GENETIC ANALYSIS OF YIELD AND LEAF CURL VIRUS RESISTANCE IN CHILLI (*Capsicum spp.*)

K. ANANDHI

Thesis submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2010

Department of Plant Breeding and Genetics
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM- 695 522

DECLARATION

I hereby declare that this thesis entitled **"Genetic analysis of yield and leaf curl virus resistance in chilli (*Capsicum spp.*)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

K. Anandhi

Vellayani,
23-02-2010

K. ANANDHI
(2006-21-108)

CERTIFICATE

Certified that this thesis entitled **"Genetic analysis of yield and leaf curl virus resistance in chilli (*Capsicum spp.*)"** is a record of research work done independently by Ms. **K. ANANDHI** (2006-21-108) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellayani,
23.02.2010

23/2/2010

Dr. K.M. Abdul Khader
(Chairman, Advisory Committee)
Professor
Department of Plant Breeding & Genetics
College of Agriculture, Vellayani
Thiruvananthapuram.

APPROVED BY

Chairman:

Dr. K.M. ABDUL KHADER
Professor,
Department of Plant Breeding and Genetics
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522

23/02/2010

Members:

Dr. D. S. RADHADEVI
Professor and Head,
Department of Plant Breeding and Genetics,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522.

23/02/10

Dr. SUNNY K. OOMMEN
Professor,
Department of Plant Breeding and Genetics,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522.

23.2.10

Dr. V. K. GIRIJA
Professor,
Department of Plant Pathology,
College of Agriculture, Vellayani,
Thiruvananthapuram – 695 522

23/02/10

Dr. VIJAYARAGHAVAKUMAR
Professor and Head,
Department of Agricultural Statistics,
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522.

23/02/10

EXTERNAL EXAMINER

Dr. Sheela M. N
Senior Scientist,
Div. of Crop improvement, CTCRI,
Sreekariyam, Trivandrum-695017

23/02/10

DEDICATED TO

TO MY FAMILY

ACKNOWLEDGEMENT

With extreme pleasure and satisfaction, I place my heartfelt thanks to my guide Dr. K. M. Abdul Khader, Professor, Department of Plant Breeding and Genetics, College of Agriculture, Vellayani for all the helps he rendered with much friendliness and affection during the entire course of research and especially in the final preparation of thesis and for the valuable corrections he made every time with keen interest.

I place my sincere gratitude to Dr. D. S Radhadevi, Professor and Head in charge of the Department of Plant Breeding & Genetics for her help. Even though she could associate with my work only in the final stage of this work, her involvement was idyllic in going through the manuscript in at most critical and immaculate manner.

I was extremely fortunate to have a professor like Dr. Vijayaraghavakumar, Professor and Head, Department of Agricultural Statistics and member of the advisory committee. His unique way of analysis and scrutinizing data helped me in analyzing and interpreting the data generated in the field work. I thank him for his enlightened guidance, keen interest and unstinted help and also for the valuable suggestions he made to beautify my thesis.

I would like to extend my thanks to Dr. V. K. Girija, Professor, and Department of Plant pathology for her timely help in the field work, sincere and healthy criticism.

I thank Dr. Sunny. K. Oommen, Professor, Department of Plant Breeding and Genetics, and member of my advisory committee for his kind, considerate and inspiring words.

I also thank my former members Dr. K. Umamaheshwaran, Professor, Department of Plant pathology and Dr. K Usha Kumari, Professor, Department of Soil Chemistry for their support during research work.

Another teacher to be mentioned is Dr. P. Manju, Professor: as a member in my advisory committee right from the beginning till the finishing stage of this research she was extremely helpful and encouraging. Even after her leaving the committee she continued to inspire me and help me in the endeavor with her valuable suggestions and critiques. Her perfect involvement in scrutinizing the manuscript gives me more confidence to present the thesis.

I am grateful to all the teaching staff of Department of Plant Breeding and Genetics for their encouragement and well wishes.

I feel happy to express my special thanks to Prabu and Rani for their encouragements and selfless helps.

I also thank Kavitha, Arpitha, Shrikant, Jayarame Gowda, Divya Krishnan, Selvaraju and Madhu Kumar for their helps.

I sincerely acknowledge Jawaharlal Nehru Memorial Fund, New Delhi for granting the scholarship for my research work.

I am in search of words to thank my parents and my sister for all the support and encouragement.

I thank the Almighty for the bountiful blessings showered on me and for lightening my life with all the happiness including this thesis.

K. Anandhi

K. Anandhi

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Introduction

1. INTRODUCTION

Capsicum is an economically important genus in the family Solanaceae, comprising of around 25 species native to tropical and temperate regions of America. Five of its members (*Capsicum annuum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L., and *C. pubescens*) are domesticated. Among this *Capsicum annuum* is a widely cultivated species of chilli. In Kerala, the acreage is 1470 ha with a production of 1417 tons and productivity 965 Kg/ha. *Capsicum frutescens* is mostly grown in the homesteads of Kerala and is preferred for its increased pungency.

Generally pepper fruits (*Capsicum spp.*) are among the most consumed vegetables as fresh green or red and dried whole or ground forms in the world. Chilli is an important condiment due to its pungency, which is due to the presence of alkaloid compounds of the capsaicinoid group in the fruit. Capsaicinoids found only in the *Capsicum* genus are used in medical, food sciences and defense weapon industry. Capsaicinoids occur in the placental tissue of *Capsicum* fruits. The two major capsaicinoids, responsible for upto 90% of pungency, are capsaicin and dihydrocapsaicin with at least nine more minor capsaicinoids occurring in chilli fruits. Oleoresin is extracted and extensively used in food preparations for uniform quality, shelf life, taste and flavour. Besides, chilli is also the source of protein, carbohydrates, minerals, carotenes, vitamin C and vitamin A.

Chilli is exported in the form of dry chilli, chilli powder and oleoresins and is of high export demand. To meet out the demand, the production has to be increased. This can be achieved by increasing the area or productivity. Increase of area under a crop invokes the cultivation under stressed environment. Cultivation of chilli under hot condition (rainfed or summer condition) had become uneconomical due to

increased stresses, the principal one being leaf curl incidence. Yield reduction due to leaf curl virus has been reported upto 50 % in chilli by Meena *et al* (2006). Its control can be achieved only with the vector, *Bemisia tabaci*. This results in only partial control of disease and also adds to cost and human and environmental hazards. Developing resistant varieties becomes a suitable proposition.

Among the various species *Capsicum frutescens* was reported to have high resistance to leaf curl virus. *Capsicum frutescens* is not preferred for its indeterminate nature, low yield and undesirable fruit quality characters like colour and small size. Characterized by its typical flavour and aroma, the species is noted for its richness in oleoresin, pungency and ascorbic acid contents. Because of the unique qualities, it can find application in food, pharmaceutical and cosmetic industries. Hence the requirement is to retain desirable qualities and eliminate undesirable ones which can be achieved by crossing with cultivated species *C. annuum.*

The compatibility between *Capsicum frutescens* and *Capsicum annuum* had been reported variably by different workers. Both compatible and incompatible crosses have been obtained and it had been found that the compatibility mainly depends on the variation in genotypes. Hence screening of crosses and selection of desirable hybrids is to be attempted with line x tester analysis in this study.

To develop varieties having resistance from *C. frutescens* and high yield potential and desirable fruit quality characters from *C. annuum,* knowledge of gene action is a pre-requisite. So an attempt was made to know the inheritance of yield and leaf curl virus resistant genes using generation mean analysis in *Capsicum frutescens* x *Capsicum annuum* hybrids and to decide the breeding programme for development of leaf curl resistant varieties in chilli.

The present investigation was undertaken with the following objectives:

1. To estimate the variability, heritability and genetic advance for fruit yield and leaf curl virus resistance in *Capsicum frutescens* x *Capsicum annuum* crosses in Line x Tester pattern.

2. To study the general combining ability of parents and specific combining ability of hybrids for various traits including yield and leaf curl virus resistance.

3. To assess the magnitude of heterosis for fruit yield, leaf curl virus resistance and other desirable economic characters.

4. To assess the additive, dominance and epistatic gene actions involved in the inheritance of yield and its component characters and leaf curl virus resistance through generation mean analysis which would help to formulate a suitable breeding programme to develop high yielding virus resistant varieties.

Review of literature

2. REVIEW OF LITERATURE

The literature pertinent to the study is reviewed and presented hereunder.

2.1 VARIABILITY

2.1.1 CROSSABILITY STUDIES

Smith and Heiser (1957) studied crossability among species of *Capsicum*. In the interspecific hybridization involving *C. annuum* and *C. frutescens*, they obtained 2% viable seeds when *C. frutescens* was used as female parent. The F_1 plants ranged from partially fertile to complete sterile.

In a crossability study when *C annuum* was taken as female and crossed with *C. frutescens* and *C. pendulum* lower percentage of fruit set was observed than in reciprocals (Radhakrishnan *et al.*, 1977).

Krishnakumari and Peter (1986) has reported that out of 12 reciprocal interspecific crosses involving two lines of *C. annuum* and three of *C. frutescens*, 10 were successful. It was clearly reported that varietal influence in the interspecific hybridization between *C. annuum* and *C. frutescens* is responsible for compatibility. They crossed *C. annuum* cultivars 'Jwala and K_2 with *C. frutescens* cultivars 'white kanthari', 'ornamental type' and 'Green chuna' as female parent and obtained perfect set between two species except in two combinations where 'white kanthari' was used as a female parent. When *C. annuum* was used as female parent the percentage of fruitset was considerably lower than the reciprocal. The failure of pollen grains of *C. frutescens* on the stigma of *C. annuum* revealed the existence of prefertilization barrier. When *C. frutescens* was used as female parent, fruit set was 17 per cent.

Pradeepkumar (1990) worked out a crossability polygon among five species of *Capsicum* and established close relationship between *C. chinense* and *C. frutescens* than *C. frutescens* and *C. annuum*.

2.1.2 VARIABILITY AMONG GENOTYPES

Availability of variability among genotypes is a pre-requisite for any crop improvement programme.

Rajput *et al.* (1981) observed high genotypic coefficient of variation for number of fruits per plant (19.20) and yield (18.28) in seven cultivars of chilli.

High variability was observed by Ramakumar *et al.* (1981) among 12 varieties for plant height, plant spread, fruit girth, number of seeds per fruit, number of fruits per plant and yield.

In a study with 12 parents and their 66 F_1 and F_2 progenies of chilli, Gupta and Yadav (1984) found that the genotypic coefficient of variation ranged from 11 per cent for plant height to 62.6 for fruit girth.

Gopalakrishnan *et al.* (1987a) observed high GCV for fruit length, main stem length, fruit weight, fruits per plant, number of primary and secondary branches, life span, number of seeds and fruit yield per plant in 38 lines of chilli.

In a study with 10 *Capsicum annuum* and 15 *Capsicum frutescens* cultivars, high levels of variation for fruits/plant, individual fruit weight and fresh fruit yield/plant were observed in both species by Adamu and Ado (1988). *Capsicum frutescens* showed high variation in 100-seed weight and dry fruit yield/plant also.

Vijayalakshmi *et al.* (1989) observed greater difference between phenotypic coefficients of variation (PCV) and genotypic coefficient of variation (GCV) for plant height, plant spread, number of flowers, number of pods, total yield and total dry pod yield indicating greater influence of environment on these characters in chilli.

Acharyya *et al.* (1992) reported high variability in 19 cultivars of chilli for number of fruits per plant, yield per plant, fruit length and circumference and seeds per fruit. Similar results were reported by Choudhary *et al.* (1985) and Gopalakrishnan *et al* (1985).

Evaluating 14 F_6 families of the cross ACC 1683 x K_2 of chilli, Pitchaimuthu and Pappiah (1992) observed very high variability for number of fruits per plant, dry and fresh weight of fruit and plant height.

Pitchaimuthu and Pappiah (1992) obtained a close association between estimates of phenotypic and genotypic coefficients of variation for several characters in F_6 families indicating low environmental influence. However, length and girth of fruit and earliness were highly sensitive to environmental factors.

Ambarus (1998) found low variability estimates (< 10 %) for plant height and fruit yield per plant whereas fruit length showed moderate variability.

Nayeema *et al.* (1998) reported high variability for all the characters studied including fruit yield in 71 genotypes of chilli. Several other workers also obtained similar results (Rani and Singh, 1996; Singh and Singh, 1998; Das and Choudhary, 1999).

Devi and Arumugam (1999) obtained very high levels of phenotypic and genotypic variations for yield of fresh fruits per plant and moderate variation for plant height, days to first flowering and dry fruit yield per plant.

A study by Munshi and Behera, (2000) involving 30 germplasm of chilli revealed the existence of considerable amount of genetic variability for all the characters studied except fruit girth. They also obtained GCV ranging from 5.32 per cent (days to first fruit harvest) to 54.94 per cent (number of fruits per plant).

In a study involving intra specific cross between a bell type 'Maor' and a small fruited pungent chilli line 'Perennial', Chaim and Paran (2000) obtained low GCV values for plant height, moderate for fruit length and high for fruit weight and fruit diameter.

In a study using a cross between *Capsicum annuum* cv. LCA 301 and *C. frutescens* cv. Pusa Sadabahar for leaf curl epidemics by Acharyya *et al.* (2002) maximum range of variation was obtained for total fresh yield per plant (237.24-298.30 g), and minimum for fruit diameter (0.66-0.75 cm) in the controlled environment. The minimum value of heritability was observed for total dry yield per plant (74.20), while the maximum (99.90) was recorded for the number of primary branches per plant. Under the epidemic environment, the lowest value was obtained for fruit diameter (76.50) and the highest for 100-seed weight (99.70). Similarly, total fresh yield per plant, leaf curl incidence, ascorbic acid, total dry yield per plant and number of fruits per plant exhibited high heritability with high genetic advance under the epidemic environment. High heritability with low genetic advance was observed for pedicel length, fresh and dry fruit weight, seed weight per fruit, 100-seed weight and capsaicin content under both the environments.

Fifty-two chilli (*C. annuum* and *C. frutescens*) genotypes (cultivars and advanced breeding lines) were evaluated by Dipendra and Gautam (2002). They found significant variation for all the characters *viz.*, plant height, number of primary branches, specific leaf weight, number of leaves per plant, days to first flowering, number of flowers and fruits per plant, fruiting percentage, fruit drop incidence, fruit length, fruit diameter, fresh and dry fruit weight and 1000 seed weight.

The analysis of variance of eight yield components in 13 chilli cultivars revealed high GCV estimates for number of fruits per plant, fresh red chilli yield per plant and plant height. (Rathod *et al.*, 2002).

Sreelathakumary and Rajamony, (2002) reported higher phenotypic and genotypic coefficients of variation for fruits per plant, fruit weight, fruit length, fruit girth, yield and leaf area.

High heritability associated with high genetic advance was recorded by Acharyya and Rajput (2003) for the total fresh yield per plant, ascorbic acid content, number of fruits per plant and total dry yield per plant in a variability study conducted for different traits of *Capsicum* on the F_1, BC_1 and BC_2 of the cross between Punjab Lal and Pusa Sadabahar.

Nandadevi and Hosamani (2003a) observed high degree of PCV and GCV for number of primary branches, fruit length, pericarp thickness, number of fruits per plant and green fruit yield per plant.

Estimation of genetic variability, heritability and genetic advance in 20 accessions of bird pepper (*C. frutescens*) revealed significant difference for plant height, stem girth, leaf area, leaf petiole length, fruits per plant, fruit length, fruit girth, fruit weight and yield per plant (Sreelathakumary and Rajamony 2003).

In a study conducted by Gibbs and Garro (2004) to assess capsaicinoid levels in a pungent Caribbean grown pepper collection, capsaicin content of 28 accessions of *Capsicum chinense* and one each of *C. annuum* and *C. frutescens* ranged from 37.6 to 497.0 mg/100 g in ripe fruits.

Olszewska and Nowaczyk (2004) reported that the wild species (*viz., C. frutescens, C. chinense* and *C. baccatum*) had significantly higher range of variability for number of fruits per plant, fruit weight, wall thickness, yield and dry matter content than the cultivated species of *C. annuum.*

Prabhakaran *et al.* (2004) reported among 97 genotypes high genotypic coefficient of variation for plant spread, number of fruits per

plant, yield per plant, fruit length, mean fruit weight, placenta length and capsaicin.

High genotypic and phenotypic coefficients of variation were observed for number of fruits per plant and fresh fruit yield per plant among 45 genotypes of chilli evaluated for 12 characters by Varkey *et al.* (2005).

High variability was noted by Prasath *et al* (2007) among 26 accessions of *Capsicum annuum* and *Capsicum baccatum* for several traits including capsaicin content, plant height, fruits per plant, fruit weight and fruit yield.

High GCV and PCV were reported for capsaicin content and yield by Sood *et al.* (2007) in chilli

Ukkund *et al.* (2007) observed high degree of variation for all characters among 80 chilli accessions.

2.2 HERITABILITY AND GENETIC ADVANCE

Heritability and genetic advance are very important parameters in selection. High heritability coupled with high genetic advance is indicative of additive genetic variance (Johnson *et al.*, 1955).

Singh and Singh (1977) reported high values for heritability and genetic advance for number of fruits per plant, number of branches, plant height, days to maturity and yield per plant in chilli.

High heritability coupled with high genetic advance for branches per plant, fruit length, fruit weight and fruits per plant was reported in a study involving 25 varieties of chilli (Bavaji and Murthy, 1982).

Nair *et al.* (1984) reported high heritability along with low genetic advance for days to flower, plant height, plant spread, number of primary branches and lifespan in chilli.

In a study with 12 varieties of chilli, Shah *et al.* (1986) obtained high heritability and expected genetic advance for plant height, number of primary branches, fruit length, fruit width and number of fruits per plant.

Ghai and Thakur (1987) reported that total yield and number of fruits exhibited the lowest value of heritability (narrow sense) in a population comprising of parents, F_1s, F_2s and backcrosses in chilli. The expected genetic advance showed a wide range from 8.82 per cent for number of fruits per plant to 73.81 for fruit weight. However, Depestre *et al.* (1989) obtained maximum narrow sense heritability and marked genetic advance for number of fruits per plant, and yield in a natural population of *C. annuum* cv Espanol.

Das *et al.*, (1989) found the highest estimates of heritability and genetic advance for yield per plant in a study involving 30 genotypes of chilli. In a genetic improvement study conducted by Tewari (1989) selection for capsaicin content in *C. frutescens* led to the development of Pusa Sadabahar with a 12% capsaicin content (vs. 8% in [*C. annuum*] Pusa Jwala).

High heritability coupled with high genetic advance was recorded for leaf area index, fruits per plant, fruit weight, seeds per fruit, plant height and fruit length (Varalakshmi and Babu, 1991).

In a study with nine cultivars of chilli, Nandi (1993) noticed high heritability and high genetic advance for length and weight of fruits and yield per plant.

Singh *et al.* (1994) reported high heritability for fruit length, weight of fresh ripe fruits, dry fruit weight, number of fruits per plant and fruit diameter.

Pitchaimuthu and Pappiah (1995) obtained high heritability with high genetic advance for number of fruits per plant, fruit length and fruit girth on evaluating 14 F_6 families of the cross ACC.1683 x K_2.

In a study with 71 genotypes of hot pepper, Nayeema *et al.* (1998) observed high heritability coupled with high genetic advance for fruit yield per plant, number of seeds per fruit, pericarp thickness and average fruit weight.

Heritability and genetic advance were high for number of fruits per plant and fruit weight in chilli (Devi and Arumugam, 1999).

In a study on 10 quantitative traits in pepper, Chaim and Paran (2000) reported high heritability (broad sense) values for fruit weight, fruit diameter, fruit length and pericarp thickness but low heritability for plant height.

Ibrahim *et al.* (2001) observed highest heritability for plant height (98.12 %) followed by fruit length (96.74 %) and number of fruits per plant (96.18 %) in chilli.

Rathod *et al.* (2002) reported high heritability for days to 50 per cent flowering, plant height, number of primary branches and fruits per plant, length and diameter of fruit, 100-seed weight, seed percentage, harvest index and fresh red chilli yield per plant. High heritability coupled with high genetic advance was recorded for number of fruits per plant, fresh red chilli yield per plant and plant height.

Acharyya *et al.* (2002) observed high heritability coupled with high genetic advance for total fresh yield per plant under both leaf curl infected and non-infected environments in chilli.

High heritability and genetic advance were noted for number of fruits per plant, fruit weight, fruit length, fruit girth, yield and leaf area by Sreelathakumary and Rajamony (2002).

In a study with 26 chilli genotypes, Nandadevi and Hosamani (2003a) reported high heritability coupled with high genetic advance for fruit length and green fruit yield per plant.

Prabhakaran *et al.* (2004) studied 97 genotypes and observed high heritability coupled with high genetic advance for yield per plant, mean fruit weight, placenta length and capsaicin.

High heritability coupled with high genetic advance were recorded for number of fruits per plant, number of seeds per fruit and dry weight per plant among 45 genotypes of chilli by Varkey *et al.* (2005).

High heritability coupled with high genetic advance was found by Bendale *et al.* (2006) for average fruit weight, yield per plant, dry weight of plant, seeds per fruit and fruits per plant.

High heritability along with genetic advance was observed for number of fruits per plant by Bharadwaj *et al.* (2007) in a study conducted with 27 chilli genotypes of diverse origin.

Sood *et al.* (2007) reported high heritability coupled with high genetic advance for capsaicin content and yield.

Ukkund *et al.* (2007) found high estimates of heritability among 80 chilli accessions for plant height (93.40%), days to first flowering (83.50%), percent fruit set (70.70%), number of fruits per plant (81.10%), fruit length (92.40%), 10 fruit weight (92.40%) and total green fruits per plant (88.40%).

High genetic advance coupled with high heritability was observed for number of fruits per plant (Tembhurne *et al.* 2008).

2.3 COMBINING ABILITY

In any breeding programme, proper choice of parents based on their ability to produce superior progeny on hybridization is a prerequisite. Combining ability also illustrate the nature and magnitude of gene action involved in the expression of desirable traits. The combining ability can be classified into two classes *viz.* the general and specific combining ability. General combining ability (*gca*), a measure of additive gene action refers to the average performance of a genotype in a series of hybrid

combinations and specific combining ability (*sca*) measures dominant gene action as it includes those effects in specific combination which significantly depart from those expected on the basis of average performance of the genotypes involved.

In a line x tester analysis involving 20 lines and three testers of *C. annuum*, Jagadeesh (1995) observed high *gca* effect for number of branches and plant height while high *sca* effect was recorded for days to flower initiation, number of fruits per plant, fruit length, fruit width and fruit yield per plant.

Patil (1997) crossed 20 lines and three testers in line x tester fashion in chilli and observed significant *gca* and *sca* effects for number of fruits per plant, average fruit weight, fruit width and number of seeds per fruit and latter alone significant for number of branches, yield per plant, fruit length and capsaicin content.

Variances due to *gca* and *sca* were significant in hot pepper indicating the involvement of both additive and non additive gene effects in the expression of plant height, fruit girth, fruit length, average fruit weight, number of fruits and total yield per plant (Ahmed *et al.*1999).

Shukla *et al.* (1999) observed significant *sca* effect for number of branches, average fruit weight, fruit yield and plant height with a 3 x 8 line x tester analysis in chilli.

Gandhi *et al.* (2000) found yield and plant height in chilli to possess significant *sca* effects in a 6 x 6 diallel cross.

In a 10 x 10 diallel cross, *gca* and *sca* effects in chilli were significant for days to flower initiation, fruit width and plant height while only *gca* effect was significant for yield per plant as reported by Lohithaswa *et al.* (2000).

Jadhav *et al.* (2001) studied combining ability among hybrids between six hot chilli cultivars and two paprika type cultivars and found

high *gca* and *sca* variances for plant height, number of fruits, fruit weight and fruit yield.

Additive and non additive components for plant height while only additive attributed for plant spread and non additive alone attributed for number of primary branches in chilli (Linganagouda *et al.* 2003).

In a 6 x 6 diallel cross analysis in chilli, Nandadevi and Hosamani (2003b) revealed that days to flowering, number of fruits per plant, average fruit weight, seeds per fruit and yield per plant were having significant *gca* and *sca* effects while fruit length was having only *gca* effect.

Pandey *et al.* (2003) studied combining ability for yield and its component traits in chilli using line x tester mating system and obtained high *sca* for plant height, number of primary branches per plant, number of secondary branches per plant, number of fruits per plant, fruit length, fruit width and yield per plant.

In chilli, line x tester analysis involving five lines and three testers, Ajith (2004) observed high *gca* and *sca* effects for fruit yield and number of seeds per fruit and *sca* alone for number of fruits per plant.

Muthuswamy (2004) studied five lines and three testers of chilli and observed high *gca* effects for fruit yield, number of fruits per plant, average green fruit weight, fruit length, fruit girth, harvest index, capsaicin content, oleoresin content and leaf curl incidence.

Forty-eight chilli hybrids, developed by crossing four genic male sterile lines and 12 male parents in a line x tester mating design were studied by Patel *et al.* (2004) which resulted in larger *sca* components than the *gca* components of variance for days to flower, fruits per plant and green fruit yield.

Jagadeesha and Wali (2005) studied 45 hybrids in chilli and found that the hybrids B-Kaddi x KDC-1, VN-2 x BC-24, VN-2 x LCA-301, B-

Kaddi x LCA-301, B-Dabbi x Arka Lohith depicted significant specific combining ability effects for dry fruit yield and other yield contributing attributes. They suggested exploitation of additive gene action.

Saritha *et al.* (2005) observed high *sca* in chilli for all the characters which include plant height, number of primary branches, fruit length, number of fruits per plant, fresh and dry fruit yield per plant, number of seeds per fruit, ascorbic acid, capsanthin, oleoresin and susceptibility to virus complex. High *gca* was also observed for all the characters except primary branches and number of seeds per fruit.

Forty-five crosses (15x3) were evaluated for combining ability by Srivastava *et al.* (2005) in chilli and obtained more *sca* effects in the inheritance of plant height, number of branches per plant, fruit width, number of fruits per plant, vitamin C content and capsaicin percentage.

When two lines and nine testers of chilli were studied the crosses AKC-8625 x PP-977268 and CA-960 x PP-977195-1 showed significant specific combining ability effects for yield/plant. (Zate *et al.* 2005)

Anand and Subbaraman (2006) reported high significant *sca* variances than *gca* variances for all the characters.

In a study with 18 hybrids in chilli the parents and F_1 crosses differed significantly for *gca* and *sca* effects for all the characters. Lines Sel-54, 7722-1 and Sel. 16 were good general combiners for red ripe and dry fruit yield per plant whereas cross combinations, namely 2003x7950, Sel.54x7950, Sel.16xSelA-4 for red-ripe fruit yield and Sel. 54x7950, A-28xSel.A-4 and 7722-1x7950 were best specific combinations for dry fruit yield per plant and other yield contributing traits. (Shekhawat *et al.* 2007)

Eighteen divergent lines and 45 F_1 hybrids of chilli were studied by Jagadeesha and Wali (2008) and reported higher proportion of *sca* effect for fruit related traits, while seed related triats were having more of *gca* effect.

The combining ability variances indicated the preponderance of non-additive gene action for the traits plant height, plant height at first branching and stem girth (Kamble and Mulge, 2008a).

Khereba *et al.* (2008) crossed four *Capsicum annuum* genotypes and three *C. chinense* genotypes in a line x tester design and found that the non-additive gene effect played the major role in the inheritance of plant height, average fruit weight, fruit diameter, fruit length, fruit flesh thickness, early yield and total yield.

Reddy *et al.* (2008) found that the *sca* variance was higher than *gca* variance for all the characters (*viz.*, plant spread, number of fruits per plant, average fruit weight, pericarp thickness and number of seeds per fruit) which indicated the predominance of nonadditive gene action.

2.5 HETEROSIS

Heterosis may be defined as the deviation of a character in an F_1 hybrid over mid parent (relative heterosis), better parent (heterobeltiosis) or a standard parent (standard heterosis). Heterosis breeding is a potential tool for achieving quantum jump in production and productivity as it breaks the yield plateau. Hybrid vigour has resulted in spectacular yield increase in maize, sorghum, bajra, sunflower and several vegetables.

Heterosis can be well exploited in chilli as economic hybrid seed production could be ensured due to high seed number per fruit and natural cross pollination. Sekar and Arumugam (1985) reported upto 68 per cent of natural cross pollination in chilli. Singh *et al.* (2006) reported the utilization of male sterile line MS12 in two widely adapted commercial hybrid CH-1 and CH-3 in north India. These reports gives a clear view that heterosis is a better avenue for the improvement of chilli. The literature on heterosis for yield and other qualitative characters has been summarized in Table 1.

Table 1. Extent of mid parent heterosis, heterobeltiosis and standard heterosis for quantitative and qualitative traits in chilli (*Capsicum spp.*)

Characters	Number of hybrids	Mid parent heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)	Reference
Days to flowering	72	-28.13 to 10.77	-7.66 to 42.33	-2.91 to 65.04	Gaddagimath (1992)
	60	-	-6.60 to 11.10	-13.80 to 6.20	Jagadeesh (1995)
	45	-	-	Upto 138.69	Echeverri *et al.* (1998)
	36	-14.81 to 15.85	-3.30 to 22.85	-9.84 to 14.82	Prasad (1999)
	-	-	-	-12.64 to 11.22	Shukla *et al.* (1999)
	45	-37.74 to 18.75	-47.76 to 10.00	-40.32 to 14.89	Lohithaswa *et al.* (2000)
Days to 50 per cent flowering	6	6.22 to 2.05	18.13 to 16.08	-	Gopalakrishnan *et al.* (1987b)
	45	-	Upto –45.23	-	Mishra *et al.* (1988)
	-	35.6 to 15.6	35.6 to 17.6	35.6 to 0.090	Patel *et al.* (1997)
Number of branches	28	-	1.86 to 33.49	-	Mishra *et al.* (1977)
	36	Upto 100.00	Upto 97.30	-	Nair *et al.* (1986)
	6	13.50 to 25.36	12.20 to 20.00	-	Gopalakrishnan *et al.* (1987b)
	45	-	Upto 75.00	-	Mishra *et al.* (1988)
	28	-11.60 to 21.00	-12.00 to 16.30	-	Patil (1990)
	72	-37.50 to 72.60	-50.00 to 70.27	-24.51 to 11.41	Gaddagimath (1992)
	60	-	-42.90 to 45.90	-38.10 to 5.30	Jagadeesh (1995)
	45	-52.76 to 25.30	-62.70 to 34.88	-38.16 to 114.47	Lohithaswa (1997)
	60	-24.22 to 112.25	-50.06 to 90.95	-45.33 to 33.30	Patil (1997)
	-	-41.17 to 50.00	-48.27 to 40.90	-48.27 to 6.89	Hemavathy (2000)
	24	-	Upto 29.69	Upto 23.98	Ahmed and Hurra (2000)
	15	-25.93 to 56.63	-41.67 to 36.59	-16.67 to 116.67	Muthuswamy (2004)
Number of fruits per plant	28	-	-13.93 to 68.83	-	Mishra *et al.* (1977)
	72	-	0.00 to 67.86	-	Sontakke (1981)
	6	-111.00 to 128.00	-	-	Depestre and Espinosa (1986)

Table 1. continued...

