42.47 to 17.26	Ganeshreddy *et al.* (2008)

66 hybrids	-37.9 to 71.13	-50.46 to 66.00	-45.47 to 15.88	Fekadu *et al.* (2009)
50 hybrids	--	-39.06 to 53.11	-20.36 to 66.21	Patel *et al*. (2010)
28 hybrids	--	-23.61 to 18.75	-26.70 to 6.92	Patil *et al*. (2012
51 hybrids	-20.87 to 83.88	-34.53 to 79.12	-5.01 to 97.70	Tembhurne and Rao (2012)
28 hybrids	--	-33.33 to 41.73	-37.22 to 7.22	Patel *et al*. (2014)
72 hybrids	-16.13 to 95.56	-21.87 to 91.3	-24.24 to 33.33	Kumar *et al*. (2014)
10 hybrids	-37.50 to 33.33	-46.41 to 20.05	--	Bhutia *et al.* (2015)
3. Days to first flowering				
24 hybrids	-37.44 to 12.64	-38.65 to 12.64	-36.18 to 3.52	Patel *et al.* (2001)
21 hybrids	--	--	-17.94 to 11.10	Shankarnag *et al* (2006)
30 hybrids	--	--	-3.22 to 13.34	Prasath and Ponnuswami (2008)
40 hybrids	6.62 to 4.51	-5.93 to 6.11	3.25 to 12.20	Ganeshreddy *et al.* (2008)
45 hybrids	--	-34.31 to 50.00	-12.61 to 42.73	Kamble *et al*. (2009)
50 hybrids	--	-21.57 to 11.64	-14.29 to 21.43	Patel *et al*. (2010)
28 hybrids	--	-17.61 to 37.21	-12.06 to 19.47	Patil *et al*. (2012
51 hybrids	-18.22 to 5.24	-24.06 to 0.40	1.59 to 32.80	Tembhurne and Rao (2012)
28 hybrids	--	-33.32 to 2.45	-26.25 to 4.99	Patel *et al*. (2014)
72 hybrids	-12.99 to 5.45	-11.24 to 11.11	-13.48 to 4.49	Kumar *et al*. (2014)
66 hybrids	--	-35.77 to 5.00	--	Singh *et al.* (2014)
10 hybrids	-17.46 to -7.98	-11.63 to -21.84	--	Bhutia *et al.* (2015)
4. Days to first harvest				
42 hybrids	--	-98.11 to 316.26	--	Rajinder and Hundal (2001)
45 hybrids	--	-64.58 to -40.11	-46.08 to 75.56	Kamble *et al*. (2009)

66 hybrids	-29.8 to 6.8	-31.5 to 6.80	-23.59 to 11.60	Fekadu *et al.* (2009)
51 hybrids	-11.53 to 0.65	-18.39 to 1.02	-0.49 to 15.93	Tembhurne and Rao (2012)
66 hybrids	--	-64.94 to 238.48	--	Singh *et al.* (2014)
10 hybrids	--	-46.51 to 72.58	-50.54 to 15.05	Ahmed *et al.* (2015)
5. Fruits per plant				
24 hybrids	-21.26 to 46.73	-48.21 to -1.28	-48.12 to 26.42	Patel *et al.* (2001)
30 hybrids	--	--	-22.99 to 137.61	Prasath and Ponnuswami (2008)
40 hybrids	-28.13 to 98.73	-46.75 to 35.34	-10.00 to 250.67	Ganeshreddy *et al.* (2008)
66 hybrids	-40.3 to 104.4	-42.86 to 79.61	-37.50 to 136.36	Fekadu *et al.* (2009)
45 hybrids	--	-66.82 to 20.96	-26.82 to 173.77	Kamble *et al.* (2009)
50 hybrids	--	-43.47 to 170.62	12.97 to 277.69	Patel *et al.* (2010)
28 hybrids	--	-20.42 to 87.17	-57.12 to 39.69	Patil *et al.* (2012)
51 hybrids	21.75 to 658.29	-1.8 to 651.37	43.02 to 397.94	Tembhurne and Rao (2012)
9 hybrids	--	-46.06 to 47.06	-41.99 to 51.09	Payakhapaab *et al.* (2012)
28 hybrids	--	-31.40 to 100.04	-22.16 to 96.86	Patel *et al.* (2014)
72 hybrids	-29.81 to 55.77	-43.62 to 49.5	-18.12 to 83.29	Kumar *et al.* (2014)
66 hybrids	--	-79.30 to 205.95	--	Singh *et al.* (2014)
10 hybrids	37.72	-44.77 to -43.32	--	Bhutia *et al.* (2015)
6. Fruit length (cm)				
24 hybrids	-8.42 to 24.98	-29.22 to 16.05	-35.87 to 15.84	Patel *et al.* (2001)
42 hybrids	--	-43.39 to 55.90	--	Rajinder and Hundal (2001)
30 hybrids	--	--	-20.59 to 39.85	Prasath and Ponnuswami (2008)
40 hybrids	-34.08 to 47.48	-37.66 to 34.42	-34.21 to 40.79	Ganeshreddy *et al.* (2008)

66 hybrids	-15.3 to 26.84	-23.8 to 26.59	-13.26 to 11.60	Fekadu *et al.* (2009)
50 hybrids	--	-31.06 to 21.53	-40.86 to 5.67	Patel *et al*. (2010)
9 hybrids	--	-24.70 to 38.68	-12.43 to 40.36	Payakhapaab *et al*. (2012)
28 hybrids	--	-26.43 to 32.41	-35.86 to 11.14	Patil *et al*. (2012)
51 hybrids	-25.88 to 86.13	-51.25 to 66.37	-67.39 to 17.72	Tembhurne and Rao (2012)
28 hybrids	--	-25.87 to 33.69	-5.10 to 58.84	Patel *et al*. (2014)
72 hybrids	-25.15 to 56.60	-34.04 to 42.16	-25.29 to 34.54	Kumar *et al*. (2014)
66 hybrids	--	-5.13 to 39.64	--	Singh *et al.* (2014)
10 hybrids	-49.43 to 28.30	-64.66 to 6.14	--	Bhutia *et al.* (2015)
10 hybrids	--	-42.47 to -1.02	-1.24 to 44.78	Ahmed *et al*. (2015)
6. Fruit girth (cm)				
24 hybrids	-31.44 to 9.69	-50.23 to 3.28	-16.50 to 27.32	Patel *et al.* (2001)
42 hybrids	--	-38.72 to 24.48	--	Rajinder and Hundal (2001)
30 hybrids	--	--	-41.82 to 29.90	Prasath and Ponnuswami (2008)
40 hybrids	-40.79 to 63.98	-53.33 to 60.90	-44.83 to 47.59	Ganeshreddy *et al.* (2008)
50 hybrids	--	-51.38 to 26.28	-29.34 to 38.42	Patel *et al*. (2010)
9 hybrids	--	-31.32 to 1.88	-29.64 to 7.92	Payakhapaab *et al*. (2012)
28 hybrids	--	-25.00 to 13.24	-29.17 to 7.29	Patil *et al*. (2012)
51 hybrids	-50.69 to 19.59	-54.05 to -1.42	-49.51 to 28.74	Tembhurne and Rao (2012)
28 hybrids	--	-35.71 to 11.91	-26.64 to 12.95	Patel *et al*. (2014)
72 hybrids	-17.57 to 67.47	-32.34 to 66.80	-31.22 to 8.29	Kumar *et al*. (2014)
66 hybrids	--	-20.60 to 10.41	--	Singh *et al.* (2014)
10 hybrids	-23.77 to 10.20	-37.88 to 4.49	--	Bhutia *et al.* (2015)
10 hybrids	--	-16.81 to 23.55	1.93 to 34.30	Ahmed *et al*. (2015)

8. Fruit weight (g)				
24 hybrids	-28.45 to 47.24	-56.00 to 41.14	-36.47 to 57.29	Patel *et al.* (2001)
42 hybrids	--	-49.87 to 111.27	--	Rajinder and Hundal (2001)
30 hybrids	--	--	-41.82 to 29.90	Prasath and Ponnuswami (2008)
40 hybrids	-56.72 to 59.37	-64.29 to 54.55	-41.67 to 112.50	Ganeshreddy *et al*. (2008)
66 hybrids	-32.94 to 74.29	-38.19 to 50.29	-50.22 to 1.31	Fekadu *et al.* (2009)
45 hybrids	--	-79.23 to 96.93	-82.63 to 4.37	Kamble *et al*. (2009)
50 hybrids	--	-51.19 to 3.60	-36.04 to 33.93	Patel *et al*. (2010)
9 hybrids	--	-56.09 to 16.73	-48.02 to 51.33	Payakhapaab *et al*. (2012)
51 hybrids	-1.09 to 84.38	-62.51 to 70.94	-84.81 to 44.15	Tembhurne and Rao (2012)
28 hybrids	--	-31.05 to 52.91	-31.05 to 79.43	Patel *et al*. (2014)
72 hybrids	-33.46 to 193.9	-35.46 to 86.79	-44.72 to 21.70	Kumar *et al*. (2014)
66 hybrids	--	-28.65 to 57.52	--	Singh *et al.* (2014)
10 hybrids	--	-13.82 to 96.73	-24.71 to 2.47	Ahmed *et al*. (2015)
9. Flesh thickness (mm)				
40 hybrids	-33.33 to 1138.10	-43.33 to 1138.10	-76 to 246.67	Ganeshreddy *et al*. (2008)
9 hybrids	--	-33.58 to 10.75	-29.37 to 15.73	Payakhapaab *et al*. (2012)
72 hybrids	-9.04 to 156.58	-26.28 to 104.7	-31.33 to 26.51	Kumar *et al*. (2014)
66 hybrids	--	-37.98 to 14.34	--	Singh *et al.* (2014)
10 hybrids	--	-21.45 to 41.07	45.80 to 111.11	Ahmed *et al*. (2015)
10. Flesh to seed ratio				
72 hybrids	-51.89 to 135.11	-44.44 to 266.67	-51.11 to 71.11	Kumar *et al*. (2014)
11. Seeds per fruit				
30 hybrids	--	--	-8.24 to 87.65	Prasath and Ponnuswami (2008)

40 hybrids	-38.26 to 84.42	-33.15 to 114.29	-30.83 to 77.50	Ganeshreddy *et al*. (2008)
51 hybrids	-54.41 to 52.92	-68.98 to 40.68	-91.11 to -20.78	Tembhurne and Rao (2012)
28 hybrids	--	-64.95 to 51.54	-48.87 to 66.49	Patel *et al*. (2014)
72 hybrids	-44.32 to 48.95	-38.40 to 80.43	-39.79 to 23.29	Kumar *et al*. (2014)
66 hybrids	--	-80.70 to 89.94	--	Singh *et al.* (2014)
10 hybrids	-30.07 to 15.79	-40.00 to -17.53	--	Bhutia *et al.* (2015)
12. Green fruit yield per plant (g)				
24 hybrids	-1.67 to 92.04	-17.26 to 85.38	-24.10 to 15.30	Patel *et al.* (2001)
42 hybrids	--	-14.85 to 108.17	--	Rajinder and Hundal (2001)
21 hybrids	--	--	-73.92 to -8.12	Shankarnag *et al* (2006)
30 hybrids	--	--	-51.84 to 99.04	Prasath and Ponnuswami (2008)
45 hybrids	--	-57.65 to 51.00	-61.59 to 69.59	Kamble *et al*. (2009)
50 hybrids	--	-36.33 to 197.55	21.47 to 448.55	Patel *et al*. (2010)
51 hybrids	-1.15 to 495.88	-42.79 to 409.86	-63.11 to 47.88	Tembhurne and Rao (2012)
9 hybrids	--	-48.33 to 73.03	-44.40 to 78.03	Payakhapaab *et al*. (2012)
28 hybrids	--	-35.37 to 90.57	-61.76 to 41.91	Patil *et al*. (2012)
28 hybrids	--	-16.07 to 106.99	-14.76 to 109.91	Patel *et al*. (2014)
66 hybrids	--	-71.82 to 331.11	--	Singh *et al.* (2014)
10 hybrids	--	-2.08 to 50.49	-0.60 to 38.74	Ahmed *et al*. (2015)
13. Dry fruit yield per plant (g)				
30 hybrids	--	--	-40.35 to 126.32	Prasath and Ponnuswami (2008)
40 hybrids	-52.80 to 152.67	-56.87 to 88.27	-62.18 to 60.51	Ganeshreddy *et al.* (2008)
66 hybrids	-52.04 to 163.8	-52.67 to 161.79	-52.67 to 92.05	Fekadu *et al.* (2009)
51 hybrids	-0.92 to 493.44	-42.79 to 402.78	-62.88 to 48.47	Tembhurne and Rao (2012)

72 hybrids	-8.44 to 71.04	-24.67 to 70.24	-26.36 to 49.09	Kumar *et al*. (2014)
14. Yield per plot (kg)				
9 hybrids	--	-48.35 to 72.96	-44.41 to 77.94	Payakhapaab *et al*. (2012)

Table 2. Combining ability variances and effects for different traits in chilli as reported by different authors

Materials used for The study	Combining ability		Gene action		Authors
	GCA	SCA	Additive	Non - additive	
1. Plant height (cm)					
6 × 6 Diallel	Non-significant	Significant	+	-	Bhagyalakshmi *et al.* (1991)
10 × 10 Half - Diallel	Highly significant	Non-significant	+	-	Lohithaswa *et al.* (2000)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al.* (2003)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Srivastava *et al.* (2004)
12 × 6 Line x Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
3 × 15 Line × Tester	Highly significant	Highly significant	+	-	Jagadeesha and Wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
6 × 6 Half - Diallel	Highly significant	Non-significant	-	+	Nsabiyera *et al*. (2013)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al.* (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
12 × 12 Half - Diallel	Significant	Highly significant	-	+	Singh *et al.* (2014)
2. Primary branches per plant					
6 × 6 Diallel	Non-significant	Highly significant	-	+	Bhagyalakshmi *et al.* (1991)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Lohithaswa *et al.* (2000)

6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al.* (2003)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Srivastava *et al.* (2004)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
3 × 15 Line × Tester	Highly significant	Highly significant	+	-	Jagadeesha and Wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al.* (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
3. Days to first flowering					
10 × 10 Half - Diallel	Significant	Highly significant	-	+	Lohithaswa et al. (2000)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	-	Srivastava *et al.* (2004)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al.* (2014)
12 × 12 Half - Diallel	Significant	Highly significant	-	+	Singh *et al.* (2014)
4. Day to first harvest					
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Srivastava et al. (2004)
12 × 6 Line × Tester	Significant	Highly significant	-	+	Lankeshkumar (2005)
6 × 6 Half - Diallel	Highly Significant	Highly significant	-	+	Nsabiyera *et al*. (2013)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)

5. Fruits per plant					
6 × 6 Diallel	Highly significant	Highly significant	-	+	Bhagyalakshmi *et al.* (1991)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Lohithaswa *et al.* (2000)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al.* (2003)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
3 × 15 Line × Tester	Highly significant	Highly significant	+	-	Jagadeesha and Wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
12 × 12 Diallel	Highly significant	Highly significant	+	-	Pandey *et al*. (2012)
6 × 6 Half - Diallel	Highly Significant	Highly significant	-	+	Nsabiyera *et al*. (2013)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
12 × 12 Half - Diallel	Highly significant	Highly significant	-	+	Singh *et al.* (2014)
6. Fruit length (cm)					
6 × 6 Diallel	Highly significant	Highly significant	-	+	Bhagyalakshmi *et al.* (1991)
6 × 6 Half - Diallel	Significant	Non-significant	+	-	Nandadevi *et al.* (2003)
6 × 6 Half - Diallel	Significant	Highly significant	+	+	Srivastava *et al.* (2004)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
12 × 12 Diallel	Highly significant	Highly significant	+	-	Pandey *et al*. (2012)

6 × 6 Half - Diallel	Highly significant	Highly significant	+	-	Nsabiyera *et al*. (2013)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
12 × 12 Half - Diallel	Highly significant	Highly significant	+	-	Singh *et al.* (2014)
7. Fruit girth (cm)					
6 × 6 Diallel	Highly significant	Significant	-	+	Bhagyalakshmi *et al.* (1991)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al.* (2003)
6 × 6 Half - Diallel	Significant	Non-significant	+	-	Srivastava *et al.* (2004)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
12 × 12 Diallel	Highly significant	Highly significant	-	+	Pandey *et al*. (2012)
6 × 6 Half - Diallel	Highly significant	Non-significant	+	-	Nsabiyera *et al*. (2013)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
12 × 12 Half - Diallel	Highly significant	Highly significant	+	-	Singh *et al.* (2014)
8. Fruit weight (g)					
10 × 10 Half - Diallel	Highly significant	Highly significant	+	-	Lohithaswa et al. (2000)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi et al. (2003)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)

3 × 15 Line × Tester	Highly significant	Highly significant	+	-	Jagadeesha and Wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
12 × 12 Diallel	Highly significant	Highly significant	+	-	Pandey *et al*. (2012)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al*. (2014)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)
12 × 12 Half - Diallel	Highly significant	Highly significant	+	-	Singh *et al*. (2014)
9. Flesh thickness (mm)					
6 × 6 Half - Diallel	Highly significant	Non significant	+	-	Nandadevi *et al*. (2003)
12 × 6 Line x Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al*. (2014)
12 × 12 Half - Diallel	Highly s ignificant	Highly significant	+	-	Singh *et al*. (2014)
10. Flesh to seed ratio					
10 × 10 Dialle	Highly significant	Highly significant	-	+	Lohithaswa *et al*. (2000)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza et al. (2014)
11. Seeds per fruit					
6 × 6 Diallel	Significant	Significant	-	+	Bhagyalakshmi *et al*. (1991)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al* (2003)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	-	Nsabiyera *et al*. (2013)

7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
12 × 12 Half - Diallel	Highly significant	Highly significant	-	+	Singh *et al.* (2014)
12. Green fruit yield per plant (g)					
6 × 6 Diallel	Non significant	Highly significant	-	+	Bhagyalakshmi *et al.* (1991)
6 × 6 Half - Diallel	Highly significant	Highly significant	+	+	Nandadevi *et al.* (2003)
6 x 6 Half - Diallel	Highly significant	Highly significant	-	-	Srivastava *et al.* (2004)
3 × 15 Line × Tester	--	Significant	+	-	Jagadeesha and wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	+	-	Prasath and Ponnuswami (2008)
12 × 12 Diallel	Highly significant	Highly Significant	+	-	Pandey *et al*. (2012)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Afroza *et al.* (2014)
12 × 12 Half - Diallel	Significant	Highly significant	-	+	Singh *et al.* (2014)
13. Dry fruit yield per plant (g)					
6 × 6 Diallel	Highly significant	Highly significant	-	+	Bhagyalakshmi *et al.* (1991)
10 × 10 Half - Diallel	Highly significant	Highly significant	-	+	Lohithaswa *et al.* (2000)
12 × 6 Line × Tester	Highly significant	Highly significant	-	+	Lankeshkumar (2005)
3 × 15 Line × Tester	Highly significant	Highly significant	+	-	Jagadeesha and Wali (2005)
6 × 6 Diallel	Highly significant	Highly significant	-	+	Prasath and Ponnuswami (2008)
7 × 7 Diallel	Highly significant	Highly significant	-	+	Navhale *et al*. (2014)
14. Yield per plot (kg)					

12 × 12 Diallel	High significant	Highly significant	+	-	Pandey *et al*. (2012)
6× 6 Diallel	High significant	Highly significant	-	+	Darshan (2014)

2.3 QUALITY CHARACTERS

Quality in chilli is mainly determined by pungency, colour, dry matter and vitamin C. The quality of red chilli powder and paprika products is based on visual and extractable red colour, pungency level and to a lesser degree the nutrition value (Bosland, 1999).

2.3.1 Capsaicin

Pungency in chilli is due to chemical compounds known as capsaicinoids, which are alkaloid compounds found only in the plant genus, *Capsicum.* The nature of the pungency has further been established as a mixture of seven homologous branched-chain alkyl vanillyl amides. It is sparingly soluble in water but highly soluble in fats, oils and alcohol.

Doshi and Shukla (2000) observed negative heterosis over better parent for capsaicin in 43 hybrids whereas in only one hybrid positive heterosis over check. Muthuswamy (2004) reported that positive standard heterosis, heterobeltiosis and relative heterosis for capsaicin content.

Dhall and Hundal (2005) reported that capsaicin content of red ripe fruits is controlled by both additive and non additive effects with partial dominance on the inheritance of this quality trait. Kumar *et al.* (2005) crossed six inbreds in a 6 × 6 diallel fashion and observed that for capsaicin content relative heterosis and heterobeltiosis ranged from -46.15 to 89.16% and -55.30 to 72.52% respectively.

Shekhawat *et al.,* (2007) reported that line × tester mating design comprising of nine lines and two testers, revealed that the parents and F_1 crosses differed significantly for *gca* and *sca* effects for capsaicin content.

Prasath and Ponnuswami (2008) reported that standard heterosis range from -53.57 % to 202.38 % for capsaicin. Patel *et al*., (2010) observed the range of heterobeltiosis and standard heterosis from -28.58 to 32.48% and from -31.66 to 10.94% for capsaicin content respectively.

