Heterosis and Combining Ability Analysis to Leaf Curl Virus in Chilli

DARSHAN S.

(2012-11-176)

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

2014

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by

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(2012-11-176)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

2014

DECLARATION

I, hereby declare that the thesis entitled **"Heterosis and Combining Ability Analysis to Leaf Curl Virus in Chilli"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellayani, **DARSHAN. S.**

Date: 08-08-14 **(2012-11-176)**

CERTIFICATE

Certified that this thesis entitled **"Heterosis and Combining Ability Analysis to Leaf Curl Virus in Chilli"** is a record of research work done independently by Mr. Darshan S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellayani,
Date: 08-08-14

Mrs. Seeja, G.
(Major Advisor, Advisory Committee)
Assistant Professor (Sr.Scale)
Department of Plant Breeding and Genetics
College of Agriculture, Vellayani.

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Darshan S (2012-11-176), a candidate for the degree of **Master of Science in Agriculture**, with major in Plant breeding and genetics, agree that this thesis entitled **"Heterosis and Combining Ability Analysis to Leaf Curl Virus in Chilli"** may be submitted by Mr. Darshan S., in partial fulfilment of the requirement for the degree.

Mrs. Seeja, G.
(Chairman, Advisory Committee)
Assistant Professor (Sr. Scale)
Department of Plant Breeding & Genetics
College of Agriculture, Vellayani
Thiruvananthapuram-695522

Dr. D. S. Radha Devi
(Member, Advisory Committee)
Professor and Head
Department of Plant Breeding & Genetics
College of Agriculture, Vellayani,
Thiruvananthapuram-695522

Dr. K. Umamaheshwaran
(Member, Advisory Committee)
Professor
Department of Plant pathology
College of Agriculture, Vellayani
Thiruvananthapuram-695522

Dr. R. V. Manju
(Member, Advisory Committee)
Associate Professor
Department of Plant Physiology
College of Agriculture, Vellayani
Thiruvananthapuram-695522

Dr. Mareen Abraham
(Member, Advisory Committee)
Associate Professor
Department of Plant Breeding & Genetics
College of Agriculture, Vellayani,
Thiruvananthapuram-695522

EXTERNAL EXAMINER
(Name and Address)

ACKNOWLEDGEMENT

"By the grace of God I am what I am"

Life is an unending process of finding and losing, living and loving, learning and moving on. I am deeply thankful to God for all his blessings. I bow my head before the mighty power for his eternal love and grace for having this way in my life.

I learned a lot of lessons even beyond the classroom and the books from **Mrs. Seeja, G.,** Chairperson of the Advisory committee, Assistant Professor (Sr. S), Department of Plant breeding and Genetics. I feel immense pleasure in extending my heartfelt gratitude for her perfectness, kindness, forgivingness, simplicity and concern for my welfare.

To, **Dr. D.S. Radha Devi**, Professor and Head, Department of Plant breeding and Genetics for her authentic advices as an advisory member for research work and valuable suggestions during the course of study.

I owe my immense gratitude with pleasure to **Dr. R.V. Manju**, advisory member and Associate Professor, Department of Plant Physiology for her timely advice, selfless help, critical suggestions during the course of study and unstinted help extended in experimental analysis.

I owe my heartful gratitude to **Dr. K. Umamaheshwaran**, Member, Advisory Committee, and Professor, Department of Plant pathology for his enlightened guidance, keen interest and suggestion to embellish this study.

I express my sincere gratitude to **Dr. Mareen Abraham,** Member, Advisory Committee and Associate Professor, Department of Plant Breeding & Genetics for her valuable suggestions during the thesis preparation.

I feel happy to express my heartful feelings to **Dr. K.M. Abdul Khader**, for his critical suggestions during the entire course of study.

To, **Dr. Arya K,** for the compassionate heart, inspiration, sharing idealisms and supporting throughout the course of study.

Words are insufficient to express my sincere thanks to all my professors. Especially**, Dr. P. Manju**, for her wonderful and lively classes. To **Dr. Maya Devi, P**. for her complete and whole hearted fidelity.

My deepest thanks to **Dr. Sunny, K. Oommen**, **Dr. D. Wilson**, **Dr. Lekha Rani** and **Dr. Jayalekshmi, V. G.,** for their charisma filled with best thoughts and warmth.

To, **Dr. C. Gokulapalan,** the man with a difference and one of the best guru I've met, thank for making all the things easier and for the criticism, timely concern and being readily available for consultation always.

To, **Dr. Suma Bai,** for allotment of experimental plot which made my work and her critical suggestions for thesis preparation.

To, non-teaching staff members of my department. Lekshmi Chechi, Reshma Chechi, Divya Chechi and other research associates of Plant physiology department, for their kind heartedness and helping nature.