Number of fruits per plant	12	-15.10 to 89.23	-32.58 to 71.47	-	Krishnakumari and Peter (1986)
	36	Upto 72.30	Upto 58.40	-	Nair *et al.* (1986)
	45	-	Upto 66.66	-	Mishra *et al.* (1988)
	28	-31.50 to 101.50	-41.80 to 68.40	-	Patil (1990)
	72	-46.23 to 183.51	-55.68 to 127.15	-6.47 to 197.06	Gaddagimath (1992)
	54	9.10 to 116.60	-7.40 to 10.53	-	Mulge (1992)
	60	-	-57.20 to 58.00	-24.80 to 189.10	Jagadeesh (1995)
	45	-	-	Upto 138.69	Echeverri *et al.* (1998)
	36	-60.49 to 239.55	-83.03 to 83.04	-85.82 to 56.36	Prasad (1999)
	24	-	Upto 71.73	Upto 71.73	Ahmed and Hurra (2000)
	45	-24.00 to 15.38	-42.5 to 67.0	-67.19 to 376.60	Lohithaswa *et al.* (2000)
	28	-45.80 to 75.48	-61.45 to 64.80	-16.92 to 132.7	Kumar and Lal (2001)
	15	-	Upto 183.60	-	Mamedov and Pyshnaja (2001)
	42	-	Upto 66.55	-	Singh and Hundal (2001b)
	-	12.60 to 128.47	-3.66 to 125.91	-20.65 to 63.16	Phillip (2004)
	-	-	Upto 94.63	Upto 84.25	Shankarnag *et al.* (2006)
Average fruit weight	6	10.3 to 11.20	-	-	Depestre and Espinosa (1986)
	36	Upto 11.20	-	-	Nair *et al.* (1986)
	72	-22.42 to 155.30	-29.67 to 127.53	-44.24 to 92.13	Gaddagimath (1992)
	72	-20.80 to 26.50	-24.70 to 9.50	-	Mulge (1992)
	60	-	-28.11 to 14.80	-38.50 to 18.70	Jagadeesh (1995)
	45	-21.23 to 66.48	-43.42 to 46.50	-25.59 to 87.29	Lohithaswa (1997)
	60	-53.63 to 31.67	-54.73 to 31.21	-36.19 to 61.90	Patil (1997)
	15	High	-	-	Zecevic (1997)
	15	High	-	-	Zecevic and Stevanovic (1997)
	24	-	Upto 71.73	10.95	Ahmed and Hurra (2000)
	15	-	Upto 129.70	-	Mamedov and Pyshnaja (2001)
	42	-	Upto 111.27	-	Singh and Hundal (2001b)
	-	12.93 to 67.35	2.98 to 54.03	47.22 to 188.74	Phillip (2004)
Yield per plant	28	-	-18.80 to 71.40	-	Mishra *et al.* (1977)

Table 1. continued...

Yield per plant	72	-	0.00 to 61.40	-	Sontakke (1981)
	30	-	>20.00	-	Chen (1985)
	12	-3.44 to 169.83	-22.22 to 157.56	-	Meshram and Mukeswar (1986)
	45	-	Upto 110.88	-	Mishra *et al.* (1988)
	28	-25.50 to 159.20	-45.50 to 88.50	-	Patil (1990)
	72	-26.29 to 223.96	-50.09 to 175.16	-55.37 to 252.89	Gaddagimath (1992)
	54	6.80 to 112.20	-4.40 to 110.00	-	Mulge (1992)
	60	-	-73.10 to 89.10	-44.00 to 72.80	Jagadeesh (1995)
	45	-41.06 to 195.19	-54.81 to 129.69	-31.64 to 316.44	Lohithaswa (1997)
	60	-64.64 to 123.77	-69.59 to 120.49	-72.06 to 77.43	Patil (1997)
	15	-	High	-	Zecevic and Stevanovic (1997)
	15	67.55	-	-	Zecevic (1997)
	45	-	-	Upto 138.69	Echeverri *et al.* (1998)
	24	-	Upto 174.52	Upto 83.53	Ahmed and Hurra (2000)
	21	-	High	-	Legesse (2000)
	28	-31.87 to 158.80	-48 to 105.87	-50.50 to 76.49	Kumar and Lal (2001)
	24	Upto 92.04	Upto 85.38	Upto 15.30	Patel *et al.* (2001)
	42	-	Upto 108.17	-	Singh and Hundal (2001b)
	30	-	Upto 219	-	Anandanayaki and Natarajan (2002)
	15	-	Upto 246.73	-	Nandadevi and Hosamani (2003b)
	-	-29.93 to 65.54	52.18 to 17.49	-	Ajith (2004)
	15	-	-	-58.61 to 92.67	Muthuswamy (2004)
	-	-	1.81 to 10021	14.22 to 187.65	Phillip (2004)
	-	7.40-33.24			Singh and Chaudhary (2005)
	-	-	23.61 to 195.54	-58.00 to 56.51	Shankarnag *et al.* (2005)
	-	High	-	-	Adpawar *et al.* (2006)
	45	-	-	High	Kamble and Mulge (2008b)
	72	-4.28 to 17.87	-	-	Sontakke (1981)
Fruit length	6	Up to 23.24	Up to 20.78	-	Gopalakrishnan *et al.* (1987b)
	45	-	Upto 63.85	-	Mishra *et al.* (1988)

Table 1. continued...

Fruit length	28	-11.10 to 61.0	-34.7 to 38.4	-	Patil (1990)
	72	-28.52 to 64.56	-46.71 to 31.93	-70.32 to 13.22	Gaddagimath (1992)
	60	-	-32.0 to 25.3	-26.7 to 25.9	Jagadeesh (1995)
	60	-9.32 to 45.85	-29.98 to 31.79	-9.44 to 58.24	Patil (1997)
	36	-14.20 to 75.82	-36.78 to 0.24	-41.56 to 6.67	Prasad (1999)
	-	-	-	9.74 to 12.66	Shukla *et al.* (1999)
	24	-	Upto 29.03	Upto 55.0	Ahmed and Hurra (2000)
	28	-13.18 to 30.02	-34.49 to 15.67	-24.49 to 33.69	Kumar and Lal (2001)
	15	-	Upto 116.3	-	Mamedov and Pshynaja (2001)
	42	-	Upto 55.00	-	Singh and Hundal (2001b)
		-21.73 to 28.06	-58.18 to 17.49	-45.57 to 6.84	Ajith (2004)
	15	-	-	-53.96 to 7.58	Muthuswamy (2004)
	-	-	Upto 9.16	Upto -14.13	Shankarnag *et al.* (2006)
	72	-	0.0 to 33.85	-	Sontakke (1981)
Fruit width	6	7.12 to 10.13	3.62 to 7.36	-	Gopalakrishnan *et al.* (1987b)
	28	-13.2 to 43.20	-22.40 to 33.50	-	Patil (1990)
	72	-25.00 to 80.26	-40.00 to 50.00	-13.4 to 173.91	Gaddagimath (1992)
	36	-20.97 to 73.13	-33.34 to 80.62	-34.78 to 124.35	Prasad (1999)
	-	-	-	-12.17 to –4.76	Shukla *et al.* (1999)
	42	-	Upto 24.48	-	Singh and Hundal (2001b)
	-	-	44.53	10.83	Shankarnag *et al.* (2006)
	12	-53.0 to 58.17	-69.45 to 4.83	-	Krishnakumari and Peter (1986)
Number of seeds per fruit	36	5.196 to 69.197	2.21 to 80.11	-	Nair *et al.* (1986)
	45	-	Up to 80.01	-	Mishra *et al.* (1988)
	72	-22.86 to 129.92	-28.91 to 123.81	-27.76 to 91.02	Gaddagimath (1992)
	45	-52.17 to 206.75	-36.24 to 139.26	-35.38 to 108.09	Lohithaswa (1997)
	60	-29.64 to 55.75	-37.32 to 50.43	-34.21 to 54.39	Patil (1997)
	28	-24.2 to 66.35	-32.7 to 60.24	-31.46 to 37.45	Kumar and Lal (2001)
	-	-	-	25.76 to 144.20	Phillip (2004)
	45	-	Upto 51.85	-	Mishra *et al.* (1988)

Table 1. continued...

100 Seed weight	-	-	-24.91 to 34.46	-	Devi and Arumugam (1999)
	28	29.6 to 43.3	-36.9 to 41.40	-20.7 to 41.40	Kumar and Lal (2001)
	-	-30.43 to 4042	-66.46 to -7.18	-37.86 to 12.89	Ajith (2004)
	-	-15.19 to 31.76	-25.27 to 17.22	-8.58 to 19.53	Phillip (2004)
	-		-24.45 to -1.25	-22.41 to 3.88	Ajith (2004)
Duration of crop	-	-8.24 to 1.12	-11.55 to 7.70	-15.17 to 0.56	Phillip (2004)
	28	-	-10.29 to 9.15	-	Mishra *et al.* (1977)
Plant height	45		-11.82 to 44.63	-	Sharma and Saini (1977)
	72	-	0.0 to 16.17	-	Sontakke (1981)
	36	Upto 30.0	Upto 30.60	-	Nair *et al.* (1986)
	45	-	Upto 22.43	-	Mishra *et al.* (1988)
	28	-14.5 to 30.5	-25.8 to 17.3	-	Patil (1990)
	72	-16.80 to 41.84	-21.66 to 41.13	-33.57 to 10.19	Gaddagimath (1992)
	54	42.5 to 50.4	19.4 to 44.3	-	Mulge (1992)
	60	-	26.7 to 9.26	-5.98 to 20.20	Jagadeesh (1995)
	45	-21.94 to 49.18	-37.84 to 50.00	-24.46 to 87.5	Lohithaswa (1997)
	60	-47.13 to 66.51	-57.27 to 44.35	-29.23 to 112.31	Patil (1997)
	36	-16.46 to 52.40	-29.59 to 8.80	-0.29 to –0.13	Prasad (1999)
	45	-	-	Upto 138.69	Echeverri *et al.* (1998)
	24	-	Upto 43.31	Upto 56.94	Ahmed and Hurra (2000)
	-	-	Upto31.02	Upto 40.00	Gandhi *et al* (2000)
	-	-26.71 to 71.30	-33.20 to 62.35	-36.13 to 49.18	Hemavathy (2000)
	28	-20.31 to 28.54	-23.76 to 12.45	-20.75 to 3.15	Kumar and Lal (2001)
	-	-12.14 to 14.67	-	-	Muthuvel (2003)
	-	-27.54 to 24.06	-3.88 to 93.26	-49.37 to 5.22	Ajith (2004)
	-	-	Upto 37.22	Upto 55.10	Shankarnag *et al.* (2006)
Plant spread	-	-	-	Positive	Shankarnag *et al.* (2005)
	-	-	15.85 (east west)	55.61 (east west)	Shankarnag *et al.* (2006)
	-	-	59.46 (north south)	46.32 (north south)	

Table 1. continued...

Plant spread	-	-	-	High	Satish and Lad (2007)
	36	Upto 9.70	Upto 61.20	-	Nair *et al.* (1986)
Capsaicin content	23	-25.98 to 42.31	-	-	Anandanayaki (1997)
	45	-34.97 to 243.08	-98.88 to 172.09	-7.45 to 447.84	Lohithaswa (1997)
	-	Upto 103.50	Upto 85.64	Upto 89.42	Tanki (1999)
	-	Upto 108.76	Upto 91.72	Upto 91.55	Hemavathy (2000)
	-	-17.80 to 34.70	-22.55 to 28.77	-	Sathiyamurthy (2002)
	-	8.84 to 34.36	-	-	Muthuvel (2003)
	15	-72.83 to 103.57	-77.68 to 58.53	-58.33 to 90.00	Muthuswamy (2004)
	-	-52.86 to 9.09	-37.44 to 40.84	-	Phillip (2004)
		-46.15 to 89.16	-55.30 to 72.52	-	Kumar *et al.* (2005)
		-	High	-	Patel *et al.* (2008)
	-	-10.92 to 17.41	-16.86 to 11.31	-21.83 to 0.68	Anandanayaki (1997)
Oleoresin	-	Upto 40.03	Upto 36.52	Upto 33.26	Tanki (1999)
	-	40.95	40.44	-	Hemavathy (2000)
	-	Upto 28.86	Upto 27.26	Upto 7.27	Malathi and Veeraragavathatham (2004)
	15	17.81 to 44.22	-31.71 to 16.43	-11.90 to 34.80	Muthuswamy (2004)

2.6 GENE ACTION

The choice of appropriate breeding method for improvement of quantitative characters depends largely on gene action. But the effects of individual genes cannot be measured. Environment also influences the phenotype expression of characters. Therefore the effect of individual genes must be considered using suitable statistical procedures to obtain genetic information.

The summary of literature pertaining to gene action on various quantitative and qualitative characters in chilli is presented below.

Bhat (1981) and Khadi (1983) observed only additive gene action for number of branches per plant while Cao and Su (1988) observed both additive and non additive gene action for the same and also for plant height.

Joshi (1988) reported both additive and non additive gene action for number of branches per plant, number of fruits per plant, average fruit weight, fruit yield per plant, plant height while dominance alone for fruit length.

Patil (1990) reported non additive gene action for number of fruits per plant and fruit width and additive gene action for number of branches per plant, fruit yield per plant and plant height. He also reported the presence of both additive and non additive gene action for fruit length.

Bhagyalakshmi *et al.* (1991) reported both additive and non additive gene action for number of branches per plant, number of fruits per plant, fruit yield per plant, fruit length, fruit width, number of seeds per fruit, seed weight and plant height.

Ahmed *et al.* (1994) reported that dominance, additive x additive, additive x dominance, dominance x dominance and the non additive gene action predominated for number of fruits per plant, fruit length and average fruit weight.

Bal and Singh (1997) observed partial dominance and additive gene action and Krishnamurthy and Deshpande (1997) only partial dominance while Murthy and Deshpande (1997) observed additive, dominance and interaction components for number of fruits per plant.

Shukla *et al.* (1999) reported non additive gene components for number of branches per plant, number of fruits per plant, average fruit weight, plant height and yield per plant.

Over dominance and additive gene action was observed for number of fruits per plant, yield per plant and fruit length while number of branches per plant showed over dominance alone. Additive and partial dominance was observed for average fruit weight, plant height and capsaicin content (Doshi and Shukla 2000).

Anandanayaki and Natarajan (2000) reported over dominance for number of branches per plant, dominance for number of fruits per plant and non additive effects for plant height.

Chaim and Paran (2000) found additive gene action predominating for average fruit weight and Todorova (2000) found overdominance for the same trait.

The predominance of non additive gene action was observed by Ibrahim *et al.* (2001) for number of fruits per plant, fruit length and plant height.

In a study with crosses from six hot chilli types x two paprika types, nonadditive gene action was dominant over additive gene actions in the inheritance of plant height, fruit number, fruit weight, and fruit yield (Jadhav *et al.* 2001).

Singh and Hundal (2001a) reported both additive and non-additive components for oleoresin, while additive components alone for capsaicin.

Rathod *et al.* (2002) found predominance of additive gene action for yield per plant, number of fruits per plant and plant height.

A report of non additive gene action was given by Ahmed *et al.* (2003) for number of branches per plant, number of fruits per plant, average fruit weight, plant height and yield per plant and additive gene action for fruit length.

Nandadevi and Hosamani (2003b) found that non additive gene action was more for number of fruits per plant and yield while additive gene action was more for number of seeds per plant and fruit length.

In a study with 27 hybrids, the non-additive component of genetic variance was predominant for stem girth and height at first branching (Mulge and Madalageri, 2003).

Dry fruit yield had higher magnitude of dominant gene action with duplicate epistasis compared to additive gene effects. Additive x Additive interaction was more predominant than other types. Fruit quality traits *viz*; fruit length, fruit width, fruit weight, pericarp weight, ascorbic acid content and capsaicin content were under the control of additive type of gene action. This was reported by Jagadeesha *et al.* (2004) while studying six diverse parents in nine different crosses

Predominant contribution of dominance and epistatic interaction components were noted for yield, number of fruits per plant, average green fruit weight, fruit length, capsaicin content, oleoresin content and vulnerability index for leaf curl virus resistance from a study using generation mean analysis by Muthuswamy (2004).

Patel *et al.*(2004) in a study with 48 chilli hybrids observed the existence of non-additive gene action for all traits. Variances due to general (*gca*) and specific combining ability (*sca*) were significant for all traits, except *gca* for fruit length and weight and *sca* for primary branches per plant, indicating the importance of both genetic variances for the inheritance of the traits. Additive components were larger than the non-

additive components of variance for days to flower, fruits per plant and green fruit yield.

The predominance of additive and dominance x dominance interactions in Jwalamukhi x Ujwala and Jwalasakhi x Ujwala for fruit weight was noted in a study with 15 hybrids by Ajith and Manju (2005).

While studying 45 crosses Srivastava *et al.* (2005) suggested that non-additive gene action had greater role in the inheritance of all the characters, (plant height, number of branches per plant, fruit length and width, number of fruits per plant, vitamin C content and capsaicin percentage) except for fruit length and red ripe fruit yield per plant, where additive gene action played an important role.

In a triallel analysis the estimation of genetic components revealed the predominance of dominance gene effect for fruit yield per plant, number of branches per plant, number of fruits per plant, average fruit weight, fruit length, fruit girth and capsaicin content while days to first flowering, plant height, number of seeds per fruit, 100 seed weight and oleoresin content had additive x dominance type of epistatic effect (Haridass 2007).

Kamboj *et al.* (2006) found the involvement of the additive gene actions predominantly in the inheritance of fruit length, fruit and seed weight of 10 fruits, seeds per fruit and test weight. However they reported that both additive and non-additive gene actions were equally important for the genetic control of pericarp - seed ratio.

Forty-five F_1 hybrids were studied by Jagadeesha and Wali (2008) and higher proportion of additive gene effect for fruit related traits was observed, while seed related triats were under the control of non-additive gene action.

The magnitude of dominance (*h*) gene effect was greater than the magnitude of additive gene effect (Somashekhar *et al.* 2008). However,

the additive x additive (*i*) component was more predominant than other types of interactions. The coexistence of *h* and *i* indicated the presence of duplicate epistasis.

2.7 GENETICS AND BREEDING FOR LEAF CURL RESISTANCE

Leaf curl is a major destructive disease of chilli. A yield loss of 80 to 100 per cent has been reported in case of early infection by leaf curl virus (Singh *et al.*, 1979). Munshi and Sharma (1996) reported that the incidence of chilli leaf curl ranged from 11.5 to 96.0 per cent.

Fugro (2000) reported that leaf curl incited by virus is an important disease of chilli. Meena *et al.* (2006) reported severe incidence of chilli leaf curl virus during winter in rainfed chilli crop of Rajasthan.

Inspite of its severity, little work has been done in identifying resistant sources for developing resistant/tolerant varieties. An attempt has been made to review the available literature on leaf curl virus disease in chilli.

2.7.1 Symptomatology

Chilli leaf curl is expressed as stunting of the plants with upward or downward curling of leaves. The newly formed leaves exhibit chlorosis. Curled leaves further become leathery and brittle. Shortening of internodes leads to dwarfing of the plant (Mishra *et al.*, 1963).

The disease causes downward curling, dark green colour and oval to rounded shape of leaves, pronounced vein-thickening and leafy outgrowths or venations on the under surface of leaves (Dhanraj and Seth, 1968). Flower and fruit production are reduced considerably.

In severe cases, axillary buds were stimulated to produce small cluster of leaves. Flower and fruit formation also gets reduced (Nair and Menon, 1983).

Histopathological studies of normal and leaf curl virus-infected *Capsicum annuum* (cv. Suryamukhi) leaves conducted showed that curling of leaves occurred mainly due to the deformation of the cellular framework(Ray and Sarkar 2001). Microtome sections (10 micro M) of virus-infected leaves showed cellular destruction in the upper epidermis. Notable changes in cell size and structure were also observed.

Solanki and Rai (2006) found that in viral infection, upper epidermis mostly deformed, the leaves and the young twig become compact to form rosette appearance. Contrary to this mites and thrips were found congregating mostly on the lower side of top young leaves, which curl downward in inverted boat shaped manner. The petioles of matured leaves were elongate, brittle and lower surface turned to silvery in appearance which gradually turned brown and curled.

2.7.2 Etiology

Chilli leaf curl is considered to be a complex disease caused by separate or combined infection of mites, thrips and viruses (Tewari, 1983 and Nawalagatti *et al.*, 1999).

As early as 1935, Ayyar *et al.* observed that *Scirtothrips dorsalis* (thrips) was involved in the disease while Khodawe and Taley (1978) reported the involvement of *Hemitarsonemus latus* in the development of leaf curl symptom. *Scirtothrips dorsalis* (thrips) and *Polyphagotarsonemus latus* (mite) also produced leaf curl symptom (Amin, 1979; Mallapur, 2000; Reddy *et al.*, 2000).

2.7.3 The virus

The virus causing leaf curl in chillies is commonly referred to as chilli leaf curl virus or tobacco leaf curl virus.

Fernando and Peiris (1957) found that the transparent kroepoek strain of tobacco leaf curl virus was involved in chilli leaf curl complex.

Dhanraj and Seth (1968) reported the presence of two distinct strains of the leaf curl virus, and found that one of the strains produced severe enation in chilli and other solanaceous hosts.

Peter (1998) reported the involvement of pepper mottle virus in the leaf curl disease complex.

Tomato leaf curl virus caused interveinal and marginal chlorosis and upward curling of the leaflet margin in *C. annuum* plants (Reina *et al.*, 1999).

A new virus named as pepper yellow leaf curl virus was found to cause yellow leaf curl disease in *C. annuum* plants in Thailand (Samretwanich *et al.*, 2000).

Gonzalez *et al.* (1993) observed that all the *Capsicum* varieties inoculated with tomato yellow leaf curl bigemini virus showed resistance. But Dalmon and Marchoux (2000) reported the tomato yellow leaf curl virus could also infect Paprika (*Capsicum annuum*).

In a study conducted with the chilli (*Capsicum annuum*) cultivars Surajmukhi, Anhra Jyoti, X 235, Chandramukhi, Pusa Jawala, Longi-Jpani, Chanchal, Chaman and Selection 54 association of a begomovirus with leaf-curl disease of chilli (*Capsicum annuum*) was reported by Raj *et al.* (2005).

2.7.4 Breeding for chilli leaf curl virus resistance

Resistant sources identified by screening the genotypes under field and or artificial conditions were utilized in breeding programmes to develop resistant varieties.

Mishra *et al.* (1963) screened 67 varieties of chilli against leaf curl virus and found that all were susceptible except Puri Red and Puri Orange.

Twenty three mutants of the variety NP 46-A along with Puri Red and Puri Orange were screened against the enation strain of leaf curl virus and all genotypes developed 100 per cent infection (Dhanraj *et al.*, 1968).

By screening 105 chilli varieties Singh (1973) found that seven of them *viz.*, EC 4020, EC 7277, EC 7338, EC 6589, EC 9293, Puri Red and Puri Orange were free from infection by leaf curl virus.

Tewari and Ramanujam (1974) derived high yielding and mosaic and leaf curl virus resistant variety Jwala from the cross NP46A X Puri Red.

From advanced generations of the cross NP 46 A x Puri Red, Sel 4, 6, 7 and 15 were superior and tolerant to the disease (Tewari 1977). Among these, Sel 4 was developed into the high yielding leaf curl virus-resistant variety Pusa Jwala. This was confirmed by Tewari and Anand (1977) who obtained higher fruit yield and high degree of resistance for Pusa Jwala compared to the susceptible variety NP 46A.

Among 33 indigenous and exotic collections of chilli including five *Capsicum spp.*, IC 31339 (*C.frutescens*), Pant C-1, Pant C-2 and *C.angulosum* were tolerant to leaf curl virus (Konai and Nariani 1980).

Singh and Kaur (1986) found that Punjab Lal selected from Perennial x Long Red was resistant to leaf curl virus.

Selections from the cross Pusa Jwala x Delhi Local *viz.*, 38-2-1, 38-3-19, 42-2-4, 52-1-6, 81-1-1, 96-4-8, 96-4-9, 96-4-9-3 and 101-2-33 were reported to be tolerant to tobacco leaf curl virus (Tewari and Viswanath, 1986).

A promising line of bird chilli (*C. frutescens*) was identified as highly resistant to mosaic and leaf curl viruses and was designated as PSP 11 (Tewari, 1987).

Memane *et al.* (1987) on screening 69 varieties against leaf curl complex (caused by thrips and leaf curl virus) obtained lower disease

incidence in Pant C-1 (40.22 %). Pant C-1, LIC 45 and NI 46 were regarded as moderately resistant to leaf curl.

Among the 34 cultivars screened, Mutant-3, Musalwadi local, Pant-C1 and DPL-C1 were reported to be moderately resistant to leaf curl virus complex by Rajput *et al.* (1988)

Sangar *et al.* (1988) screened 10 varieties of *Capsicum annuum* for resistance to tobacco mosaic tobamovirus (TMV) and tobacco leaf curl gemini virus under natural field conditions. The varieties JCA 248, JCA 218, Pant C-1, NP 46A, Pusa Jwala and JCA 196 were resistant to leaf curl virus. All varieties showed some symptoms of TMV. However TCA 248, JCA 218 and Pant C-1 were the least affected.

Brar *et al.* (1989) screened 33 genotypes against leaf curl and mosaic viruses and obtained six lines tolerant to both diseases.

Evaluating seven chilli varieties for resistance against leaf curl Naitam *et al.* (1990) reported that Jwala and Pant C-1 showed the least leaf curl incidence (25 %).

'Pusa Sadabahar' developed from Pusa Jwala x IC 31339 was found to have high degree of tolerance to leaf curl virus (Tewari, 1991).

Pant C-1 and Pant C-2 (derived from NP 46A x Kandhari) and Jawahar 218 (obtained from Kalipeeth x Pusa Jwala) were found to be tolerant/resistant to leaf curl virus (Singh, 1993).

Studying genetic control of virus resistance against chilli mosaic and leaf curl viruses (most commonly tomato mosaic, tabamovirus, cucumber mosaic cocumo virus, potato Y potyvirus and tobacco leaf curl bigemini virus) Bal *et al.* (1995) observed that susceptibility to mosaic as well as leaf curl was dominant and resistance controlled by monogenic recessive genes. The conventional method of back crossing was suitable for transferring resistant genes to commercial varieties with desirable fruit size.

Arora *et al.* (1996) reported Hisar Vijay (HC 28) and Hisar Shakti (HC 44) as resistant to leaf curl virus from among 11 pure breeding lines.

Screening 66 cultivars for resistance to leaf curl complex Munshi and Sharma (1996) reported that six lines *viz.*, Pusa Sadabahar, RHRC Clustering Erect, RHRC Clustering Pendula, LGP-8-1, LGP-18-2-4-3 and LGP-18-10-12 were resistant to the disease.

Singh *et al.* (1998) screened seven varieties of chilli against sucking pests and leaf curl virus and observed none free from infection. But Pusa Sadabahar, JM-218 and Pant C-2 showed only slight infection.

Kumar *et al.*, (1999) evaluated 37 chilli genotypes for incidence of pepper leaf curl virus and rated three (Pusa Jwala, Suryamukhi and Japani Loungi) as resistant, two moderately resistant, nineteen susceptible and thirteen highly susceptible.

"Phule Sai' (GCH-8) selected from advanced generations of Pant C1 x Kamandalow was moderately resistant to leaf curl virus under field conditions (Jadhav *et al.* 2000).

Screening of chilli for leaf curl complex resistance was conducted by Acharyya (2002) using 6 parents, namely LCA 301, LCA 312, LCA 304, Pusa sadabahar, RHRC-Clustering erect and Punjab Lal, and 6 generations, i.e. P_1, P_2, F_1, F_2, BC_1 and BC_2. The F1 progenies and BC2 generations of certain crosses were found to be resistant for leaf curl complex. However, the BC1 generation of the cross (Punjab Lal x Pusa Sadabahar) x Punjab Lal was found to be highly resistant with a much reduced coefficient of infection. Selection on plant basis of such cross combinations in the segregating generations must be done to evolve a leaf curl resistant variety.

Acharyya *et al.* (2002) reported high heritability with high genetic advance for leaf curl incidence indicating the greater proportion of additive genetic variance and consequently a high genetic gain expected

from selection. High heritability coupled with high genetic advance for total fresh yield per plant was noticed under both leaf curl infected and non-infected conditions.

Thirty-seven genotypes of chilli were evaluated by Jose and Khader (2003) for reaction to chilli leaf curl virus and reported that the genotypes Alampady local-1, Neyyattinkara local, Kottiyam local, Haripuram local, Pant C-1, Chandera local, Mangalapuram local and Kottikulam local were identified as tolerant, 27 were susceptible and two were highly-susceptible to the disease.