Chaudhary *et al*., 2013 estimated a range of capsaicin content of 0.64 (%) to 1.72 (%) in chilli hybrids. Darshan (2014) reported the range among the hybrids from 0.94 (%) to 1.92 (%) for capsaicin.

Bhutia *et al.* (2015) reported that the maximum extent of significant heterobeltiosis in desired directions was recorded from hybrids in a five-parent diallel of chilli for capsaicin content of fruit (46.67 %).

2.3.2 Oleoresin

Oleoresin consists of fixed oil, capsaicin, pigments, sugars and resin. Oleoresin is extracted from milled chilli using organic solvents.

Singh (2001) reported that additive gene effects were of prime importance for capsaicin in oleoresin and capsaicin in powder and these characters can be improved by selection in segregating generations. Muthuswamy (2004) observed additive, dominance and epistatic interaction for oleoresin.

Saritha *et al*., (2005) reported that variance for line x tester interaction was highly significant for ascorbic acid content, capsanthin and oleoresin contents which indicated the major role of non-additive gene action in the expression of these characters. Prasath and Ponnuswami (2008) reported the standard heterosis range from -9.43 % to 21.83 % for oleoresin.

Chaudhary *et al*., (2013) estimated a range of oleoresin content of 8.73 (%) to 12.33 (%) in chilli hybrids. Darshan (2014) reported the range among the hybrids 9.01 (%) to 18.08 (%) for oleoresin content.

2.3.3 Ascorbic Acid

Chilli is also among the richest known plant source of Vitamin C. It is the source for commercial preparation of vitamin C. Green chilli has the highest amount of Vitamin C, which decreases with maturity.

Bhagyalakshmi *et al*., (1991) crossed six chilli cultivars in a non-reciprocal half diallel and reported that cultivars ‘LCA960’, ‘LCA206’ and ‘G4’ were the best general combiners for ascorbic acid content. Pandey *et al.* (2002)

evaluated heterosis for ascorbic acid content in sweet pepper. Yolo Wonder x CW-51 exhibited the highest heterosis over the best parent (51.78%).

Srivastava *et al*., (2005) found greater role of non-additive gene action in the inheritance of vitamin C content and capsaicin percentage. Shekhawat *et al.*, (2007) revealed that the parents and F_1 crosses differed significantly for *gca* and *sca* effects for vitamin C.

Patel *et al*., (2010) observed the range for ascorbic acid content in heterobeltiosis and standard heterosis -45.11 to 21.1% and -22.82 to 59.07%, respectively.

Sharma *et al*., (2013) observed a high value of heterobeltiosis (30.89%) and standard heterosis (37.61%) for ascorbic acid content. Darshan (2014) reported the range among the hybrids 92.23 mg per 100 g to 207.49 mg per 100 g for ascorbic acid content.

Ahmed *et al.* (2015) recorded the maximum extent of significant positive heterobeltiosis for mature fruit ascorbic acid content (14.06%) and ripe fruit ascorbic acid content (17.56%) in sweet pepper.

2.3.4 Colour

The colour is one of the most important attributes of red chilli. The major red colour in chilli comes from capsanthin and capsorubin while the yellow-orange colour is from beta-carotene and violaxanthin but chlorophyll pigments is responsible for green colour. Colour is measured spectrophotometrically in ASTA (Amerian Spice Trade Association) units.

Nandadevi *et al*., (2003) reported that the both additive and non additive gene effects for capsaicin and fruit colour showed significant *sca* variance indicating importance of non-additive gene effect.

Dhall and Hundall (2005) reported colour value range from 190.47 ASTA units to 81.88 ASTA units. Savita (2005) reported a variation in colour value from 85.4 to 178.2 ASTA units.

Prasath (2005) reported that the heterosis for extractable colour, which ranged from -47.84 to 32.11% over better parent.

Prasath and Ponnuswami (2008) reported the standard heterosis range from -53.09 to 33.03 % for colour value and the parent P_4 (Arka Abir) was good general combiner for quality characters like total extractable colour, capsaicin and oleoresin content.

2.4 INCIDENCE OF PESTS AND DISEASES

2.4.1 Thrips

Chilli thrips, *Scirtothrips dorsalis* is serious pests of chilli (Ananthakrishnan, 1973) both in the nursery and main field. Adults and nymphs suck the sap from tender leaves and growing shoot. Affected leaves curl either upward due to thrips or downward due to mite feeding resulting in damage called ‘chilli leaf curl’. The overall reduction in yield of dry chilli ranges from 40 to 70 per cent due to the incidence of thrips and mites.

Scirtothrips dorsalis infestation results in upward curling of young top leaves in boat shaped manner and leaf lamina on both sides of the mid-rib becomes corrugated. Leaves become smaller, thickened and brittle. Stunting of plants occur due to severe infestation (Karmakar, 1995).

Kalaiyarasan *et al.,* (2002) showed that accession PS 64 recorded lower thrips population (0.47 and 0.81 thrips/leaf) in the field and in pot culture, respectively. Thrips infestation was lower in accessions PS 64, PS 69, PS 177, PS 166, PS 4, PS 171 and PS 173 in the range 12.9-17.4 per cent) compared to the other accessions.

Babu *et al.* (2002) screened 308 chilli varieties for resistance to chilli thrips and yellow mites and identified 17 promising types based on visual rating of leaf curl caused by thrips and mites. Most of the germplasm accessions reacted independently to leaf curl caused by thrips and mites. They found that one exotic entry (EC-391082, a paprika type) as resistant to leaf curl caused by both thrips and mites.

Jagadeesha *et al.,* (2004) estimated that thrips and mite resistance was under the control of dominance, additive × additive and additive × dominance gene effects. Jagadeesha and wali (2006) reported that nine crosses involving six parents having varied level of resistance were studied in a six generation mean anlysis. Leaf curl index (LCI) for thrips was found to be predominantely under the control of non additive gene action with duplicate type of gene interaction.

2.4.2 Mites

Polyphagotarsonemus latus is serious pests of chilli both in the nursery and main field. Feeding by the mites cause downward rolling of leaves, elongation of the petiole of older leaves and clustering of tender leaves at the tip of the branches and the growth of the plant is arrested.

Tatagar *et al*. (2001) screened 24 genotypes of chilli against thrips and mites to identify sources of resistance in chilli. Cultivars Pant C1, LCA-304 and LCA-312 were found to be promising sources of resistance against thrips and mites.

Khalid *et al*. (2001) screened 77 chilli cultivars to identify yellow mite resistance sources. Based on population count and damage index, these varieties were grouped into three categories (resistant, susceptible and highly susceptible). Nine cultivars namely, LCA235, LCA330, EC128946, cluster mutant, LIC19, LCA312, yellow anther mutant, LIC13 and LIC45 were considered as resistant.

Desai *et al.* (2006) screened 21 chilli genotypes against yellow mite and found ACG 77 to be promising on account of low pest population count and leaf curl intensity. Jagadeesha and wali (2006) reported that nine crosses involving six parents having varied level of resistance were studied in a six generation mean analysis. Non additive gene interaction was observed for LCI mites.

2.4.3 Bacterial Wilt

Bacterial wilt a soil-borne disease in capsicum caused by *Ralstonia solanacearum,* has become a serious problem in India (Gopalakrishnan and Peter, 1991). The drooping of leaves followed by wilting of the plants are the major symptoms. Vascular system discoloration and brown decay of the pith are associated symptoms.

The resistance of 53 *C. annuum* accessions to bacterial wilt was studied in Kerala (Fathima and Joseph, 2001). 15 accessions were found to be resistant. Robi (2003) studied the bacterial wilt resistance in 10 hot chilli accessions and found that one accession was resistant.

Lekshmi (2012) evaluated 53 accessions of paprika (Capsicum annuum L.) and reported that the accessions CA 33, CA 34, CA 35 and CA 47 recorded less incidences of bacterial wilt and leaf curl diseases.

Nsabiyera et al. (2013) reported that the exotic genotype PP0537-7504 was a significant general combiner for reducing wilt disease incidence.

2.4.4 Fruit Rot

Anthracnose is a major disease of chilli. Colletotrichum capsici generally infects ripe red fruit, while C. gloeosporioides infects both green and ripe fruits. Anthracnose is mainly a problem on mature fruits, causing both pre and post-harvest fruit decay resulting in severe economic losses. Ripe fruits turning red are affected. Green fruits are not spared once the disease starts in the field. A small, black, circular spot appears on the skin of the fruit and spreads in the direction of the long axis, thus becoming more or less elliptical.

Roy et al. (1998) evaluated 24 chilli genotypes for incidence of fruit rot based on percentage of fruits infected and found that none of the genotypes could be rated as resistant. However, six were moderately resistant (DC 1, DC 2, DC 3, DC 4, DC 14 and DC 24). Variety Phule

Sai (GCH-8) was reported to be moderately resistant to anthracnose (Jadhav et al., 2000).

Hegde and Anahosur (2001) screened 52 genotypes against fruit rot and found the cultivars LCA-301, LCA-324, K-1 and Byadagi Kaddi to be resistant. Variety Jiangshu No.4 was found to be resistant to fruit rot by Liu et al., (2001). Hybrid Xingla No.2 was reported to be resistant to fruit rot (Xio et al. 2001).

In an evaluation of chilli (Capsicum annuum L.) germplasm with ninety three genotypes for yield and resistance to anthracnose disease, three resistant donors Sin 1, Sin 2 and Sin 3 and five moderately resistant lines Arka Lohit, CC 4, KDC 1, Pepper Hot and Ujwala were chosen as potential parents to produce F1 hybrids with lesser anthracnose incidence and reasonably good fruit yield (Rani et al., 2007)

Susheela (2012) evaluated the existing methods of screening for resistance to chilli anthracnose. From the study on percentage incidence of anthracnose affected fruits under field conditions employing the spray inoculation were found to be the ideal method to identify resistant hybrids.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment entitled "Development of F_1 hybrids at chilli (*Capsicum annuum* L.) for commercial cultivation" was conducted at the Department of Olericulture, College of Agriculture, Vellayani, during the period 2014-15.

The experiment comprised of two parts.

Part 1: Production of F_1 hybrids

Part 2: Evaluation of F_1 hybrids

3.1 Part 1: PRODUCTION OF F_1 HYBRIDS

3.1.1 Materials

The materials for the study comprised of six parents, 15 hybrids and one standard check Arka Harita (IIHR). The six parents were selfed to produce the selfed seeds and these were crossed in a half diallel manner to produce 15 hybrids during 2014-15. The detailed description of parental lines and crosses are given in Tables 3 and 4 (Plate 1, 2 and 3).

Table 3. Details of parents used for hybridization.

SI. No.	Accession Number	Name of parents	Source
1	P_1	EC-391083 (CA 3)	NBPGR, Hyderabad
2	P_2	EC-596920(CA 5)	NBPGR, Hyderabad
3	P_3	EC-596940 (CA 6)	NBPGR, Hyderabad
4	P_4	EC-599969 (CA 8)	NBPGR, Hyderabad
5	P_5	Dharwad local-1 (CA 23)	Dharwad, Bangalore
6	P_6	Dharwad local-2 (CA 32)	Dharwad, Bangalore

Plate 1. Fruits of parents used in the hybridisation

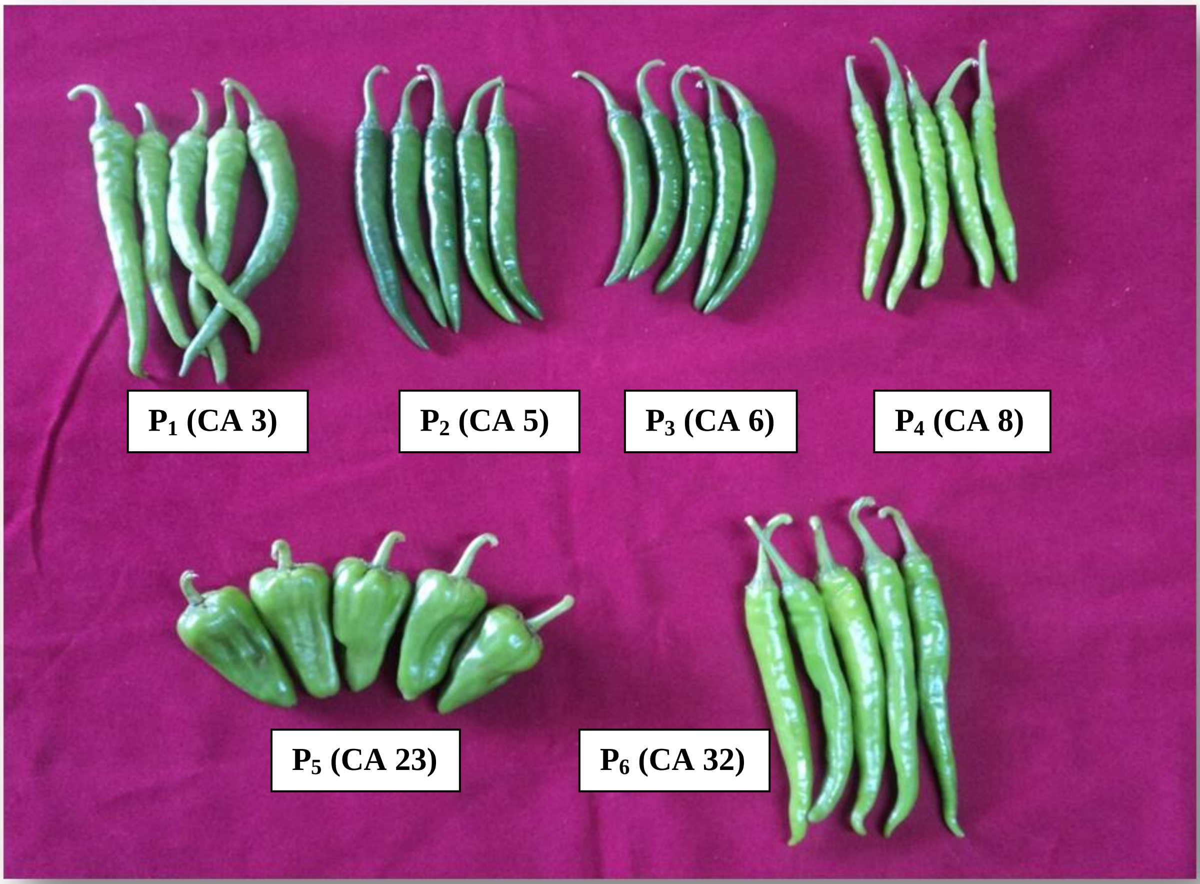


Plate 2. Parents used as experimental material

P_1 (CA 3)

P_2 (CA 5)

P_3 (CA 6)

P_4 (CA

P2

P_5 (CA 23)

P_6 (CA 32)

Table 4. Details of hybrids combination

SI. No.	Parents	Cross combinations
1	P_1 x P_2	CA 3 x CA 5
2	P_1 x P_3	CA 3 x CA 6
3	P_1 x P_4	CA 3 x CA 8
4	P_1 x P_5	CA 3 x CA 23
5	P_1 x P_6	CA 3 x CA 32
6	P_2 x P_3	CA 5 x CA 6
7	P_2 x P_4	CA 5 x CA 8
8	P_2 x P_5	CA 5 x CA 23
9	P_2 x P_6	CA 5 x CA 32
10	P_3 x P_4	CA 6 x CA 8
11	P_3 x P_5	CA 6 x CA 23
12	P_3 x P_6	CA 6 x CA 32
13	P_4 x P_5	CA 8 x CA 23
14	P_4 x P_6	CA 8 x CA 32
15	P_5 x P_6	CA 23 x CA 32
16	Check	Arka Harita

3.1.2 Selfing and crossing technique

In chilli, anthesis occurs between 8.00 to 11.00 a.m. Hence, well developed flower-buds likely to open next morning were emasculated during evening hours and bagged. On the next day morning (between 8 to 10 a.m.) emasculated buds were pollinated by the male parents. The pollinated buds were again bagged with paper bags and labeled. The mature crossed fruits were harvested and the seeds were collected separately from each cross. For maintenance of parental lines, flower buds of different parents were selfed by bagging the individual buds and properly tagged and later the seeds were collected from the mature fruits accordingly.

Plate 3. Development of F_1 hybrids

3.2 Part 2: EVALUATION OF F_1 HYBRIDS

3.2.1 Materials

Six parents, 15 hybrids and standard check Arka Harita were used for field experiment for the study of heterosis and combining ability.

3.2.2 Methods

3.2.2.1 Design and Layout

The experiment was laid out in randomized block design with 22 treatments in three replications. Thirty days old seedlings having 8-10 cm height were transplanted into the main field at a spacing of 45 x 45 cm.The crop received timely management practices as per package of practices recommendations of Kerala Agricultural University (KAU, 2011).

3.2.2.2 Biometric Observations

Five randomly selected plants were tagged in each treatment to record the observations and the average from these five plants was worked out for statistical analysis. To record dry fruit weight red ripe fruits were harvested and dried from randomly selected five plants from each treatment. Following are the observations recorded in this experiment.

3.2.2.3 Vegetative Characters

3.2.2.3.1 Plant Height (cm)

Plant height was recorded from the ground level to the top-most bud leaf of the plants at the time of peak harvest and presented in centimeters.

3.2.2.3.2 Primary Branches per Plant

Number of branches arising from the main stem was recorded at the peak harvest stage and average was worked out.

3.2.2.4 Flowering Characters

3.2.2.4.1 Days to First Flowering

Number of days from the date of transplanting to the first flowering of observational plants was recorded and the average obtained.

3.2.2.4.2 Days to First Harvest

Number of days from the date of transplanting to the first fruit harvest of observational plants was recorded and the average obtained.

3.2.2.5 Fruit and Yield Characters

3.2.2.5.1 Fruits per Plant

Total number of fruits produced per plant was counted.

3.2.2.5.2 Fruit Length (cm)

Five fruits were selected at random from the observational plants. Fruit length was measured as the distance from pedicel attachment of the fruit to the apex using twine and scale. Average was taken and expressed in centimeters.

3.2.2.5.3 Fruit Girth (cm)

Fruit girth was taken at broadest part from the fruits used for recording the fruit length. Average was taken and expressed in centimeters.

3.2.2.5.4 Fruit Weight (g)

Weight of fruits used for recording fruit length was measured and average was found out and expressed in grams.

3.2.2.5.5 Flesh Thickness (mm)

The thickness of fruit pericarp was measured and expressed in milli meters.

3.2.2.5.6 Flesh to Seed Ratio

The ratio between flesh weight and seed weight of fruit was recorded.

3.2.2.5.7 Seeds per Fruit

Seeds per fruit were counted in five fruits and average was taken.

3.2.2.5.8 Green Fruit Yield per Plant (g)

Weight of green fruits harvested from selected plants was recorded, average worked out and expressed in grams per plant.

3.2.2.5.9 Dry Fruit Yield per Plant (g)

Weight of dry fruits harvested from selected plants was recorded, average worked out and expressed in grams per plant.

3.2.2.5.10 Yield per Plot (kg)

The weight of fruits harvested from each plot was recorded.

3.2.2.5.11 Driage (%)

The driage of fruits was expressed in percentage as per the formula.

$$\text{Driage} = \frac{\text{Weight of dried fruit} \times 100}{\text{Weight of fresh fruit}}$$

3.2.2.6 Quality Characters

3.2.2.6.1 Capsaicin (%)

Capsaicin content of different accessions was determined by Folin-Dennis method. The pungent principle reacts with Folin-Dennis reagent to give a blue coloured complex which is estimated colorimetrically (Mathew *et al.*, 1971).

Reagents

i) Folin-Dennis reagent

Refluxed 750 ml distilled water, 100 g sodium tungstate, 20 g phosphomoloybdic acid and 50 ml phosphoric acid for two hours. Cooled and diluted to 1000 ml with distilled water.

ii) 25% aqueous sodium carbonate solution

iii) Acetone

Procedure

The fruits harvested at red ripe stage were dried in a hot air oven at 50^{o}C and powdered finely in a mixer grinder. 500 mg each of the sample was weighed into test tubes. Added 10 ml of acetone to it and kept overnight. Aliquot of 1ml was pipetted into 100 ml conical flask, added 25 ml of Folin-Dennis reagent and allowed to stand for 30 minutes. Added 25 ml of freshly prepared sodium carbonate solution and shook vigorously. The volume was made upto 100 ml with distilled water and the optical density was determined after 30 minutes at 725 nm against reagent blank (1 ml acetone + 25 ml Folin Dennis reagent + 25 ml aqueous sodium carbonate solution) using a UV spectrophotometer.

To determine the EI per cent value for pure capsaicin, a stock solution of standard capsaicin (200 µg ml^{-1}) was prepared by dissolving 20 mg in 100 ml acetone.From this a series of solutions of different concentrations (Prepared a standard curve using 0.5, 1.0, 1.5, 2.0 and 2.5ml of standard capsaicin solution containing 50, 100, 150, 200 and 250 µg capsaicin respectively) were prepared and their optical density measured at 725 nm. Standard graph was prepared and calculated capsaicin content in the samples.