In a study on 6 x 6 diallel analysis Nandadevi and Hosamani (2003b) reported that RHRC-Cluster-Erect, Pant C-1 and PMR-52/88/K had significant *gca* effects for resistance to leaf curl complex. The magnitude of estimated components of dominance variance was more than additive variance for resistance to leaf curl complex indicating the predominance of non-additive gene effects.

The response of 13 chilli (*Capsicum annuum*) cultivars studied by Saha *et al.* (2005a) yielded one moderately resistant (IR-8) and three moderately susceptible (Dinhata local-1, Bullet and Akashi) cultivars.

Of the nine hybrid varieties/lines tested by Saha *et al.* (2005b), two hybrid varieties/lines (ARCH 226 and ARCH-006) were found moderately resistant, two hybrid varieties/lines (INDAM-6 and ARCH-228) were moderately susceptible, one (PICADOR) was highly susceptible and remaining four (ARCH-112, F1-86235, HOE-818 and HOE-888) were susceptible to the disease.

Singh and Chowdhury (2005) screened 10 chilli cultivars and reported that two were having minimum incidence of chilli leaf curl virus incidence.

Kumar *et al.* (2006) screened three hundred and seven genotypes belonging to four cultivated and one wild species of *Capsicum* and

identified only three genotypes, *viz.* GKC-29, BS-35 and EC-497636 as symptom-less resistant sources.

In a study to identify superior segregants in the F_2 and F_3 populations of 5 chilli crosses, Somashekhar *et al.* (2006) considered the progenies 9608-7, 9632-67, 9646-18 and 9646-47 as potential sources of leaf curl resistance and high yield.

One hundred and fifteen genotypes of bird pepper (*Capsicum frutescens*) were evaluated for leaf curl virus and among them two genotypes were reported to be resistant and eight were tolerant (Khader *et al.*, 2007).

Materials and Methods

3. MATERIALS AND METHODS

This study was undertaken in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2007-2009 with a view to study the genetic basis and inheritance pattern of important quantitative and qualitative characters including yield and leaf curl virus resistance in chilli (*Capsicum spp*). The programme included three major experiments. The details of materials used and methods adopted for the study are presented below.

3.1 EXPERIMENT I: CROSSING PROGRAMME

3.1.1 Materials

The materials for the study consisted of three susceptible high yielding *Capsicum annuum* types [Jwalamukhi (T_1), Jwalasakhi (T_2) and Vellayani Athulya (T_3)] and five resistant *Capsicum frutescens* types [Mangalapuram Local (L_1), Thavanur Local (L_2), Kayankulam Local (L_3), Mavelikkara Local (L_4) and Nenmara Local (L_5)] identified from an external aided project entitled "Breeding leaf curl virus resistant chilli through interspecific hybridisation" concluded during 2007 in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani. These were selected for crossing in Line x Tester (L x T) pattern.

3.1.2 Methods

The three high yielding, leaf curl virus susceptible *Capsicum annuum* types and five resistant types of *Capsicum frutescens*, identified from the above externally aided project were selected as parental 'testers' (T) and parental 'lines' (L) respectively for developing F_1s. The five lines and three testers were raised in L x T crossing block during rabi 2007 and fifteen F_1 hybrids were produced. The technique followed for the production of selfed and crossed seeds were as follows.

3.1.2.1 Selfing

For producing selfed seeds, plants were caged before their first flower opened and was retained till fruit setting was complete.

3.1.2.2 Crossing

In the parental 'lines' (L) mature flower buds, which would open on the next day were selected in the evening and emasculated following standard manual method using forceps. The emasculated plants were covered with an insect proof cage. Care was taken to ensure that no flower had anthers that opened inside the cage. This was done either by emasculation or by removal of flower buds which may open before the fruit set of crossed flowers. Mature flower buds were kept covered in the 'tester' parents (T) also. Next morning, pollen grains from the protected flower of the 'tester' parents were transferred to the stigma of emasculated flower either from mature undehisced anthers by scooping it out through the lateral sutures with the needle or by touching a freshly dehisced anther to the stigma with forceps. After pollination, plants with crossed flowers were protected with cages. The crossed flowers were labeled with details of crossing and the labels were retained till the fruits ripen.

The fully ripened fruits of both selfed and crossed flowers were harvested and seeds were extracted separately.

3.2 EXPERIMENT II: F_1 HYBRIDS AND PARENTS (SUMMER SEASON)

3.2.1 Materials

The materials for this experiment were eight parents (five lines and three testers) and fifteen line x tester hybrids.

3.2.2 Methods

3.2.2.1 Design and layout

The experiment was conducted in Randomized Block Design (RBD) with three replications. Plot size was 5 x 0.75 m^2 with a spacing of 50 cm

between plants and 75 cm between rows. Ten plants were maintained in each plot.

3.2.2.2 Sowing and cultural operations

Seeds of each treatment were sown in separate pots during summer 2008. The seedlings were transplanted during March when they were one month old with one seedling per pit.

Cultural operations were followed as per the package of practices recommendations of the Kerala Agricultural University (KAU, 2007).

Spraying of insecticides in the field was avoided in order to permit the population build up and spread of *Bemisia tabaci*, the vector of leaf curl virus.

3.2.2.3 Inoculation of leaf curl virus

The leaf curl virus was introduced into the field using viruliferous white flies.

3.2.2.3.1 Mass culture of Bemisia tabaci

Brinjal being a good breeding host for *B.tabaci*, the pure culture of *B.tabaci* was reared and maintained on brinjal plants. Brinjal plants grown in pots were placed in wooden cages (65 x 65 x 70 cm) and *B.tabaci* were released into the cages for multiplication. The old plants inside the cages were replaced periodically with healthy and fresh ones. Care was taken to keep the cages free of the predators of white flies.

An aspirator consisting of a glass tube (30 cm long and 0.5 cm in diameter) was used for handling whiteflies. By turning the leaves slightly upwards, the white flies were gently sucked into the glass tube of the aspirator. White flies, thus collected were subsequently used either for acquisition access feeding on infected plants or for inoculation access feeding.

3.2.2.3.2 Acquisition and inoculation access feeding

Acquisition and inoculation access feeding were carried out in a single stage in an insect proof cage. Leaf curl virus infected plants and disease free seedling (one month old) were kept together. The pure culture of white flies reared on brinjal plants were released into this cage for transmitting the virus from infected to healthy one. White flies were released periodically into the cages to maintain an uniform population for transmission.

3.2.2.3.3 Acquisition feeding of whiteflies for release into the field

For acquisition feeding, plastic transmission cages designed by Nene (1972) were used. The top portion of either the main stem or fresh branches showing typical symptoms was introduced into the cage through the rectangular slit or the mouth of the cage. The transmission cage was covered by a black cloth except at the region of the wire netting which was kept facing the light source while releasing the whiteflies. The cap of the cage was immediately screwed on. The remaining portion of the rectangular slit of the cage was closed with cotton wool. The cages were kept in position by two bamboo slivers and a rubber band. After the desired feeding period the cotton wool was removed and the plant was disturbed by gently tapping it with a needle to disturb the whiteflies. This induced the whiteflies to move to the side of the cage facing the light source. The cages were then taken to the field and viruliferous whiteflies released.

3.2.2.3.4 Inoculation of mainfield

The diseased seedlings were transplanted in the field along the border. To maintain the vector population and to ensure uniform spread of the virus in the field, viruliferous white flies were released on alternate days. This was continued for a period of one month.

3.2.2.4 Biometric observations

In each treatment, five plants were selected at random in each plot for recording the following biometric observations. The data for statistical analysis were obtained as mean values worked out thereafter for each replication.

3.2.2.4.1 Plant height (cm)

Height was measured from the base of the plant to the tip of the largest branch before the last harvest of fruits.

3.2.2.4.2 Number of branches

Branches arising from the main stem were counted and recorded as number of branches.

3.2.2.4.3 Number of days to first flowering

Number of days taken from sowing to the appearance of first flower was recorded.

3.2.2.4.4 Plant spread

Plant spread at the widest point was measured and expressed in cm.

3.2.2.4.5 Duration of flowering

Number of days from first flowering to last harvest of fruits was considered as duration of flowering (fruiting span)

3.2.2.4.6 Leaf pubescence

Leaves which have just unfurled fully were observed for leaf hairs and categorized as sparse, intermediate and dense based on the density of hairs present.

3.2.2.4.7 Number of fruits per plant

Number of fruits in each harvest was recorded in each observational plant and added to get the total number of fruits per plant.

3.2.2.4.8 Fruit length (cm)

Average fruit length of ten matured fruits of second harvest at random from the observational plants was recorded, the average worked out. Length was measured including the pedicel.

3.2.2.4.9 Fruit width (cm)

Diameter was measured at the broadest part of fruits selected for recording length was taken and averaged.

3.2.2.4.10 Pedicel - fruit ratio

$$\text{Pedicel - fruit ratio} = \frac{\text{length of the pedicel}}{\text{fruit length including pedicel}}$$

3.2.2.4.11 Fruit colour at intermediate stage

Colour of the fruits were recorded just before the ripening stage as yellow, green and purple.

3.2.2.4.12 Green fruit yield per plant (g)

Weight of fresh fruits collected from the five observational plants was recorded at each harvest. Total yield per plant was obtained by adding the weight of fruits at each harvest and the mean worked out.

3.2.2.4.13 Average fruit weight(g)

Weight of ten fruits of the second harvests from the observational plants was taken and the mean weight was recorded.

3.2.2.4.14 Number of seeds per fruit

Seeds extracted from ten random ripe fruits were counted, average worked out and recorded.

3.2.2.4.15 Hundred seed weight (g)

Seeds were extracted from a random sample of ten ripe fruits and dried uniformly. The weight of 100 fully developed seeds was recorded and expressed in grams

3.2.2.4.16 Duration of the crop

Number of days from sowing to last harvest of fruits was taken as duration of the crop.

3.2.2.4.17 Vector population

White flies present on lower side of the top five leaves in observational plants were counted at three intervals (30^{th}, 45^{th} and 60^{th} day after transplanting) without disturbing the plant, added up and average worked out.

3.2.2.4.18 Vulnerability Index

Leaf curl disease scoring was done at 30^{th}, 45^{th} and 60^{th} days after planting (DAP). The observations on 45^{th} DAP was used for computation of vulnerability index (VI), during the peak fruiting period of the crop. The scoring was based on a scale 0 to 4 developed by Rajamony *et al.* (1990) with slight modification (Plate 1). The score based on the severity of symptom manifestation is as follows.

Score	Symptoms
0	No symptom
1	Slight curling of terminal leaves
2	Curling of terminal and adjacent lower leaves
3	Curling and appearance of blisters on leaves
4	Severe curling and puckering of leaves, stunted appearance of plants

The individual plant score was utilized to workout the 'severity index' or 'vulnerability index' (VI) so as to measure the degree of resistance. The index was calculated using an equation adopted by Silbernagel and Jafri (1974) for measuring the degree of resistance in snap

Plate 1. Scoring scale based on the severity of leaf curl disease

bean (*Phaseolus vulgaris*) to beet curly top virus and modified later by Bos (1982).

$$VI = \frac{0n_0 + 1n_1 + 2n_2 + 3n_3 + 4n_4}{n_t (n_c - 1)} \times 100$$

Where VI = Vulnerability index

$n_0, n_1, \ldots, n_4$ = Number of plants in the category 0,1,...,4. (as given in above table)

n_t = Total number of plants

n_c = Total number of categories (= 5)

The genotypes were classified according to vulnerability index as

VI	Category
0.00	Resistant (R)
1.00 – 25.00	Tolerant (T)
25.01 – 50.00	Susceptible (S)
> 50.00	Highly susceptible (HS)

3.2.2.4.19 Incidence of pests

i) Chilli thrips: Nymphs of chilli thrips (*Scirtothrips dorsalis*), on three leaves in observational plants (one each from top, middle and bottom region) were counted using stereobinocular microscope. Observations were taken at three intervals *viz.*, 30, 45 and 60 days after transplanting.

ii) Mites: Mites present on six terminal leaves of observational plants were counted using stereobinocular microscope. Observations were taken three times at 30, 45 and 60 days after transplanting.

iii) Minor pests: The plants were observed for minor pests of chilli like aphids, scales and mealy bugs.

3.2.2.5 Statistical Analysis

3.2.2.5.1 Analysis of variance (ANOVA)

The biometric observations recorded were subjected to ANOVA (Panse and Sukhatme, 1985) for comparison among various treatments and to estimate variance components as follows:

Source of variation	Degrees of freedom	Mean square	F
Replication	(r-1)	MSR	MSR/MSE
Treatment	(t-1)	MST	MST/MSE
Error	(r-1) (t-1)	MSE	
Total	(rt-1)		

Where, r = number of replications, t = number of treatments, MSR = Replication mean square, MST = Treatment mean square, MSE = Error variance.

Critical difference (CD) = $t_{\alpha} \sqrt{\frac{2MSE}{r}}$

Where, t_{α} is the student's t table value at error degrees of freedom.

3.2.2.5.2 Estimation of genetic parameters

a. Genetic components of variance

For each character, the phenotypic and genotypic components of variance were estimated by equating the expected value of mean squares

(MS) to the respective variance components (Jain, 1982). Based on this, the following variance components were estimated.

i. Genotypic variance (V_G)

$$V_G = \frac{MST - MSE}{r}$$

ii. Environmental variance (V_E)

$$V_E = MSE$$

iii. Phenotypic variance (V_P)

$$V_P = V_G + V_E$$

b. Coefficients of variation

Genotypic and phenotypic coefficients of variation were worked out using the estimates of V_G and V_P and expressed in percentage for each trait.

i. Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sqrt{V_P}}{\overline{(X)}} \times 100$$

ii. Genotypic coefficient of variation (GCV)

$$GCV = \frac{\sqrt{V_G}}{\overline{(X)}} \times 100$$

iii. Error coefficient of variation (ECV)

$$ECV = \frac{\sqrt{V_E}}{\overline{(X)}} \times 100$$

$\overline{X}$ is the mean of each character estimated over all the treatments.

c. Heritability

For each trait, heritability (broad sense) was calculated as the ratio of genotypic variance to phenotypic variance and expressed as percentage (Jain, 1982).

$$\text{Heritability } (H^2) = \frac{V_G}{V_P} \times 100$$

Heritability was categorised as :

< 30 %	→ low	
31 – 60 %	→ moderate	
>60 %	→ high	(Johnson *et al.*, 1955)

d. Genetic advance

Genetic advance which is the measure of genetic gain under selection, depends upon standardised selection differential, heritability and phenotypic standard deviation (Allard, 1960).

Genetic advance (GA) = $k. H^2\sqrt{V_P}$

Where k is the standardised selection differential (2.06 at 5 % intensity of selection).

$$\text{GA as percentage of mean} = \frac{k. H^2 \sqrt{V_P}}{\overline{X}} \times 100$$

Genetic advance (as % of mean) was categorised as :

< 10 %	→ low	
11 – 20 %	→ moderate	
> 20 %	→high	(Johnson *et al.*, 1955)

3.2.2.5.3 Combining ability analysis

Following the L x T method (Kempthorne, 1957) the general combining ability (*gca*) of parents and the specific combining ability (*sca*) of hybrids were estimated. The mean squares due to various sources of variation and their genetic expectations were computed as follows:

Source	df	Mean square	Expected MS
Replication	(r – 1)		
Line	(l – 1)	M_l	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.) + rt (C_{OV} H.S.)
Tester	(t – 1)	M_2	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.) + rl (C_{OV} H.S)
Line x Tester	(l – 1) (t – 1)	M_3	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.)
Error	(r – 1) (lt – 1)	M_4	MSE
Total	(rlt – 1)		

Where,

r = number of replications

g = number of genotypes

l = number of lines

t = number of testers

M_1 = Mean square of lines

M_2 = Mean square of testers

M_3 = Mean square of Line x Tester

M_4 = Mean square of error

C_{OV} H.S = covariance of half sib

C_{OV} F.S = covariance of full sib

General combining ability (*gca*) effect of parents and specific combining ability (*sca*) effect of hybrids were estimated using the following model.

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

μ = Population mean

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

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

s_{ij} = *sca* effect of ij^{th} hybrid

e_{ijk} = error associated with ijk^{th} observation

i = 1,2,...,l

j = 1,2,..., t

k = 1,2,...,r

The individual effects were estimated as follows :

$$\text{Mean} = \frac{x...}{rlt}$$

i. *gca* effect of lines

$$g_i = \frac{x_{i..}}{rt} - \frac{x...}{rlt} \quad i=1,2,...,l$$

ii. *gca* effect of testers

$$g_j = \frac{x_{.j.}}{rl} - \frac{x...}{rlt} \quad j= 1,2,...,t$$

iii. *sca* effect of hybrids

$$s_{ij} = \frac{x_{ij.}}{r} - \frac{x_{i..}}{rt} - \frac{x_{.j.}}{rl} + \frac{x_{...}}{rlt}$$

Where,

$x_{...}$ = Total of all hybrids over 'r' number of replications

$x_{i..}$= Total of all hybrids involving i^{th} line as one parent over 't' testers and 'r' replications

$x_{.j.}$ = Total of all hybrids involving j^{th} tester as one parent over 'l' lines and 'r' replications

xij. = Total of the hybrids between i^{th} line and j^{th} tester over 'r' replications

Standard error for combining ability effects was calculated as follows :

1. SE of *gca* (lines) = $\sqrt{\frac{MSE}{rt}}$

2. SE of *gca* (testers) = $\sqrt{\frac{MSE}{rl}}$

3. SE of *sca* of hybrids = $\sqrt{\frac{MSE}{r}}$

The significance of these effects were tested by computing critical values as effect / (SE of the effect) and were compared with Student 't' table values at error degrees of freedom at 5 per cent level of significance.

3.2.2.5.4 Proportional contribution

Proportional contribution of lines, testers and their interaction to total variance was calculated (Singh and Chaudhary, 1985).

$$\text{Contribution of lines} = \frac{\text{SS (lines)}}{\text{SS (hybrids)}} \times 100$$

$$\text{Contribution of testers} = \frac{\text{SS (testers)}}{\text{SS (hybrids)}} \times 100$$

$$\text{Contribution of interaction} = \frac{\text{SS (l x t)}}{\text{SS (hybrids)}} \times 100$$

3.2.2.5.5 Genetic components of variance

$$gca \text{ variance. } \sigma^2 gca = \frac{1}{4} (1 + F)\, \sigma^2 a$$

$$sca \text{ variance. } \sigma^2 sca = \frac{1}{2} (1 + F)^2\, \sigma^2 d$$

When F = 1

$$\sigma^2 gca = \frac{\sigma^2 a}{2}$$

$$\sigma^2 sca = 2\, \sigma^2 d$$

Where F = coefficient of inbreeding

$\sigma^2 a$ = additive genetic variance

$\sigma^2 d$ = dominance genetic variance

3.2.2.5.6 Heterosis

Extent of heterosis was computed for all the 15 hybrids as relative heterosis (RH), standard heterosis (SH) and heterobeltiosis (HB) using the following formulae and expressed as percentage. For estimating standard heterosis, Jwalamukhi was used as the standard variety.

i. Relative heterosis (RH) = $\frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$

ii. Standard heterosis (SH) = $\frac{\overline{F_1} - \overline{SV}}{\overline{SV}} \times 100$

iii. Heterobeltiosis (HB) = $\frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$

Where,

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

$\overline{MP}$ = Mid parental value

$\overline{SV}$ = Mean of standard variety (Jwalamukhi)

BP = Mean of better parent in that particular cross

The significance of different types of heterosis was tested by the 't' test.

't' for RH = $\frac{\left|\overline{F_1} - \overline{MP}\right|}{\sqrt{\frac{3\,MSE}{2r}}}$

't' for SH = $\frac{\left|\overline{F_1} - \overline{SV}\right|}{\sqrt{\frac{2\,MSE}{r}}}$

't' for HB = $\frac{\left|\overline{F_1} - \overline{BP}\right|}{\sqrt{\frac{2\,MSE}{r}}}$

Where,

MSE = estimate of error variance

r = number of replications

3.3 EXPERIMENT III A: DEVELOPMENT OF SEGREGATING GENERATIONS

Two superior F_1s [Mavellikara Local (L_4) x Jwalasakhi (T_2) and Nenmara Local (L_5) x Vellayani Athulya (T_3)] were selected based on Experiment II results. These were backcrossed to their respective parents to produce B_1 and B_2 generations during rabi 2008. The F_1s were selfed to develop F_2 generation. Thus six generations were generated for each cross (P_1, P_2, F_1, F_2, B_1 and B_2), making a total of 12 treatments.

3.4 EXPERIMENT III B: EVALUATION OF GENERATIONS

3.4.1 Materials

The materials for this experiment consisted of P_1, P_2, F_1, F_2, B_1 and B_2 of the each F_1 hybrid.

3.4.2 Methods

3.4.2.1 Design and layout

The design and layout followed were same as described on experiment II.

The six generations (P_1, P_2, F_1, F_2, B_1 and B_2) of each F_1 hybrid combination (12 treatments) were evaluated during summer (January to June) 2009 in a randomized block design with three replications.

3.4.2.2 Sowing and cultural operations

The cultural practices followed were as described in Experiment II.

3.4.2.3 Inoculation of leaf curl virus

The methodology followed was as described in Experiment II.

3.4.2.4 Biometrical observation

From every treatment, five plants each were selected at random for recording observations in P_1, P_2 and F_1 generations, 15 plants each were selected for B_1 and B_2 generations and thirty plants each in F_2 as observational plants. Observations were recorded for various characters and the methods followed in different characters were same as described earlier. Individual plant observations were used for statistical analysis. Instead of Vulnerability index leaf curl virus disease score (%) on the 45th day were subjected to statistical analysis. Apart from these characters capsaicin content and oleoresin content were also estimated in this experiment whose methods are described below.

3.4.2.4.1 Capsaicin content

The capsaicin content of fruits was estimated by colorimetric method.

Procedure

Fruits harvested at red ripe stage were dried in a hot air oven at 50°C and powdered finely. A quantity of 0.5 g dry chilli powder was transferred to a volumetric flask into which 10 ml acetone was added and shaken it for 3 hours in a mechanical shaker. The contents were allowed to settle down. From this, 1 ml of the clear supernatant was pipetted into a test tube and kept in a hot water bath for evaporate to dryness. The residue was dissolved by adding 5 ml of 0.4 per cent sodium hybroxide solution and 3 ml of 3 per cent phosphomolybdic acid was added. The content was shaken and allowed to stand for 1 hour. The solution was filtered into centrifuge tubes and centrifuged at about 5000 rpm for 10-15 min. The clear blue coloured solution was transferred into the cuvette and the absorbance was recorded at 650 nm using spectrophotometer.

To determine the per cent value of pure capsaicin a stock solution of standard capsaicin was prepared by dissolving 50 mg capsaicin in 50 ml of 0.4 per cent sodium hydroxide solution (1000 µg/ml). From this stock

solution a series of solutions of different concentrations were prepared and their absorbance read at 650 nm using spectrophotometer. A standard graph was prepared from which capsaicin content in the samples was found out.

3.4.2.4.2 Oleoresin content

Oleoresin in chilli was extracted in Soxhlet apparatus using solvent acetone following the method suggested by Sadasivam and Manickam (1992).

Procedure

Red ripe chilli fruits were dried in a hot air oven at 50^0C, powdered finely in a mixer grinder. Two grams of this powder was weighed and packed in filter paper and placed in a Soxhlet apparatus. Two hundred 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 solvent. After complete extraction the solvent was evaporated to dryness under vacuum.

Oleoresin content on dry weight basis was calculated using the formula

$$\text{Oleoresin, \%} = \frac{\text{Weight of oleoresin}}{\text{Weight of sample}} \text{ X } 100$$

3.4.2.5 Statistical analysis

Six parameter model (Hayman, 1958) was used for the analysis which consisted of the following steps.

i. Development of scales

Using the scaling test proposed by Mather (1949), estimation of additive (D) and dominance (H) components of genetic variance were made using the mean and variance of six generations *viz.*, P_1, P_2, F_1, F_2, B_1 and B_2.

$$A = 2\bar{B}_1 - \bar{P}_1 - \bar{F}_1$$

$$V_A = 4\,V(\bar{B}_1) + V(\bar{P}_1) + V(\bar{F}_1)$$

$$B = 2\bar{B}_2 - \bar{P}_2 - \bar{F}_1$$

$$V_B = 4\,V(\bar{B}_2) + V(\bar{P}_2) + V(\bar{F}_1)$$

$$C = 4(\bar{F}_2) - 2\bar{F}_1 - \bar{P}_1 - \bar{P}_2$$

$$V_C = 16\,V(\bar{F}_2) + 4\,V(\bar{F}_1) + V(\bar{P}_1) + V(\bar{P}_2)$$

$$D = 2(\bar{F}_2) - \bar{B}_1 - \bar{B}_2$$

$$V_D = 4\,V(\bar{F}_2) + V(\bar{B}_1) + V(\bar{B}_2)$$

Where $\bar{P}_1$, $\bar{P}_2$, $\bar{F}_1$, $\bar{F}_2$, $\bar{B}_1$ and $\bar{B}_2$ are the means of respective generations over all replications and $V(P_1)$, $V(P_2)$, $V(F_1)$, $V(F_2)$, $V(B_1)$ and $V(B_2)$ are the respective variances. The standard errors of A, B, C and D obtained as square root of V_A, V_B, V_C and V_D.

ii. Testing for epistasis

Significance of any of the four scales indicates the inadequacy of additive-dominance model and presence of epistasis. For testing the significance of A, B, C and D scales, 't' test was employed.

$$t_A = \frac{A}{\sqrt{V_A}}$$

$$t_B = \frac{B}{\sqrt{V_B}}$$

$$t_C = \frac{C}{\sqrt{V_C}}$$

$$t_D = \frac{D}{\sqrt{V_D}}$$

If the calculated 't' value of these scales is higher than 1.96, it is considered as significant. Significance of each of these scales reveals the presence of specific type of epistasis as detailed below :

a. The significance of either one or both of A and B scales indicates the presence of all three types of non-allelic interaction *viz.*, additive x additive (i), additive x dominance (j) and dominance x dominance (l)

b. The significance of scale C denotes dominance x dominance type of non-allelic interaction

c. The significance of scale D reveals additive x additive type of gene interaction

d. The significance of both C and D scales depicts additive x additive and dominance x dominance type of epistasis.

iii. Estimation of genetic components

When the scales A, B, C and D were significantly different from zero, a digenic interaction model was assumed and the following six parameters were estimated (Jinks and Jones, 1958).

$$m = \overline{F_2}$$

$$d = \overline{B_1} - \overline{B_2}$$

$$h = \overline{F_1} - 4\,\overline{F_2} - \tfrac{1}{2}\,\overline{P_1} - \tfrac{1}{2}\,\overline{P_2} + 2\,\overline{B_1} + 2\,\overline{B_2}$$

$$i = 2\,\overline{B_1} + 2\,\overline{B_2} - 4\,\overline{F_2}$$

$$j = (\overline{B_1} - \tfrac{1}{2}\,\overline{P_1}) - (\overline{B_2} - \tfrac{1}{2}\,\overline{P_2}) = \overline{B_1} - \tfrac{1}{2}\,\overline{P_1} - \overline{B_2} + \tfrac{1}{2}\,\overline{P_2}$$

$$l = \overline{P_1} + \overline{P_2} + 2\,\overline{F_1} + 4\,\overline{F_2} - 4\,\overline{B_1} - 4\,\overline{B_2}$$

Where,

m= mean

d= additive effect

h= dominance effect

i= additive x additive interaction

j= additive x dominance interaction

l= dominance x dominance interaction

The variances of these six genetic parameters were computed as follows :

$$V(m) = V(\bar{F}_2)$$

$$V(d) = V(\bar{B}_1) + V(\bar{B}_2)$$

$$V(h) = V(\bar{F}_1) + 16V(\bar{F}_2) + \tfrac{1}{4}V(\bar{P}_1) + \tfrac{1}{4}V(\bar{P}_2) + 4V(\bar{B}_1) + 4V(\bar{B}_2)$$

$$V(i) = 4V(\bar{B}_1) + 4V(\bar{B}_2) + 16V(\bar{F}_2)$$

$$V(j) = V(\bar{B}_1) + \tfrac{1}{4}V(\bar{P}_1) + V(\bar{B}_2) + \tfrac{1}{4}V(\bar{P}_2)$$

$$V(l) = V(\bar{P}_1) + V(\bar{P}_2) + 4V(\bar{F}_1) + 16V(\bar{F}_2) + 16V(\bar{B}_1) + 16V(\bar{B}_2)$$

The above genetic parameters were tested for significance using 't' test as in the case of scaling test.

3.4.2.6 Transgressive segregants (%)

$$\text{Transgressive segregants (\%)} = \frac{\text{Number of plants better than superior parent}}{\text{Total number of } F_2 \text{ plants}} \times 100$$

Results

4. RESULTS

The results obtained from various experiments are detailed here under.

4.1 EVALUATION OF PARENTS AND F_1 HYBRIDS

4.1.1. Analysis of variance (ANOVA)

The qualitative characters were recorded and given in Table 2. The results of analysis of variance (ANOVA) for 16 characters which were used to compare the performance of 23 treatments (eight parents and 15 F_1 hybrids) are presented in Table 3.

Differences were significant with respect to all characters in the genotypes.

4.1.2 *Per se* performance of parents and hybrids

Per se performance of the five lines, three testers and their 15 hybrids with respect to 16 characters is presented in Table 4.

4.1.2.1 Plant height

The lines having maximum and minimum plant height were L_3 (66.23 cm) and L_4 (41.73 cm) respectively while in testers T_2 had maximum (40.27 cm) and T_3 minimum (35.55 cm) values. L_4 significantly differed among lines. The hybrid L_1 x T_3 showed the maximum value (62.17 cm) which was on par with L_1 x T_2 (59.58 cm), L_3 x T_2 (58.79 cm), L_5 x T_3 (55.60 cm), L_3 x T_1 (54.56 cm), L_2 x T_2 (52.60 cm), L_2 x T_3 (52.52 cm) and L_5 x T_2 (52.27 cm) while L_4 x T_3 had the minimum plant height of 24.10 cm. All the testers were on par.

4.1.2.2 Number of branches

The number of branches was highest (8.00) for L_4 and lowest (4.93) for L_2 among the lines while T_2 and T_1 recorded the highest (5.07) and

Table 2. Qualitative characters of 23 treatments (eight parents and 15 F_1 hybrids) in chilli (*Capsicum spp*)

Sl.No	Treatments	Leaf pubescence	Fruit colour at intermediate stage
1.	Mangalapuram Local (L_1)	Sparse	Yellow
2.	Thavanur Local (L_2)	Sparse	Purple
3.	Kayamkulam Local (L_3)	Intermediate	Purple
4.	Mavelikkara Local (L_4)	Intermediate	Purple
5.	Nenmara Local (L_5)	Sparse	Purple
6.	Jwalamukhi (T_1)	Sparse	Green
7.	Jwalasakhi (T_2)	Sparse	Green
8.	Vellayani Athulya (T_3)	Sparse	Green
9.	$L_1 \times T_1$	Sparse	Yellow
10.	$L_1 \times T_2$	Sparse	Yellow
11.	$L_1 \times T_3$	Sparse	Yellow
12.	$L_2 \times T_1$	Sparse	Green
13.	$L_2 \times T_2$	Sparse	Yellow
14.	$L_2 \times T_3$	Sparse	Purple
15.	$L_3 \times T_1$	Intermediate	Purple
16.	$L_3 \times T_2$	Intermediate	Green with purple tinge
17.	$L_3 \times T_3$	Intermediate	Purple
18.	$L_4 \times T_1$	Intermediate	Purple
19.	$L_4 \times T_2$	Intermediate	Purple
20.	$L_4 \times T_3$	Intermediate	Purple
21.	$L_5 \times T_1$	Sparse	Purple
22.	$L_5 \times T_2$	Sparse	Green with purple tinge
23.	$L_5 \times T_3$	Sparse	Purple
	Percentage values	Sparse 65.22% Intermediate 34.78%	Purple 52.17% Green 17.39% Yellow 21.74% Green with purple tinge 9.69%

Table 3. Analysis of variance for 16 characters in 23 treatments (eight parents and 15 F1 hybrids) of chilli (*Capsicum spp*)

Sl.No	Characters	Mean squares	
		Treatment	Error
1	Plant height (cm)	311.53**	36.24
2	Number of branches	5.49**	1.56
3	Days to first flowering	818.26**	15.13
4	Plant spread (cm)	308.32**	49.82
5	Duration of flowering	936.28**	45.34
6	Number of fruits per plant	1801.41**	106.83
7	Fruit length (cm)	22.42**	0.88
8	Fruit width (cm)	0.5239**	0.0130
9	Pedicel- fruit ratio	0.0229**	0.0012
10	Green fruit yield / plant (g)	24098.64**	794.38
11	Average fruit weight (g)	7.68**	0.21
12	Number of seeds per fruit	1271.75**	48.27
13	Hundred seed weight (g)	0.0156**	0.0014
14	Duration of crop	2699.66**	44.14
15	Vector population	45.89**	4.21
16	Vulnerability index	603.27**	70.33

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

Table 4. Mean values of 16 characters in chilli (*Capsicum spp*)

Sl.No	Treatments	Plant height (cm)	Number of branches	Days to first flowering	Plant spread (cm)	Duration of flowering	Number of fruits / plant	Fruit length (cm)	Fruit width (cm)	Pedicel - fruit ratio
1.	Mangalapuram Local (L_1)	57.67	5.80	98.20	46.60	121.10	62.42	6.16	0.82	0.43
2.	Thavanur Local (L_2)	65.40	4.93	96.87	50.73	115.40	42.53	6.33	1.21	0.41
3.	Kayamkulam Local (L_3)	66.23	7.10	101.77	45.48	126.50	63.13	7.04	0.99	0.48
4.	Mavelikkara Local (L_4)	41.73	8.00	94.93	45.00	129.57	37.00	3.52	1.57	0.50
5.	Nenmara Local (L_5)	57.00	6.00	101.97	54.07	129.30	65.53	6.73	1.31	0.40
6.	Jwalamukhi (T_1)	39.47	4.83	54.00	33.07	78.07	15.13	12.62	1.73	0.26
7.	Jwalasakhi (T_2)	40.27	5.07	51.17	31.73	80.83	14.77	12.41	1.59	0.26
8.	Vellayani Athulya (T_3)	35.55	4.95	51.53	19.42	83.13	12.99	12.34	1.76	0.22
9.	$L_1 \times T_1$	51.23	6.67	65.37	36.27	63.67	75.60	5.67	0.81	0.48
10.	$L_1 \times T_2$	59.58	7.90	62.00	52.05	84.57	91.06	6.13	0.88	0.44
11.	$L_1 \times T_3$	62.17	7.07	66.30	45.60	78.37	53.97	6.06	0.77	0.48
12.	$L_2 \times T_1$	48.00	6.43	63.93	52.35	109.33	86.33	9.49	1.54	0.32
13.	$L_2 \times T_2$	52.60	6.47	57.20	43.33	101.67	62.53	9.46	1.50	0.32
14.	$L_2 \times T_3$	52.52	7.87	67.50	45.30	105.83	59.67	10.46	1.67	0.25
15.	$L_3 \times T_1$	54.56	6.40	65.90	41.47	104.23	58.80	10.29	1.48	0.35
16.	$L_3 \times T_2$	58.79	8.17	68.53	47.54	106.73	63.13	11.01	1.30	0.34
17.	$L_3 \times T_3$	49.93	7.73	68.77	35.47	102.60	25.60	11.47	1.52	0.29
18.	$L_4 \times T_1$	38.77	9.25	62.00	30.06	91.87	28.78	4.13	1.61	0.45
19.	$L_4 \times T_2$	52.07	8.80	68.37	53.17	103.20	91.80	7.63	1.94	0.41
20.	$L_4 \times T_3$	24.10	9.03	50.97	21.67	91.60	20.77	6.88	2.61	0.35
21.	$L_5 \times T_1$	47.49	7.90	59.73	50.85	114.30	49.33	7.07	1.48	0.34
22.	$L_5 \times T_2$	52.27	7.67	67.40	54.55	104.10	57.27	10.63	1.46	0.31
23.	$L_5 \times T_3$	55.60	8.33	66.60	49.87	108.97	80.27	10.59	1.68	0.24
	CD (0.05)	8.30	1.72	5.37	9.73	9.28	14.12	1.29	0.15	0.05
	SE	4.92	1.02	3.18	5.76	5.50	8.44	0.77	0.09	0.03

Table 4. Contd...

Sl.No	Treatments	Green fruit yield per plant (g)	Average fruit weight (g)	Number of seeds / fruit	Hundred seed weight (g)	Duration of crop	Vulnerability Index	Vector population
1.	Mangalapuram Local (L_1)	107.51	0.83	28.33	0.49	215.97	0.81(5.16)	0.27(2.99)
2.	Thavanur Local (L_2)	136.80	1.95	41.20	0.62	208.93	0.81(5.16)	0.38(3.54)
3.	Kayamkulam Local (L_3)	127.00	1.57	47.81	0.47	221.60	3.56(10.88)	0.44(3.82)
4.	Mavelikkara Local (L_4)	123.53	2.13	62.27	0.49	217.83	0.81(5.16)	0.23(2.76)
5.	Nenmara Local (L_5)	139.25	1.95	55.30	0.67	224.60	0.81(5.16)	0.30(3.12)
6.	Jwalamukhi (T_1)	89.20	6.18	50.46	0.58	132.07	66.83(54.83)	5.65(13.76)
7.	Jwalasakhi (T_2)	67.37	5.45	51.90	0.53	132.00	58.40(49.83)	6.01(14.19)
8.	Vellayani Athulya (T_3)	83.10	6.32	94.20	0.47	134.67	63.41(52.78)	6.79(15.11)
9.	$L_1 \times T_1$	39.97	1.02	29.74	0.37	129.03	23.25(28.83)	3.12(10.18)
10.	$L_1 \times T_2$	70.27	0.81	29.73	0.55	146.57	7.62(16.02)	1.12(6.09)
11.	$L_1 \times T_3$	38.43	0.74	20.79	0.43	144.67	3.54(10.85)	0.77(5.03)
12.	$L_2 \times T_1$	219.30	2.37	68.68	0.59	173.27	32.58(34.81)	3.73(11.13)
13.	$L_2 \times T_2$	187.97	3.13	65.00	0.58	158.87	26.02(30.67)	3.05(10.06)
14.	$L_2 \times T_3$	226.33	4.07	69.73	0.57	173.33	39.36(38.86)	4.27(11.92)
15.	$L_3 \times T_1$	146.07	2.47	75.73	0.46	170.13	34.48(35.96)	4.01(11.56)
16.	$L_3 \times T_2$	197.20	3.15	62.40	0.51	175.27	28.22(32.09)	3.47(10.73)
17.	$L_3 \times T_3$	63.10	2.67	57.33	0.51	171.37	21.46(27.60)	2.60(9.29)
18.	$L_4 \times T_1$	31.83	2.55	67.53	0.46	153.87	25.00(30.00)	3.12(10.17)
19.	$L_4 \times T_2$	368.97	4.08	90.17	0.50	171.57	8.16(16.60)	1.11(6.05)
20.	$L_4 \times T_3$	63.20	3.08	93.47	0.63	142.57	33.26(35.22)	3.96(11.48)
21.	$L_5 \times T_1$	115.12	2.18	76.13	0.47	174.03	26.02(30.67)	2.99(9.96)
22.	$L_5 \times T_2$	182.77	3.10	61.60	0.47	171.50	36.37(37.09)	4.35(12.05)
23.	$L_5 \times T_3$	343.27	4.40	76.92	0.58	175.57	8.16(16.60)	1.09(5.99)
	CD (0.05)	38.84	0.62	9.57	0.05	9.16	11.56	2.83
	SE	23.01	0.37	5.67	0.03	5.42	6.85	1.68

Transformed values in brackets

lowest (4.83) values respectively among the testers. The maximum number of branches was observed for the hybrid L_4 x T_1 (9.25) which was on par with L_4 x T_3 (9.03), L_4 x T_2 (8.80), L_5 x T_3 (8.33), L_3 x T_2 (8.17), L_1 x T_2 (7.90), L_5 x T_1 (7.90), L_2 x T_3 (7.87), L_3 x T_3 (7.73) and L_5 x T_2 (7.67). The minimum number of branches was recorded in the hybrid L_3 x T_1 (6.40).

4.1.2.3 Days to first flowering

The earliest flowering line was L_4 (94.93 days) and the tester was T_2 (51.17 days) while the late flowering line was L_5 (101.97 days) and the tester was T_1 with 54.00 days. All lines except L_4 and L_2 were on par. All testers were on par. Among the hybrids the earliest was L_4 x T_3 (50.97 days) which was on par with L_2 x T_2 (57.20 days) and the late one was L_3 x T_3 (68.77 days) which was on par with L_3 x T_2 (68.53 days), L_4 x T_2 (68.37days), L_2 x T_3 (67.50 days), L_5 x T_2 (67.40 days), L_5 x T_3 (66.60 days), L_1 x T_3 (66.30 days), L_3 x T_1 (65.90 days), L_1 x T_1 (65.37 days) and L_2 x T_1 (63.93 days). Hybrids differed significantly.

4.1.2.4 Plant spread

Lines did not differ significantly with the character. Among the lines, L_5 had maximum (54.07 cm) value for plant spread while L_4 had minimum value (45.00 cm). Testers T_1 and T_3 possessed the maximum and minimum (33.07 cm) and (19.42 cm) values respectively for the character. T_1 & T_2 were significantly high among testers. Plant spread among hybrids was maximum for L_5 x T_2 (54.55 cm) which was on par with L_4 x T_2 (53.17 cm), L_2 x T_1 (52.35 cm), L_1 x T_2 (52.05 cm), L_5 x T_1 (50.85 cm), L_5 x T_3 (49.87 cm), L_3 x T_2 (47.54 cm), L_1 x T_3 (45.60 cm), L_2 x T_3 (45.30 cm) and L_2 x T_2 (43.33 cm) while it was minimum for L_4 x T_3 (21.67 cm) which was on par with L_4 x T_1 (30.06 cm).

4.1.2.5 Duration of flowering

The shortest duration (115.4) was recorded by the line L_2 and

longest by L_4 (129.57). Among the testers the shortest flowering duration was for T_1 (78.07) and longest flowering duration was recorded by T_3 (83.13). The hybrid having the shortest duration of flowering (63.67) was L_1 x T_1 and the one having the longest (114.3) was L_5 x T_1 which was on par with L_2 x T_1 (109.33), L_5 x T_3 (108.97), L_3 x T_2 (106.73) and L_2 x T_3 (105.83).

4.1.2.6 Number of fruits per plant

Among the lines the maximum number of fruits (65.53) was recorded by L_5 and the minimum by L_4 (37.00) while among the testers the maximum was found with T_1 (15.13) and the minimum with T_3 (12.99). All lines except L_4 and L_2 were on par and all testers were on par. Among the hybrids the maximum was exhibited by L_4 x T_2 (91.80) which was on par with L_1 x T_2 (91.06), L_2 x T_1 (86.33) and L_5 x T_3 (80.27) and the minimum by L_4 x T_3 (20.77) which was on par with L_3 x T_3 (25.60) and L_4 x T_1 (28.78).

4.1.2.7 Fruit length

The longest fruits among the lines was in L_3 (7.04 cm) and shortest in L_4 (3.52 cm). Testers T_1 and T_3 produced longest (12.62 cm) and shortest fruits (12.34 cm) respectively. Among the hybrids the maximum fruit length was found in L_3 x T_3 (11.47 cm) which was on par with L_3 x T_2 (11.01 cm), L_5 x T_2 (10.63 cm), L_5 x T_3 (10.59 cm), L_2 x T_3 (10.46 cm) and L_3 x T_1 (10.29 cm). The hybrid L_4 x T_1 had minimum (4.13 cm) length.

4.1.2.8 Fruit width

The fruit width varied between the values 1.57 cm (L_4) and 0.82 cm (L_1) among lines and from 1.76 cm (T_3) to 1.59 cm (T_2) for testers. The line with maximum fruit width significantly differed from others.T_2 differed significantly from T_3. The hybrid L_4 x T_3 (2.61 cm) had maximum width and the hybrid L_1 x T_3 had the minimum width (0.77 cm)

which was on par with L_1 x T_1 (0.81) and L_1 x T_2 (0.88).

4.1.2.9 Pedicel - fruit ratio

The line L_5 had minimum value (0.40) for the trait while the maximum was scored by L_4 (0.50). The tester T_3 recorded the minimum value (0.22) while the testers T_2 and T_1 (0.26) were having the maximum value. Among the hybrids, the minimum value for the ratio was given by L_5 x T_3 (0.24) which was on par with L_2 x T_3 (0.25) while the maximum value for the trait was given by L_1 x T_1 and L_1 x T_3 (0.48) and was on par with L_4 x T_1 (0.45) and L_1 x T_2 (0.44).

4.1.2.10 Green fruit yield per plant

Among the lines L_5 (139.25 g) had maximum yield (on par with all other lines) and L_1 had the minimum yield (107.51 g). The tester T_1 recorded the highest yield (89.20 g) while T_2 recorded the lowest (67.37 g) and all testers were on par. Among hybrids the maximum yield (368.97 g) was recorded by L_4 x T_2 which was on par with L_5 x T_3 (343.27 g). The minimum value for the same trait recorded by L_4 x T_1 (31.83 g) was on par with six hybrids namely L_1 x T_2 (70.27), L_4 x T_3 (63.20), L_3 x T_3 (63.10), L_1 x T_1 (39.97) and L_1 x T_3 (38.43).

4.1.2.11 Average fruit weight

The maximum average fruit weight was scored by the line L_4 (2.13 g) and the minimum by L_1 (0.83 g). The tester T_3 had maximum (6.32 g) value while T_2 the minimum (5.45 g). The hybrid L_5 x T_3 with the maximum (4.40 g) average fruit weight was on par with L_4 x T_2 (4.08 g) and L_2 x T_3 (4.07 g) while the hybrid L_1 x T_3 with minimum (0.74 g) value was on par with L_1 x T_2 (0.81 g) and L_1 x T_1 (1.02 g).

4.1.2.12 Number of seeds per fruit

The maximum number of seeds (62.27) among the lines was given by L_4 and the minimum by the line L_1 (28.33). The tester T_3 recorded the maximum value (94.2) while T_1 (50.46) had the minimum. Among the

hybrids highest number (93.47) was observed for L_4 x T_3 which was on par with L_4 x T_2 (90.17) and the minimum was observed for L_1 x T_3 (20.79).

4.1.2.13 Hundred seed weight

The highest value (0.67 g) was recorded by line L_5 and tester T_1 (0.58 g) for hundred seed weight. The line and tester showing the lowest value of 0.47g were L_3 and T_3 respectively. The hundred seed weight was the highest (0.63 g) for the hybrid L_4 x T_3 which was on par with L_2 x T_1 (0.59 g), L_2 x T_2 (0.58 g) and L_5 x T_3 (0.58 g). The lowest value was expressed by L_1 x T_1 (0.37g).

4.1.2.14 Duration of crop

The line L_2 had the shortest duration (208.93) while the longest duration (224.60) was recorded by L_5. The tester with minimum value was T_2 (132.00) and the one with maximum value was T_3 (134.67). The hybrid having the shortest duration (129.03) was L_1 x T_1. The hybrid with longest duration (175.57) was L_5 x T_3 and the on par values were 175.27 (L_3 x T_2), 174.03 (L_5 x T_1), 173.33 (L_2 x T_3), 173.27 (L_2 x T_1), 171.57 (L_4 x T_2), 171.50 (L_5 x T_2), 171.37 (L_3 x T_3) and 170.13 (L_3 x T_1).

4.1.2.15 Vulnerability Index

All the lines recorded the same value of 0.81 for the character except L_3 while among the testers the range was between 58.40 (T_2) and 66.83 (T_1). The minimum value recorded by two hybrids namely L_1 x T_3 (3.54) which was on par with L_1 x T_2 (7.62), L_4 x T_2 (8.16) and L_5 x T_3 (8.16) while the maximum value was 39.36 observed in L_2 x T_3.

4.1.2.16 Vector population

All testers were on par with T_1 showing minimum insect count of 5.65 and T_3 with maximum of 6.79. The value ranged between 0.23 (L_4) and 0.44 (L_3) for lines. Among the hybrids L_1 x T_3 (0.77) had the

minimum vector population which was on par with L_5 x T_3 (1.09), L_4 x T_2 (1.11) and L_1 x T_2 (1.12). The cross L_5 x T_2 (4.35) had maximum value.

4.1.2.17 Incidence of pests

The count of thrips, mites, aphids, mealy bugs and scales were found to be negligible.

4.1.3 Genetic parameters

The genetic parameters *viz.*, the phenotypic and genotypic coefficients of variation, heritability and genetic advance estimated for each character are presented in Table 5.

Maximum variability was observed in green fruit yield per plant (67.19 and 64.00) at phenotypic and genotypic levels respectively. Minimum variability at phenotypic and genotypic levels was recorded for fruit width with the same value of 0.01.

For all the characters, the PCV and GCV values were found to be closer indicating the predominant influence of genetic component over the environmental effect in their phenotype.

Heritability and genetic advance are presented in Fig. 1. Maximum heritability (90.72 %) was observed for green fruit yield per plant and minimum (26.31%) for fruit width. Maximum genetic advance (% of mean) was observed for average fruit weight (98.77) and minimum was recorded by fruit width (0.07).

4.1.4 Combining ability analysis

Combining ability effects of lines, testers and hybrids were estimated and the results are presented below.

The analysis of variance for combining ability was carried out for 16 characters and is presented in Table 6. The general combining ability (*gca*) and specific combining ability (*sca*) effects were found to be significant for most of the characters.

Table 5. Components of total variance for 16 traits in chilli (*Capsicum spp*)

Sl. No.	Characters	PCV %	GCV %	ECV %	Heritability %	Genetic advance (as % of mean)
1	Plant height	22.38	18.94	11.91	71.69	16.71
2	No. of branches	23.99	16.23	17.67	45.75	1.60
3	Days to first flowering	24.48	23.11	8.08	89.12	44.94
4	Plant spread	27.21	21.66	16.47	63.36	15.22
5	Duration of flowering	18.23	16.98	6.63	86.76	33.07
6	No. of fruits per plant	50.66	46.54	20.00	84.41	45.51
7	Fruit length	35.37	29.12	20.08	67.76	4.09
8	Fruit width	0.01	0.01	0.02	26.31	0.07
9	Pedicel-fruit ratio	25.26	23.39	9.53	85.77	44.63
10	Green fruit yield / plant	67.19	64.00	20.47	90.72	98.67
11	Average fruit weight	59.56	53.44	26.31	80.49	98.77
12	No. of seeds per fruit	35.70	33.75	11.61	89.42	65.75
13	Hundred seed weight	15.05	13.21	7.20	77.08	0.12
14	Duration of crop	17.89	17.46	3.90	90.25	59.82
15	Vector population	18.10	13.89	4.21	76.74	6.73
16	Vulnerability index	66.23	56.05	35.27	71.64	23.24

PCV- Phenotypic coefficient of variation

GCV-Genotypic coefficient of variation

ECV-Environmental coefficient of variation

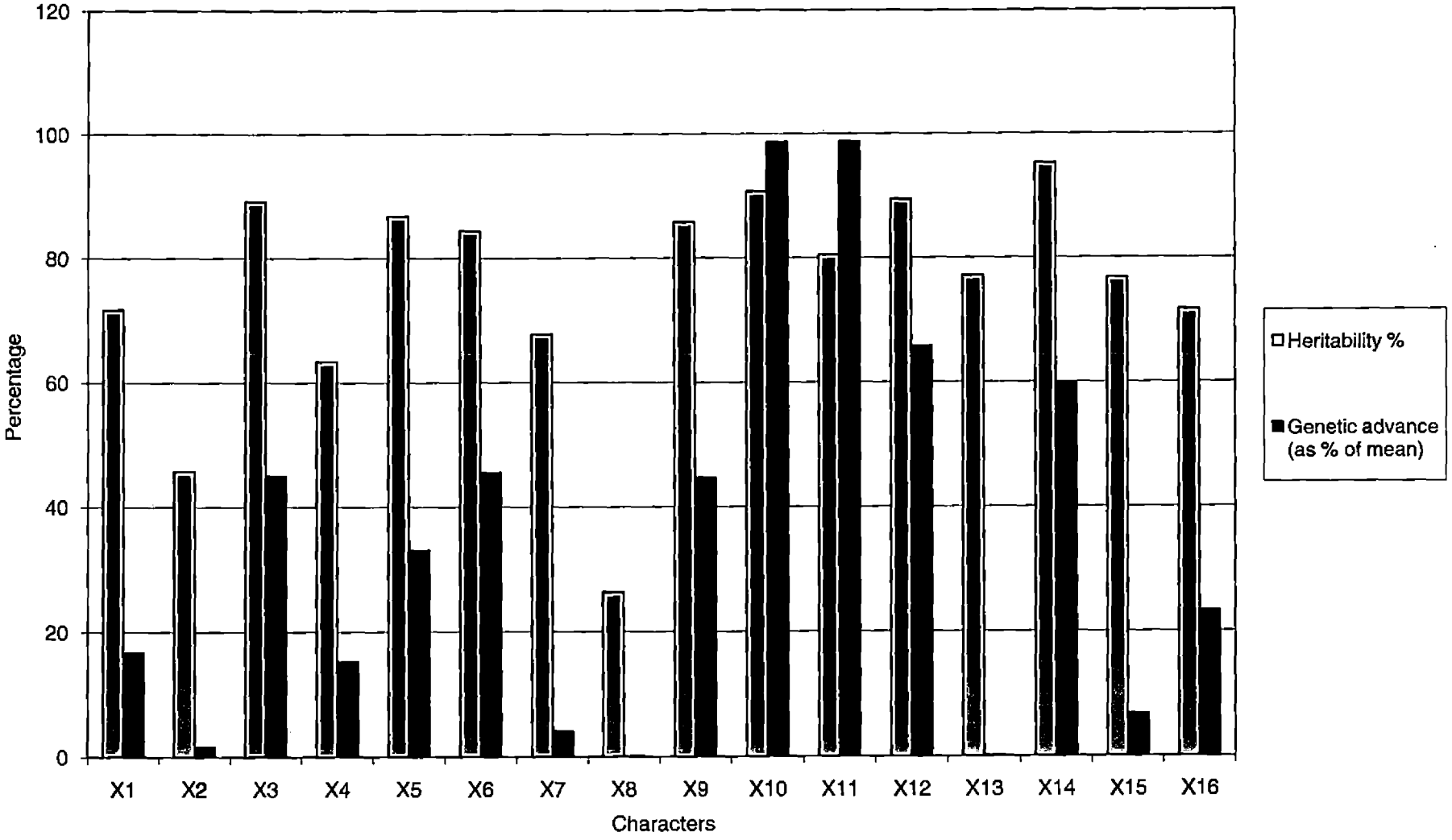


Fig. 1. Heritability and genetic advance (as percentage of mean)

Table 6. MSE for combining ability for various characters in chilli (*Capsicum spp*)

Sl.No	Source	Plant height (cm)	Number of branches	Days to first flowering	Plant spread (cm)	Duration of flowering	Number of fruits per plant	Fruit length (cm)	Fruit width (cm)
1.	Replication	509.16**	19.46**	53.83	415.52**	9.75	188.23	2.33	0.0027
2.	Treatments	311.53**	5.49**	818.26**	308.32**	936.28**	1801.41**	22.42**	0.5239**
3.	Parents	467.11**	4.07*	74.14**	405.79**	559.92**	1579.01**	37.38**	0.3648**
4.	Parents Vs Crosses	0.91	55.13**	1756.78**	160.81	1602.78**	6693.44**	0.07	0.1852**
5.	Crosses	255.93**	2.66	4666.36**	270.12**	1539.79**	1541.75**	16.53**	0.6276**
6.	Lines	488.49	6.18*	64.07	354.26	1653.46**	1263.85	45.40**	1.7536**
7.	Tester	222.18	1.80	6.47	452.51	46.65	2367.03	14.53*	0.3150
8.	Lines x Tester	148.09**	1.11	96.09**	182.45**	141.46**	1474.38**	2.60*	0.1427**
9.	Error	36.24	1.56	15.13	49.82	45.34	106.83	0.88	0.0130

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

Table 6. Contd....

Sl. No	Source	Pedicel-fruit ratio	Green fruit yield / plant(g)	Average fruit weight(g)	Number of seeds per fruit	Hundred seed weight (g)	Duration of crop	Vulnerability index	Vector population
1.	Replication	0.0003	1842.78	0.04	69.28	0.00	11.96	581.45**	9.51
2.	Treatments	0.0229**	24098.64**	7.68**	1271.75**	0.02**	2699.66**	714.30**	45.89**
3.	Parents	0.0353**	2151.83*	15.48**	1100.62**	0.02**	680.29**	1730.07**	99.86**
4.	Parents Vs Crosses	0.0034	29890.88**	6.48**	1297.71**	0.01**	5851.94**	317.45*	64.76**
5.	Crosses	0.0181**	34658.31**	3.87**	1355.46**	0.02**	8904.87**	234.76**	17.56**
6.	Lines	0.0511**	40692.00	9.47**	4148.80**	0.02	1800.41**	338.58	20.81
7.	Tester	0.0159**	31449.82	3.33	16.7	0.02	86.35	175.45	15.27
8.	Lines x Tester	0.0022	32443.58**	1.21	293.48**	0.01**	268.72**	197.68*	16.51**
9.	Error	0.0012	794.38	0.21	48.27	0.00	44.14	63.67	4.21

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

The treatment effects were significant among genotypes in all the characters and hence subjected to combining ability analysis in a line x tester model.

Among the parents there were significant differences in all the characters studied. Significant differences were noted among crosses for all the characters except number of branches. In parents vs crosses significant differences were observed for majority of the characters except plant height, plant spread, fruit length and pedicel - fruit ratio.

Lines varied significantly for number of branches, duration of flowering, fruit length, fruit width, pedicel - fruit ratio, average fruit weight, number of seeds per fruit and duration of crop while testers exhibited significant variation for fruit length and pedicel - fruit ratio alone. Line x Tester interaction mean square was significant for all the characters except number of branches, pedicel - fruit ratio and average fruit weight.

The *gca* effects of parents and *sca* effects of hybrids in 14 characters are given in the Tables 7 and 8 respectively.

4.1.4.1 Plant height

The line L_1 expressed significant positive *gca* effect (7.02) while L_4 expressed it negatively (-12.33). None of the testers and hybrids had significant positive *sca* effects though L_4 x T_3 had negative significant effect (-12.43).

4.1.4.2 Number of branches

None of the lines except L_4 (1.32) had positive significant *gca* effect while among the testers and hybrids none had significant *sca* effect.

4.1.4.3 Days to first flowering

The lines and testers showed no significant *gca* effects while the hybrid L_4 x T_3 (-9.47) alone exhibited desirable negative significant *sca*

Table 7. General combining ability (*gca*) effect of lines and testers for 14 characters

Treatments	Plant height (cm)	Number of branches	Days to first flowering	Plant spread (cm)	Duration of flowering	Number of fruits per plant	Fruit length (cm)
L_1	7.02*	-0.5	0.52	0.67	-22.54**	13.22**	-2.51**
L_2	0.39	-0.79	-1.16	3.03	7.54*	9.18	1.34**
L_3	3.78	-0.28	3.7	-2.48	6.45*	-11.15*	2.46**
L_4	-12.33**	1.32*	-3.59	-9.01**	-2.51	-13.21**	-2.25**
L_5	1.14	0.25	0.54	7.79*	11.05**	1.96	0.96
CD	7.66	1.59	7.21	8.98	8.57	13.16	1.20
SE	2.84	0.59	2.67	3.33	3.17	4.87	0.44
T_1	-2.64	-0.38	-0.65	-1.77	-1.39	-0.56	-1.13**
T_2	4.42	0.09	0.66	6.16*	1.98	12.83**	0.51
T_3	-1.78	0.29	-0.01	-4.39	-0.60	-12.27**	0.63
CD	5.94	1.23	5.59	6.96	6.64	10.19	0.93
SE	2.20	0.46	2.07	2.58	2.46	3.77	0.34

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

Table 7. Contd....