3.2.2.6.2 Oleoresin (%)

Oleoresin in chilli was extracted in a Soxhlet's apparatus using solvent acetone (Sadasivam and Manickam, 1992).

Procedure

Chilli fruits harvested at red ripe stage were dried in a hot air oven at 50^{o}C and powdered finely in a mixer grinder. Weighed two grams of chilli powder and packed in filter paper and placed in Soxhlet's apparatus. 200 ml of acetone was taken in the round bottom flask of the apparatus and heated in a water bath. The temperature was maintained at the boiling point of the solvent (around 60^{o}C). After complete extraction (4 - 5hours) the solvent was evaporated to dryness.

Yield of oleoresin on dry weight basis was calculated using the formula

$$\text{Oleoresin (\%)} = \frac{\text{Weight of oleoresin}}{\text{Weight of sample}} \times 100$$

3.2.2.6.3 Ascorbic acid (mg per 100 g fresh fruit weight)

Ascorbic acid content of fruit was estimated by 2,6-dichlorophenol indophenol dye method (Sadasivam and Manickam, 1992).

Reagents

1. Oxalic acid (4 %)
2. Ascorbic acid standard

Stock solution was prepared by dissolving 100 mg of ascorbic acid in 100 ml of four per cent oxalic acid. 10 ml of this stock solution was diluted to 100 ml with four per cent oxalic acid to get working standard solution.

3. 2, 6-dichlorophenol indophenol dye

Forty two mg sodium bicarbonate was dissolved in a small volume of distilled water. 52 mg of 2,6-dichlorophenol indophenol was added into this and made up to 200 ml with distilled water.

4. Working standard

Diluted 10 ml of stock solution to 100 ml with 4% oxalic acid. The concentration of working standard is 100 mg per ml.

Procedure

Pippeted out 5 ml of the working standard solution into a 100 ml conical flask and added 10 ml of 4% oxalic acid. Titrated it against the dye (V_1 ml). End point is the appearance of pink colour which persisted for at least 5 seconds.

Five g of fresh fruit was extracted in four per cent oxalic acid medium, filtered the extract and volume was made upto 100 ml using oxalic acid. From this five ml of aliquat was taken, added 10 ml of four % oxalic acid and titrated as above against the dye and determined the endpoint (V_2 ml).

Ascorbic acid content of the sample was calculated using the formula

$$\text{Amount of ascorbic acid in mg/100g sample} = \frac{0.5 \times V_2 \times 100 \times 100}{V_1 \times 5 \times \text{Weight of sample}}$$

3.2.2.6.4 Colour

Red ripe chillies were dried and the stalk and seeds were removed before powdering. 0.1 g of ground chilli powder was transferred into a 250 ml Erlenmeyer flask with 100 ml isopropanol and kept overnight at room temperature. The contents were filtered through a Whatman No. 42 filter paper. The first 10 ml was discarded and 25 ml of the filtrate was pipetted into a volumetric flask and diluted to the mark with isopropanol. The absorbance was read at 450 nm against isopropanol as blank. Standard colour solution was prepared by dissolving 0.5 mg per ml of reagent grade potassium dichromate in 1.8M sulphuric acid.

$$\text{Colour value (ASTA units)} = \frac{\text{Absorbance of sample at 450 nm x 200}}{\text{Absorbance of standard solution at 450 nm}}$$

Extractable colour in ASTA units

3.2.2.7 Incidence of pests and diseases.

. Bacterial wilt and fruit rot disease were the major problems during the study. Bacterial wilt was observed and the number of wilted plants were recorded. Fruit rot was observed and recorded the number of fruits infected per plant. Among the pests, thrips and mites were found to be major problems during the study. Based on visual symptoms scoring was done.

3.2.2.7.1 Thrips and Mites.

The scoring was based on 0 to 4 scale (Table 6). The plant damage was recorded based on visual score of the characteristic symptom of each observational plant. The observation was taken at 30^{th}, 60^{th} and 90^{th} days after planting (DAT).

Percentage damage index (PDI) of thrips and mites were calculated using the formula

$$\text{PDI/LCI} = \frac{\text{Sum of grades of plant} \quad \text{x} \quad 100}{\text{Total number of plants assessed x Maximum damage category}}$$

Table 5. Scoring procedure for sucking pest thrips and mites

Score	Symptoms
0	No symptom
1	1 to 25% leaves per plant showing curling or damage
2	26 to 50% leaves per plant showing curling – moderately damaged
3	51 to 75% leaves per plant showing curling, heavily damaged, malformation of growing points, and reduction in plant height.
4	>75% leaves per plant showing curling, severe and complete destruction of growing points, drastic reduction in plant height, defoliation and severe malformation

3.2.2.7.2 Bacterial wilt

Daily observation of plants was done for incidence of bacterial wilt and recorded the number of plants wilted per plot.

3.2.2.7.3 Fruit rot

Daily observation of plants was done for incidence of fruit rot and scoring of the disease was done using the 0 - 4 scale developed by Vishwakarma and Sitaramaiah (1986). Scoring chart was described as in Table 5.

Percentage disease index (PDI) of fruit rot was calculated using the formula developed by Mc Kinney 1923.

$$\text{PDI} = \frac{\text{Sum of individual rating} \times 100}{\text{Total number of fruit assessed} \times \text{Maximum disease category}}$$

Table 6. Disease scale for scoring fruit rot of chilli

Score	Symptoms
0	No symptom
1	1 to 5 % fruit infected
2	6 to 25 % fruit infected
3	26 to 50 % fruit infected
4	51 - 100 % fruit infected

3.2.3 Statistical analysis

3.2.3.1 Analysis of Variance

Analysis of variance (ANOVA) for individual character was carried out on the basis of mean value per entry per replication as suggested by Panse and Sukhatme (1967) for Randomized Block Design (RBD). The model of analysis of variance is as given below.

ANOVA for each character

Source	**d.f.**	**Mean squares**	**Expectation of mean squares**
Replications	(r-1)	M_r	$\sigma^2e + g\ \sigma^2r$
Genotypes	(g-1)	M_g	$\sigma^2e + r\ \sigma^2g$
Parents	(p-1)	M_p	
Hybrids	(h-1)	M_h	
Parents Vs. hybrids	1	M_pVs. M_h	
Error	(r-1) (g-1)	M_e	σ^2e

Where,

r = number of replications

g = number of genotypes

p = number of parents

h = number of hybrids

Significance of the treatments was tested at 5 and 1 per cent level of probability.

3.2.3.2 Test of Significance

Test of significance for various components was carried out by ‘F’ test. The ‘F’ values were calculated as under.

$$\text{Genotypes} = \frac{M_g}{M_e}$$

$$\text{Parents} = \frac{M_p}{M_e}$$

$$\text{Hybrids} = \frac{M_h}{M_e}$$

$$\text{Parents vs. hybrids} = \frac{M_{p\ vs}M_h}{M_e}$$

M_g= mean squares of genotypes

M_p= mean squares of parents

M_h=mean squares of hybrids

M_e = mean squares of error

3.2.3.3 Critical Difference of the Estimates

To test the significance of differences of the estimates, critical difference is calculated as.

$$\text{S. E. D} = \sqrt{\frac{2M_e}{r}} \quad \text{and S.E.M} = \sqrt{\frac{M_e}{r}}$$

C. D. = S. E. D x t

Where,

t = Table‘t’ value for error degree of freedom at 0.01 and 0.05 levels of probability.

3.2.3.4 Co-efficient of Variation

The co-efficient of variation for each character was calculated as under,

$$C.V.\% = \frac{\sqrt{M_e}}{\overline{X}} x100$$

Where,

M_e = error mean square

$\overline{X}$ = general mean for the character

3.2.4 Heterosis

The magnitude of heterosis was estimated as percentage increase or decrease of F_1s over the mid parent (MP), better parent (BP) and standard check (Arka Harita). Estimation of heterosis was carried out following the methods suggested by Turner (1953) and Hayes *et al.* (1955).

Mid parent value (MP) = $\frac{P_1 + P_2}{2}$

a) Heterosis over mid parent (MP) $= \frac{F_1 - \overline{MP}}{\overline{MP}} \text{ x } 100$ (**Relative heterosis**)

Where,

$\overline{MP}$ = Mean performance of parent P_1 and P_2

$\overline{F_1}$ = Mean performance of hybrid

b) Heterosis over better parent (BP) $= \frac{F_1 - \overline{BP}}{\overline{BP}} \text{ x } 100$ (**Heterobeltiosis)**

Where,

$\overline{BP}$ = Mean performance of better parent

$\overline{F_1}$ = Mean performance of F_1 hybrid

c) Heterosis over standard check (SC) = $\frac{F_1 - \overline{SC}}{\overline{SC}}$ x 100 (**Standard heterosis)**

Where,

$\overline{SC}$ = Mean performance of standard check

3.2.4.1 Test of Significance

Test of significance was done by comparing the mean deviation with values of critical difference (CD) obtained separately for MP, BP and SC by using the following formula.

Mean deviation for heterosis over MP = $\sqrt{\frac{3 \text{ x mse}}{2r}}$ x't' value

Mean deviation for heterosis over BP & SC = $\sqrt{\frac{2 \text{ x mse}}{r}}$ x 't' value

Where,

r = Number of replications

t = Table value of 't' at error degree of freedom at 0.01 and 0.05 levels of probability

m.s.e = Error mean sum of squares

3.2.5 Combining ability Analysis

Combining ability analysis was performed with the data obtained for parents and hybrids according to Model-I, Method-II proposed by Griffing (1956).This includes partitioning of variation among sources attributable to genenral combining ability (*gca*) and specific combining ability (*sca*) components. The analysis of variance for the combining ability is based on the following statistical model.

$Y_{ijk} = \mu + g_i + g_j + s_{ij} + \varepsilon_{ij}$

Where,

Y_{ijk} = mean value of hybrid involving i^{th} and j^{th} parent in k^{th} replication

μ = general mean

g_i = *gca* effect of i^{th} parent

g_j = *gca* effect of j^{th} parent

s_{ij} = *sca* effect for the cross between i^{th} and j^{th} parents such that $s_{ij} = s_{ji}$

ε_{ij}= uncontrolled variation associated with ijk^{th} observation

i, j = 1,2,………p (p = number of parents)

k = 1,2,………b (b = number of blocks)

The form of ANOVA for combining ability and expectation of mean square are given in Table 3.3.

Analysis of variance for combining ability

Source	**d.f.**	**S.S.**	**M.S.**	**Expectation of mean squares**
GCA	(p -1)	S_g	M_g	$\sigma^2 e + \frac{(p+2)}{(p-1)} \sum_i g^2{}_i$
SCA	$\frac{p(p-1)}{2}$	S_s	M_s	$\sigma^2 e + \frac{2}{p(p-1)} \sum_i \sum_j s^2{}_{ij}$
Error	(r-1)(g-1)	S_e	M_e	$\sigma^2{}_e$

Sum of squares due to various sources were calculated as follow:

$$S_g = \frac{1}{(p+2)}\left[\left(\sum_i (Xi. + Xii)^2\right) - \frac{4}{p} X^2 \ldots\right]$$

$$S_s = \sum_i \sum_j X^2{}_{ij} - \frac{1}{(p+2)} \sum (Xi. + Xii)^2 + \frac{2}{(p+1)(p+2)} X^2..$$

S_g= Sum of square due to general combining ability

S_s= Sum of square due to specific combining ability

p= number of parents

$X_{i.}$ = mean value of i^{th} parent

X.. = grand total of all the progenies and parental mean values

M_e = error mean square (M_e /r)

Further, the components of variance determining the additive and non-additive gene actions were computed using the following formula.

$$\sigma^2 gca = \frac{M_g - M_e}{p+2}$$

$$\sigma^2 sca = M_s - M_e$$

Where,

M_g = mean sum of square due to *gca* effect

M_s = mean sum of square due to *sca* effect

$M_e = M_e / b$ = error mean square

3.2.5.1 Test of Significance of Combining ability

The error mean square for combining ability (M_e) was obtained by dividing error mean square (M_e) in ANOVA for each character by number of replications.

The following F ratios were used to test *gca* and *sca* variances

gca mean square : F = M_g / M_e

*sca*mean square : F = M_s / M_e

3.2.5.2 Estimation of General and Specific Combining ability Effects

The general and specific combining ability effects were estimated as under

$$\text{Population mean } (\mu) = \frac{2}{p\,(p+1)} Y..$$

$$gca \text{ effect } = (g_i) = \frac{1}{(p+2)} (\Sigma(Yi. + Yii) \; - \frac{2}{p} Y..)$$

$$sca\text{effect} = (s_{ij}) = Y_{ij} - \frac{1}{(p+2)} (Y_{i.} + Y_{ii} + Y_{.j} + Y_{jj}) + \frac{2}{(p+1)(p+2)} Y..$$

Where,

p = number of parents

g_i = general combining ability effect of i^{th} parent

s_{ij}= specific combining ability effect of the

Cross involving i^{th} and j^{th} parents

$Y_{i.}$ = total of array involving i^{th} parent

$Y_{.j}$ = total of array involving j^{th} parent

Y_{ii} = parental value of the i^{th} parent

Y_{jj} = parental value of the j^{th} parent

$Y...$ = Total of all $\frac{p\,(p+1)}{2}$ items of the diallel table

Various standard errors required to test the significance of *gca* and *sca* effects and differences between them are calculated as

$$S.E.(g_i) = \sqrt{\frac{(p-1)}{p\,(p+2)} M_e}$$

$$S.E.(s_{ij}) = \sqrt{\frac{(p^2+p+2)}{(p+1)\,(p+2)} M_e}$$

3.2.5.3 Test of Significance

The‘t’ test was used to test the significance of individual *gca* and *sca*effects as under.

To test $g_i : t = \frac{|\,g_i\,|}{S.E.(g_i)}$

To test $s_{ij} : t = \frac{|\,s_{ij}\,|}{S.E.(s_{ij})}$

To test the significance of differences of two estimates, critical differences (CD) was calculated as product of the‘t’ for error degree of freedom and the standard error of difference of two estimates.

RESULTS

4. RESULTS

The results obtained from the present study entitled “Development of F_1 hybrids in chilli (*Capsicum annuum* L.) for commercial cultivation” are presented here under the following headings. Field view of this experiment was given in Plate 4.

1. Analysis of variance for experimental design
2. Mean performance of parents and hybrids
3. Estimation of heterosis
    a) Relative heterosis (RH)
    b) Heterobeltiosis (HB)
    c) Standard heterosis (SH)
4. Combining ability analysis
    a) Analysis of variance for combining ability
    b) Estimates of combining ability (*gca* and *sca*) effects
5. Gene action

4.1 ANALYSIS OF VARIANCE FOR EXPERIMENTAL DESIGN

. Analysis of variance revealed that, significant difference among the treatment for all the traits studied. Variance due to parents was significant for all characters except primary branches per plant, days to first flowering, days to first harvest and driage. The parents vs. hybrids showed significant differences for all the traits except flesh thickness and driage for this study (Table 7). This indicated that materials used for present investigation had adequate diversity for different traits.

4.2 MEAN PERFORMANCE OF PARENTS AND HYBRIDS

The mean values of parents and hybrids for biometric characters are presented in Table 8 and the fruits of different hybrid combinations were given in Plate 5. The performance of hybrids has been compared with check for different

Plate 4. Evaluation of F_1 hybrids and parents (Field view)

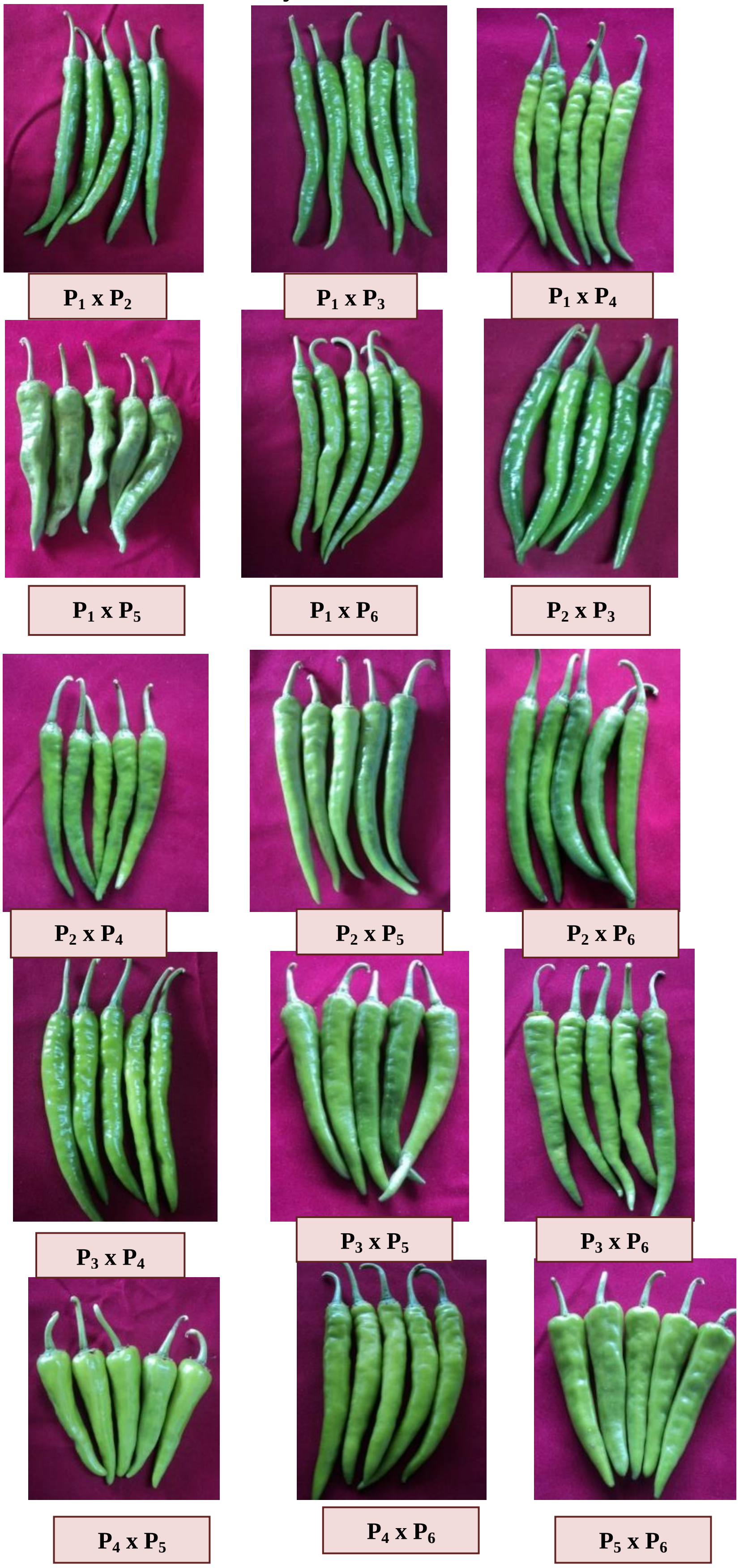
Table 7. Diallel cross ANOVA summary

Source of variation	d.f	Plant height (cm)	Primary branches/plant	Days to first flowering	Days to first harvest	Fruits/ plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Flesh thickness (mm)
Replication	2	10.39	0.23	5.79	1.52	74.58	1.58	0.10	0.069	0.009
Treatments	20	114.45 **	0.82 **	19.28 **	47.43 **	2775.72 **	10.42 **	4.69 **	12.68 **	0.32 **
Parents	5	113.93 **	0.32	3.17	4.08	1612.66 **	26.78 **	9.86 **	12.82 **	0.56 **
Hybrids	14	103.75 **	0.97 **	19.96 **	59.28 **	2615.83 **	3.65 **	3.10 **	13.24 **	0.26 **
Parents Vs. Hybrids	1	266.90 **	1.19 **	90.40 **	98.25 **	10829.43 **	23.39 **	1.21 **	4.02 *	0.01
Error	40	9.42	0.16	1.89	1.73	52.07	0.96	0.10	0.90	0.01

Source of variation	d.f	Flesh to seed ratio	Seeds/ fruit	Green fruit yield/plant (g)	Dry fruit yield/plant (g)	Yield/plot (kg)	Driage (%)	Capsaicin (%)	Oleoresin (%)	Ascorbic acid (mg/100g)	Colour (ASTA units)
Replication	2	0.44	218.11	850.40	14.481	10.213	5.29	0.000	0.17	10.85	127.99
Treatments	20	6.35 **	579.78 **	149841.70 **	3157.76 **	124.92 **	10.20 **	0.008 **	49.27 **	1154.92 **	1336.57 **
Parents	5	9.56 **	573.03 *	31181.25 **	1395.08 **	40.89 **	3.96	0.001 **	10.73 **	535.82 **	1112.76 **
Hybrids	14	5.27 **	472.87 *	133129.40 **	2676.44 **	91.95 **	12.94 **	0.01 **	59.64 **	1421.95 **	1276.75 **
Parents Vs. Hybrids	1	5.41 **	2110.17 **	977116.30 **	18709.63 **	1006.72 **	2.90	0.01 **	96.84 **	512.01 **	3293.02 **
Error	40	0.52	199.61	1438.86	5.191	3.63	2.66	0.00	1.11	40.54	48.82

*Significant at 5 per cent level **Significant at 1 per cent level

Plate 5. Fruits of different hybrid combinations



characters. The salient features for each character are described in ensuing paragraphs.

4.2.1 Plant Height (cm)

Plant height ranged from 42.57cm (P_5) to 60.74 cm (P_6) for parents. The minimum plant height was recorded in P_1 x P_5 (36.97 cm). The tallest hybrid was P_5 x P_6 (63.04 cm) followed by P_3 x P_5 (59.67 cm) and P_2 x P_6 (59.17 cm).

4.2.2 Primary Branches per Plant

The primary branches per plant for parents ranged from 3.20 (P_5) to 4.10 (P_4). Among hybrids the range was 2.10 (P_1 x P_5) to 4.60 (P_3 x P_6).

4.2.3 Days to First Flowering

Among parents, P_1 (26.86) was the earliest for flowering and P_3 (29.73) was the latest for flowering. Among hybrids earliest flowering was observed in P_5 x P_6 (23.13) and delayed flowering was observed in P_1 x P_5 (32.80).

4.2.4 Days to First Harvest

Among parents, earliest harvest was recorded in P_1 (46.93) and the latest harvest was observed in P_5 (50.00). Among hybrids P_2 x P_6 (41.13) took the minimum days for harvest and the latest harvest was observed in P_1 x P_5 (60.73).

4.2.5 Fruits per Plant

Among parents, fruits per plant ranged between 39.33 (P_5) and 109.00 (P_4). Among hybrids, the maximum fruits per plant was observed in P_3 x P_4 (147.33) followed by P_4 x P_6 (141.66), P_3 x P_5 (137.00) and P_4 x P_5 (128.66). It was minimum in P_1 x P_5 (20.66).

4.2.6 Fruit Length (cm)

The longest fruit was produced by the parent P_1 (15.21cm) and shortest fruit was recorded in P_5 (6.30 cm). Fruit length of hybrids ranged from 10.96 cm (P_1 x P_5) to 14.46 cm (P_1 x P_6).

Table 8. Mean values of 6 parents and 15 hybrids for biometric characters.

Parents and crosses	Plant height (cm)	Primary branches/ plant	Days to first flowering	Days to first harvest	Fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Flesh thickness (mm)
P_1	47.42	3.20	26.86	46.93	88.66	15.21	5.36	10.99	2.30
P_2	50.26	3.60	29.26	47.80	91.00	11.08	4.64	7.93	2.14
P_3	50.15	3.50	29.73	49.73	79.66	10.86	4.73	7.44	2.14
P_4	46.31	4.10	28.35	48.20	109.00	11.41	4.53	6.76	1.95
P_5	42.57	3.20	29.20	50.00	39.33	6.30	9.28	11.21	3.18
P_6	60.74	3.50	29.13	48.66	78.33	13.33	5.35	11.07	2.46
P_1 x P_2	53.65	4.40	29.00	46.26	109.33	13.20	4.61	8.68	2.12
P_1 x P_3	50.02	3.80	26.53	44.46	101.00	13.60	4.67	9.55	2.25
P_1 x P_4	52.59	4.00	27.00	45.20	116.33	12.87	3.88	6.34	2.14
P_1 x P_5	36.97	2.10	32.80	60.73	20.66	10.96	7.18	11.53	3.21
P_1 x P_6	53.34	3.30	27.06	46.20	97.00	14.46	5.20	11.17	2.40
P_2 x P_3	55.37	3.70	28.53	47.40	97.66	11.09	4.55	7.55	2.19
P_2 x P_4	51.80	3.80	24.33	44.33	119.33	12.42	4.59	7.91	2.08
P_2 x P_5	53.73	3.80	25.20	45.23	102.33	13.11	6.37	11.64	2.40
P_2 x P_6	59.17	3.90	23.20	41.13	117.00	12.82	5.22	10.51	2.10
P_3 x P_4	58.55	3.60	23.93	43.46	147.33	11.56	4.55	7.02	2.09
P_3 x P_5	59.67	4.20	26.53	46.53	137.00	13.28	5.33	11.16	2.34
P_3 x P_6	56.20	4.60	24.73	44.60	114.66	13.54	5.26	9.87	2.32
P_4 x P_5	52.71	3.80	24.20	44.22	128.66	10.98	6.61	9.61	2.49
P_4 x P_6	55.15	4.20	25.40	45.50	141.66	13.98	4.96	9.97	2.10
P_5 x P_6	63.04	4.10	23.13	42.10	100.33	12.83	7.15	14.43	2.63
Check	72.31	4.80	31.66	52.13	186.00	8.49	3.44	3.52	1.54
S.E.M	1.77	0.22	0.79	0.74	4.73	0.55	0.18	0.53	0.08
CD 5%	5.062	0.648	2.262	2.125	13.502	1.590	0.524	1.531	0.232
CV (%)	5.71	10.32	5.07	2.75	7.76	7.93	5.95	9.92	6.11

Parents and crosses	Flesh to seed ratio	Seeds per fruit	Green fruit yield/plant (g)	Dry fruit yield/plant (g)	Yield/plot (kg)	Driage (%)	Capsaicin (%)	Oleoresin (%)	Ascorbic acid (mg/100g)	Colour (ASTA units)
P_1	6.93	103.00	574.26	93.71	14.29	23.26	0.23	15.00	130.27	117.18
P_2	3.55	109.00	484.96	70.29	10.10	22.07	0.23	13.00	154.00	120.87
P_3	3.41	124.00	445.31	71.11	8.96	21.67	0.21	15.00	133.33	142.10
P_4	4.35	83.66	520.07	80.63	10.96	23.11	0.22	13.00	154.00	157.89
P_5	4.55	116.33	311.20	39.47	6.07	20.86	0.18	11.66	120.90	114.34
P_6	7.65	103.00	590.02	100.48	16.30	23.95	0.23	16.50	141.66	155.00
P_1 x P_2	6.69	122.33	779.86	111.06	20.23	22.59	0.36	11.83	164.33	146.64
P_1 x P_3	4.88	120.66	689.40	103.92	16.84	21.37	0.28	23.50	156.00	151.35
P_1 x P_4	4.52	105.66	628.70	103.38	17.78	23.43	0.25	20.33	116.65	160.64
P_1 x P_5	7.06	99.66	177.66	20.01	3.04	18.94	0.18	12.33	115.33	119.49
P_1 x P_6	7.12	147.33	744.15	109.26	20.92	23.52	0.20	17.66	93.41	167.34
P_2 x P_3	3.86	113.66	558.78	91.06	16.33	21.40	0.31	11.33	147.91	161.62
P_2 x P_4	4.40	114.66	684.93	117.57	18.31	20.16	0.22	13.16	133.33	156.36
P_2 x P_5	6.25	131.00	861.39	134.78	23.21	23.60	0.16	13.33	120.50	197.96
P_2 x P_6	6.13	116.00	822.66	130.00	22.44	26.05	0.28	20.16	156.25	162.31
P_3 x P_4	4.33	115.66	754.15	128.48	20.14	22.69	0.25	25.50	129.16	157.18
P_3 x P_5	6.93	126.33	993.60	139.89	24.59	25.32	0.20	15.66	104.08	179.92
P_3 x P_6	6.22	129.00	910.93	119.63	21.68	22.96	0.27	15.50	141.33	167.23
P_4 x P_5	4.47	99.00	877.80	129.11	23.41	22.41	0.21	13.50	112.43	143.23
P_4 x P_6	4.79	121.33	917.47	139.72	24.18	26.81	0.32	20.33	158.33	169.63
P_5 x P_6	8.17	127.33	1048.21	133.52	26.34	23.20	0.20	19.50	141.68	117.18
Check	2.80	69.66	663.84	114.18	15.91	24.85	0.28	14.00	125.00	185.56
S.E.M	0.41	7.98	21.73	1.29	1.08	0.93	0.007	0.59	3.58	3.97
CD 5%	1.173	22.795	62.033	3.701	3.085	2.657	0.0215	1.711	10.242	11.345
CV(%)	13.14	12.18	5.50	2.16	10.78	7.03	5.35	6.47	4.63	4.46

4.2.7 Fruit Girth (cm)

Fruit girth was maximum for the parent P_5 (9.28 cm) and the minimum for P_4 (4.53 cm). The hybrids with maximum and minimum fruit girth were observed in P_1 x P_5 (7.18 cm) and P_1 x P_4 (3.88 cm) respectively.

4.2.8 Fruit Weight (g)

The fruit weight among the parents ranged from 6.76 g (P_4) to 11.21 g (P_5). The hybrids showed a variation from 6.34 g (P_1 x P_4) to 14.43 g (P_5 x P_6).

4.2.9 Flesh Thickness (mm)

The flesh thickness among the parents ranged from 1.95 mm (P_4) to 3.18 mm (P_5). The hybrids showed a variation from 2.08 mm (P_2 x P_4) to 3.12 mm (P_1 x P_5).

4.2.10 Flesh to Seed Ratio

The flesh to seed ratio among the parents ranged from 3.41 (P_3) to 7.65 (P_6). The hybrids showed a variation from 3.86 (P_2 x P_3) to 8.17 (P_5 x P_6).

4.2.11 Seeds per Fruit

Among the parents maximum seeds per fruit was produced in P_3 (124.00) and minimum number was noticed in P_4 (83.66). Maximum seeds per fruit among hybrids was observed in P_1 x P_6 (147.33) which was on par with P_2 x P_5 (131.00), P_3 x P_6 (129.00) and P_5 x P_6 (127.33). The minimum seeds per fruit was observed in hybrid P_4 x P_5 (99.00).

4.2.12 Green Fruit Yield per Plant (g)

The parent P_6 recorded the maximum green fruit yield per plant 590.00 g and P_5 recorded the minimum 311.20 g. The hybrid P_5 x P_6 recorded maximum green fruit yield per plant (1048.21 g) which was on par with P_3 x P_5 (993.60 g). Other high yielding hybrids were P_4 x P_6 (917.47 g), P_3 x P_6 (910.93 g), P_4 x P_5 (877.80 g), P_2 x P_5 (861.39 g) and P_2 x P_6 (822.66 g) and yield was lowest for P_1 x P_5 (177.66 g).

4.2.13 Dry Fruit Yield per Plant (g)

The parent P_6 recorded the maximum dry fruit yield per plant 100.48 g and P_5 recorded the minimum 39.47 g. The hybrid P_3 x P_5 recorded maximum dry fruit yield per plant 139.89 g which was on par with P_4 x P_6 (139.72 g). Other high yielding hybrids were P_2 x P_5 (134.78 g), P_5 x P_6 (133.52 g), P_2 x P_6 (130.00 g) and P_4 x P_5 (129.11g) while yield was lowest in P_1 x P_5 (20.01 g).

4.2.14 Yield per Plot (kg)

The parent P_6 recorded the maximum yield per plot (16.30 kg) and it was minimum for P_5 (6.07 kg). The hybrid P_5 x P_6 recorded maximum yield per plot (26.34 kg) which was on par with P_3 x P_5 (24.59 kg) and P_4 x P_6 (24.18 kg). Other high yielding hybrids were P_4 x P_5 (23.41 kg) P_2 x P_5 (23.21 kg) and P_2 x P_6 (22.44 kg) while yield was lowest in P_1 x P_5 (3.04 kg).

4.2.15 Driage (%)

The maximum driage percentage was observed in parent P_6 (23.95%) and minimum in P_5 (20.86%). Among the hybrids maximum driage was observed in P_4 x P_6 (26.81%) followed by P_2 x P_6 (26.05%). The minimum driage percentage was noticed in P_1 x P_5 (18.94%).

4.2.16 Capsaicin (%)

The parents $P_{1,}$ P_2 and P_6 recorded the maximum capsaicin (0.23%) and P_5 recorded minimum (0.18%). The hybrids showed a variation from 0.16% (P_2 x P_5) to 0.36% (P_1 x P_2).

4.2.17 Oleoresin (%)

The oleoresin among the parents ranged from 11.66 % (P_5) to 16.50 % (P_6). The hybrids showed a variation from 11.33 % (P_2 x P_3) to 25.50 % (P_3 x P_4).

4.2.18 Ascorbic Acid (mg/100 g)

The ascorbic acid among the parents ranged from 120.90 mg/100 g (P_5) to 154 mg/100 g (P_4). The hybrids showed a variation from 93.41 mg/100 g (P_1 x P_6) to 158.33 mg/100 g (P_4 x P_6).

4.2.19 Colour (ASTA units)

The colour value among the parents ranged from 114.34 ASTA units (P_5) to 157.89 ASTA units (P_4). The hybrids showed a variation from 117.18 ASTA units (P_5 x P_6) to 197.96 ASTA units (P_2 x P_5).

4.3 ESTIMATION OF HETEROSIS

The magnitude of heterosis, estimated as per cent increase or decrease of F_1 value over mid-parent (RH), better parent (HB) and standard check (SH) for various characters were presented in Tables 9 to 14. The character wise results are summarized in the following paragraphs.

4.3.1 Plant Height (cm)

Among 15 hybrids, eight hybrids exhibited significant positive heterosis and one hybrid showed negative heterosis over mid parent respectively. The magnitude of heterosis over mid parent ranged between -17.84% (P_1 x P_5) to 28.72% (P_3 x P_5). Heterobeltiosis for plant height ranged from -22.04% (P_1 x P_5) to 18.99% (P_3 x P_5). Among 15 hybrids, three hybrids showed significant positive and three hybrids significant negative heterosis over better parent respectively. Fifteen hybrids showed significant desirable heterosis over standard check.

4.3.2 Primary Branches per Plant

The magnitude of heterosis ranged between -34.02% (P_1 x P_5) to 30.19% (P_3 x P_6) over mid parent and -34.69% (P_1 x P_5) to 30.19% (P_3 x P_6) over better parent, respectively. Most of the hybrids showed non significant heterosis over mid and better parents. None of the hybrids showed possitive heterosis over standard check.

Table 9. Heterosis (%) for plant height, primary branches per plant and days to first flowering

Crosses	Plant height (cm)			Primary branches per plant			Days to first flowering		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1 x P_2	9.85 *	6.74	-25.80 **	29.41 **	22.22 *	-9.59	3.33	-0.91	-8.42 *
P_1 x P_3	2.53	-0.25	-30.82 **	14.85	9.43	-20.55 **	-6.24	-10.76 **	-16.21 **
P_1 x P_4	12.21 *	10.89	-27.27 **	9.09	-3.23	-17.81 *	-2.20	-4.76	-14.74 **
P_1 x P_5	-17.84 **	-22.04 **	-48.87 **	-34.02 **	-34.69 **	-56.16 **	17.00 **	12.33 **	3.58
P_1 x P_6	-1.37	-12.18 **	-26.23 **	-0.99	-5.66	-31.51 **	-3.33	-7.09	-14.53 **
P_2 x P_3	10.29 *	10.17	-23.42 **	4.67	3.70	-23.29 **	-3.28	-4.04	-9.89 **
P_2 x P_4	7.28	3.06	-28.36 **	0.00	-6.45	-20.55 **	-15.53 **	-16.86 **	-23.16 **
P_2 x P_5	15.77 **	6.91	-25.68 **	12.62	7.41	-20.55 **	-13.80 **	-13.90 **	-20.42 **
P_2 x P_6	6.61	-2.58	-18.17 **	10.28	9.26	-19.18 **	-20.55 **	-20.73 **	-26.74 **
P_3 x P_4	21.40 **	16.76 **	-19.02 **	-6.09	-12.90	-26.03 **	-17.59 **	-19.51 **	-24.42 **
P_3 x P_5	28.72 **	18.99 **	-17.47 **	23.53 **	18.87	-13.70	-9.95 **	-10.76 **	-16.21 **
P_3 x P_6	1.36	-7.48	-22.28 **	30.19 **	30.19 **	-5.48	-15.97 **	-16.82 **	-21.89 **
P_4 x P_5	18.61 **	13.82 *	-27.10 **	2.70	-8.06	-21.92 **	-15.90 **	-17.12 **	-23.58 **
P_4 x P_6	3.03	-9.21 *	-23.73 **	11.30	3.23	-12.33	-11.63 **	-12.81 **	-19.79 **
P_5 x P_6	22.04 **	3.79	-12.81 **	21.57 *	16.98	-15.07 *	-20.69 **	-20.78 **	-26.95 **

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

4.3.3 Days to First Flowering

Among 15 hybrids, nine hybrids showed significant negative relative heterosis. The hybrid P_5 x P_6 (-20.69%) showed earliness in flowering over mid parent followed by P_2 x P_6 (-20.55%). Ten hybrids showed significant negative heterobeltiosis. The hybrid P_5 x P_6 (-20.78%) showed earliness in flowering over better parent followed by P_2 x P_6 (-20.73%). Fourteen hybrids recorded significant negative heterosis over the standard check. The hybrid P_5 x P_6 (-26.95%) showed earliness in flowering followed by P_2 x P_6 (-26.74%).

4.3.4 Days to First Harvest

The estimates of relative heterosis revealed that out of 15 hybrids, 11 hybrids had significant and negative heterosis over mid parent for days to first harvest. The relative heterosis ranged from -14.72% (P_2 x P_6) to 25.31% (P_1 x P_5). Heterobeltiosis for days to first harvest ranged from -15.80% (P_5 x P_6) to 21.47% (P_1 x P_5). Thirteen hybrids had significant negative heterobeltiosis while 14 hybrids exhibited significant negative heterosis over standard check. The estimates of standard heterosis varied from -21.10% (P_2 x P_6) to 16.50% (P_1 x P_5).

4.3.5 Fruits per Plant

Among the 15 hybrids, 14 hybrids showed positive heterosis over mid parent with maximum heterosis of 130.25% (P_3 x P_5). Heterosis over better parent ranged from -76.69% (P_1 x P_5) to 71.97% (P_3 x P_5) and eight hybrids exhibited significant positive heterobeltiosis. None of the hybrid showed positive heterosis over standard.

4.3.6 Fruit Length (cm)

Among 15 hybrids, five hybrids showed significant positive relative heterosis. The magnitude of heterosis ranged between -3.33% (P_1 x P_4) and 54.84% (P_2 x P_5) over mid parent. Two hybrids showed significant positive heterobeltiosis. The heterosis over better parent varied between -27.94% (P_1 x P_5) and 22.31% (P_3 x P_5). Fifteen hybrids showed significant positive standard

Table 10. Heterosis (%) for days to first harvest, fruits per plant and fruit length.

Crosses	Days to first harvest			Fruits per plant			Fruit length (cm)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1 x P_2	-2.32	-3.21	-11.25 **	21.71 **	20.15 **	-41.22 **	0.44	-13.17 *	55.56 **
P_1 x P_3	-8.00 **	-10.59 **	-14.71 **	20.00 **	13.91	-45.70 **	4.32	-10.59	60.19 **
P_1 x P_4	-4.98 *	-6.22 **	-13.30 **	17.71 **	6.73	-37.46 **	-3.33	-15.38 **	51.59 **
P_1 x P_5	25.31 **	21.47 **	16.50 **	-67.71 **	-76.69 **	-88.89 **	1.91	-27.94 **	29.09 **
P_1 x P_6	-3.35	-5.07 *	-11.38 **	16.17 *	9.40	-47.85 **	1.37	-4.89	70.40 **
P_2 x P_3	-2.80	-4.69 *	-9.08 **	14.45 *	7.33	-47.49 **	1.11	0.09	30.70 **
P_2 x P_4	-7.64 **	-8.02 **	-14.96 **	19.33 **	9.48	-35.84 **	10.44	8.85	46.37 **
P_2 x P_5	-7.50 **	-9.53 **	-13.24 **	57.03 **	12.45	-44.98 **	50.84 **	18.28 *	54.46 **
P_2 x P_6	-14.72 **	-15.48 **	-21.10 **	38.19 **	28.57 **	-37.10 **	5.05	-3.80	51.08 **
P_3 x P_4	-11.23 **	-12.60 **	-16.62 **	56.18 **	35.17 **	-20.79 **	3.83	1.31	36.24 **
P_3 x P_5	-6.68 **	-6.93 **	-10.74 **	130.25 **	71.97 **	-26.34 **	54.83 **	22.31 **	56.50 **
P_3 x P_6	-9.35 **	-10.32 **	-14.45 **	45.15 **	43.93 **	-38.35 **	11.92	1.55	59.48 **
P_4 x P_5	-9.98 **	-11.60 **	-15.22 **	73.48 **	18.04 **	-30.82 **	23.95 **	-3.82	29.33 **
P_4 x P_6	-7.09 **	-7.53 **	-13.68 **	51.25 **	29.97 **	-23.84 **	13.02 *	4.90	64.74 **
P_5 x P_6	-14.66 **	-15.80 **	-19.25 **	70.54 **	28.09 **	-46.06 **	30.70 **	-3.77	51.12 **

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

heterosis which ranged from 29.09% (P_1 x P_5) to 70.40% (P_1 x P_6) over standard check.