Treatments	Fruit width (cm)	Pedicel-fruit ratio	Green fruit yield / plant(g)	Average fruit weight (g)	Number of seeds per fruit	Hundred seed weight (g)	Duration of crop
L_1	-0.66**	0.11**	-103.36**	-1.80**	-36.24**	-6.05**	-22.02**
L_2	0.08	-0.06**	58.28**	0.53	4.8	0.07**	6.38
L_3	-0.04	-0.03**	-17.46	0.11	2.16	-0.02	10.15
L_4	0.57**	0.04**	1.75	0.58	20.72**	0.02	-6.11
L_5	0.05	-0.06**	60.80**	0.57	8.55**	-0.01	11.59
CD	0.15	0.04	35.87	0.96	8.84	0.05	8.46
SE	0.05	0.02	13.29	0.36	3.28	0.02	3.13
T_1	-0.09*	0.03**	-42.46**	-0.54	0.57	-0.04**	-2.04
T_2	-0.06	0.01	48.51**	0.20	-1.22	0.01	2.65
T_3	0.16**	-0.04**	-6.05	0.34	0.65	0.03*	-0.61
CD	0.11	0.03	27.79	0.74	6.85	0.04	6.55
SE	0.04	0.01	10.29	0.28	2.54	0.01	2.43

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

Table 8. Specific combining ability (*sca*) effect of lines x tester hybrids for 14 characters

Sl.No	Treatments	Plant height (cm)	Number of branches	Days to first flowering	Plant spread (cm)	Duration of flowering	Number of fruits per plant	Fruit length (cm)
1.	L_1 x T_1	-3.79	-0.16	1.46	-6.60	-10.48	2.62	0.85
2.	L_1 x T_2	-2.49	0.60	-3.22	1.25	7.05	4.69	-0.33
3.	L_1 x T_3	6.29	-0.44	1.76	5.35	3.43	-7.30	-0.52
4.	L_2 x T_1	-0.40	-0.11	1.71	7.13	5.11	17.38*	0.82
5.	L_2 x T_2	-2.86	-0.54	-6.34	-9.82	-5.93	-19.81*	-0.85
6.	L_2 x T_3	3.26	0.65	4.63	2.69	0.82	2.43	0.03
7.	L_3 x T_1	2.77	-0.65	-1.18	1.75	1.10	10.18	0.50
8.	L_3 x T_2	-0.05	0.65	0.14	-0.11	0.23	1.12	-0.42
9.	L_3 x T_3	-2.71	0.01	1.04	-1.64	-1.33	-11.30	-0.08
10.	L_4 x T_1	3.09	0.60	2.21	-3.14	-2.30	-17.78*	-0.95
11.	L_4 x T_2	9.34	-0.32	7.26*	12.04*	5.66	31.85**	0.91
12.	L_4 x T_3	-12.43*	-0.29	-9.47**	-8.91	-3.36	-14.07	0.04
13.	L_5 x T_1	-1.66	0.32	-4.19	0.86	6.57	-12.40	-1.23
14.	L_5 x T_2	-3.94	-0.39	2.16	-3.36	-7.01	-17.85*	0.70
15.	L_5 x T_3	-3.79	-0.16	1.46	-6.60	-10.48	30.25**	0.85
	CD	13.27	2.75	12.49	15.56	14.84	22.79	2.08
	SE	4.92	1.02	4.63	5.76	5.50	8.44	0.77

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

Table 8. Contd....

Sl.No	Treatments	Fruit width (cm)	Pedicel - fruit ratio	Green fruit yield per plant (g)	Average fruit weight (g)	Number of seeds per fruit	Hundred seed weight (g)	Duration of crop
1.	$L_1 \times T_1$	0.0864	-0.01	32.87	0.70	-1.00	-0.04	-9.02
2.	$L_1 \times T_2$	0.1264	-0.04	-27.80	-0.25	0.33	0.09**	3.83
3.	$L_1 \times T_3$	-0.2129*	0.05	-5.07	-0.45	0.67	-0.06	5.18
4.	$L_2 \times T_1$	0.0687	-0.01	50.56*	-0.28	5.67	0.05	6.82
5.	$L_2 \times T_2$	-0.0047	0.02	-71.75**	-0.26	-4.67	-0.01	-12.27*
6.	$L_2 \times T_3$	-0.0640	-0.01	21.19	0.54	-1.00	-0.04	5.45
7.	$L_3 \times T_1$	0.1487	-0.01	53.07*	0.24	0.11	0.01	-0.08
8.	$L_3 \times T_2$	-0.0647	0.01	13.23	0.19	1.44	0.01	0.36
9.	$L_3 \times T_3$	-0.0840	0.00	-66.30**	-0.43	-1.56	-0.02	-0.28
10.	$L_4 \times T_1$	-0.3413*	0.02	-80.37**	-0.15	-7.11	-0.03	-0.09
11.	$L_4 \times T_2$	-0.0447	0.00	165.79**	0.64	-5.78	-0.04	12.92*
12.	$L_4 \times T_3$	0.3860**	-0.02	-85.42**	-0.49	12.89**	0.07*	-12.83*
13.	$L_5 \times T_1$	0.0376	0.01	-56.14**	-0.51	2.33	0.01	2.37
14.	$L_5 \times T_2$	-0.0124	0.01	-79.47**	-0.33	8.67	-0.05	-4.85
15.	$L_5 \times T_3$	-0.0251	-0.01	135.61**	0.70	-11.00	0.04	2.47
	CD	0.25	0.08	62.13	1.67	15.32	0.08	14.65
	SE	0.09	0.03	23.01	0.62	5.67	0.03	5.42

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

effect. L_4 x T_2 (7.26) exhibited significance but in positive direction.

4.1.4.4 Plant spread

Line L_5 (7.79) and tester T_2 (6.16) alone had positive significant *gca* effects while L_4 had significant *gca* effect in negative direction (-9.01). Among the hybrids L_4 x T_2 had positive significant *sca* effect (12.04).

4.1.4.5 Duration of flowering

The lines L_3 (6.45), L_2 (7.54) and L_5 (11.05) exhibited significant positive *gca* effects for duration of flowering while L_1 (-22.54) had significant negative values for the trait. Among the testers and hybrids the combining ability effects were not significant.

4.1.4.6 Number of fruits per plant

Line L_1 possessed significant positive *gca* effect (13.22) while L_4 (-13.21) and L_3 (-11.15) expressed significant effects in the negative direction. Testers T_2 (12.83) and T_3 (-12.27) exhibited significant *gca* effects in positive and negative direction respectively. Three among the hybrids *viz.*, L_5 x T_3 (30.25), L_4 x T_2 (31.85) and L_2 x T_1 (17.38) showed positive significant effects for *sca* while three other hybrids *viz.*, L_4 x T_1 (-17.78), L_5 x T_2 (-17.85) and L_2 x T_2 (-19.81) showed significant negative effects for the trait.

4.1.4.7 Fruit length

The lines L_3 (2.46) and L_2 (1.34) showed significant positive *gca* effects while L_1 (-2.51) and L_4 (-2.25) possessed significant negative values. Tester T_1 exhibited (-1.13) significant negative *gca* effect. No significant *sca* effect was noticed among hybrids.

4.1.4.8 Fruit width

Positive significant *gca* was exhibited by line L_4 (0.57) and tester T_3 (0.16) whereas negative significant value was exhibited by line L_1 (-

0.66). The hybrid L_4 x T_3 (0.3860) showed positive significant *sca* but the hybrids L_4 x T_1 (-0.3413) and L_1 x T_3 (-0.2129) recorded negative significant values.

4.1.4.9 Pedicel - fruit ratio

All the five lines showed significant *gca* effects in which only two were positive *viz.*,L_1 (0.11) and L_4 (0.04) while the lines L_3 (-0.03), L_2 (-0.06) and L_5 (-0.06) had significant negative values. The tester T_1 (0.03) exhibited significant positive *gca* effect whereas tester T_3 (-0.04) had significant negative effects. None of the hybrids showed significance for *sca* effects.

4.1.4.10 Green fruit yield per plant

The lines that exhibited significant positive *gca* effects were L_5 (60.80) and L_2 (58.28) and the one that exhibited significant negative *gca* effects was L_1 (-103.36). Among the testers T_2 (48.51) expressed positive significance whereas T_1 (-42.46) expressed it in negative direction. Eleven of the hybrids expressed significant *sca* effects among which only four *viz.*, L_4 x T_2 (165.79), L_5 x T_3 (135.61), L_3 x T_1 (53.07) and L_2 x T_1 (50.56) had positive values whereas the remaining six *viz.*, L_5 x T_1 (-56.14), L_3 x T_3 (-66.30), L_2 x T_2 (-71.75), L_5 x T_2 (-79.47), L_4 x T_1 (-80.37), and L_4 x T_3 (-85.42) had negative effects.

4.1.4.11 Average fruit weight

Only one line L_1 (-1.80) exhibited significant *gca* effects but in undesirable negative direction. All other lines and testers expressed positive values with no significance. None of the hybrids showed significant *sca* effects.

4.1.4.12 Number of seeds per fruit

Positive significant *gca* effects was given by the lines L_4 (20.72)

and L_5 (8.55) whereas L_1 showed significant negative effect (-36.24). None of the testers showed any significant effect. Only one hybrid L_4 x T_3 (12.89) showed positive significant *sca* effects and all the other hybrids showed no significance.

4.1.4.13 Hundred seed weight

The *gca* effects of the line L_2 (0.07) and tester T_3 (0.03) were significant and positive while that of the line L_1 (-6.05) and tester T_1 (-0.04) were negative. Only two hybrids *viz.*, L_1 x T_2 (0.09) and L_4 x T_3 (0.07) were found to be significant and positive.

4.1.4.14 Duration of crop

The line L_1 (-22.02) possessed desirable negative significant *gca* effect whereas all the other lines were having non significant value for the trait. Among the hybrids L_4 x T_3 (-12.83) and L_2 x T_2 (-12.27) had significant negative *sca* effects whereas the hybrid L_4 x T_2 (12.92) had positive significant *sca* effect.

4.1.5 Proportional contribution of parents and hybrids

Proportional contribution of lines, testers and line x tester hybrids to total variance estimated is presented in Table 9 and Fig 2. Among the different characters, proportional contribution of lines ranged from 23.42 per cent for number of fruits per plant to 87.45 for number of seeds per fruit. Among the testers the values varied from 0.18 per cent for number of seeds per fruit to 23.93 per cent for plant spread. In line x tester hybrids the range was from 6.9 per cent for pedicel - fruit ratio to 74.06 per cent for days to first flowering.

4.1.6 Genetic components of variance

The additive variance (σ^2a) and dominance variance (σ^2d) estimated are presented in Table 10. The dominance variance was greater than

Table 9. Proportional contribution of lines, testers and hybrids to the total variance

Sl.No.	Characters	Line (%)	Tester (%)	Hybrid
1	Plant height (cm)	54.53	12.40	33.06
2	Number of branches	66.49	9.70	23.82
3	Days to first flowering	24.69	1.25	74.06
4	Plant spread (cm)	37.47	23.93	38.60
5	Duration of flowering	84.37	1.19	14.44
6	Number of fruits per plant	23.42	21.93	54.65
7	Fruit length (cm)	78.45	12.55	9.00
8	Fruit width (cm)	79.83	7.17	12.99
9	Pedicel- fruit ratio	80.61	12.50	6.90
10	Green fruit yield / plant (g)	33.55	12.96	53.49
11	Average fruit weight (g)	69.89	12.28	17.83
12	Number of seeds per fruit	87.45	0.18	12.37
13	Hundred seed weight (g)	39.97	18.61	41.42
14	Duration of crop	75.62	1.81	22.57
15	Vector population	33.86	12.43	53.72
16	Vulnerability index	41.21	10.68	48.12

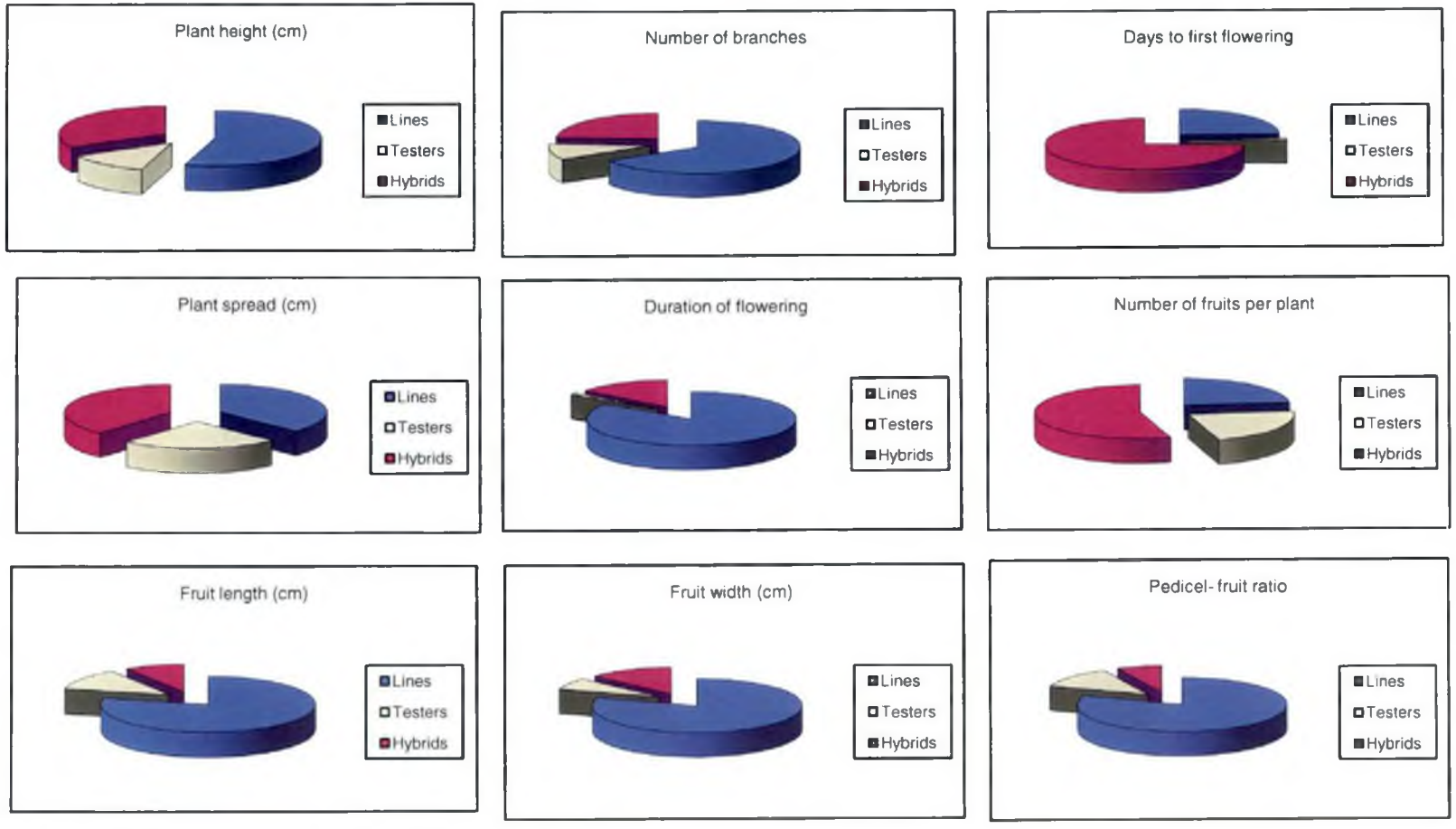


Fig. 2. Proportional contribution of parents and hybrids

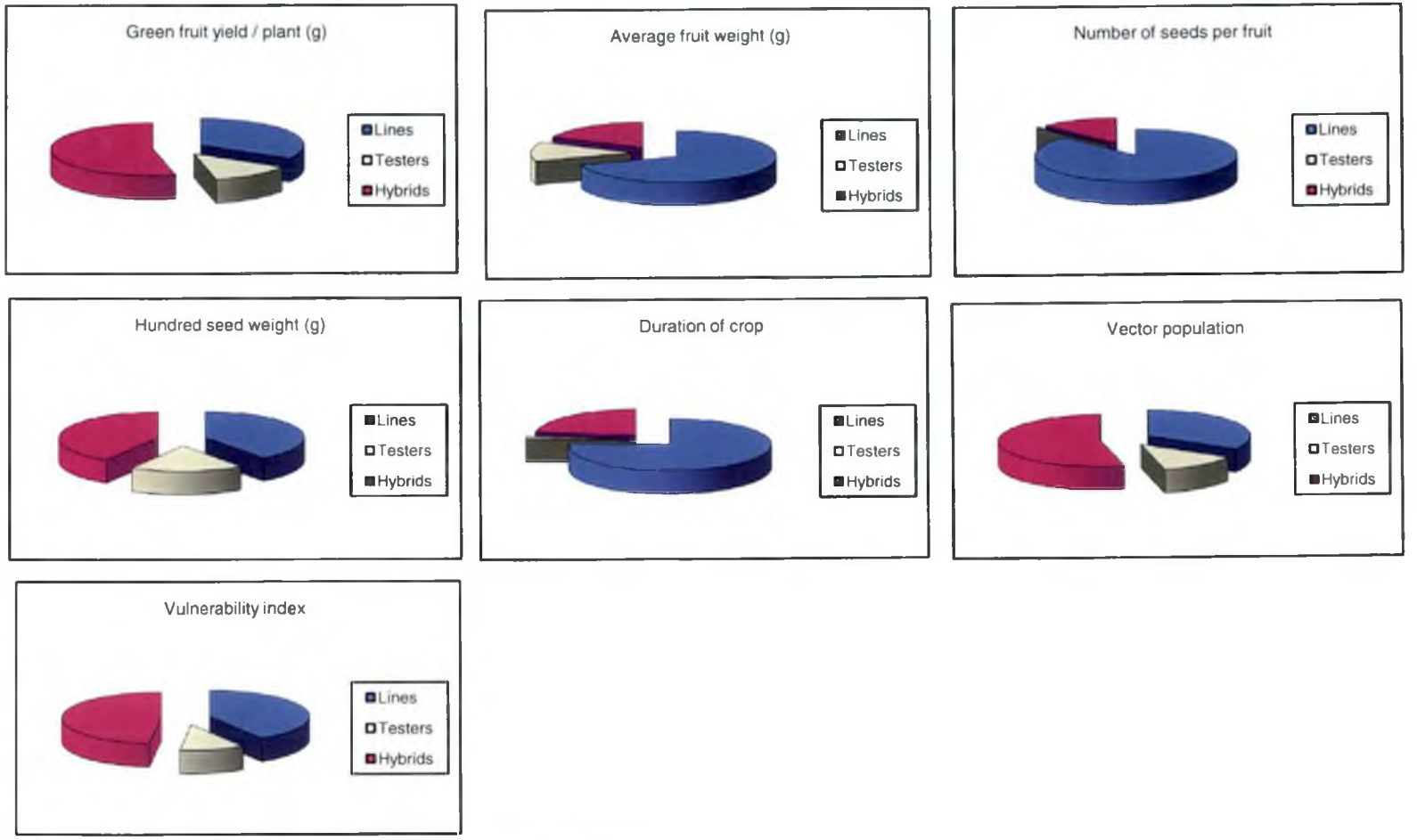


Fig. 2. Proportional contribution of parents and hybrids (Continued...)

Table 10. Genetic components of variance (when F = 1)

Sl.No.	Characters	Additive variance σ^2a	Dominance variance σ^2d	σ^2a/σ^2d
1	Plant height (cm)	7.63	36.59	0.21
2	Number of branches	0.11	0.17	0.65
3	Days to first flowering	0.15	4.94	0.03
4	Plant spread (cm)	6.2	42.52	0.15
5	Duration of flowering	29.59	75.03	0.39
6	Number of fruits per plant	4.76	262.65	0.02
7	Fruit length (cm)	0.99	2.67	0.37
8	Fruit width (cm)	0.03	0.10	0.35
9	Pedicel - fruit ratio	0.0012	0.0029	0.41
10	Green fruit yield / plant (g)	156.6	5573.50	0.03
11	Average fruit weight (g)	0.19	0.56	0.34
12	Number of seeds per fruit	8.65	189.615	0.05
13	100 seed weight (g)	0.0002	0.0025	0.0800
14	Duration of crop	29.10	92.99	0.31
15	Vector population	0.07	2.17	0.03
16	Vulnerability index	2.62	26.07	0.1

additive variance for all the characters studied. When F=1, additive to dominance variance ratio ranged from 0.03 (for number of fruits per plant) to 0.65 (for number of branches per plant).

4.1.7 Heterosis

Relative heterosis, heterobeltiosis and standard heterosis were estimated for 15 hybrids with respect to 16 characters and the results are furnished in Table 11 and Fig 3. Standard heterosis was calculated for each character based on the standard variety Jwalamukhi.

4.1.7.1 Plant height

Significant and positive heterosis was noticed with mid parent value for L_1 x T_3 (33.38), L_4 x T_2 (26.99), L_1 x T_2 (21.68) and L_5 x T_3 (20.15) while with better parent significant negative heterosis was observed in eight hybrids. Only one hybrid L_4 x T_2 (24.76) showed significant positive heterobeltiosis. All the hybrids except two showed significant positive standard heterosis with maximum value of L_1 x T_3 (57.52) and a minimum value of L_5 x T_1 (20.33). L_4 x T_1 showed no significance and L_4 x T_3 showed negative significance.

4.1.7.2 Number of branches

Among the hybrids L_2 x T_3 (59.19), L_5 x T_3 (52.21), L_5 x T_1 (45.85), L_1 x T_2 (45.40), L_4 x T_1 (44.16), L_4 x T_3 (39.51), L_5 x T_2 (38.55), L_4 x T_2 (34.69), L_3 x T_2 (34.25), L2 x T_1 (31.74), L_1 x T_3 (31.47) and L_3 x T_3 (28.35) showed positive significant relative heterosis. Heterobeltiosis significance was noted for five hybrids L_2 x T_3 (58.92), L_5 x T_3 (38.89), L_1 x T_2 (36.21), L_5 x T_1 (31.67) and L_5 x T_2 (27.78). Significant positive standard heterosis was recorded in L_4 x T_1 (91.38), L_4 x T_3 (86.90), L_4 x T_2 (82.07), L_5 x T_3 (72.41), L_3 x T_2 (68.97), L_1 x T_2 (63.45), L_5 x T_1 (63.45), L_2 x T_3 (62.76), L_3 x T_3 (60.00), L_5 x T_2 (58.62), L_1 x T_3 (46.21),

Table 11. Estimation of percentage heterosis over mid, better and standard parents for various characters

Sl. No.	Hybrids	Plant height			Number of branches			Days to first flowering			Plant spread		
		RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
1.	$L_1 \times T_1$	5.49	-11.16	29.81**	25.39	14.94	37.93*	-14.10**	-33.44**	21.05**	-8.95	-22.18*	9.68
2.	$L_1 \times T_2$	21.68**	3.32	50.97**	45.40**	36.21**	63.45**	-16.98**	-36.86**	14.82*	32.89**	11.69	57.40**
3.	$L_1 \times T_3$	33.38**	7.80	57.52**	31.47*	21.84	46.21**	-11.44*	-32.49**	22.78**	38.13**	-2.15	37.90**
4.	$L_2 \times T_1$	-8.46	-26.61**	21.62*	31.74*	30.41	33.10*	-15.25**	-34.00**	18.40**	24.94*	3.19	58.32**
5.	$L_2 \times T_2$	-0.44	-19.57**	33.28**	29.33	27.63	33.79*	-22.72**	-40.95**	5.93	5.09	-14.59	31.05*
6.	$L_2 \times T_3$	4.05	-19.70**	33.07**	59.19**	58.92**	62.76**	-9.03	-30.32**	25.00**	29.14*	-10.71	37.00**
7.	$L_3 \times T_1$	3.23	-17.63**	38.24**	7.26	-9.86	32.41*	-15.39**	-35.24**	22.04**	5.58	-8.83	25.40
8.	$L_3 \times T_2$	10.40	-11.24*	48.96**	34.25**	15.02	68.97**	-10.38*	-32.66**	26.91**	23.14*	4.53	43.78**
9.	$L_3 \times T_3$	-1.88	-24.61**	26.52**	28.35*	8.92	60.00**	-10.29*	-32.43**	27.35**	9.29	-22.02*	7.26
10.	$L_4 \times T_1$	-4.52	-7.11	-1.77	44.16**	15.63	91.38**	-16.74**	-34.69**	14.82*	-23.00*	-33.21**	-9.10
11.	$L_4 \times T_2$	26.99**	24.76**	31.93**	34.69**	10.00	82.07**	-6.41	-27.99**	26.61**	38.58**	18.15	60.79**
12.	$L_4 \times T_3$	-37.63**	-42.25**	-38.94**	39.51**	12.92	86.90**	-30.41**	-46.31**	-5.62	-32.74*	-51.85**	-34.48*
13.	$L_5 \times T_1$	-1.54	-16.68*	20.33*	45.85**	31.67*	63.45**	-23.40**	-41.42**	10.62	16.71	-5.96	53.77**
14.	$L_5 \times T_2$	7.47	-8.30	32.43**	38.55**	27.78*	58.62**	-11.97*	-33.90**	24.82**	27.16**	0.89	64.97**
15.	$L_5 \times T_3$	20.15*	-2.46	40.88**	52.21**	38.89**	72.41**	-13.23**	-34.69**	23.33**	35.71**	-7.77	50.81**

Table 11. Contd...

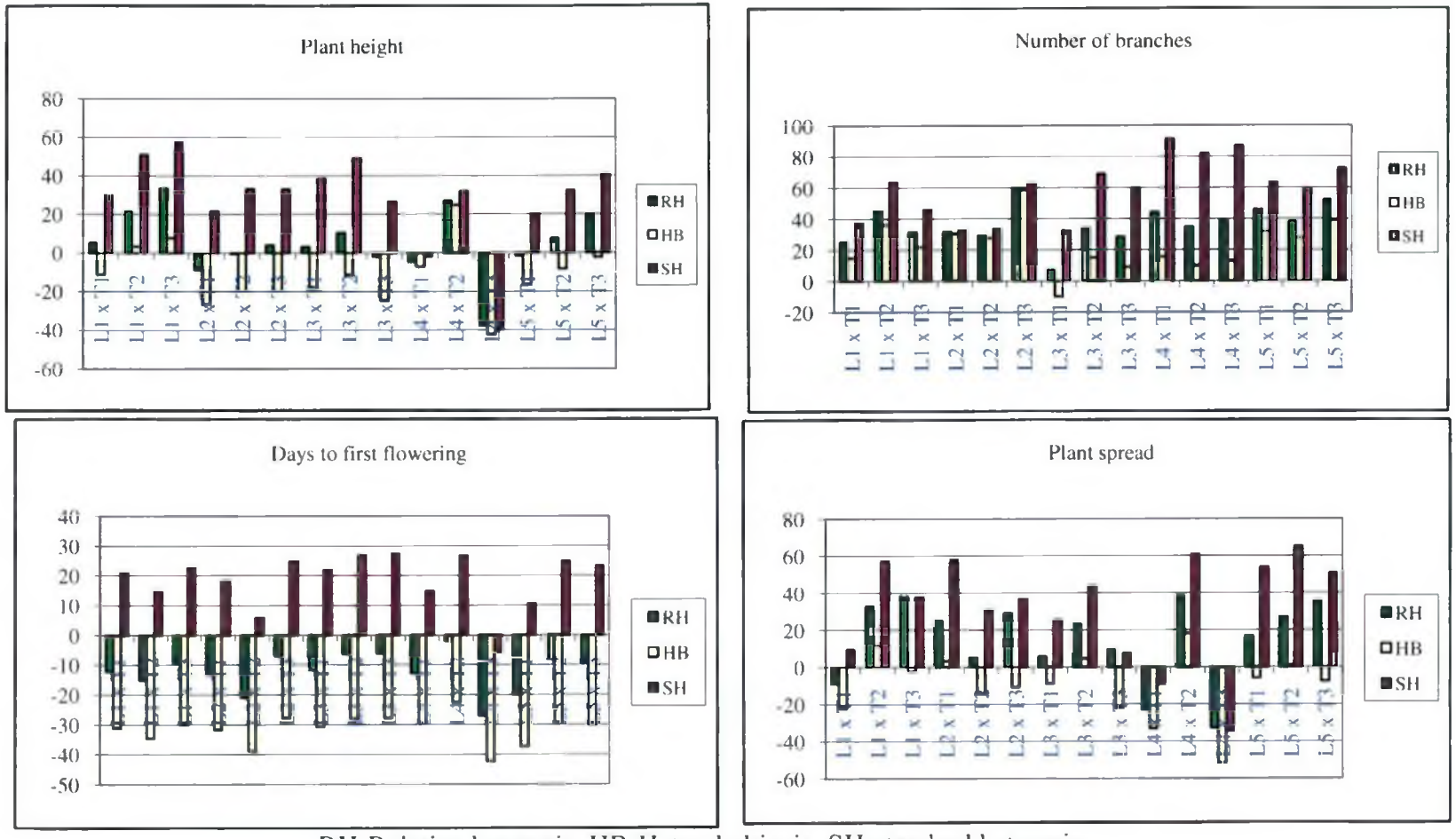
Sl. No.	Hybrids	Duration of flowering			Number of fruits per plant			Fruit length			Fruit width		
		RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
1.	$L_1 \times T_1$	-36.07**	-47.43**	-18.45**	94.96**	21.12*	45.88**	-39.65**	-55.11**	-55.11**	-36.90**	-53.46**	-53.46**
2.	$L_1 \times T_2$	-16.24**	-30.17**	8.33	135.95**	-13.54	399.56**	-34.00**	-50.63**	-51.47**	-27.17**	-44.77**	-49.23**
3.	$L_1 \times T_3$	-23.26**	-35.29**	0.38	43.12*	501.72**	256.61**	-34.52**	-50.93**	-52.02**	-40.21**	-56.14**	-55.39**
4.	$L_2 \times T_1$	13.03**	-5.26	40.05**	199.42**	102.98**	470.49**	0.16	-24.80**	-24.80**	4.53	-11.15**	-11.15**
5.	$L_2 \times T_2$	3.62	-11.90**	30.23**	118.27**	47.02**	313.22**	0.94	-23.77**	-25.06**	6.89	-5.86	-13.46**
6.	$L_2 \times T_3$	6.62	-8.29*	35.57**	114.91**	40.28**	294.27**	11.98	-15.29**	-17.16*	12.43*	-5.10	-3.46
7.	$L_3 \times T_1$	1.91	-17.60**	33.52**	50.26**	-6.86	288.55**	4.68	-18.46**	-18.46*	9.07	-14.42**	-14.42**
8.	$L_3 \times T_2$	2.96	-15.63**	36.72**	62.09**	0.00	317.18**	13.19**	-11.28*	-12.78	1.03	-18.20**	-24.81**
9.	$L_3 \times T_3$	-2.12	-18.89**	31.43**	-32.74	-59.45**	69.16	18.36**	-7.05	-9.11	10.30*	-13.99**	-12.50**
10.	$L_4 \times T_1$	-11.51**	-29.10**	17.68**	10.40	-22.23	90.15*	-48.88**	-67.31**	-67.31**	-2.42	-6.92	-6.92
11.	$L_4 \times T_2$	-1.90	-20.35**	32.20**	254.67**	148.11**	506.61**	-4.25	-38.54	-39.58**	22.74**	21.97**	12.12**
12.	$L_4 \times T_3$	-13.87**	-29.30**	17.34**	-16.92	-43.87*	37.23	-13.26	-44.26**	-45.50**	56.24**	47.83**	50.39**
13.	$L_5 \times T_1$	10.24*	-11.60**	46.41**	22.31	-24.72*	225.99**	-26.96*	-44.02**	-44.02**	-3.06	-14.81**	-14.81**
14.	$L_5 \times T_2$	-0.92	-19.49**	33.35**	42.63**	-12.61	278.41**	11.10**	-14.34**	-15.79	0.46	-8.37	-15.77**
15.	$L_5 \times T_3$	2.59	-15.73**	39.58**	104.43**	22.48*	430.40**	11.03	-14.23**	-16.13	9.21*	-4.73	-3.08

Table 11. Contd...