4.3.7 Fruit Girth (cm)

None of the hybrids showed positive heterosis over mid and better parents. Fourteen hybrids showed significant positive heterosis over standard check which ranged from 12.88% (P_1 x P_4) to 108.71% (P_1 x P_5).

4.3.8 Fruit Weight (g)

The heterosis over mid parent varied from -28.57% (P_1 x P_4) to 29.53% (P_5 x P_6). Three hybrids showed significant desirable heterosis over mid parent in positive direction. Only one hybrid 28.75% (P_5 x P_6) recorded significant positive heterosis over the better parent. Fifteen hybrids showed significant positive heterosis over standard check which ranged from 79.87% (P_1 x P_4) to 309.36% (P_5 x P_6).

4.3.9 Flesh Thickness (mm)

The hybrid P_1 x P_5 (17.25%) only recorded positive heterosis over mid parent while none of the hybrids showed positive heterosis over better parent. Fifteen hybrids showed significant positive heterosis over standard check which ranged from 35.50% (P_2 x P_4) to 108.87% (P_1 x P_5).

4.3.10 Flesh to Seed Ratio

The heterosis over mid parent varied from -20.16% (P_4 x P_6) to 74.07% (P_3 x P_5). Five hybrids showed significant desirable heterosis over mid parent in positive direction. Only two hybrids 52.23% (P_3 x P_5) and 37.23% (P_2 x P_5) recorded significant positive heterosis over the better parent while 14 hybrids showed significant positive heterosis over standard check which ranged from 37.98% (P_2 x P_3) to 192.02% (P_5 x P_6).

Table 11. Heterosis (%) for fruit girth, fruit weight and flesh thickness.

Crosses	Fruit girth (cm)			Fruit weight (g)			Flesh thickness (mm)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1 x P_2	-7.80	-13.99 **	33.88 **	-8.26	-21.01 **	146.22 **	-4.49	-7.80	38.10 **
P_1 x P_3	-7.56	-12.87 *	35.62 **	3.40	-13.28	170.32 **	1.20	-2.31	46.32 **
P_1 x P_4	-21.43 **	-27.49 **	12.88	-28.57 **	-42.30 **	79.87 **	0.86	-6.94	39.39 **
P_1 x P_5	-1.82	-22.56 **	108.71 **	3.90	2.88	227.13 **	17.25 **	1.15	108.87 **
P_1 x P_6	-2.95	-2.99	51.02 **	1.28	0.90	216.92 **	0.84	-2.43	56.28 **
P_2 x P_3	-2.95	-4.01	32.24 **	-1.84	-4.87	114.08 **	2.17	2.17	42.42 **
P_2 x P_4	0.07	-1.08	33.30 **	7.59	-0.34	124.29 **	1.87	-2.80	35.50 **
P_2 x P_5	-8.43 *	-31.32 **	85.09 **	21.57 **	3.80	230.06 **	-9.89 **	-24.53 **	55.84 **
P_2 x P_6	4.57	-2.43	51.79 **	10.55	-5.12	198.02 **	-8.96 *	-14.86 **	36.36 **
P_3 x P_4	-1.83	-4.01	32.24 **	-1.13	-5.64	99.24 **	2.20	-2.48	35.93 **
P_3 x P_5	-23.98 **	-42.56 **	54.79 **	19.69 **	-0.42	216.64 **	-11.89 **	-26.21 **	52.38 **
P_3 x P_6	4.22	-1.74	52.86 **	6.64	-10.83	180.06 **	0.87	-5.68	51.08 **
P_4 x P_5	-4.20	-28.70 **	92.16 **	6.93	-14.27	172.59 **	-2.79	-21.59 **	61.90 **
P_4 x P_6	0.37	-7.34	44.14 **	11.75	-9.99	182.70 **	-4.60	-14.59 **	36.80 **
P_5 x P_6	-2.21	-22.88 **	107.84 **	29.53 **	28.75 **	309.36 **	-6.73	-17.19 **	71.00 **

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

4.3.11 Seeds per Fruit

The two hybrids which showed positive heterosis over mid parent were 43.04% (P_1 x P_6) and 30.00% (P_4 x P_6). Only one hybrid (P_1 x P_6) recorded significant positive heterosis (43.04%) over the better parent, while 15 hybrids showed significant positive heterosis over standard check which ranged from 42.11% (P_4 x P_5) to 111.48% (P_1 x P_6).

4.3.12 Green Fruit Yield per Plant (g)

The magnitude of heterosis for green fruit yield ranged from 14.90% (P_1 x P_4) to 162.68% (P_3 x P_5), -69.06% (P_1 x P_5) to 123.13% (P_3 x P_5) and -73.24% (P_1 x P_5) to 57.90% (P_5 x P_6) over mid parent, better parent and standard check, respectively. Fifteen hybrids showed significant desirable heterosis over mid parent in positive direction. Fourteen hybrids recorded significant positive heterosis over the better parent while 10 hybrids showed significant positive heterosis over standard check. Among the hybrids maximum standard heterosis recorded in P_5 x P_6 (57.90%) followed by P_3 x P_5 (49.67%), P_4 x P_6 (38.21%), P_3 x P_6 (37.22%), P_4 x P_5 (32.23%), P_2 x P_5 (29.76%), P_2 x P_6 (23.92%) and P_3 x P_4 (13.60%). Superior hybrids for green fruit yield per plant presented in Plate 6.

4.3.13 Dry Fruit Yield per Plant (g)

The magnitude of heterosis for dry fruit yield ranged from -69.95% (P_1 x P_5) to 153.00% (P_3 x P_5), -78.65% (P_1 x P_5) to 96.71% (P_3 x P_5) and -82.48% (P_1 x P_5) to 22.52% (P_3 x P_5) over mid parent, better parent and standard check, respectively. Out of 15 hybrids, 14 hybrids exhibited significant positive relative heterosis and heterobeltiosis while eight hybrids showed significant positive standard heterosis. Among the hybrids maximum standard heterosis recorded in P_3 x P_5 (22.52%) followed by P_4 x P_6 (22.36%), P_2 x P_5 (18.04%), P_5 x P_6 (16.93%) and P_2 x P_6 (13.85%).

Table 12. Heterosis (%) for flesh to seed ratio, seeds per fruit and green fruit yield per plant.

Crosses	Flesh to seed ratio			Seeds per fruit			Green fruit yield per plant (g)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1xP_2	27.74 **	-3.42	139.05 **	15.41	12.23	75.60 **	47.25 **	35.80 **	17.48 **
P_1xP_3	-5.58	-29.53 **	74.40 **	6.31	-2.69	73.21 **	35.23 **	20.05 **	3.85
P_1xP_4	-19.85 *	-34.73 **	61.55 **	13.21	2.59	51.67 **	14.90 **	9.48	-5.29
P_1xP_5	22.98 *	1.92	152.26 **	-9.12	-14.33	43.06 *	59.87 **	-69.06 **	-73.24 **
P_1xP_6	-2.29	-6.88	154.40 **	43.04 **	43.04 **	111.48 **	27.83 **	26.12 **	12.10 *
P_2xP_3	10.96	8.83	37.98	-2.43	-8.33	63.16 **	20.13 **	15.22 *	-15.83 **
P_2xP_4	11.47	1.15	57.38 **	19.03	5.20	64.59 **	36.30 **	31.70 **	3.18
P_2xP_5	54.28 **	37.23 **	123.33 **	16.27	12.61	88.04 **	116.39 **	77.62 **	29.76 **
P_2xP_6	9.58	-19.78 *	119.17 **	9.43	6.42	66.51 **	53.06 **	39.43 **	23.92 **
P_3xP_4	11.45	-0.61	54.64 *	11.40	-6.72	66.03 **	56.24 **	45.01 **	13.60 **
P_3xP_5	74.07 **	52.23 **	147.74 **	5.13	1.88	81.34 **	162.68 **	123.13 **	49.67 **
P_3xP_6	12.44	-18.69 *	122.14 **	13.66	4.03	85.17 **	75.97 **	54.39 **	37.22 **
P_4xP_5	0.37	-1.83	59.76 **	-1.00	-14.90	42.11 *	111.19 **	68.78 **	32.23 **
P_4xP_6	-20.16 *	-37.34 **	71.19 **	30.00 **	17.80	74.16 **	65.30 **	55.50 **	38.21 **
P_5xP_6	33.97 **	6.88	192.02 **	16.11	9.46	82.78 **	132.62 **	77.66 **	57.90 **

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

Plate 6. Superior hybrids for green fruit yield per plant.

P_5 x P_6

P_3 x P_5

P_3 x P_6

P_4 x P_5

4.3.14 Yield per Plot (kg)

The magnitude of heterosis for yield per plot ranged from -70.08% (P_1 x P_5) to 227.18% (P_3 x P_5), -78.68% (P_1 x P_5) to 174.48% (P_3 x P_5) and -80.86% (P_1 x P_5) to 65.53% (P_5 x P_6) over mid parent, better parent and standard check, respectively. Fourteen hybrids exhibited significant positive relative heterosis, 13 hybrids exhibited significant positive heterobeltiosis and and 10 hybrids recorded significant positive standard heterosis. Among the hybrids maximum standard heterosis recorded in P_5 x P_6 (65.53%) followed by P_3 x P_5 (54.51%), P_4 x P_6 (51.94%), P_4 x P_5 (47.08%), P_2 x P_5 (45.86%) and P_2 x P_6 (40.98%).

4.3.15 Driage (%)

The relative heterosis ranged from -14.15% (P_1 x P_5) to 19.05% (P_3 x P_5) and heterobeltiosis ranged from -18.58% (P_1 x P_5) to 16.82% (P_3 x P_5). Three hybrids exhibited significant positive heterosis over mid parent while two hybrids recorded significant positive heterosis over better parent while none of the hybrids showed desirable heterosis over standard check

4.3.16 Capsaicin (%)

The magnitude of heterosis over mid parent varied from -19.35% (P_2 x P_5) to 54.61% (P_1 x P_2). Eight hybrids showed significant desirable heterosis over mid parent in positive direction. Seven hybrids recorded significant positive heterosis over better parent. The heterosis over better parent varied from -28.57% (P_2 x P_5) to 53.52% (P_1 x P_2). Three hybrids P_1 x P_2 (26.74%), P_2 x P_3 (8.14%) and P_4 x P_6 (12.79%) showed significant positive standard heterosis.

4.3.17 Oleoresin (%)

The magnitude of heterosis over mid parent varied from -15.48% (P_1 x P_2) to 76.88% (P_3 x P_4). Eight hybrids showed significant desirable heterosis over mid parent in positive direction. Six hybrids recorded significant positive heterosis

Table 13. Heterosis (%) for dry fruit yield/plant, yield/plot and driage.

Crosses	Dry fruit yield per plant (g)			Yield per plot (kg)			Driage (%)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1 x P_2	35.44 **	18.52 **	-2.73	65.82 **	41.53 **	27.10 **	-0.32	-2.88	-9.08
P_1 x P_3	26.10 **	10.90 **	-8.99 **	44.87 **	17.84	5.82	-4.89	-8.14	-14.00 *
P_1 x P_4	18.60 **	10.33 **	-9.46 **	40.82 **	24.42 *	11.73	1.04	0.72	-5.71
P_1 x P_5	-69.95 **	-78.65 **	-82.48 **	-70.08 **	-78.68 **	-80.86 **	-14.15 *	-18.58 **	-23.78 **
P_1 x P_6	12.53 **	8.74 **	-4.31 *	36.78 **	28.33 **	31.48 **	-0.35	-1.77	-5.34
P_2 x P_3	28.79 **	28.05 **	-20.25 **	71.36 **	61.64 **	2.64	-2.15	-3.02	-13.88 *
P_2 x P_4	55.83 **	45.84 **	2.99	73.80 **	67.01 **	15.04	-10.74	-12.76 *	-18.86 **
P_2 x P_5	145.57 **	91.74 **	18.04 **	186.98 **	129.72 **	45.86 **	9.94	6.95	-5.03
P_2 x P_6	52.25 **	29.38 **	13.85 **	69.91 **	37.61 **	40.98 **	13.23 *	8.78	4.83
P_3 x P_4	69.33 **	59.33 **	12.52 **	102.21 **	83.73 **	26.55 **	1.31	-1.85	-8.70
P_3 x P_5	153.00 **	96.71 **	22.52 **	227.18 **	174.48 **	54.51 **	19.05 **	16.82 **	1.89
P_3 x P_6	39.47 **	19.09 **	4.80 **	71.61 **	32.95 **	36.21 **	0.64	-4.13	-7.62
P_4 x P_5	114.99 **	60.12 **	13.07 **	174.82 **	113.53 **	47.08 **	1.90	-3.06	-9.83
P_4 x P_6	54.29 **	39.05 **	22.36 **	77.36 **	48.30 **	51.94 **	13.95 **	11.97 *	7.90
P_5 x P_6	90.81 **	32.88 **	16.93 **	135.45 **	61.57 **	65.53 **	3.53	-3.13	-6.65

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

Table 14. Heterosis (%) for capsaicin, oleoresin, ascorbic acid and colour.

Crosses	Capsaicin (%)			Oleoresin (%)			Ascorbic acid (mg/100g)			Colour (ASTA units)		
	RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
P_1 x P_2	54.61 **	53.52 **	26.74 **	-15.48 **	-21.11 **	-15.48 *	15.62 **	6.71	31.47 **	11.53 **	3.20	-20.97 **
P_1 x P_3	23.53 **	18.31 **	-2.33	52.43 **	48.42 **	67.86 **	18.36 **	17.00 **	24.80 **	8.59 *	-4.14	-18.44 **
P_1 x P_4	10.14 *	7.04	-11.63 **	45.24 **	35.56 **	45.24 **	-17.93 **	-24.25 **	-6.68	15.62 **	2.31	-13.43 **
P_1 x P_5	-13.60 **	-23.94 **	-37.21 **	-7.50	-17.78 **	-11.90	-8.16 *	-11.47 **	-7.73	1.60	-1.14	-35.61 **
P_1 x P_6	-13.48 **	-14.08 **	-29.07 **	12.17 *	7.07	26.19 **	-31.30 **	-34.06 **	-25.27 **	21.32 **	7.96 *	-9.82 **
P_2 x P_3	37.78 **	32.86 **	8.14 *	-21.39 **	-28.42 **	-19.05 **	2.96	-3.95	18.33 **	7.75 *	2.36	-12.90 **
P_2 x P_4	-3.65	-5.71	-23.26 **	1.28	1.28	-5.95	-13.42 **	-13.42 **	6.67	4.55	-0.41	-15.74 **
P_2 x P_5	-19.35 **	-28.57 **	-41.86 **	8.11	2.56	-4.76	-12.33 **	-21.75 **	-3.60	54.39 **	39.31 **	6.68 *
P_2 x P_6	22.86 **	22.86 **	0.00	36.72 **	22.22 **	44.05 **	5.69	1.46	25.00 **	9.26 **	4.71	-12.53 **
P_3 x P_4	13.64 **	11.94 *	-12.79 **	76.88 **	61.05 **	82.14 **	-10.09 **	-16.13 **	3.33	-0.17	-0.45	-15.29 **
P_3 x P_5	4.20	-4.62	-27.91 **	13.94 *	-1.05	11.90	-18.12 **	-21.94 **	-16.73 **	32.19 **	13.96 **	-3.04
P_3 x P_6	21.48 **	17.14 **	-4.65	-4.12	-6.06	10.71	2.79	-0.24	13.07 **	6.89 *	5.92	-9.88 **
P_4 x P_5	5.79	-4.48	-25.58 **	9.46	3.85	-3.57	-18.20 **	-26.99 **	-10.05 *	5.56	-8.78 *	-22.81 **
P_4 x P_6	41.61 **	38.57 **	12.79 **	37.85 **	23.23 **	45.24 **	7.10 *	2.81	26.67 **	8.73 **	8.03 *	-8.59 **
P_5 x P_6	0.00	-11.43 *	-27.91 **	38.46 **	18.18 **	39.29 **	7.92 *	0.01	13.35 **	-12.99 **	-24.40 **	-36.85 **

RH-Relative heterosis HB-Heterobeltiosis SH-Standard heterosis *Significant at 5 per cent level ** Significant at 1 per cent level

over the better parent. Seven hybrids showed significant positive heterosis over standard check which ranged from -19.05% (P_2 x P_3) to 82.14% (P_3 x P_4).

4.3.18 Ascorbic Acid (mg/100 g)

Among the 15 hybrids, four hybrids showed positive heterosis over mid parent with maximum heterosis of 18.36% (P_1 x P_3). Heterosis over better parent ranged from -34.06% (P_1 x P_6) to 17.00% (P_1 x P_3). Seven hybrids showed significant positive heterosis over standard check which ranged from -25.27% (P_1 xP_6) to 31.47% (P_1 x P_2).

4.3.19 Colour (ASTA units)

The magnitude of heterosis over mid parent varied from -12.99% (P_5 x P_6) to 54.39% (P_2 x P_5). Ten hybrids showed significant desirable heterosis over mid parent in positive direction. Four hybrids recorded significant positive heterosis over the better parent. The magnitude of heterosis over better parent varied from -24.40% (P_5 x P_6) to 39.31% (P_2 x P_5). The only one hybrid P_2 x P_5 (6.68%) exhibited significant positive heterosis over standard check.

4.4 COMBINING ABILITY ANALYSIS

The analysis of variance for combining ability revealed significance of general combining ability (*gca*) and specific combining ability (*sca*) for all the characters.

4.4.1 Estimation of combining ability (*gca* and *sca*) effects

The general combing ability effects (*gca*) and specific combing ability effects (*sca*) were estimated for six parents and 6 x 6 diallel crosses without reciprocals respectively. The estimates for all the characters including yield, yield component and quality traits are presented in Tables 15 to 16 and the results are given below.

Table 15. General combining ability effects of parents

Characters	P_1	P_2	P_3	P_4	P_5	P_6
Plant height (cm)	-3.54 **	0.55	1.28 *	-0.79	-2.31 **	4.82 **
Primary branches/plant	-0.27 **	0.08	0.09	0.18 *	-0.20 **	0.12
Days to first flowering	1.01 **	0.094	0.21	-0.81 **	0.27	-0.78 **
Days to first harvest	1.33 **	-0.76 **	-0.01	-0.93 **	1.59 **	-1.21 **
Fruits/plant	-11.30 **	1.94	5.61 **	19.90 **	-18.05 **	1.90
Fruit length (cm)	1.15 **	-0.18	-0.18	-0.20	-1.56 **	0.99 **
Fruit girth (cm)	-0.22 **	-0.42 **	-0.52 **	-0.54 **	1.64 **	0.06
Fruit weight (g)	0.22	-0.66 **	-0.92 **	-1.63 **	1.66 **	1.33 **
Flesh thickness (mm)	0.04	-0.14 **	-0.10 **	-0.19 **	0.38 **	0.01
Flesh to seed ratio	0.67 **	-0.54 **	-0.71 **	-0.94 **	0.40 **	1.12 **
Seeds/fruit	-0.98	0.76	5.47 *	-10.73 **	0.80	4.68
Green fruit yield/plant (g)	-77.94 **	-14.28 *	0.70	13.91	-26.34 **	103.95 **
Dry fruit yield/plant (g)	-10.91 **	0.33	0.35	7.14 **	-10.76 **	13.84 **
Yield/plot (kg)	-1.83 **	-0.16	-0.56	0.46	-1.16 **	3.26 **
Driage (%)	-0.42	-0.23	-0.33	0.24	-0.57	1.33 **
Capsaicin (%)	0.008 **	0.01 **	0.008 **	0.002	-0.04 **	0.009 **
Oleoresin (%)	0.34	-2.13 **	1.28 **	0.74 **	-1.90 **	1.66 **
Ascorbic acid (mg/100g)	-4.42 **	11.08 **	0.44	2.03	-13.22 **	4.08 **
Colour (ASTA units)	-10.15 **	5.08 **	8.08 **	4.07 **	-10.24 **	3.15 *

*Significant at 5 per cent level **Significant at 1 per cent level

4.4.1.1 Plant Height (cm)

Estimates of *gca* effect of parents revealed that two parents showed significant negative *gca* effect for this trait *i.e.*, P_1 (-3.54) and P_5 (-2.31) indicating that they were good combiners for dwarfness while P_3 (1.28) and P_6 (4.82) registered significant and positive *gca* effect indicating that they were good general combiners for tallness.

Magnitude of *sca* effect revealed that the hybrid P_1 x P_5 (-9.99) was considered to be best for dwarfness. The hybrids P_3 x P_5 (7.87), P_5 x P_6 (7.70), P_3 x P_4 (5.23), P_1 x P_4 (4.10) and P_1 x P_2 (3.81) showed significant and positive *sca* effect for plant height and were best hybrids with respect to tallness.

4.4.1.2 Primary Branches per Plant

Among the parents positive significant *gca* effect was shown by P_4 (0.18) while P_1 and P_5 had negative and significant *gca* effect. The hybrids P_1 x P_2 (0.83), P_3 x P_6 (0.62), P_3 x P_5 (0.55) and P_5 x P_6 (0.45) were found to have significant positive *sca* effect for primary branches per plant.

4.4.1.3 Days to First Flowering

Two parents *viz.*, P_4 (-0.81) and P_6 (-0.78) exhibited significant negative *gca* effect for days to first flowering and P_1 (1.01) exhibited significant positive *gca* effect.

Among the hybrids *sca* effect ranged between -3.22 (P_5 x P_6) to 4.64 (P_1 x P_5). Eight hybrids showed significant negative *sca* effect, while one hybrid showed significant positive *sca* effect. Among the hybrids P_5 x P_6 (-3.22) was the best for days to first flowering followed by P_2 x P_6 (-2.97) and P_3 x P_4 (-2.33).

4.4.1.4 Days to First Harvest

Table 16. Specific combining ability effects of hybrids

Characters	Plant height (cm)	Primary branches per plant	Days to first flowering	Days to first harvest	Fruits per plant	Fruit length (cm)	Fruit girth (g)	Fruit weight (g)	Flesh thickness (mm)
P_1 x P_2	3.81 *	0.83 **	1.03	-0.88	16.96 **	-0.09	-0.17	-0.51	-0.11
P_1 x P_3	-0.54	0.28	-1.55 *	-3.43 **	4.96	0.30	-0.02	0.59	-0.02
P_1 x P_4	4.10 *	0.33	-0.06	-1.78 *	6.00	-0.40	-0.78 **	-1.88 **	-0.04
P_1 x P_5	-9.99 **	-1.14 **	4.64 **	11.22 **	-51.70 **	-0.95	0.32	0.005	0.44 **
P_1 x P_6	-0.76	-0.27	-0.02	-0.50	4.67	-0.01	-0.07	-0.01	0.002
P_2 x P_3	0.69	-0.20	1.36	1.59 *	-11.61 **	-0.86	0.06	-0.49	0.11
P_2 x P_4	-0.78	-0.16	-1.81 *	-0.55	-4.24	0.48	0.12	0.56	0.08
P_2 x P_5	2.66	0.23	-2.03 *	-2.17 **	16.71 **	2.53 **	-0.28	0.99	-0.17 *
P_2 x P_6	0.96	-0.03	-2.97 **	-3.47 **	11.42 **	-0.32	0.15	0.20	-0.10
P_3 x P_4	5.23 **	-0.43	-2.33 **	-2.16 **	20.08 **	-0.37	0.18	-0.05	0.05
P_3 x P_5	7.87 **	0.55 *	-0.81	-1.62 *	47.71 **	2.71 **	-1.23 **	0.78	-0.26 **
P_3 x P_6	-2.74	0.62 **	-1.56 *	-0.75	5.42	0.39	0.29	-0.16	0.08
P_4 x P_5	2.99	0.06	-2.13 **	-3.03 **	25.08 **	0.42	0.07	-0.06	-0.03
P_4 x P_6	-1.70	0.19	0.12	0.56	18.13 **	0.86	0.01	0.63	-0.05
P_5 x P_6	7.70 **	0.45 *	-3.22 **	-4.86 **	14.75 **	1.06	0.01	1.79 **	-0.10

*Significant at 5 per cent level

**Significant at 1 per cent level

Table 16. Continued

Crosses	Flesh to seed ratio	Seeds/fruit	Green fruit yield/plant (g)	Dry fruit yield/plant (g)	Yield/plot (kg)	Driage (%)	Capsaicin (%)	Oleoresin (%)	Ascorbic acid (mg/100g)	Colour (ASTA units)
P_1 x P_2	1.02 *	6.90	187.54 **	18.44 **	4.78 **	0.42	0.09 **	-2.50 **	23.14 **	-0.91
P_1 x P_3	-0.61	0.53	82.09 **	11.28 **	1.80	-0.69	0.02 **	5.74 **	25.46 **	0.79
P_1 x P_4	-0.74	1.73	8.17	3.95 **	1.71	0.78	0.002	3.11 **	-15.48 **	14.08 **
P_1 x P_5	0.44	-15.80 *	-402.59 **	-61.50 **	-11.39 **	-2.88 **	-0.02 **	-2.23 **	-1.53	-12.74 **
P_1 x P_6	-0.20	27.98 **	33.59	3.13 *	2.05	-0.20	-0.05 **	-0.46	-40.77 **	21.70 **
P_2 x P_3	-0.42	-8.22	-112.18 **	-12.83 **	-0.36	-0.85	0.04 **	-3.94 **	1.87	-4.17
P_2 x P_4	0.35	8.98	0.74	6.91 **	0.57	-2.67 **	-0.03 **	-1.57 *	-14.30 **	-5.43
P_2 x P_5	0.84 *	13.78	217.48 **	42.01 **	7.10 **	1.57	-0.04 **	1.24 *	-11.88 **	50.49 **
P_2 x P_6	0.01	-5.09	48.44 *	12.62 **	1.90	2.12 *	0.02 **	4.51 **	6.55	1.43
P_3 x P_4	0.44	5.28	54.97 *	17.77 **	2.81 *	-0.04	-0.002	7.34 **	-7.82 *	-7.61
P_3 x P_5	1.70 **	4.40	334.69 **	47.10 **	8.88 **	3.40 **	0.002	0.15	-17.65 **	29.45 **
P_3 x P_6	0.27	3.19	121.72 **	2.26	1.54	-0.86	0.01 *	-3.57 **	2.28	3.35
P_4 x P_5	-0.52	-6.72	205.67 **	29.53 **	6.67 **	-0.08	0.01	-1.46 *	-10.89 **	-3.23
P_4 x P_6	-0.92 *	11.73	115.05 **	15.53 **	3.01 **	2.41 *	0.07 **	1.80 **	17.69 **	9.75 *
P_5 x P_6	1.11 **	6.19	286.05 **	27.24 **	6.80 **	-0.38	0.001	3.61 **	16.30 **	-28.36 **

*Significant at 5 per cent level

**Significant at 1 per cent level

The parents P_2 (-0.76), P_4 (-0.93) and P_6 (-1.21) had significant negative *gca* effect for days to first harvest while P_1 (1.33) and P_5 (1.59) had significant positive *gca* effect.

Among the hybrids *sca* effect ranged between -4.86 (P_5 x P_6) to 11.22 (P_1 x P_5). Eight hybrids showed significant negative *sca* effect while two hybrids showed significant positive *sca* effect. Among the hybrids P_5 x P_6 (-4.86) was best for days to first harvest followed by P_2 x P_6 (-3.47) and P_1 x P_3 (-3.43).

4.4.1.5Fruits per Plant

Among the six parents, two parents (P_3 and P_4) recorded significant and positive *gca* effect for fruits per plant. Two parents (P_1 and P_5) had *gca* effect in negative direction. The *gca* effect ranged from -18.05 (P_5) and 19.90 (P_4).

Out of 15 hybrids, eight hybrids had positive significant *sca* effect while two hybrids showed significant negative *sca* effect. The maximum *sca* effect was noticed in P_3 x P_5 (47.71) followed by P_4 x P_5 (25.08), P_4 x P_6 (18.13) and P_1 x P_2 (16.96).

4.4.1.6 Fruit Length (cm)

Among the parents P_1 (1.15) and P_6 (0.99) showed significant positive *gca* effect and P_5 (-1.56) had significant negative *gca* effect. $P_{2,}$ P_3 and P_4 parents showed none significant *gca* effect.

The hybrids P_2 x P_5 (2.53) and P_3 x P_5 (2.71) had significant positive *sca* effect and all other hybrids showed non significant *sca* effect.

4.4.1.7 Fruit Girth (cm)

Highly significant and positive *gca* effect was observed in P_5 (1.64) parent for fruit girth. P_1 (-0.22), P_2 (-0.42), P_3 (-0.52) and P_4 (-0.54) recorded significant negative *gca* effect.

The hybrids P_1 x P_4 (-0.78) and P_3 x P_5 (-1.23) had significant negative *sca* effect and all other hybrids showed non significant *sca* effect.

4.4.1.8 Fruit Weight (g)

Two parents P_5 (1.66) and P_6 (1.33) exhibited positive and significant *gca* effect for fruit weight. Three parents *viz.*, P_2 (-0.66), P_3 (-0.92) and P_4 (-1.63) recorded significant negative *gca* effect.

Among the hybrids P_5 x P_6 (1.79) had positive and significant *sca* effect and P_1 x P_4 (-1.88) showed negative and significant *sca* effect.

4.4.1.9 Flesh Thickness (mm)

Among the parents P_5 (0.38) exhibited positive and significant *gca* effect for flesh thickness. Three parents *viz.*, P_2 (-0.14), P_3 (-0.10) and P_4 (-0.19) recorded significant and negative *gca* effect.

The hybrid P_1 x P_5 (0.44) had significant and positive *sca* effect. P_2 x P_5 (-0.17) and P_3 x P_5 (-0.26) showed negative and significant *sca* effect.

4.4.1.10 Flesh to Seed Ratio

Significant *gca* effect was observed for all the parents. Positive values were recorded for P_1 (0.67), P_5 (0.40) and P_6 (1.12) and negative for P_2 (-0.54), P_3 (-0.71) and P_4 (-0.94).

Among the hybrids P_1 x P_2 (1.02), P_2 x P_5 (0.84), P_3 x P_5 (1.70) and P_5 x P_6 (1.11) had significant and positive *sca* effect and P_4 x P_6 (-0.92) showed negative and significant *sca* effect.

4.4.1.11 Seeds per Fruit

P_3 (5.47) exhibited positive and significant *gca* effect for number of seeds per fruit and P_4 (-10.73) recorded negative *gca* effect.

Among the hybrids P_1 x P_6 (27.98) had significant and positive *sca* effect and P_1 x P_5 (-15.80) had negative and significant *sca* effect. All other hybrids showed non significant *sca* effect.

4.4.1.12 Green Fruit Yield per Plant (g)

Among the six parents, P_6 recorded significant and positive *gca* effect for green fruit yield per plant. Three parents $P_{1,}$ P_2 and P_5 had *gca* effect in negative direction. The *gca* effect ranged from -77.94 (P_1) and 103.95 (P_6).

Out of 15 hybrids, 12 had significant *sca* effect, of which 10 hybrids had positive significant *sca* effect, while two hybrids showed negative significant *sca* effect. The *sca* effect ranged from -402.59 (P_1 x P_5) and 334.69 (P_3 x P_5). The maximum *sca* effect was noticed in P_3 x P_5 (334.69) followed by P_5 x P_6 (286.05), P_2 x P_5 (217.48) and P_4 x P_5 (205.67).

4.4.1.13 Dry Fruit Yield per Plant (g)

1Among the six parents, P_4 and P_6 recorded significant and positive *gca* effect for dry fruit yield per plant. P_1 and P_5 had *gca* effect in negative direction. The *gca* effect ranged from -10.91 (P_1) and 13.84 (P_6).

Out of 15 hybrids, 14 had significant *sca* effect, of which 12 hybrids had positive significant *sca* effect while two hybrids showed significant negative *sca* effect. The *sca* effect ranged from -61.50 (P_1 x P_5) and 47.10 (P_3 x P_5).

4.4.1.14 Yield per Plot (kg)

Parent P_6 (3.26) recorded significant positive *gca* effect for yield per plot and P_1 (-1.83) and P_5 (-1.16) showed significant negative *gca* effect.

The results revealed significant positive *sca* effect for seven hybrids and one hybrid had negative *sca* effect. The highest *sca* effect was observed in cross P_3 x P_5 (8.88) followed by P_2 x P_5 (7.10).

4.4.1.15 Driage (%)

Among the parents P_6 (1.33) recorded significant positive *gca* effect for driage percentage and remaining five parents showed non significant *gca* effect.

Three hybrids had significant and positive *sca* effect and two hybrids showed negative and significant *sca* effect. The *sca* effect ranged among the hybrids from -2.88 (P_1 x P_5) and 3.40 (P_3 x P_5).

4.4.1.16 Capsaicin (%)

Among the parents, P_5 (-0.04) recorded significant negative *gca* effect for capsaicin and P_1, P_2, P_3 and P_6 showed significant positive *gca* effect and P_4 showed non significant *gca* effect. The *gca* effect ranged among the parents from P_5 (-0.04) to P_2 (0.01).

Six hybrids had significant and positive *sca* effect and four hybrids showed negative and significant *sca* effect. The *sca* effect ranged from -0.05 (P_1 x P_6) and 0.09 (P_1 x P_2).

4.4.1.17 Oleoresin (%)

Among the six parents, P_3, P_4 and P_6 recorded significant and positive *gca* effect for oleoresin. Two parents P_2 and P_5 had *gca* effect in negative direction. The *gca* effect ranged from -2.13 (P_2) and 1.66 (P_6).

Among the hybrids seven hybrids had significant and positive *sca* effect and six hybrids showed negative and significant *sca* effect. The *sca* effect ranged from -3.94 (P_2 x P_3) to 7.34 (P_3 x P_4).

4.4.1.18 Ascorbic Acid (mg/100 g)

Among the six parents, P_2 and P_6 recorded significant and positive *gca* effect for ascorbic acid. Two parents (P_1 and P_5) had *gca* effect in negative direction. The *gca* effect ranged from -13.22 (P_5) to 11.08 (P_2).

The results revealed significant positive *sca* effect for four hybrids and significant negative *sca* effect for seven hybrids. The highest *sca* effect was observed in cross P_1 x P_3 (25.46) followed by P_1 x P_2 (23.14) and P_4 x P_6 (17.69).

4.4.1.19 Colour (ASTA units)

Significant *gca* effect was observed for all the parents. Positive values were recorded for P_2 (5.08), P_3 (8.08), P_4 (4.079) and P_6 (3.15) and negative for P_1 (-10.15) and P_5 (-10.24).

Among the hybrids, P_1 x P_4 (14.08), P_1 x P_6 (21.70), P_2 x P_5 (50.49) and P_3 x P_5 (29.45) and P_4 x P_6 (9.75) had significant and positive *sca* effect and P_1 x P_5 (-12.74) and P_5 x P_6 (-28.36) hybrids showed negative and significant *sca* effect for colour.

4.5 GEAN ACTION

The estimation of SCA variance was higher than GCA variance for all characters except fruit girth, fruit weight and flesh thickness (Table 17). The proportion of variance due to GCA/SCA was found to be less for all characters except fruit girth, fruit weight and flesh thickness, hence exhibited dominance / non additive gene action.

4.6 SCREENING FOR INCIDENCE OF PESTS AND DISEASES

The crop was monitored for the incidence of the pests and diseases. The percentage of incidence for thrips, mites, bacterial wilt and fruit rot were given in Table 18.

Highest incidence of thrips was noticed in P_1 x P_5 (61.66%) and lowest incidence was noticed in P_2 x P_6 (10.00%), P_4 x P_6 (11.55%) and P_1 x P_2 (11.55%)

Mites incidence ranged from zero to 40.74%. The incidence was maximum in hybrid P_1 x P_5 (40.74%) which was on par with P_5 (36.97%).

Table 17. Analysis of variance for combining ability of different characters in chilli.

Character	GCA	SCA	` Error	$\sigma^2 gca$	$\sigma^2 sca$	$\sigma^2 gca/ \sigma^2 sca$
Plant height (cm)	70.12 **	27.49 **	3.14	8.37	24.35	0.34
Primary branches/plant	0.29 **	0.26 **	0.05	0.03	0.21	0.13
Days to first flowering	3.86 **	7.28 **	0.63	0.40	6.64	0.06
Days to first harvest	11.57 **	17.22 **	0.57	1.37	16.64	0.08
Fruits/plant	1422.12 **	759.61 **	17.35	175.59	742.25	0.23
Fruit length (cm)	7.83 **	2.02 **	0.32	0.93	1.69	0.55
Fruit girth (cm)	5.63 **	0.21 **	0.03	0.70	0.17	3.96
Fruit weight (g)	13.72 **	1.06 **	0.30	1.67	0.76	2.20
Flesh thickness (mm)	0.35 **	0.02 **	0.006	0.04	0.02	2.01
Flesh to seed ratio	5.70 **	0.92 **	0.17	0.69	0.74	0.92
Seeds/fruit	270.91 **	167.37 *	66.55	25.54	100.82	0.25
Green fruit yield/plant (g)	28757.39 **	57010.50 **	479.62	3534.72	56530.88	0.06
Dry fruit yield/plant (g)	764.85 **	1148.50 **	1.73	95.39	1146.77	0.08
Yield/plot (kg)	25.49 **	47.02 **	1.21	3.03	45.81	0.06
Driage (%)	4.01 **	3.19 **	0.88	0.39	2.30	0.16
Capsaicin (%)	0.004 **	0.002 **	0.00	0.00	0.002	0.23
Oleoresin (%)	21.19 **	14.83 **	0.37	2.60	14.46	0.18
Ascorbic acid (mg/100 g)	541.49 **	332.80 **	13.51	65.99	319.28	0.20
Colour (ASTA units)	521.31 **	420.26 **	16.27	63.13	403.98	0.15

*Significant at 5 per cent level **Significant at 1 per cent level

There was no significant difference among the parents and hybrids for the incidence of bacterial wilt.

The minimum incidence of fruit rot was observed in P_2 x P_6 (2.24%), P_1 x P_3 (2.60%), P_1 x P_2 (2.87%), P_4 x P_6 (3.24%), P_2 x P_4 (3.41%) and P_3 x P_5 (3.44%). Among the parents highest incidence of fruit rot was observed in P_5 (11.25) which was found to be on par with P_1 (10.47%) and P_4 (9.52%).

Table 18. Incidence of pests and diseases of parents and hybrids

Parents and crosses	Thrips (%)	Mites (%)	Bacterial wilt (%)	Disease index of fruit rot
P_1	19.79 (4.45)*	13.23 (3.77)*	1.04 (1.34)*	10.47 (18.88)**
P_2	13.32 (3.64)	0.00 (1.00)	0.00 (1.00)	7.52 (15.91)
P_3	13.32 (3.64)	0.00 (1.00)	1.04 (1.34)	4.44 (12.16)
P_4	23.27 (4.82)	0.00 (1.00)	0.00 (1.00)	9.52 (17.96)
P_5	28.15 (5.31)	36.97 (6.08)	1.04 (1.34)	11.25 (19.59)
P_6	17.74 (4.21)	11.56 (3.54)	0.00 (1.00)	4.25 (11.89)
P_1 x P_2	11.55 (3.40)	13.23 (3.77)	1.04 (1.34)	2.87 (9.75)
P_1 x P_3	16.59 (4.07)	0.00 (1.00)	0.00 (1.00)	2.60 (9.28)
P_1 x P_4	25.00 (5.00)	0.00 (1.00)	0.00 (1.00)	5.55 (13.63)
P_1 x P_5	61.24 (7.83)	40.74 (6.46)	0.00 (1.00)	8.67 (17.12)
P_1 x P_6	13.32 (3.64)	0.00 (1.00)	1.04 (1.34)	5.1 (13.05)
P_2 x P_3	13.32 (3.64)	0.00 (1.00)	2.08 (1.56)	4.14 (11.73)
P_2 x P_4	13.33 (3.64)	0.00 (1.00)	2.08 (1.56)	3.41 (10.64)
P_2 x P_5	23.37 (4.82)	18.26 (4.39)	1.04 (1.34)	5.43 (13.47)
P_2 x P_6	10.00 (3.16)	0.00 (1.00)	0.00 (1.00)	2.24 (8.61)
P_3 x P_4	21.38 (4.62)	0.00 (1.000	3.12 (1.74)	5.72 (13.83)
P_3 x P_5	24.54 (4.95)	16.59 (1.00)	4.16 (2.12)	3.44 (10.68)
P_3 x P_6	16.59 (4.07)	0.00 (1.00)	3.12 (1.90)	4.81 (12.68)
P_4 x P_5	36.63 (6.05)	19.80 (4.56)	5.20 (2.30)	4.18 (11.79)
P_4 x P_6	11.55 (3.4)	0.00 (1.00)	2.08 (1.56)	3.24 (10.37)
P_5 x P_6	15.00 (3.87)	13.23 (3.77)	6.25 (2.64)	4.78 (12.63)
Check	23.27 (4.82)	0.00 (1.00)	6.25 (2.64)	5.95 (14.11)
CD 5%	0.817	0.669	NS	2.199

(* Figures given in parenthesis are square root transformed values)

(** Figures given in parenthesis are angular transformed values)

DISCUSSION

5. DISCUSSION

Chilli, due to its pungent component capsaicin, is used worldwide as an important vegetable, spice, medicinal and cash crop. Capsicum species are usually self-compatible and *Capsicum annuum* is a partially self-pollinating crop (Allard, 1960). In open field out-crossing commonly occurs from and therefore it is considered facultative cross-pollinating species in field research. It thus provides an opportunity to breed homozygous true breeding and productive lines which may be used as variety and also F_1 hybrids for commercial exploitation of heterosis.

Chilli has considerable preference for pungency and colour of fruits. Therefore chilli breeders have to aim at evolving genotypes based on regional preference and that show substantial increase over the existing types in respect to yield and other quality characters. This would mainly depend upon the nature, magnitude and inter-relationship of heritable variation.

The salient results like mean performance, heterosis, *gca* and *sca* effects of each character gathered in the present investigation are discussed hereunder.