Sl. No.	Hybrids	Pedicel: fruit ratio			Green fruit yield / plant			Average fruit weight			Number of seeds per fruit		
		RH	HB	SH	RH	HB	SH	RH	HB	SH	RH	HB	SH
1.	$L_1 \times T_1$	38.76**	11.54*	83.54**	-59.36**	-62.82**	-55.19**	-70.95**	-83.56**	-83.56**	-24.51*	-41.06**	-41.06**
2.	$L_1 \times T_2$	26.92**	1.54	67.09**	-19.64	-34.64*	-21.23	-74.15**	-85.14**	-86.90**	-25.88*	-42.71**	-41.07**
3.	$L_1 \times T_3$	47.21**	11.54*	83.54**	-59.67**	-64.25**	-56.91**	-79.35**	-88.34**	-88.09**	-66.06**	-77.93**	-58.79**
4.	$L_2 \times T_1$	-5.42	-22.58**	21.52*	91.99**	57.49**	145.85**	-41.80**	-61.73**	-61.73**	49.86**	36.11**	36.11**
5.	$L_2 \times T_2$	-4.95	-22.58**	21.52*	81.95**	34.99**	110.73**	-15.32	-42.51**	-49.33**	39.64**	25.24**	28.82**
6.	$L_2 \times T_3$	-21.47**	-39.52**	-5.06	103.59**	62.54**	153.74**	-1.61	-35.62**	-34.23**	2.99	-25.98**	38.19**
7.	$L_3 \times T_1$	-7.14	-28.28**	31.65**	35.12*	15.01	63.75**	-36.34**	-60.11**	-60.11**	54.14**	50.10**	50.10**
8.	$L_3 \times T_2$	-7.62	-28.97**	30.38**	102.92**	55.28**	121.08**	-10.21	-42.20**	-49.06**	25.16*	20.23**	23.67**
9.	$L_3 \times T_3$	-16.98**	-39.31**	11.39	-39.93**	-50.32**	-29.26	-32.35**	-57.78**	-56.87**	-19.26**	-39.14**	13.63
10.	$L_4 \times T_1$	16.52**	-11.26*	69.62**	-70.07**	-74.23**	-64.31**	-38.68**	-58.76**	-58.76**	19.82**	8.46	33.84**
11.	$L_4 \times T_2$	7.42	-18.54**	55.70**	286.56**	198.68**	313.64**	7.69	-25.08**	-33.96**	57.96**	44.81**	78.70**
12.	$L_4 \times T_3$	-4.59	-31.13**	31.65**	-38.83*	-48.84**	-29.15	-27.02*	-51.19**	-50.14**	19.47**	-0.78	85.24**
13.	$L_5 \times T_1$	1.00	-16.53**	27.85**	1.87	-15.85	29.06	-46.39**	-64.74**	-64.74**	43.98**	37.67**	50.89**
14.	$L_5 \times T_2$	-6.53	-23.14**	17.72**	79.04**	33.60*	104.90**	-16.13	-43.06**	-49.81**	14.93	11.39	22.09*
15.	$L_5 \times T_3$	-23.40**	-40.50**	-8.86	212.21**	150.93**	284.84**	6.45	-30.34**	-28.84**	2.91	-18.34**	52.45**

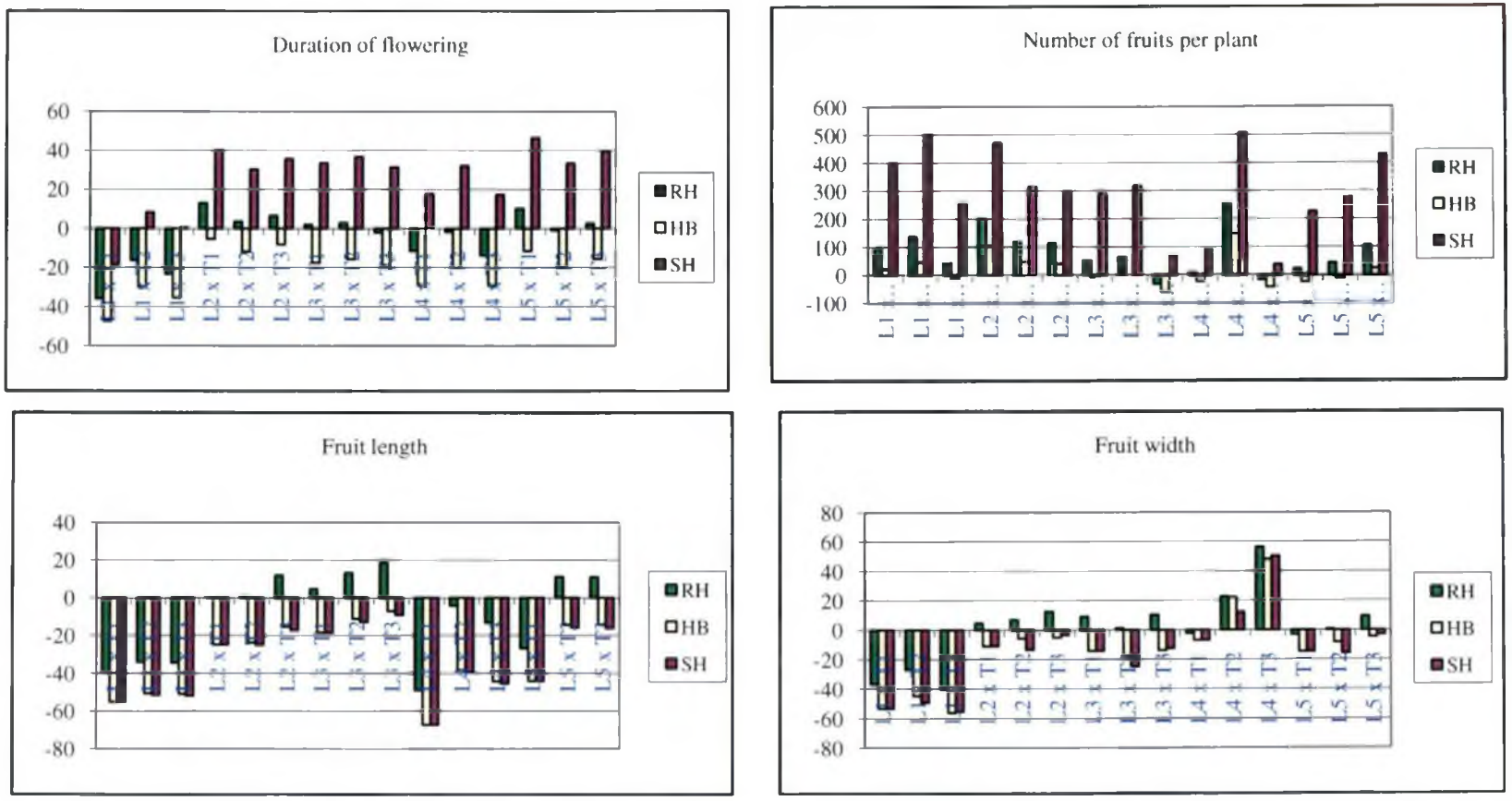
Table 11. Contd...

Sl. No.	Hybrids	Hundred seed weight			Duration of crop		
		RH	HB	SH	RH	HB	SH
1.	$L_1 \times T_1$	-30.00**	-35.63**	-35.63**	-25.85**	-40.25**	-2.30
2.	$L_1 \times T_2$	8.50	3.75	-4.60	-15.76**	-32.14**	10.98**
3.	$L_1 \times T_3$	-10.49*	-12.33*	-26.44**	-17.48**	-33.01**	9.54**
4.	$L_2 \times T_1$	-1.11	-4.30	2.30	1.62	-17.07**	31.20**
5.	$L_2 \times T_2$	0.58	-6.45	0.00	-6.81**	-23.96**	20.29**
6.	$L_2 \times T_3$	5.52	-7.53*	-1.15	0.89	-17.04**	31.25**
7.	$L_3 \times T_1$	-12.10**	-20.69**	-20.69**	-3.79	-23.23**	28.82**
8.	$L_3 \times T_2$	1.33	-5.00	-12.64**	-0.87	-20.91**	32.71**
9.	$L_3 \times T_3$	8.57	8.57	-12.64**	-3.80	-22.67**	29.76**
10.	$L_4 \times T_1$	-13.67**	-20.12**	-20.12**	-12.05**	-29.37**	16.51**
11.	$L_4 \times T_2$	-2.60	-6.25	-13.79**	-1.92	-21.24**	29.91**
12.	$L_4 \times T_3$	31.94**	28.38**	9.20*	-19.11**	-34.55**	7.95*
13.	$L_5 \times T_1$	-24.06**	-29.00**	-18.39**	-2.41	-22.51**	31.78**
14.	$L_5 \times T_2$	-22.22**	-30.00**	-19.54**	-3.81	-23.64**	29.86**
15.	$L_5 \times T_3$	2.35	-13.00**	0.00	-2.26	-21.83**	32.94**



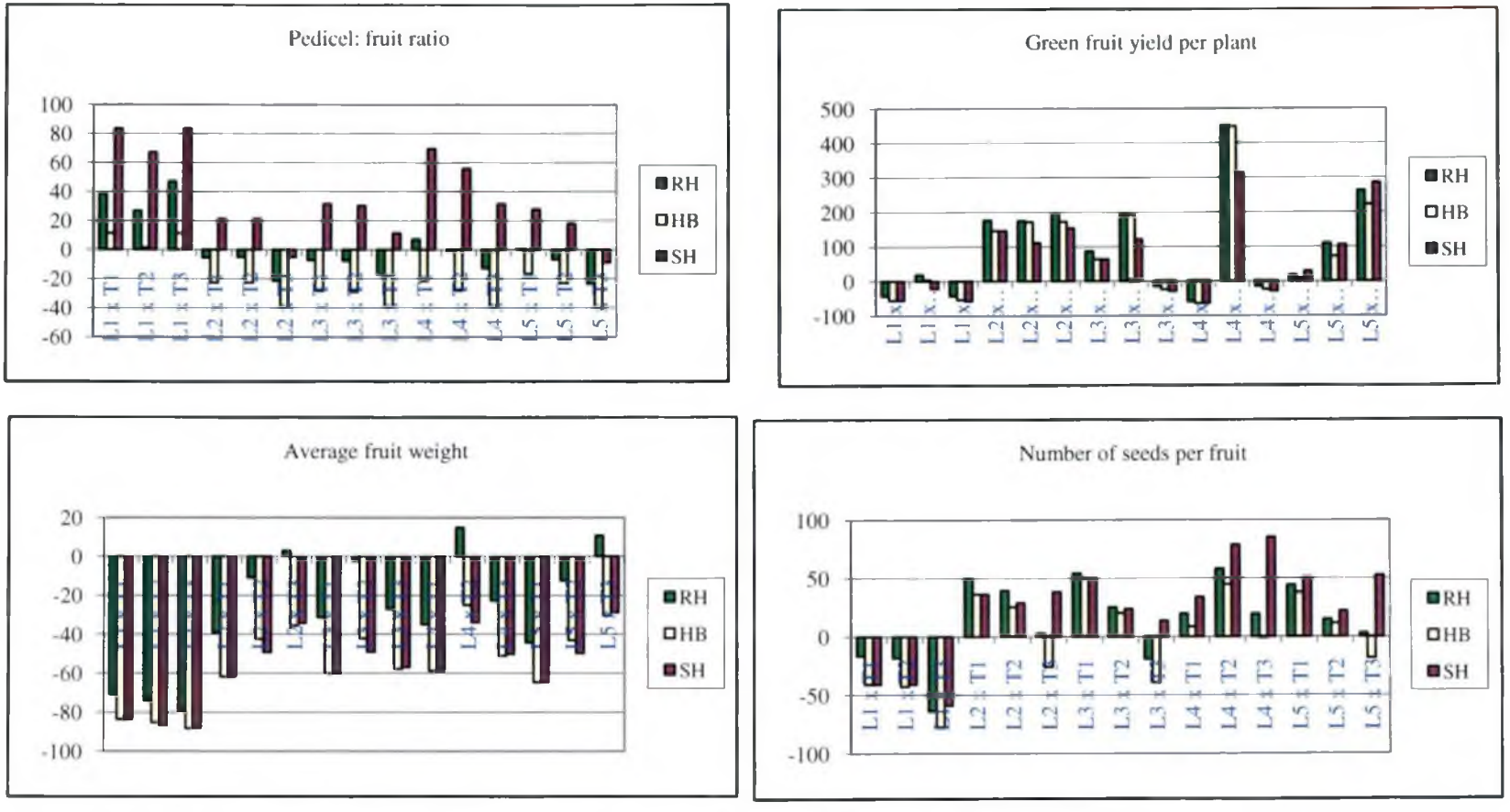
RH-Relative heterosis, HB-Heterobeltiosis, SH-standard heterosis

Fig. 3. Heterosis



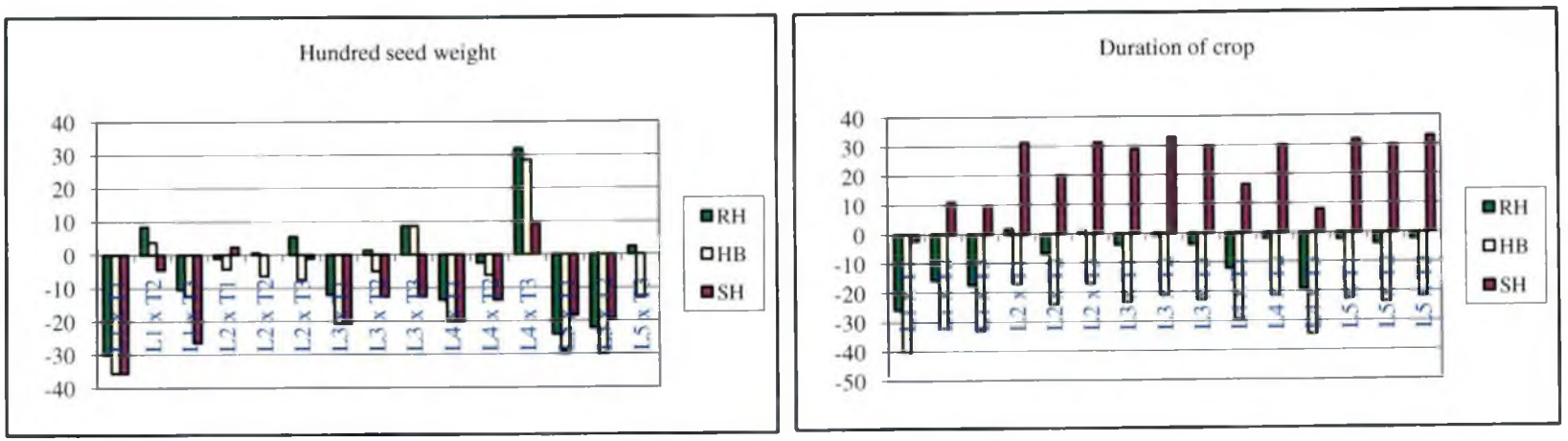
RH-Relative heterosis, HB-Heterobeltiosis, SH-standard heterosis

Fig. 3. Heterosis (continued…)



RH-Relative heterosis, HB-Heterobeltiosis, SH-standard heterosis

Fig. 3. Heterosis (continued…)



RH-Relative heterosis, HB-Heterobeltiosis, SH-standard heterosis

Fig. 3. Heterosis (continued…)

L_1 x T_1 (37.93), L_2 x T_2 (33.79), L_2 x T_1 (33.10) and L_3 x T_1 (32.41).

4.1.7.3 Days to first flowering

Thirteen hybrids exhibited significant negative relative heterosis. They were L_4 x T_3 (-30.41), L_5 x T_1 (-23.40), L_2 x T_2 (-22.72), L_1 x T_2 (-16.98), L_2 x T_1 (-15.25), L_4 x T_1 (-16.74), L_3 x T_1 (-15.39), L_1 x T_1 (-14.10), L_1 x T_3 (-11.44), L_5 x T_3 (-13.23), L_5 x T_2 (-11.97), L_3 x T_2 (-10.38) and L_3 x T_3 (10.29). All the 15 hybrids showed significant negative heterobeltiosis. The range varied between (-27.99) to (-46.31). All the hybrids showed significant positive standard heterosis except three hybrids with only one in desirable negative direction but non significant.

4.1.7.4 Plant spread

Eight hybrids showed positive significant relative heterosis which were L_4 x T_2 (38.58), L_1 x T_3 (38.13), L_5 x T_3 (35.71), L_1 x T_2 (32.89), L_2 x T_3 (29.14), L_5 x T_2 (27.16), L_2 x T_1 (24.94), and L_3 x T_2 (23.14). Significant negative heterobeltiosis was observed in four hybrids. Ten hybrids were found with significant positive standard heterosis *viz.*, L_5 x T_2 (64.97), L_4 x T_2 (60.79), L_2 x T_1 (58.32), L_1 x T_2 (57.40), L_5 x T_1 (53.77), L_5 x T_3 (50.81), L_3 x T_2 (43.78), L_1 x T_3 (37.90), L_2 x T_3 (37.00), and L_2 x T_2 (31.05).

4.1.7.5 Duration of flowering

Five of the hybrids showed negative significant relative heterosis. They were L_1 x T_1 (-36.07), L_1 x T_3 (-23.26), L_1 x T_2 (-16.24), L_4 x T_3 (-13.87) and L_4 x T_1 (-11.51). All hybrids showed significant negative heterobeltiosis except one (L_2 x T_1). The hybrid L_1 x T_1 (-47.43) had the maximum heterobeltiosis value which alone had negative standard heterosis with a value of -18.45 while 12 other hybrids showed positive standard heterosis ranging between 17.34 (L_4 x T_3) and 46.41 (L_5 x T_1).

4.1.7.6 Number of fruits per plant

Significant positive relative heterosis was observed for L_4 x T_2 (254.67), L_2 x T_1 (199.42), L_1 x T_2 (135.95), L_2 x T_2 (118.27), L_2 x T_3 (114.91), L_5 x T_3 (104.43), L_1 x T_1 (94.96), L_3 x T_2 (62.09), L_3 x T_1 (50.26), L_1 x T_3 (43.12) and L_5 x T_2 (42.63). The hybrids L_1 x T_3 (501.72), L_4 x T_2 (148.11), L_2 x T_1 (102.98), L_2 x T_2 (47.02), L_2 x T_3 (40.28), L_5 x T_3 (22.48) and L_1 x T_1 (21.12) exhibited significant positive heterobeltiosis. All the hybrids except L_3 x T_3 and L_4 x T_3 showed significant positive standard heterosis. The highest significant standard heterosis was noticed for hybrid L_4 x T_2 (506.61).

4.1.7.7 Fruit length

Two hybrids, L_3 x T_2 (13.19) and L_5 x T_2 (11.10) exhibited significant positive relative heterosis for fruit length. Thirteen and 11 hybrids possessed significant heterobeltiosis and standard heterosis but in negative direction.

4.1.7.8 Fruit width

The hybrids showing significant positive relative heterosis were L_4 x T_3 (56.24), L_4 x T_2 (22.74), L_2 x T_3 (12.43), L_3 x T_3 (10.30) and L_5 x T_3 (9.21). Positive significant heterobeltiosis and standard heterosis were observed in the hybrids L_4 x T_2 (21.97 and 12.12) and L_4 x T_3 (47.83 and 50.39) respectively.

4.1.7.9 Pedicel - fruit ratio

Four hybrids i.e., L_1 x T_2 (26.92), L_1 x T_1 (38.76) and L_1 x T_3 (47.21) showed positive significant relative heterosis. Two hybrids (L_1 x T_1 and L_1 x T_3) having the same value of 11.54 alone showed positive significant heterobeltiosis. All the hybrids except two had positive standard heterosis. Standard heterosis was positive and significant in 12 hybrids *viz.*, L_5 x T_2 (17.72), L_2 x T_1 (21.52), L_2 x T_2 (21.52), L_5 x T_1 (27.85), L_3 x T_2 (30.38), L_3 x T_1 (31.65), L_4 x T_3 (31.65), L_4 x T_2 (55.70),

L_1 x T_2 (67.09), L_4 x T_1 (69.62), L_1 x T_1 (83.54) and L_1 x T_3 (83.54). None was significant in the negative direction for standard heterosis.

4.1.7.10 Green fruit yield per plant

Relative heterosis was significant and positive for L_4 x T_2 (286.56) L_5 x T_3 (212.21), L_2 x T_3 (103.59), L_3 x T_2 (102.92), L_2 x T_1 (91.99), L_2 x T_2 (81.95), L_5 x T_2 (79.04) and L_3 x T_1 (35.12). Positive significant heterobeltiosis was expressed by L_4 x T_2 (198.68), L_5 x T_3 (150.93), L_2 x T_3 (62.54), L_2 x T_1 (57.49), L_3 x T_2 (55.28), L_2 x T_2 (34.99) and L_5 x T_2 (33.60). Standard heterosis was positive and significant for L_4 x T_2 (313.64), L_5 x T_3 (284.84), L_2 x T_3 (153.74), L_2 x T_1 (145.85), L_3 x T_2 (121.08), L_2 x T_2 (110.73), L_5 x T_2 (104.90) and L_3 x T_1 (63.75). Three hybrids showed negative significant standard heterosis.

4.1.7.11 Average fruit weight

All the hybrids showing significance were negative for all the three type of heterosis. Among the six hybrids that showed non significant relative heterosis only one had positive value.

4.1.7.12 Number of seeds per fruit

Relative heterosis was significant and positive for eight hybrids *viz.*, L_4 x T_2 (57.96), L_3 x T_1 (54.14), L_2 x T_1 (49.86), L_5 x T_1 (43.98), L_2 x T_2 (39.64), L_3 x T_2 (25.16), L_4 x T_1 (19.82) and L_4 x T_3 (19.47). Six hybrids *viz.*, L_3 x T_1 (50.10), L_4 x T_2 (44.81), L_5 x T_1 (37.67), L_2 x T_1 (36.11), L_2 x T_2 (25.24) and L_3 x T_2 (20.23) exhibited positive significant heterobeltiosis. Significant positive standard heterosis was expressed by 11 hybrids [L_4 x T_3 (85.24), L_4 x T_2 (78.70), L_5 x T_3 (52.45), L_5 x T_1 (50.89), L_3 x T_1 (50.10), L_2 x T_3 (38.19), L_2 x T_1 (36.11), L_4 x T_1 (33.84), L_2 x T_2 (28.82), L_3 x T_2 (23.67) and L_5 x T_2 (22.09)].

4.1.7.13 Hundred seed weight

Only one hybrid (L_4 x T_3) with relative heterosis 31.94, heterobeltiosis 28.38 and standard heterosis 9.20 showed positive

significant values. Negative significant values were showed by six hybrids for relative heterosis, seven hybrids for heterobeltiosis and nine for standard heterosis.

4.1.7.14 Duration of crop

Six of the hybrids *viz.*, $L_1 \times T_1$ (-25.85), $L_4 \times T_3$ (-19.11), $L_1 \times T_3$ (-17.48), $L_1 \times T_2$ (-15.76), $L_4 \times T_1$ (-12.05) and $L_2 \times T_2$ (-6.81) showed significant negative relative heterosis. All the hybrids showed significant negative heterobeltiosis. The maximum was given by the hybrid $L_1 \times T_1$ (-40.25) followed by $L_4 \times T_3$ (-34.55), $L_1 \times T_3$ (-33.01), $L_1 \times T_2$ (-32.14), $L_4 \times T_1$ (-29.37), $L_2 \times T_2$ (-23.96), $L_5 \times T_2$ (-23.64), $L_3 \times T_1$ (-23.23), $L_3 \times T_3$ (-22.67), $L_5 \times T_1$ (-22.51), $L_5 \times T_3$ (-21.83), $L_4 \times T_2$ (-21.24), $L_3 \times T_2$ (-20.91), $L_2 \times T_1$ (-17.07) and $L_2 \times T_3$ (-17.04). The standard heterosis was found to be positive and significant for all the hybrids except one ($L_1 \times T_1$) which was negative but not significant.

4.2 GENERATION MEAN ANALYSIS

Generation mean analysis (proposed by Hayman, 1958 and Jinks and Jones, 1958) is based on six different generations of a cross namely parents, their F_1, F_2 and backcrosses ($B_1 = F_1 \times P_1$ and $B_2 = F_1 \times P_2$). This analysis is used for the estimation of genetic components of variation in the presence of epistasis or non-allelic interaction. In the present experiment generation mean analysis was done to estimate the genetic effects i.e., additive, dominance and their three types of interactions additive x additive, additive x dominance and dominance x dominance with respect of 16 different characters in two crosses of chilli using two superior F_1 hybrids Mavelikkara Local (L_4) x Jwalasakhi (T_2) (cross 1) and Nenmara Local (L_5) x Vellayani Athulya (T_3) (cross 2), their respective parents and the backcrosses and F_2 generation. The two superior F_1 hybrids mentioned above were selected from Line x Tester analysis. The identification of

hybrids were based mainly on yield and leaf curl virus resistance score.

The results of generation mean analysis are presented in Table 12.

4.2.1 Plant height

The lowest mean (34.18) was recorded by F_2 and highest mean (48.95) by P_1 in cross 1 while in cross 2 the lowest (31.32) was recorded by B_2 and the highest (42.51) by P_1.

Scale *B* and *C* were significant for both the crosses indicating non allelic interaction while scale *D* was significant for cross 1 only.

Additive effect (*d*) was significant for both the crosses while dominance was significant for only cross 1. Significance of (*i*) and (*j*) indicates the presence of additive x additive and additive x dominance interaction in cross 1 while no significance was observed for any non allelic interaction in cross 2.

4.2.2 Number of branches

In both the crosses, the back cross B_2 (4.02 in cross 1 and 4.91 in cross 2) scored the minimum value while the hybrid F_1 (6.67 in cross 1 and 6.93 in cross 2) scored the maximum value for number of branches.

Scales *B* and *C* showed significance in both the crosses indicating presence of non allelic interaction specifically dominance x dominance and additive x dominance.

Additive effect significant for both the crosses. Among epistatic effects significance was noted in cross 1 for (*j*) and (*l*) indicating additive x dominance and dominance x dominance effects while cross 2 showed no significance for any interactions.