5.1 HALF DIALLEL ANALYSIS

Half diallel analysis is a method (Griffing, 1956) in which the selected parents are crossed in all possible combinations excluding reciprocals. Combining ability analysis enables a plant breeder to decide the choice of parents for hybridization. It also helps to employ suitable selection procedures.

To develop hybrids, the most important task for the plant breeder is the choice of parental lines. The selection of parents on the basis of per se performance does not necessarily lead to desirable results (Allard, 1960). It is therefore essential to find out the combining ability of desirable genotypes to be involved in breeding programme for effective transfer of desirable genes in the resultant progenies. Three biometrical techniques, *viz.,* diallel, partial diallel and line × tester analyses are commonly used for the analysis of combining ability. The approach of diallel analysis proposed by Griffing (1956) is based on the estimates of combining ability variances and effects. Of four methods given by him, method two includes one way crosses and parents and is the most commonly used method of combining ability analysis from a diallel cross (Singh and Narayanan, 2000). This method helps in determining general combining ability (*gca*) effects of parents, specific combining ability (*sca*) effects of cross combinations, relative proportion of additive and non-additive genetic variance along with narrow sense heritability.

Half diallel analysis was carried out to evaluate the parents and hybrids on the basis of mean performance, general combining ability of parents and specific combining ability of hybrids. Significant variations existed for most of the characters are revealed by ANOVA.

5.2 COMBINING ABILITY AND HETEROSIS

The knowledge of combining ability is necessary for selection of appropriate parents in hybridization. It gives an idea whether a particular parent combines well in a cross and also denote the specific performance of a cross combination against the expectations from the *gca* of the parents. The concept of general and specific combining ability (Sprague and Tatum, 1942) helps the breeder to assess the general combining ability effects of the parents and specific combining ability effects of the hybrids. Exploitation of heterosis or hybrid vigour is an important approach of crop improvement adopted in many of the crops all over the world. For exploitation of heterosis, choice of suitable parents is an important pre-requisite.

5.3 GENE ACTION

Gene action measured by *gca* and *sca* variances is particularly useful in deciding the inheritance of characters and thereby selection of a suitable breeding programme. Greater *gca* variance for a character indicates the predominance of additive gene action and if *sca* variance is greater non-additive gene action plays an important role in controlling that trait. Simple selection is enough for a character controlled by additive gene action as it as fixable, but if non-additive gene action is predominant for a character, which is non-fixable, heterosis breeding may be rewarding. Griffing (1956) reported that, analysis of combining ability is one of the potential tools for identifying productive parents to develop commercial F_1 hybrids. Information on the relative importance of general combining ability (GCA) and specific combining ability (SCA) are of great values in the breeding programs for the species which are amenable to the development of F_1 hybrids.

In the present study, the characters *viz.,* plant height, primary branches per plant, days to first flowering, days to first harvest, fruits per plant, fruit length, flesh to seed ratio, seed per fruit, green fruit yield per plant, dry fruit yield per plant, yield per plot, driage, capsaicin, oleoresin, ascorbic acid and colour were influenced by non-additive gene action as evidenced from the low additive: dominance (σ^2A/σ^2D) ratio. Fruit weight, fruit girth and flesh thickness were governed by additive gene action. Similar findings were reported for fruit weight by Jagdeesh and Wali (2005), Prasanth and Ponnuswami (2008), Rodrigues *et al.,* (2012) and Singh *et al.,* (2014) and for fruit girth by Nandadevi and Hosamani (2003) and Venkataraman *et al.,* (2005). Rodrigues *et al.,* (2012) and Singh *et al.* (2014) reported similar results for flesh thickness in chilli.

Similar findings which were influenced by non - additive gene action were reported for days to first flowering, fruits per plant, fruit length, flesh to seed ratio, green fruit yield per plant, dry fruit yield per plant by Shekhawat *et al.* (2007), for plant height and days to first harvest by Singh *et al.,* (2014), for primary branches per plant by Nsabiyera *et al.,* (2013), for seeds per fruit by Bhagyalakshmi *et al.,* (1991), for capsaicin and colour by Nandadevi and Hosamani (2003), for oleoresin and ascorbic acid by Saritha *et al*., (2005).

Considering the preponderance of non-additive gene action for most of the characters, it can be concluded that heterosis breeding would yield better results in the improvement of those characters.

5.4 EVALUATION OF PARENTS

According to Yadav and Murthy (1966), the choice of parents especially for heterosis breeding should be based on the combining ability test and their mean performance. Combining ability is a measurement of plant genotype ability in crossing to produce superior plants. Combining ability which is obtained from a cross between two parental lines can provide information regarding cross combinations for better heredity. Therefore, the parents chosen for present study were assessed based on their mean performance and general combining ability effects.

The general combining ability effects represent the additive nature of gene action. A high general combiner parent is characterized by its better breeding value when crossed with a number of other parents. Based on *gca* estimates, it revealed that parent P_1 was a good combiner for fruit length, flesh to seed ratio, and capsaicin. P_2 was good general combiner for capsaicin and ascorbic acid while P_3 parent showed superiority for traits like plant height, fruits per plant, seeds per fruit, oleoresin and colour. P_4 was good for days to first flowering, days to first harvest, primary branches per plant, fruits per plant, dry fruit yield per plant and colour. P_5 showed superiority for fruit girth, fruit weight, flesh thickness and flesh to seed ratio. For fruit yield and yield related characters P_6 was the best compared to other parents and it showed good performance for days to first flowering, days to first harvest, fruit length, fruit weight, flesh to seed ratio, green fruit yield per plant, dry fruit yield per plant, yield per plot, driage percentage and all quality characters *viz.*, capsaicin, oleoresin, ascorbic acid and colour.

Table 19. Evaluation of parents based on *gca* effects and mean performance.

Character	Mean performance	*gca* effects	Mean performance & *gca* effects
Plant height (cm)	P_6, P_2, P_3	P_6, P_3	P_6, P_3
Primary branches/plant	P_4, P_2	P_4	P_4
Days to first flowering	P_1, P_4	P_4, P_6	P_4
Days to first harvest	P_1, P_2	P_6, P_4, P_2	P_2
Fruits/plant	P_4, P_2	P_3, P_4	P_4
Fruit length (cm)	P_1, P_6	P_1, P_6	P_1, P_6
Fruit girth (cm)	P_5, P_1, P_6	P_5	P_5
Fruit weight (g)	P_5, P_6, P_1	P_5, P_6	P_5, P_6
Flesh thickness (mm)	P_5, P_6, P_1	P_5	P_5
Flesh to seed ratio	P_6, P_1, P_5	P_6, P_1, P_5	P_6, P_1, P_5
Seeds/fruit	P_3, P_5	P_3	P_3
Green fruit yield/plant (g)	P_6, P_1, P_4	P_6	P_6
Dry fruit yield/plant (g)	P_6, P_1, P_4	P_4, P_6	P_4, P_6
Yield/plot (kg)	P_6, P_1	P_6	P_6
Driage (%)	P_6, P_1, P_4	P_6	P_6
Capsaicin (%)	P_1, P_2, P_6	P_1, P_2, P_3, P_6	P_1, P_2, P_6
Oleoresin (%)	P_6, P_1, P_3	P_3, P_4, P_6	P_3, P_6
Ascorbic acid (mg/100g)	P_2, P_4, P_6	P_2, P_6	P_2, P_6
Colour (ASTA units)	P_4, P_6, P_3	P_2, P_3, P_4, P_6	P_3, P_4, P_6

Considering overall performance, superiority can be attributed to P_6 (CA 32) for yield related traits and quality traits.

The parents P_2 (CA 5) and P_3 (CA 6) showed best performance for quality characters. P_4 (CA 8) was good for number of primary branches, days to first flowering and fruits per plant and dry fruit yield per plant while P_5 (CA 23) was superior for fruit weight and fruit girth.

None of the parents revealed significant and desirable *gca* effect for all the traits simultaneously. Different parents exhibited significant *gca* effect for different traits. Similar results have also been reported by Jagadesha and Wali (2008) and Kamble *et al.* (2009). As none of the parents was a good general combiner for all the traits simultaneously, the parents with desirable *gca* for maximum traits could be selected for use in further breeding programme.

5.5 EVALUATION OF HYBRIDS

Heterosis is the increase of size, yield and vigour through cross-breeding rather than interbreeding. Heterosis breeding is a potential method to achieve improvement in production and productivity of chilli that otherwise cannot be achieved through existing traditional methods. Creating hybrid variety is utilizing heterosis effect. Heterosis is the increasing of character value of F_1 hybrids compared to the average value of both parents. The information concerning the effect of heterosis in crossing determines the choice of potential parental lines to obtain high productivity hybrids as well as having a good endurance. Better hybrids were generally identified based on their mean performance, *sca* effects and standard heterosis expression. The hybrids thus obtained can either be used as F_1 hybrid to exploit heterosis or forwarded to further generations for selecting superior recombinants with desirable gene combinations from the segregating population.

5.5.1 Plant Height (cm)

Plant height is an important growth parameter from productivity and crop management point of view. On the basis of mean performance, the hybrids P_5 x $P_{6,}$ P_3 x $P_{5,}$ P_2 x P_6 and P_3 x P_4 were found to be superior. The female parent in hybrid P_3 x P_4 and male parent in hybrid P_5 x P_6 were good general combiners. High mean performance of crosses between poor and general combiners can be attributed to interaction between genes. High *sca* effect was noticed for the crosses P_3 x $P_{5,}$ P_5 x $P_{6,}$ P_3 x $P_{4,}$ P_1 x P_4 and P_1 x P_2. None of the hybrids exhibited positive standard heterosis but 15 hybrids exhibited negative standard heterosis for this character. The hybrids P_5 x $P_{6,}$ P_3 x P_5 and P_3 x P_4 were superior based on mean performance and *sca* effect. Similar findings have also been reported by earlier workers, Kamble *et al.* (2009), Tembhurne and Rao (2012), Navhale *et al.* (2014) and Patel *et al.* (2014).

5.5.2 Primary Branches per Plant

The number of primary branches per plant is one of the major parameters contributing for total yield per plant. With respect to mean performance P_3 x $P_{6,}$ P_1 x $P_{2,}$ P_3 x P_5 and P_4 x P_6 were superior. The female parent in hybrid P_4 x P_6 was good general combiner for primary branches per plant. For this hybrid parent P_4 was good general combiner indicating the promising interaction between desirable and undesirable alleles. High mean performance and high *sca* effect were shown by P_3 x $P_{6,}$ P_1 x $P_{2,}$ and P_3 x P_5. No hybrid exhibited positive standard heterosis but P_1 x P_2 and P_3 x P_6 showed significant positive heterosis over mid parent and better parent. Patil *et al.* (2012), Navhale *et al.* (2014), Kumar (2014) and Bhutia *et al.* (2015) also observed similar results.

5.5.3 Days to First Flowering

Early flowering in chilli is generally an indication of early yield and earliness is considered an important character in any crop improvement programme. With respect to mean performance P_5 x $P_{6,}$ P_2 x $P_{6,}$ P_3 x $P_{4,}$ and P_4 x P_5

Table 20. Evaluation of hybrids on the basis of mean performance, *sca* effects and standard heterosis

Character	Mean performance	*sca* effects	Standard heterosis	Superior hybrids
Plant height (cm)	P_5 x P_6, P_3 x P_5, P_2 x P_6, P_3 x P_4	P_3 x P_5, P_5 x P_6, P_3 x P_4	P_5 x P_6, P_3 x P_5, P_2 x P_6, P_3 x P_4	P_5 x P_6, P_3 x P_5, P_3 x P_4
Primary branches/plant	P_3 x P_6, P_1 x P_2, P_3 x P_5, P_4 x P_6	P_1 x P_2, P_3 x P_6, P_3 x P_5, P_5 x P_6	--	--
Days to first flowering	P_5 x P_6, P_2 x P_6, P_3 x P_4, P_4 x P_5	P_5 x P_6, P_2 x P_6, P_3 x P_4, P_4 x P_5	P_5 x P_6, P_2 x P_6, P_3 x P_4, P_4 x P_5	P_5 x P_6, P_2 x P_6, P_3 x P_4, P_4 x P_5
Days to first harvest	P_2 x P_6, P_5 x P_6, P_3 x P_4, P_4 x P_5	P_5 x P_6, P_2 x P_6, P_1 x P_3, P_4 x P_5	P_2 x P_6, P_3 x P_4, P_5 x P_6, P_4 x P_5	P_2 x P_6, P_5 x P_6, P_4 x P_5
Fruits per plant	P_3 x P_4, P_4 x P_6, P_3 x P_5, P_4 x P_5	P_3 x P_5, P_4 x P_5, P_3 x P_4, P_4 x P_6	--	--
Fruit length (cm)	P_1 x P_6, P_4 x P_6, P_1 x P_2, P_1 x P_3, P_3 x P_6, P_3 x P_5	P_3 x P_5, P_2 x P_5	P_1 x P_6, P_1 x P_3, P_4 x P_6, P_3 x P_6, P_3 x P_5	P_3 x P_5
Fruit girth (cm)	P_1 x P_5, P_5 x P_6, P_4 x P_5, P_2 x P_5	--	P_1 x P_5, P_5 x P_6, P_4 x P_5, P_2 x P_5	--
Fruit weight (g)	P_5 x P_6, P_2 x P_5, P_1 x P_5, P_1 x P_6	P_5 x P_6	P_5 x P_6, P_2 x P_5, P_1 x P_5, P_1 x P_6	P_5 x P_6
Flesh thickness (mm)	P_1 x P_5, P_5 x P_6, P_4 x P_5, P_2 x P_5	P_1 x P_5	P_1 x P_5, P_5 x P_6, P_4 x P_5, P_2 x P_5	P_1 x P_5
Flesh to seed ratio	P_5 x P_6, P_1 x P_6, P_1 x P_5, P_3 x P_5, P_1 x P_2	P_3 x P_5, P_5 x P_6, P_1 x P_2, P_2 x P_5	P_5 x P_6, P_1 x P_6, P_1 x P_5, P_3 x P_5, P_1 x P_2	P_5 x P_6, P_3 x P_5, P_1 x P_2
Seeds per fruit	P_1 x P_6, P_2 x P_5, P_3 x P_6, P_5 x P_6	P_1 x P_6	P_1 x P_6, P_2 x P_5, P_3 x P_6, P_5 x P_6	P_1 x P_6
Green fruit yield/plant (g)	P_5 x P_6, P_3 x P_5, P_4 x P_6, P_3 x P_6, P_4 x P_5, P_2 x P_5, P_2 x P_6, P_3 x P_4	P_5 x P_6, P_3 x P_5, P_2 x P_5, P_4 x P_5, P_1 x P_2, P_3 x P_6, P_4 x P_6, P_2 x P_6, P_3 x P_4	P_5 x P_6, P_3 x P_5, P_4 x P_6, P_3 x P_6, P_2 x P_5, P_4 x P_5, P_2 x P_6, P_3 x P_4	P_5 x P_6, P_3 x P_5, P_4 x P_6, P_3 x P_6, P_4 x P_5, P_2 x P_5, P_2 x P_6, P_3 x P_4
Dry fruit yield/plant (g)	P_3 x P_5, P_4 x P_6, P_5 x P_6, P_2 x P_5, P_2 x P_6, P_4 x P_5, P_3 x P_4	P_3 x P_5, P_2 x P_5, P_4 x P_5, P_5 x P_6, P_3 x P_4, P_4 x P_6, P_2 x P_6	P_3 x P_5, P_4 x P_6, P_2 x P_5, P_5 x P_6, P_2 x P_6, P_4 x P_5, P_3 x P_4	P_3 x P_5, P_4 x P_6, P_2 x P_5, P_5 x P_6 P_2 x P_6, P_4 x P_5, P_3 x P_4
Yield/plot (kg)	P_5 x P_6, P_3 x P_5, P_4 x P_6, P_4 x P_5,	P_3 x P_5, P_2 x P_5, P_5 x P_6, P_4 x P_5	P_5 x P_6, P_3 x P_5, P_4 x P_6, P_4 x P_5	P_5 x P_6, P_3 x P_5, P_4 x P_5
Driage (%)	P_4 x P_6, P_2 x P_6, P_3 x P_5, P_2 x P_5	P_4 x P_6, P_2 x P_6	--	--
Capsaicin (%)	P_1 x P_2, P_4 x P_6, P_2 x P_3, P_2 x P_6, P_1 x P_3, P_3 x P_6	P_1 x P_2, P_4 x P_6, P_2 x P_3, P_1 x P_3, P_2 x P_6, P_3 x P_6	P_1 x P_2, P_4 x P_6, P_2 x P_3	P_1 x P_2, P_4 x P_6, P_2 x P_3
Oleoresin (%)	P_3 x P_4, P_1 x P_3, P_4 x P_6, P_1 x P_4	P_3 x P_4, P_1 x P_3, P_2 x P_6, P_5 x P_6	P_3 x P_4, P_1 x P_3, P_4 x P_6, P_1 x P_4	P_3 x P_4, P_1 x P_3
Ascorbic acid (mg/100g)	P_1 x P_2, P_4 x P_6, P_1 x P_3, P_2 x P_6	P_1 x P_3, P_1 x P_2, P_4 x P_6, P_5 x P_6	P_1 x P_2, P_4 x P_6, P_2 x P_6, P_1 x P_3	P_1 x P_2, P_1 x P_3, P_4 x P_6
Colour (ASTA units)	P_2 x P_5, P_3 x P_5, P_4 x P_6, P_1 x P_6	P_2 x P_5, P_3 x P_5, P_1 x P_6, P_1 x P_4	P_2 x P_5	P_2 x P_5

were superior. P_4 and P_6 were good general combiners for this trait. P_5 x P_6, P_2 x P_6, P_3 x P_4 and P_4 x P_5 were found good with regard to *sca* effect. The hybrids P_5 x P_6, P_2 x P_6, P_3 x P_4 and P_4 x P_5 had significant and negative standard heterosis whereas P_2 x P_4, P_2 x P_5, P_3 x P_5, P_3 x P_6 and P_4 x P_6 had significant and negative relative heterosis as well as heterobeltiosis for earliness. P_5 x P_6 and P_2 x P_6 were projected as the best hybrids for earliness. Similar results were also reported by Kamble *et al*. (2009), Navhale *et al.* (2014) and Kumar *et al*. (2014).

5.5.4 Days to First Harvest

Early harvest which is profitable as the produce gets better price in the market. The hybrids P_2 x P_6 (good x good general combiner), P_5 x P_6 (poor x good general combiner) and P_4 x P_5 (good x poor general combiner) were superior based on mean performance, *sca* effect and standard heterosis. While P_1 x P_3, P_1 x P_4, P_1 x P_5, P_2 x P_4, P_2 x P_5, P_3 x P_4, P_3 x P_5, P_3 x P_6 and P_4 x P_6 had significant and negative standard heterosis as well as heterobeltiosis and average heterosis for the days to first harvest. The parents P_2, P_4 and P_6 were good general combiners for this trait. P_2 x P_6 and P_5 x P_6 were projected as the best hybrids for early harvest. Early harvest was also reported by Kamble *et al*. (2009), Navhale *et al*. (2014) and Ahmed *et al*. (2015).

5.5.5 Fruits per Plant

In chilli, fruits per plant is the most important primary component of total yield. The mean value and *sca* effect were high for the hybrids P_3 x P_4, P_4 x P_6, P_3 x P_5 and P_4 x P_5. Of these cross P_3 and P_4 parents were good general combiners. None of the hybrids exhibited positive standard heterosis while 14 hybrids showed significant positive heterosis over mid parent and eight hybrids showed significant positive heterosis over better parent. The crosses P_3 x P_4 (147.33) and P_4 x P_6 (141.66) were projected as the best for number of fruits per plant. Similar findings have also been reported by Lankeshkumar (2005), Ganeshreddy *et al*. (2008), Payakhapaab *et al*. (2012) and Navhale *et al*. (2014).

5.5.6 Fruit Length (cm)

Fruit length is an important parameter in deciding consumer preference. The hybrids P_1 x P_6, P_4 x P_6, P_1 x P_3 and P_3 x P_6 differed from other hybrids in having high mean value and standard heterosis. Among the parents P_1 and P_6 were good general combiners. The hybrid P_3 x P_5 had high *sca* effect and significant standard heterosis. All hybrids exhibited positive significant standard heterosis. P_1 x P_6 and P_4 x P_6 were projected as the best hybrids for fruit length. Similar findings have also been reported by earlier workers, Ganeshreddy et al. (2008), Payakhapaab *et al*. (2012), Kumar (2014), Navhale *et al*. (2014) and Darshan (2014).

5.5.7 Fruit Girth (cm)

Average fruit girth directly contributes towards total yield and has a key role in acceptance of produce by the consumer. Best *per se* performance for fruit girth was exhibited by P_1 x P_5. The hybrids P_1 x P_5, P_5 x P_6, P_4 x P_5 and P_2 x P_5 were superior based on mean value and standard heterosis but *sca* effect were not satisfactory. The male and female parents in the hybrid P_5 x P_6 were good general combiners and the interaction of additive factors lead to hybrid vigour fixable by selection. Fourteen hybrids had significant positive standard heterosis while all of the hybrids were having negative heterobeltiosis. These results are in conformity with that of obtained by Prasath and Ponnuswami (2008), Tembhurne and Rao (2012) and Payakhapaab *et al*. (2012) and Singh *et al.* (2014).

5.5.8 Fruit Weight (g)

Fruit weight is one of the component characters directly influencing the fruit yield. The hybrid P_5 x P_6 (good x good general combiner) was superior based on the mean performance, *sca* effect and standard heterosis. Other hybrids P_2 x P_5, P_1 x P_5 and P_1 x P_6 also had high mean performance and significant standard heterosis but *sca* effect were not satisfactory. Among the parents P_1, P_2, P_3 and P_4 were poor combiners. All 15 hybrids recorded significant positive heterosis over the check while most of the hybrids showed negative average heterosis and heterobeltiosis. Among the hybrids P_5 x P_6 was best for fruit weight. Similar findings have also been reported by Jagadeesha and Wali (2005), Ganeshreddy *et al*. (2008), Payakhapaab *et al*. (2012) Kumar *et al*. (2014) and Singh *et al.* (2014).

5.5.9 Flesh Thickness (mm)

The hybrid P_1 x P_5 (poor x good general combiner) was superior based on the high mean value, with high *sca* effect and standard heterosis for this trait. Other hybrids P_1 x P_5, P_5 x P_6, P_4 x P_5 and P_2 x P_5 also had high mean performance and significant standard heterosis whereas *sca* effect was not satisfactory. P_5 alone was a good general combiner among the parents for flesh thickness. Fifteen hybrids had significant standard heterosis while all of the hybrids showed negative heterosis over better parent. In earlier studies, Kumar *et al*. (2014) and Singh *et al.* (2014) also found similar results in chilli.

5.5.10 Flesh to Seed Ratio

Standard heterosis for flesh to seed ratio were observed for P_5 x P_6, P_1 x P_6, P_1 x P_5 and P_3 x P_5. As for as mean value and *sca* effect were concerned P_5 x P_6, P_1 x P_6, P_1 x P_5, P_3 x P_5, and P_1 x P_2 exhibited high values. P_5 and P_6 were good general combiners for this trait. Fourteen hybrids recorded significant positive heterosis over the check while five hybrids showed significant positive heterosis over better parent and two hybrids over mid parents. Similar findings have also been reported by Lohithaswa *et al.* (2000) and Afroza *et al.* (2014)

5.5.11 Seeds per Fruit

Number of seeds per fruit should be less to make it more acceptable to the consumer. The hybrid P_1 x P_6 was superior based on the mean performance, *sca* effect and standard heterosis. Other hybrids P_2 x P_5, P_3 x P_6 and P_5 x P_6 also had high mean performance and significant standard heterosis. The female parent in hybrid P_3 x P_6 was good general combiner. Fifteen hybrids had significant standard heterosis while most of the hybrids were had negative heterobeltiosis and relative heterosis. Similar results were reported by Ganeshreddy *et al*. (2008) and Navhale *et al*. (2014)

5.5.12 Green Fruit Yield per Plant (g)

High total fruit yield per plant is one of the most important breeding objectives in any crop improvement programme. Here the hybrids P_5 x $P_{6,}$ P_3 x $P_{5,}$ P_4 x $P_{6,}$ P_3 x $P_{6,}$ P_4 x $P_{5,}$ P_2 x $P_{5,}$ P_2 x P_6 and P_3 x P_4 having highest yield per plant based on high mean value, *sca* effect and standard heterosis. The maximum heterosis over the mid parent and better parent were observed in the cross P_3 x P_5 and P_5 x P_6. Fifteen hybrids showed significant positive heterosis over mid parent, 13 hybrids over better parent and 10 hybrids over check. These results are in conformation with the results of earlier workers Prasath and Ponnuswami (2008), Patel *et al*. (2010), Tembhurne and Rao (2012), Patil *et al*. (2012) and Navhale *et al*. (2014)

Among 15 F_1hybrids, 6 exhibited more than 50% heterobeltiosis for total green fruit yield per plant. These crosses were P_3 x P_5 (123.13%), P_5 x P_6 (77.66%), P_2 x P_5 (77.62%), P_4 x P_5 (68.78%), P_4 x P_6 (55.50%) and P_3 x P_6 (54.39%). All of these 6 hybrids had significant positive *sca* effect indicating the importance of non-additive gene action.

The study revealed the superiority of certain hybrids for yield and quality attributes. In the present study P_6 was the best general combiner. The manifestation of heterosis was at different levels for different characters. None of the hybrids were found to be superior for all the characters studied. However the superior hybrids P_5 x $P_{6,}$ P_3 x $P_{5,}$ P_4 x $P_{6,}$ P_3 x $P_{6,}$ P_4 x $P_{5,}$ P_2 x P_5 and P_2 x P_6 exhibited desirable standard heterosis for 11 characters *viz.*, days to first flowering, days to first harvest, fruit length, fruit girth, fruit weight, flesh thickness, flesh to seed ratio, seeds per fruit, green fruit yield per plant, dry fruit yield per plant and yield per plot.

Yield per plant had close relationship between the *per se* performance of the parents and corresponding *gca* effect, which suggest importance of *per se* performance of line along with *gca* effect for selecting better parents in hybridization programme as suggested by Bhagyalakshmi *et al.* (1991).

5.5.13 Dry Fruit Yield per Plant (g)

The hybrids P_3 x P_5, P_4 x P_6, P_2 x P_5, P_5 x P_6, P_2 x P_6, P_4 x P_5 and P_3 x P_4 were having highest yield per plant based on high mean value, *sca* effect and standard heterosis. The parents P_4 and P_5 were good general combiners for this trait. Out of 15 hybrids, 14 hybrids showed positive relative heterosis and heterobeltiosis while eight hybrids showing positive standard heterosis.

Of 15 F_1hybrids, four exhibited more than 50% heterobeltiosis for total dry fruit yield per plant. These crosses were P_3 x P_5 (96.71 %), P_2 x P_5 (91.74 %), P_4 x P_5 (60.12 %) and P_3 x P_4 (59.33 %). Similar findings have also been reported by earlier workers Lohithaswa *et al.* (2000), Ganeshreddy *et al.* (2008), Payakhapaab *et al*. (2012), Kumar *et al*. (2014) and Navhale *et al*. (2014).

Based on mean performance, standard heterosis and *sca* effects CA 8 x CA 32 (P_4 x P_6), CA 5 x CA 32 (P_2 x P_6) and CA 6 x CA 8 (P_3 x P_4) were adjudged as superior dual purpose hybrids with good quality traits. Superior hybrids for dual purpose (green and dry fruit yield per plant) presented in Plate 7.

5.5.14 Yield per Plot (kg)

The ultimate aim of any breeding programme is to increase the yield. The hybrids P_5 x P_6, P_3 x P_5 and P_4 x P_5 having highest yield per plot based on high mean value, *sca* effect and standard heterosis. The parent P_6 was good general combiner for this trait. Out of 15 hybrids, 10 had significant and positive standard

Plate 7. Dual purpose superior hybrids (green and dry fruit yield per plant).

P_4 x P_6

P_2 x P_6

P_3 x P_4

heterosis while 13 had positive heterobeltiosis and 14 had positive average heterosis for yield per plot.

Of 15 F_1hybrids, 3 exhibited more than 50% standard heterosis for total yield per plot. These crosses were P_5 x P_6 (65.53 %), P_3 x P_5 (54.51 %) and P_4 x P_6 (51.94 %). This suggests a strong influence of gene action in determining fruit yield per plot. It indicates that chances of the development of potential high yielding hybrids. The similar results are obtained by Pandey *et al*. (2012) and Darshan (2014).

5.5.15 Driage (%)

With respect to mean performance P_4 x $P_{6,}$ P_2 x $P_{6,}$ P_3 x P_5 and P_2 x P_5 were superior. The male parent P_6 was good general combiners for this trait. P_4 x P_6 and P_2 x P_6 were found good with regard to *sca* effect. No hybrid exhibited positive standard heterosis over standard check while P_3 x P_5 and P_4 x P_6 had significant relative heterosis as well as heterobeltiosis for driage. P_4 x P_6 and P_2 x P_6 were projected as the best hybrids for driage. Similar findings have also been reported by earlier worker Singh and Hundal (2001).

5.5.16 Capsaicin (%)

Capsaicin is the active component of chilli and capsaicin is an important parameter deciding consumer preference. The hybrids P_1 x $P_{2,}$ P_4 x P_6 and P_2 x P_3 were different from other hybrids in having high mean value with *sca* effect and standard heterosis. Among the parents P_1, $P_{2,}$ P_3 and P_6 were good general combiners for this trait. P_2 x $P_{6,}$ P_1 x P_3 and P_3 x P_6 hybrids also had high mean performance and with *sca* effect but standard heterosis was not satisfactory. Eight hybrids had positive and significant average heterosis while seven hybrids had positive heterobeltosis. Similar results were observed by Prasath and Ponnuswami (2008), Chaudhary *et al*. (2013) and Navhale *et al*. (2014).

5.5.17 Oleoresin (%)

Oleoresin is another important character which represents the total flavour of extract of ground spice. Based mean performance and standard heterosis the hybrids P_3 x P_4, P_4 x P_6, P_1 x P_4 and P_1 x P_3 were superior. The parents P_3, P_4 and P_6 were good general combiners for oleoresin. The hybrids P_3 x P_4, P_1 x P_3 and P_2 x P_6 were exhibited positive *sca* effect. Seven hybrids showed significant standard heterosis while six hybrids were showed significant heterobeltiosis. Among the hybrids P_3 x P_4 and P_1 x P_3 were best for oleoresin. Similar findings have also been reported by earlier workers, Prasath and Ponnuswami (2008), Chaudhary *et al*. (2013) and Darshan (2014).

5.5.18 Ascorbic Acid (mg/100 g)

Chilli is considered to be rich source of ascorbic acid and minerals. It is the source for commercial preparation of vitamin C. With respect to mean performance, *sca* effect and standard heterosis P_1 x P_2, P_1 x P_3 and P_4 x P_6 hybrids were superior. The parents P_2 and P_6 were good general combiners for this trait. P_2 x P_6 had significant standard heterosis with good mean performance. Seven hybrids showed significant standard heterosis. P_1 x P_2, P_1 x P_3 and P_4 x P_6 projected as the best hybrids for Ascorbic acid. Similar finding were reported by Sharma *et al*. (2013) and Ahmed *et al.* (2015).

5.5.19 Colour (ASTA units)

The colour value is the principal criterion for assessing the quality of chilli. The hybrids P_2 x P_5, P_3 x P_5 and P_1 x P_6 were superior based on mean performance, *sca* effect. With respect to mean performance P_4 x P_6 and P_3 x P_6 were superior but *sca* effect was not satisfactory. The parents P_2, P_3, P_4 and P_6 were good general combiners for oleoresin. P_2 x P_5 alone exhibited positive standard heterosis while four hybrids showing significant heterobeltiosis and ten hybrids showing significant average heterosis. Similar results were observed by Nandadevi *et al.* (2003) and Prasath and Ponnuswami (2008).

5.6 INCIDENCE OF PESTS AND DISEASES.

Highest incidence of thrips was noticed in P_1 x P_5 (61.66%) and lowest incidence was noticed in P_2 x P_6 (10.00%), P_4 x P_6 (11.55%) and P_1 x P_2 (11.55%)

Mites incidence ranged from zero to 40.74%. The incidence was maximum in hybrid P_1 x P_5 (40.74%) which was on par with P_5 (36.97%).

There was no significant difference among the parents and hybrids for the incidence of bacterial wilt.

The minimum incidence of fruit rot was observed in P_2 x P_6 (2.24%), P_1 x P_3 (2.60%), P_1 x P_2 (2.87%), P_4 x P_6 (3.24%), P_2 x P_4 (3.41%) and P_3 x P_5 (3.44%). Among the parents highest incidence of fruit rot was observed in P_5 (11.25) which was found to be on par with P_1 (10.47%) and P_4 (9.52%).

SUMMARY

6. SUMMARY

The present investigation on “Development of F_1 hybrids in chilli (*Capsicum annuum* L.) for commercial cultivation” was conducted at the College of Agriculture, Vellayani during 2014-2015 with the major objective to develop superior dual purpose chilli F_1 hybrids with medium pungency, deep red colour, high dry matter and vitamin C content.

Materials for the study consisted of six parents *viz.*, CA 3 (P_1), CA 5 (P_2), CA 6 (P_3), CA 8 (P_4), CA 23 (P_5) and CA 32 (P_6) and 15 F_1s produced in diallel mating design excluding reciprocals. The hybrid Arka Harita was used as check for the estimation of standard heterosis. The experiment was laid out in Randomized Block Design (RBD) with 22 treatments and three replications. They were evaluated for following traits *viz.*, plant height (cm), primary branches per plant, days to first flowering, days to first harvest, fruits per plant, fruit length (cm), fruit girth (cm), fruit weight (g), flesh thickness (mm), flesh to seed ratio, seeds per fruit, green fruit yield per plant (g), dry fruit yield per plant (g), yield per plot (kg), driage (%), capsaicin (%), oleoresin (%), ascorbic acid (mg/100 g), colour (ASTA units) and incidence of thrips, mites, bacterial wilt and fruit rot.

The important findings of the present study are summarized below.

Analysis of variance revealed that, significant difference among the treatment for all the traits studied. Variance due to parents was significant for all characters except primary branches per plant, days to first flowering, days to first harvest and driage. The parents vs. hybrids showed significant differences for all the traits except flesh thickness and driage for this study. This indicated that materials used for present investigation had adequate diversity for different traits.

The data on heterosis calculated over standard check Arka Harita revealed superiority of some outstanding cross combinations.

The hybrids *viz.*, CA 23 x CA 32 (P_5 x P_6), CA 8 x CA 32 (P_4 x P_6), CA 8 x CA 23 (P_4 x P_5), CA 6 x CA 32 (P_3 x P_6), CA 6 x CA 23 (P_3 x P_5), CA 6 x CA 8 (P_3 x P_4), CA 5 x CA 32 (P_2 x P_6) and CA 5 x CA 23 (P_2 x P_5) were showed significant and desirable standard heterosis for 12 characters *viz.*, plant height, days to first flowering, days to first harvest, fruit length, fruit girth, fruit weight, flesh thickness, flesh to seed ratio, seeds per fruit, green fruit yield per plant, dry fruit yield per plant and yield per plot.

Among the above hybrids CA 8 x CA 32 (P_4 x P_6) showed significant and desirable standard heterosis for capsaicin, CA 6 x CA 8 (P_3 x P_4) and CA 8 x CA 32 (P_4 x P_6) were showed significant and desirable standard heterosis for oleoresin, CA 23 x CA 32 (P_5 x P_6), CA 8 x CA 32 (P_4 x P_6), CA 6 x CA 32 (P_3 x P_6), CA 6 x CA 23 (P_3 x P_5) and CA 5 x CA 32 (P_2 x P_6) were showed significant and desirable standard heterosis for ascorbic acid and CA 5 x CA 23 (P_2 x P_5) had significant and desirable standard heterosis for colour.

The incidence of thrips, mites, bacterial wilt and fruit rot were less in the parents and hybrid combinations.

Heterosis indicated that the hybrids CA 23 x CA 32 (57.59%), CA 6 x CA 23 (49.67%), CA 8 x CA 32 (38.21%), CA 6 x CA 32 (37.22%) and CA 8 x CA 23 (32.23%) were found to be most promising for green fruit yield and other desirable traits. For dry fruit yield and other desirable traits the hybrids CA 6 x CA 23 (22.52%) and CA 8 x CA 32 (22.36%) were found to be superior. Hence these could be further evaluated to exploit the heterosis or utilize in future breeding programme to obtain desirable sergeants for the development of superior genotypes.

The general and specific combining ability variances were significant for all the traits. The $\sigma^2 gca$ and $\sigma^2 sca$ ratio indicated that non-additive gene action was predominant for all the traits except fruit girth, fruit weight and flesh thickness.

The estimates of general combining ability suggested that parent CA 32 (P6) was a good general combiner for yield (green as well as dry) and quality characters. CA 8 (P4) good general combiner for days to first flowering, days to first harvest, fruits per plant, dry fruit yield per plant, oleoresin and colour. CA 3 (P1) was a good general combiner for fruit length and capsaicin. CA 5 (P2) was a good general combiner for capsaicin, ascorbic acid and colour. CA 6 (P3) was a good general combiner for plant height, seeds per fruit, capsaicin and colour.

The estimates of *sca* effects revealed that the cross combinations CA 23 x CA 32 (P_5 x P_6), CA 8 x CA 32 (P_4 x P_6), CA 8 x CA 23 (P_4 x P_5), CA 6 x CA 23 (P_3 x P_5), CA 6 x CA 8 (P_3 x P_4), CA 5 x CA 32 (P_2 x P_6), CA 5 x CA 23 (P_2 x P_5) and CA 3 x CA 5 (P_1 x P_2) were most promising for green fruit yield, dry fruit yield and fruits per plant.

Based on mean performance, standard heterosis and *sca* effects CA 8 x CA 32 (P_4 x P_6), CA 5 x CA 32 (P_2 x P_6) and CA 6 x CA 8 (P_3 x P_4) were adjudged as superior dual purpose hybrids with good quality traits. CA 23 x CA 32 (P_5 x P_6), CA 6 x CA 23 (P_3 x P_5), CA 6 x CA 32 (P_3 x P_6) and CA 8 x CA 23 (P_4 x P_5) were found to be most promising for green fruit yield and other desirable traits.

The above mentioned promising hybrids can be directly popularised as hybrids or can be carried forward to evolve high yielding superior genotypes.

6.1 FUTURE LINE OF WORK

1. The stability of the superior hybrids need to be assessed and the superior hybrids can be released for cultivation.
2. Pedigree method of selection can be followed to select superior recombinants from the segregating generations which on attaining uniformity can be released as varieties for cultivation.
3. It is suggested to test the superior hybrids along with few more in multilocation trial to confirm their potentiality and to know their stability over different agro-climatic situations.

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DEVELOPMENT OF F_1 HYBRIDS IN CHILLI (*Capsicum annuum* L.) FOR COMMERCIAL CULTIVATION

by

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ABSTRACT

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ABSTRACT

The present study entitled "Development of F_1 hybrids in chilli (*Capsicum annuum* L.) for commercial cultivation" was conducted at College of Agriculture, Vellayani during 2014-15 with major objective to develop superior dual purpose chilli F_1 hybrids with medium pungency, deep red colour, high dry matter and vitamin C content.

The experimental material consisted of six parents *viz.*, CA 3 (P_1), CA 5 (P_2), CA 6 (P_3), CA 8 (P_4), CA 23 (P_5) and CA 32 (P_6) and 15 F_1s produced in diallel mating design excluding reciprocals. The hybrid Arka Harita was used as check for the estimation of standard heterosis. The experiment was laid out in Randomized Block Design (RBD) with 22 treatments and three replications. Analysis of variance revealed significant differences among the treatments for all the traits except primary branches per plant, days to first flowering and days to first harvest for parents.

Based on standard heterosis the hybrids P_5 x P_6 (57.59%), P_3 x P_5 (49.67%), P_4 x P_6 (38.21%), P_3 x P_6 (37.22%), P_4 x P_5 (32.23%), P_2 x P_5 (29.76%) and P_2 x P_6 (23.92%) were found to be most promising for green fruit yield and other desirable traits. For dry fruit yield and other desirable traits the hybrids P_3 x P_5 (22.52%), P_4 x P_6 (22.36%), P_2 x P_5 (18.04%), P_5 x P_6 (16.93%), P_2 x P_6 (13.85%), P_4 x P_5 (13.07%) and P_3 x P_4 (12.52%) were found to be most superior.

The incidence of thrips, mites, bacterial wilt and fruit rot were less in the parents and hybrid combinations.

The general and specific combining ability variances were significant for all the traits. The σ^2*gca* and σ^2*sca* ratio indicated that non-additive gene action was predominant for all the traits except fruit girth, fruit weight and flesh thickness.

The estimates of general combining ability effects suggested that parent P_6 was a good general combiner for both green as well as dry fruit yield per plant and quality characters. P_4 was good general combiner for days to first flowering, days

to first harvest, fruits per plant, and dry fruit yield per plant. P_1 was a good general combiner for fruit length and capsaicin whereas P_2 and P_3 were showed good general combining ability for quality characters.

The estimates of specific combining ability effects indicated that cross combinations *viz.*, P_3 x $P_{5,}$ P_5 x $P_{6,}$ P_2 x $P_{5,}$ P_4 x $P_{5,}$ P_1 x $P_{2,}$ P_4 x $P_{6,}$ P_3 x P_4 and P_2 x P_6 were the most promising for green fruit yield, dry fruit yield and fruits per plant.

Based on mean performance, standard heterosis and *sca* effects CA 8 x CA 32 (P_4 x P_6), CA 5 x CA 32 (P_2 x P_6) and CA 6 x CA 8 (P_3 x P_4) were adjudged as superior dual purpose hybrids with good quality traits.