4.2.3 Days to first flowering

In both the crosses, mean values of the days to first flowering was

Table 12 Generation means (±SE), scale values (± SE) and estimates of genetic components (± SE) in two selected crosses of chilli (*Capsicum spp.*)

	Plant height		Number of branches		Days to first flowering		Plant spread		Duration of flowering		Number of fruits/plant	
	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2
Generation means												
P_1	48.95 ±3.51	42.51 ±7.64	6.47 ±0.92	5.20 ±0.78	89.80 ±5.91	85.13 ±9.45	50.68 ±4.60	39.61 ±6.72	134.40 ±8.41	140.40 ±10.74	32.4 ±0.86	53.33 ±1.17
P_2	45.64 ±7.76	33.76 ±5.89	4.73 ±0.88	4.93 ±0.70	55.27 ±3.65	56.47 ±5.30	41.33 ±5.13	18.75 ±3.07	73.60 ±4.27	73.00 ±9.87	19.2 ±0.81	19.00 ±1.28
F_1	47.50 ±6.20	41.85 ±8.97	6.67 ±1.23	6.93 ±1.28	66.93 ±3.65	85.80 ±5.75	48.17 ±5.87	39.67 ±8.53	107.33 ±7.77	98.53 ±7.15	44.27 ±0.90	49.00 ±1.52
F_2	34.18 ±10.42	33.91 ±11.37	4.84 ±1.78	5.27 ±2.16	86.39 ±10.08	90.36 ±11.92	33.65 ±10.33	31.32 ±10.14	101.33 ±42.49	118.43 ±34.01	23.6 ±1.62	26.48 ±1.24
B_1	43.84 ±15.04	40.37 ±13.13	5.93 ±2.27	5.87 ±2.43	93.16 ±10.66	94.91 ±10.76	40.63 ±12.52	36.02 ±7.75	106.67 ±34.58	100.96 ±35.67	45.22 ±3.20	40.91 ±4.56
B_2	35.73 ±12.78	31.32 ±9.43	4.02 ±1.62	4.91 ±1.74	90.00 ±15.12	87.69 ±13.77	34.37 ±11.96	30.02 ±9.12	72.71 ±28.92	82.09 ±33.23	22.644 ±1.83	17.29 ±1.69
Scales												
A	-8.77 ±4.85	-3.62 ±4.96	-1.27 ±0.79	-0.40 ±0.82	29.58** ±3.65	18.89** ±4.29	-17.59** ±4.20	-7.23* ±3.63	-28.40** ±10.724	-37.02** ±11.145	13.78* ±6.51	-20.51* ±9.32
B	-21.68** ±4.59	-12.94** ±3.95	-3.36** ±0.62	-2.04** ±0.64	57.80** ±4.70	33.11** ±4.57	-20.76** ±4.10	1.62 ±3.59	-35.51** ±8.92	-7.36 ±10.40	-18.18** ±3.85	-33.42** ±3.92
C	-52.85** ±5.86	-24.33** ±7.11	-5.16** ±1.04	-2.93* ±1.16	66.62** ±4.98	48.22** ±6.47	-53.76** ±5.60	-12.40 ±6.43	-17.33 ±18.52	63.27** ±15.28	-45.73** ±6.81	-64.42** ±6.05
D	-11.20** ±3.67	-3.87 ±3.40	-0.27 ±0.56	-0.24 ±0.64	-10.38** ±3.48	-1.89 ±3.62	-7.70* ±3.38	-3.39 ±2.78	23.29* ±11.20	53.82** ±10.21	-20.67** ±4.9	-5.24 ±5.46
Genetic components												
m	34.18** ±1.10	33.91** ±1.20	4.84** ±0.19	5.27** ±0.23	86.39** ±1.06	90.36** ±1.26	33.65** ±1.09	31.32** ±1.07	101.33** ±4.48	118.43** ±3.58	23.60** ±1.62	26.48** ±1.24
d	8.11** ±2.94	9.05** ±2.41	1.91** ±0.42	0.96* ±0.45	3.16 ±2.76	7.22** ±2.60	6.26* ±2.58	6.00** ±1.78	33.96** ±6.72	18.87* ±7.27	67.87** ±3.68	58.20** ±4.86
h	22.61** ±7.60	11.46 ±7.29	1.60 ±1.18	2.35 ±1.32	15.16* ±7.08	18.78* ±7.52	17.57* ±6.98	17.27** ±6.06	-43.24 ±22.52	-115.81** ±20.59	706.23** ±9.86	723.53** ±8.47
i	22.40** ±7.34	7.74 ±6.80	0.53 ±1.12	0.49 ±1.27	20.76** ±6.96	3.78 ±7.24	15.41* ±6.75	6.78 ±5.57	-46.58* ±22.40	-107.64** ±20.42	41.33** ±9.80	10.49 ±10.91
j	6.45* ±3.14	4.67 ±2.71	1.04* ±0.45	0.82 ±0.47	-14.11** ±2.90	-7.11* ±2.96	1.59 ±2.73	-4.42* ±2.02	3.56 ±6.83	-14.83* ±7.51	15.98** ±3.73	6.46 ±4.94
l	8.05 ±13.15	8.84 ±11.98	4.09* ±1.96	1.96 ±2.12	-108.13** ±12.10	-55.78** ±12.26	22.94 ±11.74	-1.17 ±9.60	110.49** ±32.64	152.02** ±32.84	-36.93* ±16.23	43.44* ±20.38

Table 12. Contd

	Fruit length		Fruit width		Pedicel - fruit ratio		Green fruit yield per plant		Average fruit weight		Number of seeds per fruit	
	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2
Generation means												
P_1	3.49 ±0.28	11.16 ±0.60	1.43 ±0.14	1.36 ±0.10	0.50 ±0.03	0.27 ±0.02	51.49 ±2.78	92.45 ±1.51	1.57 ±0.21	1.73 ±0.17	59.93 ±3.52	56.47 ±4.26
P_2	6.31 ±0.28	13.30 ±1.08	1.49 ±0.10	1.82 ±0.15	0.46 ±0.03	0.56 ±0.83	105.68 ±5.53	114.17 ±8.55	5.52 ±0.48	5.86 ±0.36	52.07 ±2.37	87.53 ±13.26
F_1	6.89 ±0.48	10.09 ±0.49	1.86 ±0.11	1.69 ±0.12	0.42 ±0.03	0.89 ±1.09	178.49 ±5.39	225.19 ±6.48	4.11 ±0.34	4.61 ±0.31	72.93 ±7.12	80.33 ±9.15
F_2	5.37 ±1.08	5.18 ±1.41	1.64 ±0.30	1.57 ±0.32	0.43 ±0.10	0.29 ±0.06	94.63 ±5.32	113.11 ±4.78	3.78 ±1.13	3.88 ±1.06	47.44 ±11.39	46.46 ±13.89
B_1	4.45 ±0.95	6.17 ±1.17	1.59 ±0.31	1.69 ±0.24	0.46 ±0.10	0.31 ±0.05	111.43 ±5.68	118.16 ±5.75	2.68 ±0.75	3.00 ±0.84	43.29 ±14.01	44.93 ±16.49
B_2	4.36 ±1.03	7.58 ±2.07	1.43 ±0.33	1.38 ±0.24	0.39 ±0.07	0.28 ±0.08	109.63 ±6.87	88.86 ±6.22	4.59 ±0.88	4.59 ±0.94	53.49 ±15.84	47.18 ±17.34
Scales												
A	-1.47** ±0.32	-8.91** ±0.40	-0.12 ±0.10	0.33** ±0.08	-0.01 ±0.03	-0.54 ±0.28	-7.12 ±12.87	-81.32** ±13.29	-0.32 ±0.25	-0.33 ±0.27	-46.29** ±4.65	-46.93** ±5.56
B	-4.48** ±0.34	-8.24** ±0.69	-0.49** ±0.11	-0.76** ±0.09	-0.11** ±0.02	-0.88* ±0.36	-64.91** ±15.76	-161.65** ±16.42	-0.45 ±0.30	-1.29** ±0.31	-18.02** ±5.10	-73.51** ±6.64
C	-2.08** ±0.53	-23.91** ±0.72	-0.10 ±0.14	-0.28 ±0.15	-0.09* ±0.04	-1.45* ±0.60	-135.63** ±24.65	-204.57** ±24.69	-0.19 ±0.53	-1.31** ±0.49	-68.09** ±6.14	-118.84** ±8.34
D	1.93** ±0.31	-3.38** ±0.46	0.26** ±0.09	0.08 ±0.08	0.02 ±0.03	-0.02 ±0.02	-31.80* ±13.88	19.20 ±12.78	0.29 ±0.30	0.16 ±0.29	-1.89 ±3.96	0.80 ±4.61
Genetic components												
m	5.37** ±0.11	5.18** ±0.15	1.64** ±0.03	1.57** ±0.03	0.43** ±0.01	0.29** ±0.01	94.63** ±5.32	113.11** ±4.78	3.78** ±0.12	3.88** ±0.11	47.44** ±1.20	46.46** ±1.46
d	0.09** ±0.21	-1.41** ±0.35	0.16* ±0.07	0.32** ±0.05	0.07** ±0.02	0.03 ±0.01	221.06** ±8.91	207.02** ±8.47	-1.91** ±0.17	-1.58** ±0.19	-10.20** ±3.15	-2.25 ±3.57
h	-1.88** ±0.63	4.63** ±0.95	-0.11 ±0.19	-0.05 ±0.17	-0.09 ±0.06	0.51 ±0.30	2616.03** ±28.45	2914.68** ±26.71	-0.02 ±0.60	0.49 ±0.59	20.71* ±8.15	6.73 ±9.69
i	-3.87** ±0.62	6.77** ±0.92	-0.51** ±0.18	-0.15 ±0.17	-0.03 ±0.05	0.04 ±0.04	63.60* ±27.76	-38.39 ±25.55	-0.58 ±0.59	-0.32 ±0.58	3.78 ±7.92	-1.60 ±9.23
j	1.50** ±0.22	-0.33 ±0.39	0.18** ±0.07	0.55** ±0.06	0.05** ±0.02	0.17 ±0.11	28.89** ±9.43	40.17** ±9.51	0.07 ±0.19	0.48* ±0.19	-14.13** ±3.20	13.29** ±3.99
l	9.81** ±0.99	10.38** ±1.59	1.12** ±0.31	0.58* ±0.25	0.15 ±0.09	1.38* ±0.61	8.43 ±43.34	281.35** ±41.91	1.35 ±0.87	1.93* ±0.89	60.53** ±14.03	122.04** ±16.52

Table 12. Contd

	Hundred seed weight		Duration of crop		Oleoresin content		Capsaicin content		Vector population		Leaf curl virus score on 45 days	
	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2	Cross1	Cross2
Generation means												
P_1	0.50 ±0.02	0.63 ±0.06	224.13 ±6.83	225.53 ±4.58	6.22 ±0.14	6.54 ±0.12	0.54 ±0.02	0.53 ±0.01	1.28 ±0.37	1.32 ±0.30	5.25** ±5.07	12.36** ±4.72
P_2	0.53 ±0.02	0.47 ±0.05	128.87 ±3.48	129.47 ±7.84	5.22 ±0.07	4.65 ±0.08	0.40 ±0.01	0.35 ±0.02	2.13 ±0.18	2.32 ±0.29	45.81** ±8.20	48.39** ±11.61
F_1	0.52 ±0.03	0.57 ±0.03	173.47 ±5.89	184.33 ±7.16	6.30 ±0.06	8.45 ±0.13	0.69 ±0.01	0.71 ±0.01	1.78 ±0.20	1.66 ±0.21	18.43** ±5.60	30.05** ±4.80
F_2	0.52 ±0.14	1.10 ±5.43	187.71 ±44.26	208.73 ±34.28	9.61 ±0.22	9.79 ±0.27	0.47 ±0.02	0.37 ±0.02	1.99 ±0.46	1.74 ±0.33	40.76** ±20.94	32.21** ±12.70
B_1	0.50 ±0.09	0.60 ±0.07	199.82 ±35.65	195.96 ±39.46	8.71 ±0.29	9.45 ±0.38	0.33 ±0.02	0.28 ±0.03	1.51 ±0.39	1.60 ±0.43	22.36** ±13.53	28.04** ±15.33
B_2	0.52 ±0.08	0.49 ±0.09	162.80 ±37.00	169.33 ±38.84	9.51 ±0.32	8.51 ±0.25	0.18 ±0.02	0.20 ±0.02	2.02 ±0.47	2.10 ±0.36	40.94** ±18.86	41.31** ±12.25
Scales												
A	-0.03 ±0.03	-0.01 ±0.03	2.04 ±10.88	-17.96 ±11.97	4.91** ±0.60	3.90** ±0.78	-0.58** ±0.05	-0.68** ±0.06	-0.04 ±0.16	0.21 ±0.16	21.05** ±4.48	13.66** ±4.89
B	-0.01 ±0.03	-0.07* ±0.03	23.27* ±11.17	24.87* ±11.90	7.51** ±0.64	3.90** ±0.52	-0.73** v0.03	-0.65** ±0.04	0.13 ±0.16	0.22 ±0.14	17.63** ±6.18	4.18** ±4.89
C	-0.01 ±0.06	2.16 ±2.29	50.91** ±19.01	111.27** ±15.10	14.38** ±0.91	11.07** ±1.14	-0.45** ±0.09	-0.80** ±0.10	0.97** ±0.24	-0.02 ±0.21	75.10** ±9.62	7.99** ±6.73
D	0.01 ±0.03	1.12 ±1.14	12.80 ±12.07	52.18** ±10.97	0.99 ±0.62	1.63* ±0.71	0.43** ±0.05	0.27** ±0.06	0.44** ±0.13	-0.22* ±0.11	18.21** ±5.61	-4.93** ±3.97
Genetic components												
m	0.52** ±0.01	1.10 ±0.57	187.71** ±4.67	208.73** ±3.61	9.61** ±0.22	9.79** ±0.27	0.47** ±0.02	0.37** ±0.02	1.99** ±0.05	1.74** ±0.03	40.76** ±18.46	32.21** ±24.06
d	-0.02 ±0.02	0.11** ±0.02	37.02** ±7.66	26.62** ±8.25	-0.80 ±0.43	0.94* ±0.45	0.15** ±0.03	0.08* ±0.04	-0.51** ±0.09	-0.50** ±0.08	-18.58** ±-5.37	-13.27** ±-4.54
h	-0.02 ±0.07	-2.20 ±2.29	-28.63 ±24.21	-97.52** ±22.05	-1.40 ±1.24	-0.40 ±1.43	-0.63** ±0.10	-0.27* ±0.12	-0.81** ±0.27	0.29 ±0.23	-43.52** ±-3.82	9.53 ±1.16
i	-0.03 ±0.07	-2.23 ±2.29	-25.60 ±24.15	104.36** ±21.94	-1.97 ±1.23	-3.26* ±1.42	-0.85** ±0.10	-0.54** ±0.12	-0.89** ±0.26	0.45* ±0.22	-36.42** ±11.22	9.86** ±7.93
j	-0.01 ±0.02	0.03 ±0.02	-10.61 ±7.72	-21.41* ±8.34	-1.30** ±0.44	0.00 ±0.46	0.08** ±0.03	-0.01 ±0.04	-0.09 ±0.11	-0.00 ±0.10	1.71** ±3.68	4.74** ±3.34
l	0.06 ±0.09	2.30 ±2.29	0.29 ±36.06	97.44** ±36.31	-10.44** ±1.94	-4.55* ±2.14	2.15** ±0.14	1.87** ±0.18	0.80 ±0.44	-0.88* ±0.39	-2.27** ±16.85	-27.70** ±13.50

the lowest for P_2 (55.27 in cross 1 and 56.47 in cross 2) and the highest for B_1 (93.16 in cross 1 and 94.91 in cross 2).

Significance was noted for all scales in cross 1 and all except *D* in cross 2.

Dominance effects were significant in both the crosses while additive was significant only in cross 2. Among the non allelic interactions significance of (*i*), (*j*) and (*l*) was noted in cross 1 and (*j*) and (*l*) alone in cross 2.

The significance of scales and genetic components significance indicate the presence of all the three types of interactions (additive x additive, additive x dominance, and dominance x dominance) in cross 1 and all excepting additive x additive in cross 2.

4.2.4 Plant spread

Among the generations, the means varied from 33.65 (F_2) to 50.68 (P_1) in cross 1and from 18.75 to 39.67 for P_2 and F_1 in cross 2.

Significance of all the scales was observed in cross 1 but only scale *A* was significant in cross 2. This indicates presence of non allelic interaction.

Significance of dominance and additive interaction were found on both the crosses while significance of (*i*) additive x additive interaction was noted in cross 1 and that of (*j*) additive x dominance was noted in cross 2.

4.2.5 Duration of flowering

Minimum duration of flowering was recorded in B_2 (72.71) in cross 1 and P_2 (73.60) in cross 2 while maximum was observed in P_1 (134.40 for cross 1 and 140.40 for cross 2) in both the crosses.

Significance was observed for the scales *A*, *B* and *D* in cross 1 while for *A*, *C* and *D* in cross 2 both indicating presence of non allelic

interactions.

Significance of (*d*), (*i*) and (*l*) was noted for cross 1 while dominance, additive and all the three non allelic (additive x additive, additive x dominance, and dominance x dominance) interactions were significant in cross 2.

4.2.6 Number of fruits per plant

Maximum value for number of fruits was observed in B_1 (45.22) in cross 1 and P_1 (53.33) in cross 2. It was minimum for P_2 (19.2 in cross 1 and 19 in cross 2) in both the crosses.

All the scales and genetic components (both allelic and non allelic) were significant in cross 1 but in cross 2 all scales except *D* was non significant indicating absence of additive effect alone. Cross 2 showed significance only for (*d*), (*h*) and (*l*) indicating presence of additive, dominance and dominance x dominance interaction alone.

4.2.7 Fruit length

The maximum value (6.89) was observed for F_1 and the minimum value (3.49) was for P_1 in cross 1 while the maximum value (13.30) was observed for P_2 and the minimum value (5.18) was for F_2 in cross 2.

Significance of all the scales was observed in both the crosses indicating the presence of all non allelic interactions.

Significance of all the effects (*d, h, i, j* and *l*) were observed in cross 1 proving the presence of both additive and dominance with all three types of interactions while in cross 2 all except (*j*) were significant showing additive x additive and dominance x dominance interaction along with dominance and additive effects.

4.2.8 Fruit width

Among the generations the minimum value (1.43) was recorded by P_1 and B_2 in cross 1 and (1.36) by P_1 in cross 2. The maximum value was

given by F_1 (1.86) in cross 1 and P_2 (1.82) cross 2.

Scales *B* and *D* were significant in cross 1 while *A* and *B* were significant in cross 2.

Significance of additive effects (*d*) and absence of dominance effects (*h*) was found in both the crosses. All the three non allelic (additive x additive (*i*), additive x dominance (*j*), and dominance x dominance (*l*) genetic components were significant in cross 1 and only (*j*) and (*l*) were significant in cross 2.

4.2.9 Pedicel - fruit ratio

P_1 exhibited the maximum value (0.50) in cross 1 while F_1 was with maximum value (0.89) in cross 2. Minimum value was expressed by B_2 and P_1 in crosses 1 and 2 respectively.

Significance of *B* and *C* was noted in both the crosses indicating presence of non allelic interaction especially dominance x dominance type.

In cross 2 (*l*) was significant supporting the above while in cross 1 (*j*) was significant indicating additive x dominance interaction along with additive effect *d*.

4.2.10 Green fruit yield per plant

P_1 recorded the lowest yield in cross 1 (51.49) and B_2 (88.86) in cross 2 and the hybrid F_1 recorded the highest yield (178.49 for cross 1 and 225.19 for cross 2).

B, *C* and *D* were the scales significant in cross 1 while *A*, *B* and *C* was significant in cross 2.

Genetic components (*d*), (*h*) and (*j*) were significant in both the crosses while (*i*) also was significant in cross 1 and (*l*) in cross 2. Thus the presence of additive, dominance and non allelic interactions were observed in both the crosses for the trait.

Significance was observed only in scale *B* and additive effects (*d*) of cross 2. In cross 1 no significance was observed for scales and genetic components.

4.2.14 Duration of crop

In both the crosses, the minimum values for duration of crop was observed in P_2 (128.87 in cross 1 and 129.47 in cross 2). Maximum values were exhibited by P_1 (224.13 in cross 1 and 225.53 in cross 2).

Scales *B* and *C* were significant in both the crosses while *D* was significant in cross 2 alone.

None of the genetic components except additive (*d*) was significant in cross 1 while all the allelic effects and non allelic (dominance, additive, additive x additive, additive x dominance, and dominance x dominance) interactions were significant in cross 2.

4.2.15 Capsaicin content

High capsaicin content (0.69 for cross 1 and 0.71 for cross 2) was observed in F_1 and low content (0.18 for cross 1 and 0.20 for cross 2) for B_2 in both the crosses.

Significance of all the scales was observed in both the crosses indicating presence of additive, dominance type and non allelic interaction.

Dominance (*h*) and additive (*d*) effects were significant in both the crosses. In cross 1 all the non allelic interactions were significant while in cross 2 additive x dominance was not significant.

4.2.16 Oleoresin content

Minimum oleoresin content was recorded by P_2 in cross 1 (5.22) and in cross 2 (4.65). The maximum value was given by F_2 (9.61) in cross 1 and (9.79) in cross 2.

A, *B* and *C* were the scales significant in cross 1 while all the scales

showed significance in cross 2. This suggests the presence of non allelic interaction in both crosses with greater dominance effect in cross 2 and both additive and dominance effects in cross 1.

The genetic components additive x dominance (*j*) and dominance x dominance (*l*) were significant in cross 1 while additive (*d*), additive x additive (*i*) and dominance x dominance (*l*) were significant in cross 2.

4.2.17 Vector population

Lowest count was recorded by P_1 (1.28 for cross 1 and 1.32 for cross 2) and highest by P_2 (2.13 for cross 1 and 2.32 for cross 2).

Scales *C* and *D* were significant in cross 1 while scale *D* alone in cross 2. The genetic component, dominance was significant in cross 1 and dominance x dominance in cross 2 while additive and additive x additive effects were significant in both the crosses.

4.2.18 Leaf curl score on 45 days

Minimum score was found in P_1 (5.25 for cross 1 and 12.36 for cross 2) and maximum score was in P_2 (45.81 for cross 1 and 48.39 for cross 2) for both the crosses.

All the four scales were significant in both the crosses indicating the presence of non allelic interaction. All the genetic components (dominance, additive, additive x additive, additive x dominance, and dominance x dominance) were significant in cross 1 while dominance alone was insignificant in cross 2.

4.3 TRANSGRESSIVE SEGREGANTS

Transgressive segregants observed for the characters in both the crosses L_4 x T_2 (cross 1) and L_5 x T_3 (cross 2) are presented in Table 13. In both the crosses oleoresin content (96.67% in cross 1 and 86.67% in cross 2) exhibited the maximum number of transgressive segregants

Table 13. Transgressive segregants in two crosses of chilli

Sl.No.	Characters	Transgressive segregants	
		Cross 1	Cross 2
1	Plant height	0.00	3.33
2	Number of branches	6.67	14.44
3	Days to first flowering	0.00	0.00
4	Plant spread	0.00	2.22
5	Duration of flowering	38.89	11.11
6	Number of fruits per plant	12.22	0.00
7	Fruit length	7.78	0.00
8	Fruit width	37.78	8.89
9	Pedicel: fruit ratio	40.00	0.00
10	Green fruit yield per plant	11.11	7.78
11	Average fruit weight	0.00	1.11
12	Number of seeds per fruit	5.56	0.00
13	Hundred seed weight	41.11	6.67
14	Duration of crop	0.00	0.00
15	Capsaicin content	18.89	16.67
16	Oleoresin content	96.67	86.67
17	Vector population	0.00	0.00
18	Leaf curl score on 45 days	0.00	0.00

followed by hundred seed weight (41.11%) in cross 1 and capsaicin content (16.67%) in cross 2.

Discussion

5. DISCUSSION

Chilli an important commercial crop of India grown for its green and red fruits is an indispensable food adjunct. It is liked for its pungent component capsaicin and the oleosresin present in it and is widely used in processed food and pharmaceuticals. One of the major constraints in the crop is the disease caused by leaf curl virus transmitted by white fly (*Bemisia tabaci*). Considering these aspects an attempt was made with the objective to assess the magnitude of heterosis, combining ability, inheritance of leaf curl virus resistance and other desirable economic traits for formulating a programme to develop high yielding resistant varieties. Results obtained in the present study are discussed below.

5.1 VARIABILITY STUDIES

As the observed variability is the sum of genotypic and environmental effects, knowledge on the nature and magnitude of genetic variation contributing to gain under selection is of utmost importance. In the present study highly significant variations among the treatments was obtained for all the 16 characters studied. Similar results were reported by Nayeema *et al.* (1998) and Prasath *et al* (2007).

Green fruit yield recorded very high phenotypic and genotypic coefficient of variation. Several reports are available for yield as analyzing divergent genotypes and exerting selection for the economically important character, yield is the primary objective of any study. Few of the recent reports with high GCV for yield were reported by Rathod *et al.*, (2002), Sreelathakumary and Rajamony (2002), Nandadevi and Hosamani (2003a), Prabhakaran *et al.* (2004), Varkey *et al.* (2005) and Prasath *et al* (2007) and with high PCV for yield was reported by Devi and Arumugam (1999), Sreelathakumary and Rajamony (2002), Nandadevi and Hosamani (2003a) and Varkey *et al.* (2005).

Genetic component was predominant and the environmental effect in the phenotype was negligible as PCV and GCV values were closer for all the characters.

Days to first flowering, pedicel - fruit ratio, duration of flowering, duration of crop, number of fruits per plant, green fruit yield per plant, number of seeds per fruit and vulnerability index had high heritability coupled with high genetic advance. Similar results were reported by Singh and Singh (1977), Rathod *et al.* (2002) and Sreelathakumary and Rajamony (2002) for number of fruits per plant and yield.

Bavaji and Murthy (1982), Shah *et al.* (1986), Singh *et al.* (1994), Devi and Arumugam (1999) and Tembhurne *et al.* (2008) reported similarly for number of fruits per plant while Das *et al.*, (1989), Nayeema *et al.* (1998), Acharyya *et al.* (2002), Nandadevi and Hosamani (2003a) and Prabhakaran *et al.* (2004) for yield. The results of Bendale *et al.* (2006) corroborate the present study for the traits yield per plant, seeds per fruit and fruits per plant.

Reports of Varalakshmi and Babu (1991), Pitchaimuthu and Pappiah (1995) and Varkey *et al.* (2005) support the results of having high heritability with high GA for number of fruits per plant and number of seeds per fruit while the findings of Ukkund *et al.* (2007) supported the results for days to first flowering, number of fruits per plant and total green fruits per plant.

5.2 LINE x TESTER ANALYSIS

Five leaf curl virus resistant lines identified in a previous study (Khader *et al.* 2007) and three high yielding varieties (Plate 2 and 3) along with their 15 hybrids were evaluated to select the parents and hybrids based on their mean performance, *gca*, *sca* and heterosis estimates for development of hybrids. The results are discussed under two broad categories *viz.*,

i) Evaluation and selection of parents

ii) Evaluation and selection of hybrids

PLATE 2. LINES

MANGALAPURAM LOCAL

THAVANUR LOCAL

KAYAMKULAM LOCAL

MAVELIKKARA LOCAL

NENMARA LOCAL

PLATE 3. TESTERS

JWALAMUKHI

JWALASAKHI I

VELLAYANI ATHULYA

5.2.1 Evaluation and selection of parents

Inbreds usually differ in genetic prepotency and thereby vary in their relative contribution of the concerned trait. This emphasizes that choice of parents should be based on their *per se* performance along with general combining ability estimates (Yadav and Murthy, 1966). Hence combining ability analysis was conducted to understand the performance of inbreds regarding the yield components and leaf curl virus resistance which will help to determine the appropriate parents and crosses for the investigated traits.

5.2.1.1 Per se performance of parents

All the lines showed negligible leaf curl virus disease reaction (Table 4). Mavelikkara Local was superior among the five lines tested for days to first flowering, plant spread, number of branches, average fruit weight, fruit width and number of seeds per fruit. Likewise, Nenmara Local had best *per se* performance for green fruit yield per plant, number of fruits per plant, pedicel - fruit ratio and hundred seed weight. Thavanur Local and Kayamkulam Local were having noteworthy performance with respect to two traits (duration of flowering and duration of crop for Thavanur Local and plant height and fruit length for Kayamkulam Local) while Mangalapuram Local was not superior for any traits.

Among the testers Jwalamukhi was found to be superior with respect to green fruit yield per plant, number of fruits per plant, duration of flowering, plant spread, fruit length, and hundred seed weight. Jwalasakhi showed superiority for the traits *viz.*, days to first flowering, plant height, number of branches and duration of crop while Vellayani Athulya exhibited superiority for number of seeds per fruit, pedicel - fruit ratio, average fruit weight and fruit width. All the testers showed fairly high leaf curl virus disease reaction (vulnerability index).

5.2.1.2 General combining ability effects of parents

The identification of parents that could produce better combination of economically important traits is the prime requirement to exploit their heterosis in hybrid combinations.

Besides having significant general combining ability for green fruit yield Nenmara Local showed significant *gca* effect for plant spread, average fruit weight, duration of flowering, duration of crop and number of seeds per fruit (Table 7). Mavelikkara Local displayed desirable significant *gca* effect for number of branches, average fruit weight, fruit width, pedicel - fruit ratio and number of seeds per fruit. High *gca* effect for fruit yield was reported by Lohithaswa *et al.* (2000), Ajith (2004) and Muthuswamy (2004)

Mangalapuram Local (L_1) exhibited significant *gca* effects for plant height, duration of flowering, duration of crop and number of fruits per plant in desirable direction. However, it was having negative *gca* effects for yield. Thavanur Local (L_2) exhibited significant *gca* effects for fruit length, pedicel - fruit ratio, green fruit yield per plant and hundred seed weight. The line Kayamkulam (L_3) was having significant *gca* effect in desirable direction for fruit length only.

All the testers were on par with respect to green fruit yield. Among testers Jwalasakhi (T_2) expressed significant *gca* for green fruit yield, number of fruits per plant and plant spread and Vellayani Athulya (T_3) for pedicel - fruit ratio and hundred seed weight. Jwalamukhi (T_1) had negative significant *gca* for important characters like fruit yield, fruit length and fruit width.

None of the testers showed significant *gca* in positive direction for fruit length, number of seeds per fruit, number of branches, plant height, duration of flowering, days to first flowering and duration of crop. This may be because the hybrids expressed the indeterminate nature of *Capsicum frutescens* which resulted in increased duration and plant height. Again the fruit length is too less for the *C. frutescens* parents which were having significant *gca* effects.

5.2.1.3 Choice of superior parents

Considering the overall performance and *gca* effects together the lines Mavelikkara Local and Nenmara Local were selected for having desirable *gca* effects along with *per se* performance in one or other economic traits. Among the testers only Jwalamukhi was having undesirable *gca* effect. Hence the other two testers were selected though they had significant *gca* effects only for few traits.

5.2.2 Evaluation and selection of hybrids

For exploiting heterosis, identification of superior cross combinations based on *sca* effects is of prime importance. Study of heterotic values should be given due weightage as hybrids with high *sca* effects may posses low heterosis estimate and hybrids with low *sca* effects and high heterosis may also be found. Hence consideration of mean performance, *sca* effect and standard heterosis become necessary for choice of appropriate and desirable crosses.

5.2.2.1 *Per se* performance of hybrids

Among the hybrids, Mavelikkara Local x Jwalasakhi recorded the highest yield and was on par with Nenmara Local x Vellayani Athulya (Table 4). Mavelikkara Local x Jwalasakhi also showed good performance for plant spread, number of branches, average fruit weight, number of fruits per plant, number of seeds per fruit and vulnerability index.

Nenmara Local x Vellayani Athulya exhibited good performance for plant spread, number of branches, average fruit weight, fruit length, pedicel - fruit ratio, number of fruits per plant, hundred seed weight and vulnerability index.

Mavelikkara Local x Vellayani Athulya and Thavanur Local x Jwalasakhi were the hybrids with good performance for days to first flowering. Mavelikkara Local x Vellayani Athulya was with good performance for plant height also. Mangalapuram Local x Jwalamukhi showed superiority for the traits duration of flowering and duration of crop.

PLATE 4. SUPERIOR HYBRIDS

MAVELIKKARA LOCAL X JWALASAKHI

NENMARA LOCAL X VELLAYANI ATHULYA

Based on *per se* performance Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya could be selected for crop improvement programme.

5.2.2.2 Heterosis

Heterosis breeding makes use of the hybrid vigour in the crosses for attaining noticeable increase in production and productivity of crop plants. Existence of significant amount of dominance variance is essential for undertaking heterosis breeding programme. Even, the expression of small magnitude of heterosis for certain characters may be much rewarding in breeding.

In the present study, the relative heterosis, heterobeltiosis and standard heterosis were estimated for the 15 crosses with respect to the different characters.

Negative heterobeltiosis and relative heterosis indicating earliness was observed for days to first flowering, duration of flowering and duration of crop for most of the hybrids. The maximum significant value in the desirable direction was recorded by L_4 x T_3 for days to first flowering and L_1 x T_1 for duration of flowering and duration of crop. Significant negative heterosis for crop duration was reported by Ajith (2004).

Positive heterosis indicates the superiority of the hybrid for remaining characters viz., plant height, number of branches, plant spread, number of fruits per plant, fruit length, fruit width, average fruit weight, green fruit yield, number of seeds and hundred seed weight.

High magnitude of all three types of heterosis for green fruit yield was recorded by L_4 x T_2 followed by L_5 x T_3. This was conformity with the reports of Singh and Hundal (2001b), Adpawar *et al.* (2006) and Kamble and Mulge (2008b).

Significant positive standard heterosis was exhibited by all the hybrids for number of branches. The hybrid L_4 x T_1 exhibited the maximum. The positive

significance was found for relative heterosis and heterobeltiosis for majority of the hybrids and the maximum was given by L_2 x T_3. The reports of Mishra *et al.* (1977) and Gopalakrishnan *et al.* (1987b) support the present findings.

L_1 x T_3 exhibited highly significant standard and relative heterosis for plant height but heterosis over better parent was not significant. Only L_4 x T_2 showed positive significance for heterobeltiosis. This was in agreement with the reports of Muthuvel (2003).

L_5 x T_2 had highest magnitude of positive heterosis over mid and standard parent for plant spread while none showed positive significant heterobeltiosis. Shankarnag *et al.* (2006) and Satish and Lad (2007) reported similarly for standard heterosis while Nair *et al.* (1986) reported for relative heterosis.

Positive significance was observed in majority of the hybrids for number of fruits per plant. The hybrid L_4 x T_2 had high significant positive values for relative and standard heterosis while it was next to L_1 x T_3 in heterobeltiosis. These findings corroborate with Prasad (1999), Lohithaswa *et al.* (2000), Kumar and Lal (2001), Phillip (2004) and Shankarnag *et al.* (2006).

Positive heterosis was observed for number of seeds per plant. The maximum was given by the hybrid L_4 x T_2 for relative heterosis and by L_3 x T_1 and L_4 x T_3 for better and standard parent respectively followed by L_4 x T_2. The studies of Gaddagimath (1992), Lohithaswa (1997), Patil (1997) and Kumar and Lal (2001) corroborate the present findings.

High positive heterosis for fruit width was observed with all the three types of heterosis with L_4 x T_3. Similar reports were given by Gaddagimath (1992) and Prasad (1999).

Standard heterosis of hybrids

The variety Jwalamukhi was taken as standard variety for evaluating heterosis. Eight of the 15 hybrids exhibited significant positive standard heterosis for yield. Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya were the hybrids that showed maximum standard heterosis for yield.

They also expressed significant positive standard heterosis for number of fruits per plant, number of seeds per fruit, plant spread, number of branches and average fruit weight. Mavelikkara Local x Jwalasakhi and Mavelikkara Local x Vellayani Athulya showed positive significance for fruit width.

Mavelikkara Local x Vellayani Athulya alone exhibited significant standard heterosis for hundred seed weight while Mangalapuram Local x Jwalamukhi for duration of flowering.

Significant standard heterosis in desirable direction was not observed for the traits days to first flowering, fruit length, pedicel - fruit ratio and crop duration in any of the hybrids.

Based on standard heterosis Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya were identified as desirable for yield attributes.

5.2.2.3 Sca effect of hybrids

The significance sca effects for yield are in conformity with the reports of Shukla *et al.* (1999), Gandhi *et al.* (2000), Saritha *et al.* (2005) and Khereba *et al.* (2008). Reddy *et al.* (2008) reported high *sca* effect for plant spread and number of fruits per plant while Pandey *et al.* (2003) reported for fruits per plant and fruit yield. Significant *sca* effect for days to flower, number of fruits per plant and fruit yield per plant was reported by Jagadeesh (1995) and Patel *et al.* (2004).

Mavelikkara Local x Jwalasakhi, Nenmara Local x Vellayani Athulya, Kayamkulam Local x Jwalamukhi, Thavanur Local x Jwalamukhi, Mangalapuram Local x Jwalamukhi were the hybrids that expressed desirable significant *sca* effects for green fruit yield per plant. Among these Mavelikkara Local x Jwalasakhi also showed desirable significant effects for number of fruits per plant, average fruit weight and plant spread. The hybrid Nenmara Local x Vellayani Athulya displayed desirable significant *sca* effect for average fruit weight and number of fruits per plant.

Athulya displayed desirable significant *sca* effect for average fruit weight and number of fruits per plant.

In spite of having positive significant *sca* effect for number of seeds per fruit, hundred seed weight, duration of crop, fruit width and days to first flowering Mavelikkara Local x Vellayani Athulya was not desirable on having negative *sca* effects for yield.

Mangalapuram Local x Jwalamukhi and Thavanur Local x Vellayani Athulya expressed significant *sca* effects for average fruit weight while the hybrid Thavanur Local x Jwalasakhi alone showed significance for duration of crop. The hybrid Mangalapuram Local x Jwalasakhi exhibited significance for hundred seed weight and pedicel - fruit ratio and Nenmara Local x Jwalasakhi also showed significance only for number of seeds per fruit.

Thavanur Local x Jwalamukhi and Kayamkulam Local x Jwalamukhi was observed to have significant *sca* effects for number of fruits per plant.

Considering the above the hybrids Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya could be identified as desirable single crosses.

5.2.2.4 Selection of hybrids

On the basis of the *per se* performance, standard heterosis and *sca* effects, the hybrids Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya were found to have better performance than the others (Plate 4).

5.2.3 Proportional contribution of parents and hybrids

Contribution of lines towards variability was maximum for majority of the traits *viz*., plant height, number of branches, average fruit weight, fruit width, fruit length, pedicel - fruit ratio, duration of flowering, duration of crop and number of seeds per fruit. The line x tester had maximum variability for days to first flowering, number of fruits per plant, green fruit yield / plant and vector population. Both the lines and hybrids contributed almost equally for plant spread and

vulnerability index. However the testers did not contribute substantially for any of the characters.

5.2.4 Genetic components of variance

The dominance variance was greater than additive variance for all the characters studied (Table 10). Shukla *et al.* (1999), Gandhi *et al.* (2000), Nandadevi and Hosamani (2003b), Pandey *et al.* (2003), Patel *et al.* (2004), Saritha *et al.* (2005), Srivastava *et al.* (2005), Zate *et al.* 2005, Anand and Subbaraman (2006), Jagadeesha and Wali (2008) and Khereba *et al.* (2008) had also reported the predominance of non additive gene action for various character studied by them.

5.3 GENERATION MEAN ANALYSIS

An understanding of the gene interaction is required to study the nature of inheritance of characters. Generation mean analysis provides information on nature and magnitude of gene actions involved by estimating epistatic gene effects namely additive x additive, additive x dominance and dominance x dominance. The concept of generation mean analysis was formulated by Hayman (1958). Of the varying models available, six-parameter model was utilized for the current study in which six generations (P_1, P_2, F_1, F_2, B_1 and B_2) of chilli (*Capsicum spp.*) were utilized and informations on six parameters were derived. The evaluation of 15 hybrids in line x tester analysis resulted in identification of two superior cross combinations *viz.* Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya. These two crosses were utilized for generation mean analysis.

The scaling tests (*A*, *B*, *C* and *D*) indicated that one or more of the tests were significant in both the crosses indicating the presence of non allelic interaction (epistasis) (Table 12).

5.3.1 Plant height

Mavelikkara Local x Jwalasakhi exhibited significance for additive, additive x additive and additive x dominance components indicating direct selection and recombination breeding programmes as beneficial for improving the trait. In Nenmara Local x Vellayani Athulya only additive was significant indicating usefulness of direct selection for the trait.

Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis in both the crosses.

Doshi and Shukla (2000), Rathod *et al.* (2002) and Srivastava *et al.* (2005) reported additive gene action while Cao and Su (1988), Joshi (1988) and Bhagyalakshmi *et al.* (1991) reported both additive and non additive gene action and Haridass (2007) reported presence of additive x dominance gene action for plant height and these reports endorse the present findings.

5.3.2 Number of branches

Direct selection could be used to improve number of branches as additive gene effect was significant for both Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya. Apart from this Mavelikkara Local x Jwalasakhi has significant additive x dominance and dominance x dominance interactions and hence recombination breeding can also be used.

Similar signs of '*h*' and '*l*' indicated complementary epistasis in both the crosses.

The reports of Bhat (1981), Khadi (1983) and Patil (1990) showing additive gene action for number of branches per plant support the present findings. Cao and Su (1988), Joshi (1988) and Bhagyalakshmi *et al.* (1991) also found additive gene action for the trait but along with non additive gene action.

5.3.3 Days to first flowering

Though dominance and additive gene actions were significant they were in the undesirable positive direction for days to first flowering. The non allelic effects additive x dominance, and dominance x dominance were alone in desirable negative direction in both Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya. Hence heterosis and recurrent selection can be effectively used to improve days to first flowering.

Opposite signs of '*h*' and '*l*' indicated duplicate gene action in both the crosses.

Haridass (2007) earlier reported that days to first flowering had additive x dominance type of epistatic effect.

5.3.4 Plant spread

Significance of dominance and additive effects along with additive x additive interaction was found in Mavelikkara Local x Jwalasakhi and complementary epistasis exists for the trait, while in Nenmara Local x Vellayani Athulya dominance and additive effects were found significant. Though additive x dominance was significant for this cross it was in negative direction indicating the presence of duplicate epistasis. Heterosis breeding and selection of superior recombinants in the advanced generations will be useful for improving plant spread.

The predominance of non additive gene action for plant spread reported by Reddy *et al.* (2008) support the present finding.

5.3.5 Duration of flowering

Only additive x additive interaction was having negative significance in Mavelikkara Local x Jwalasakhi making direct selection most suitable. In Nenmara Local x Vellayani Athulya dominance, additive x additive and additive x dominance were having negative

significance indicating heterosis and recombination breeding as useful for improving flowering duration.

Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis in both the crosses.

5.3.6 Number of fruits per plant

All the genetic components additive, dominance, additive x additive, additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi. Hence direct selection, heterosis and recombination breeding can be effectively utilized for improving number of fruits per plant. The trait has duplicate nature of epistasis in this cross as opposite signs of '*h*' and '*l*' were noted.

In Nenmara Local x Vellayani Athulya additive, dominance and dominance x dominance interaction were significant. Hence direct selection and heterosis could improve the trait. Complementary gene action was indicated by the presence of similar signs of '*h*' and '*l*'.

Similar to the present findings Murthy and Deshpande (1997) observed additive, dominance and interaction components for number of fruits per plant and Joshi (1988) and Bhagyalakshmi *et al.* (1991) reported both additive and non additive gene actions.

On the contrary, Doshi and Shukla (2000) and Rathod *et al.* (2002) found predominance of additive gene action while only non additive gene action was reported by Patil (1990), Ahmed *et al.* (1994), Bal and Singh (1997), Krishnamurthy and Deshpande (1997), Shukla *et al.* (1999), Anandanayaki and Natarajan (2000), Ibrahim *et al.* (2001), Ahmed *et al.* (2003), Nandadevi and Hosamani (2003b), Muthuswamy (2004), Srivastava *et al.* (2005) and Haridass (2007).

5.3.7 Fruit length

In Mavelikkara Local x Jwalasakhi, all the genetic components *viz.*, additive (*d*), dominance (*h*), additive x additive (*i*), additive x

dominance (*j*), dominance x dominance (*l*) components were positive and significant. However, only additive and its interactions were positive indicating direct selection and recombination breeding as useful tool for improving the trait. Opposite signs of '*h*' and '*l*' indicated duplicate nature of epistasis.

In Nenmara Local x Vellayani Athulya all the genetic components except additive x dominance effect were significant and existence of complementary gene action was noted. However additive effect was in negative direction hence heterosis breeding can alone be used for improving the fruit length.

The reports indicating the presence of additive and non additive by Patil (1990) and Bhagyalakshmi *et al.* (1991); dominance, additive x additive, additive x dominance, dominance x dominance by Ahmed *et al.* (1994); over dominance and additive gene action by Doshi and Shukla (2000); non additive gene action by Ibrahim *et al.* (2001); additive gene action by Nandadevi and Hosamani (2003b), Jagadeesha *et al.* (2004), Srivastava *et al.* (2005) and Kamboj *et al.* (2006); dominance gene effect by Joshi (1988), Muthuswamy (2004) and Haridass (2007) corroborate the present findings.

5.3.8 Fruit width

Significance in positive direction was observed only with additive, additive x dominance and dominance x dominance effects for both Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya. Hence direct selection and recombination breeding are recommended for improving this trait.

Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis in both the crosses.

A similar report indicating the presence of additive gene action was given by Jagadeesha *et al.* (2004). Bhagyalakshmi *et al.* (1991) reported both additive and non additive gene actions for this trait.

5.3.9 Pedicel - fruit ratio

Among the different genetic components only additive and additive x dominance were significant in Mavelikkara Local x Jwalasakhi and duplicate gene action exists in this trait. Dominance x dominance alone was significant in Nenmara Local x Vellayani Athulya and existence of complementary gene action was noted for the crosses.

5.3.10 Green fruit yield

The presence of significant additive, dominance, additive x additive and additive x dominance effects were observed in Mavelikkara Local x Jwalasakhi. Exploitation of the trait could be effectively done by use of direct selection, heterosis and recombination breeding.

In Nenmara Local x Vellayani Athulya also a similar significance was noted with additive, dominance, additive x dominance and dominance x dominance effects and hence the techniques of direct selection, heterosis and recombination breeding can be exploited.

Similar signs of '*h*' and '*l*' indicated the presence of complementary gene action in both the crosses.

Both additive and non additive components were found in this study. Similar results were reported by Joshi (1988) and Bhagyalakshmi *et al.* (1991). The other reports revealed that non additive gene components were dominant over additive gene actions in the inheritance of yield per plant. (Shukla *et al.* 1999; Jadhav *et al.* 2001; Ahmed *et al.* 2003; Nandadevi and Hosamani 2003b)

The predominance of dominance gene effect for fruit yield per plant was reported by Muthuswamy (2004) and Haridass (2007).

Over dominance and additive gene actions were observed for yield per plant by Doshi and Shukla (2000). Patil (1990), Rathod *et al.* (2002) and Patel *et al.*, (2004) reported that additive components were larger than the non-additive components for green fruit yield.

5.3.11 Average fruit weight

Only additive effect but in negative direction was significant in Mavelikkara Local x Jwalasakhi. Opposite signs of '*h*' and '*l*' in Mavelikkara Local x Jwalasakhi indicated duplicate nature of epistasis. Positive significance was noted only for additive x dominance and dominance x dominance in Nenmara Local x Vellayani Athulya suggesting heterosis and recurrent selection for the trait. Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis in Nenmara Local x Vellayani Athulya.

Earlier Doshi and Shukla (2000) reported over dominance and additive gene actions while Joshi (1988) reported additive and non additive gene action for average fruit weight and Chaim and Paran (2000) and Jagadeesha *et al.* (2004) reported only additive gene action for the trait.

5.3.12 Number of seeds per fruit

Dominance, additive, additive x dominance and dominance x dominance were all significant in Mavelikkara Local x Jwalasakhi suggesting the use of direct selection, heterosis and recombination breeding programmes. Additive x dominance and dominance x dominance were found significant in Nenmara Local x Vellayani Athulya indicating the use of heterosis and recurrent selection for number of seeds per fruit.

Complementary nature of epistasis was indicated by similar signs of '*h*' and '*l*' in both the crosses.

Bhagyalakshmi *et al.* (1991) observed both additive and non additive gene action for the trait. Nandadevi and Hosamani (2003b) and Kamboj *et al.* (2006) noted that additive gene action was more for number of seeds per plant while Haridass (2007) reported additive x dominance type of epistatic effect for the same trait. Jagadeesha and Wali (2008) found that seed related triats were under the control of non-additive gene action. All these studies support the present findings.

5.3.13 Hundred seed weight

None of the genetic components were significant in Mavelikkara Local x Jwalasakhi for the trait. Direct selection can be used as additive gene effects were alone significant in Nenmara Local x Vellayani Athulya.

Duplicate nature of epistasis was indicated by opposite signs of '*h*' and '*l*' in both the crosses.

Corroborative to the present results, Kamboj *et al.* (2006) and Jagadeesha and Wali (2008) also found the involvement of the additive gene action in the inheritance of seed weight of ten fruits. On the contrary Bhagyalakshmi *et al.* (1991) observed both additive and non additive gene actions and Haridass (2007) observed additive x dominance effect for the same trait.

5.3.14 Duration of crop

Only additive effect was significant but in positive direction for Mavelikkara Local x Jwalasakhi. Negative significance was observed for dominance and additive x dominance and positive significance for additive x additive and dominance x dominance in Nenmara Local x Vellayani Athulya. Heterosis can be exploited for improving crop duration.

Presence of duplicate epistasis was ascribed with opposite signs of '*h*' and '*l*' in both the crosses.

5.3.15 Capsaicin content

The genetic components of all types namely additive, dominance, additive x additive, additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi. Hence direct selection, heterosis and recombination breeding can be effectively utilized for improving number of fruits per plant.

Nenmara Local x Vellayani Athulya had significance for only additive, dominance and additive x dominance interaction. Hence direct selection heterosis and recombination breeding could improve the trait.

Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis in both the crosses.

Similar results were obtained with additive gene action by Doshi and Shukla (2000), Singh and Hundal (2001a) and Jagadeesha *et al.* (2004) while the non-additive gene action for the same trait was corroborated by Muthuswamy (2004), Srivastava *et al.* (2005) and Haridass (2007).

5.3.16 Oleoresin content

The genetic components additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi. Hence the character can be improved through heterosis and recurrent selection. Additive, additive x additive and dominance x dominance were significant in Nenmara Local x Vellayani Athulya. So, direct selection and heterosis can be utilized to improve the trait.

Opposite signs of '*h*' and '*l*' in both the crosses indicated the existence of duplicate nature of epistasis.

Singh and Hundal (2001a) earlier reported the presence of both additive and non-additive components for oleoresin while Haridass (2007) reported additive x dominance effect for the trait.

5.3.17 Vector population

Dominance effect was significant in the cross Mavelikkara Local x Jwalasakhi and dominance x dominance in Nenmara Local x Vellayani Athulya while additive and additive x additive effects were significant in both the crosses. Hence direct selection and heterosis can be utilized to improve the trait.

5.3.18 Leaf curl score on 45 days

Direct selection, heterosis and recombination breeding can be used to improve the resistance to leaf curl virus as all the genetic components were significant in Mavelikkara Local x Jwalasakhi. Similar signs of '*h*' and '*l*' indicated complementary nature of epistasis.

In Nenmara Local x Vellayani Athulya due to absence of dominance only direct selection and recombination breeding can be utilized for improving the trait. Opposite signs of '*h*' and '*l*' in this cross indicated the existence of duplicate nature of epistasis.

Muthuswamy (2004) noticed additive x additive and additive x dominance effects for the trait.

5.4 TRANSGRESSIVE SEGREGANTS

Transgressive segregants were obtained (Table 13) for many of the characters studied but in both the crosses none were found for leaf curl score on 45 days, duration of crop and days to first flowering. Transgressive segregants were found in undesirable direction due to inheritance of indeterminate character from the *Capsicum frutescens* parent.

Mavelikkara Local x Jwalasakhi expressed more number of transgressive segregants than that of Nenmara Local x Vellayani Athulya for all the characters except plant height, plant spread and average fruit weight where no transgressive segregants were obtained for this cross.

In Nenmara Local x Vellayani Athulya no transgressive segregants was obtained for number of fruits per plant, fruit length, pedicel - fruit ratio and number of seeds per fruit.

Estimates of transgressive segregants (%) in F_2 were the highest for oleoresin content in both the crosses (96.67 and 86.67) followed by hundred seed weight (41.11) in Mavelikkara Local x Jwalasakhi.

The presence of transgressive segregants indicates the possibility of identifying desirable recombinants, which could be further utilized for developing superior variety (Plate 5).

Plate 5. Recombinant with high yield & LCV resistance

Summary

6. SUMMARY

The present project entitled "Genetic analysis of yield and leaf curl virus resistance in Chilli (*Capsicum spp.*)" was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2007-2009 as three major experiments to develop various crosses between identified leaf curl virus disease resistant *C. frutescens* accessions and high yielding released varieties of *C. annuum* in order to understand inheritance of yield, its component characters and leaf curl virus resistance in chilli (*Capsicum spp*)

In experiment I, five resistant *C. frutescens* accessions identified from a previous experiment conducted in the department were taken as lines (Mangalapuram Local, Thavanur Local, Kayamkulam Local, Mavelikkara Local and Nenmara Local) and crossed in L x T pattern with three high yielding susceptible varieties as testers (Jwalamukhi, Jwalasakhi and Vellayani Athulya) and 15 F_1s were produced.

The parents and F_1 hybrids were evaluated (experiment II) for yield and its component characters using randomized block design with three replications. In the experimental field releasing viruliferous white flies and growing infected susceptible plants were done to ensure leaf curl virus incidence artificially. Observations were recorded on 16 characters *viz.*, plant height (cm), number of branches, number of days to first flowering, plant spread (cm), duration of flowering (fruiting span), number of fruits per plant, fruit length (cm), fruit width (cm), pedicel - fruit ratio, green fruit yield per plant (g), average fruit weight (g), number of seeds per fruit, 100-seed weight (g), duration of crop, vector population and vulnerability index calculated on the basis of virus disease scoring.

The findings from the Experiment II are presented below.

1. Analysis of variance revealed significant differences among the genotypes for all the characters studied.

2. Higher estimates of phenotypic and genotypic coefficients of variation (PCV and GCV) were recorded for vulnerability index and green fruit yield per plant. Except fruit width all the other characters studied exhibited moderate to high variability.
3. High heritability coupled with high genetic advance were exhibited for days to first flowering, duration of flowering, number of fruits per plant, green fruit yield per plant, number of seeds per fruit, duration of crop and vulnerability index.
4. Combining ability analysis revealed significant differences for all the characters studied among parents. Significant differences were noted among crosses for all the characters except number of branches. In parents vs crosses significant differences were observed for majority of the characters except plant height, plant spread, fruit length and pedicel - fruit ratio.
5. The *sca* variance was greater than *gca* variance for all the characters indicating that non-additive gene action is predominant than additive gene action.
6. The line Mavelikkara Local and Nenmara Local were alone good general combiners for fruit yield. Hence Mavelikkara Local and Nenmara Local were good combiners.
7. Four hybrids *viz.*, Mavelikkara Local x Jwalasakhi, Nenmara Local x Vellayani Athulya, Kayamkulam Local x Jwalamukhi and Thavanur Local x Jwalamukhi exhibited significant *sca* effect for fruit yield.
8. Eight hybrids exhibited significant standard heterosis for green fruit yield and all hybrids exhibited significant negative standard heterosis for vulnerability index. The two hybrids having significance in desirable direction for both characters were Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya.

9. Considering *per se* performance, standard heterosis and *sca* effect of hybrids together, two hybrids Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya were chosen as the best hybrids.

Generation mean analysis was carried out in experiment III using two superior F_1 hybrids Mavelikkara Local x Jwalasakhi (cross 1) and Nenmara Local x Vellayani Athulya (cross 2), their respective parents (P_1 and P_2) and the backcrosses (B_1 and B_2) and F_2 generation. These six populations were evaluated in randomized block design with three replications during summer 2009. Leaf curl virus incidence was ensured artificially by growing susceptible plants and releasing viruliferous white flies in the experimental field. Through generation mean analysis additive, dominance and epistatic gene effects were estimated for 16 traits. The salient conclusions of generation mean analysis are summarized here under.

1. Significance of scaling tests indicated the presence of epistasis (non allelic interaction) for all the traits studied.
2. Significant and positive values for additive, dominance, additive x additive, additive x dominance components were noticed in both the crosses for green fruit yield per plant. In addition, additive x additive was significant in Mavelikkara Local x Jwalasakhi and dominance x dominance in Nenmara Local x Vellayani Athulya
3. All the genetic components additive, dominance, additive x additive, additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi. While in Nenmara Local x Vellayani Athulya additive, dominance and dominance x dominance interaction alone were significant.
4. Significance in positive direction was observed only with additive, additive x dominance and dominance x dominance effect in both the crosses for fruit width.

5. In Mavelikkara Local x Jwalasakhi, all the genetic components additive (d), dominance (h), additive x additive (i), additive x dominance (j), dominance x dominance (l) components were positive and significant for fruit length while in Nenmara Local x Vellayani Athulya all the genetic components except additive x additive effect were significant
6. The genetic components of all types namely additive, dominance, additive x additive, additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi for capsaicin content whereas in Nenmara Local x Vellayani Athulya significance was found only for additive, dominance and additive x dominance interaction for the trait.
7. The genetic components additive x dominance and dominance x dominance were significant in Mavelikkara Local x Jwalasakhi while additive, additive x additive and dominance x dominance were significant in Nenmara Local x Vellayani Athulya.
8. All genetic effects were negatively significant in Mavelikkara Local x Jwalasakhi for leaf curl virus score. Nenmara Local x Vellayani Athulya exhibited significant and negative additive and dominance x dominance effects for the trait.
9. The significance of all genetic components was noted for yield and majority of the yield contributing characters including leaf curl virus score. Hence direct selection, heterosis and recombinant breeding can be utilized to design a variety with all the desirable characters.

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*Originals not seen

GENETIC ANALYSIS OF YIELD AND LEAF CURL VIRUS RESISTANCE IN CHILLI (*Capsicum spp.*)

K. ANANDHI

Abstract of the
thesis submitted in partial fulfilment of the requirement
for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2010

Department of Plant Breeding and Genetics
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM- 695 522

ABSTRACT

Pepper fruits (*Capsicum spp.*) are among the most consumed vegetables as fresh green or red and dried whole or ground forms in the world for its pungency. Leaf curl virus is an important biotic stress transmitted by the vector, *Bemisia tabaci*. Controlling the vector can be the only way to manage the disease and results in only partial control of disease. The incidence of disease is more in summer season and makes the cultivation uneconomical. There is an immediate need to develop leaf curl resistant varieties especially for summer cultivation. Hence the present investigation was undertaken at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2007-2009 with the objective of estimating the combining ability, heterosis and gene action involved in the inheritance of yield and leaf curl virus resistance.

Five resistant *C. frutescens* accessions Mangalapuram Local, Thavanur Local, Kayamkulam Local, Mavelikkara Local and Nenmara Local were crossed in L x T pattern with three high yielding susceptible varieties Jwalamukhi, Jwalasakhi and Vellayani Athulya and 15 F_1s were produced and evaluated along with the parents in randomized block design. Analysis of variance revealed highly significant genotypic difference for all the characters studied.

The observations recorded were plant height (cm), number of branches, number of days to first flowering, plant spread (cm), duration of flowering (fruiting span), number of fruits per plant, fruit length (cm), fruit width (cm), pedicel - fruit ratio, fruit colour at intermediate stage, green fruit yield per plant (g), average fruit weight (g), number of seeds per fruit, hundred seed weight (g), duration of crop, vector population and virus disease scoring.

Higher estimates of PCV and GCV were recorded for vulnerability index and green fruit yield per plant.

High heritability coupled with high genetic advance were exhibited for days to first flowering, duration of flowering, number of fruits per plant, green fruit yield per plant, number of seeds per fruit, duration of crop and vulnerability index.

Combining ability analysis showed that the line Mavelikkara Local and Nenmara Local were alone good general combiners for fruit yield along with leaf curl resistance. Four hybrids *viz.*, Mavelikkara Local x Jwalasakhi, Nenmara Local x Vellayani Athulya, Kayamkulam Local x Jwalamukhi and Thavanur Local x Jwalamukhi exhibited significant *sca* effect for fruit yield.

Considering *per se* performance, standard heterosis and *sca* effect two hybrids Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya were found to be superior.

Generation mean analysis was carried out using six-parameter model. Six generations *viz.* P_1, P_2, F_1, F_2, B_1, B_2 were built up among the crosses Mavelikkara Local x Jwalasakhi and Nenmara Local x Vellayani Athulya. Presence of additive, dominance and epistatic interaction for all the characters indicated that hybridization or recombination-breeding programme can be followed for future breeding.