Everything went well with the presence of my loving friends, Anju, Manju, Raju and Henry during my study period.

I would like to express my deepest gratitude to loving brother and senior Ashish who made my thesis worth.

Many thanks go to my seniors, Sreenivas, Gangadhar, Rajib Das, Ramling, Ravi^2, Vijayaraj, Mady, Abhijatha, Vinetha, Vidya Gowda, Lekshmi and Asha for their loving support and valuable suggestions during my studies and research.

I feel happy to thank all my lovely batchmates, Loki, Jayasheela, Hemanth, Prasanth, Pavan, Kishore, Jayanth, Nikil, Jacob, Sreejith, Dipin, Anees, Safeer, Anjali, Anupama, Reshma, Annie, Karolin, Revoo, Pinto and junior friends for their everlasting love and care.

Best friendship knows no distance and I want to thank my ever loyal friends back home. To, Subbu, Suri, Jeevan, Gowri, Kiran, Bhavya and Ashwini. To my dear *Yogitha*, you always bring comfort and sound advice when I badly need one.

To, my ever loving guru **Shivakumar, M. S**. for lighting the flame within me again and bringing me back to academics with love and care.

I sincerely acknowledge the Kerala Agricultural University for financial support in the form of KAU Junior Research Fellowship during my studies.

My heartful thanks are due to NBPGR (New Delhi), IIHR (Bengaluru) and GBPUAT (Pantnagar) for providing the experimental seed material.

To my very reasons for living: Dad-Mr. Shambhu, mom-Mrs. Kamala, for support and love. To my loving sisters Lavanya and Sowmya who have always been so proud of me.

Above all, I am very greatful to the Eternal Power guiding me throughout this course programme.

DARSHAN S.

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LIST OF ABBREVIATIONS

%	Percentage
µg	Microgram
µl	Microlitre
a.m.	Anti-meridian
A_{663}	Absorbance at 663 nm wavelength
A_{645}	Absorbance at 645 nm wavelength
A_{510}	Absorbance at 510 nm wavelength
A_{480}	Absorbance at 480 nm wavelength
et al.	and Co-workers/ co-authors
F_1	First filial generation
g	gram
ha	Hectare
i.e.,	That is
kg	Kilogram
M	Molar
mg	Milligram
min	Minute
ml	Millilitre
m*M*	Millimolar
N	Normal
nm	Nanometre
^oC	Degree celsius
sp.	Species
spp.	Species (plural)
t	Tonne

Introduction

1. INTRODUCTION

Chilli [*Capsicum annuum* (L.)] belongs to family Solanaceae is one of the most important crops grown for its green form as vegetable and red form as spice. Besides, it is used in processing industries for preparing various products such as pepper sauce, pickled pepper, ground pepper and dried pepper. Originated in Latin American regions of New Mexico, Guatemala and Bulgaria (Saffarod 1926). It was first introduced in India from Brazil by the Portugese towards the end of 15th century and its cultivation became popular in the 17th century. India stands 11th among the chilli producing nations in the world. India is the leading producer, consumer and exporter of chillies in the world. It exports chilli to USA, UK, Russia, Canada, Italy, Netherlands, Singapore, Saudi Arabia, UAE and Germany in the form of dried pods, chilli powder and oleoresins.

Immature chilli fruits contain phytonutrients, ascorbic acid, carotenoids and rutin which are valued for pharmaceutical needs (Purseglove 1977). Chillies have two important qualities; biting pungency and attractive red colour attributed due to capsaicin and capsanthin, respectively. Capsaicin, a crystalline acrid volatile alkaloid present in the placenta of fruit, carries diverse prophylactic and therapeutic uses in allopathic and ayurvedic medicines. Red coloured pigment is used as a natural colour additive in food, drugs and cosmetics. These pigments are also rich in bioflavonoids, which are powerful antioxidants and inhibit the progression of chronic diseases such as muscular degeneration, cardiovascular diseases and cancer. Oleoresin extracted from dried and ground chillies is the total flavour extract which has gained industrial importance through its utilization in processed products and pharmaceutical formulations. Oleoresin is gaining more importance especially from export point of view as it offers uniform quality, longer shelf-life, and freedom from micro-organisms and lesser freight charges.

Chilli is grown extensively throughout the country, both under rainfed and irrigated conditions, in almost all the states covering an area of 9.15

lakh ha with annual production of 11 lakh tonnes (Anon., 2012). In Kerala, the acreage under chilli is 1910 ha with annual production of 1302 tonnes (Anon., 2012).

However, the average yield is low due to various constraints such as non-availability of suitable cultivars/hybrids, biotic and abiotic stresses and genetic drift in cultivars.

This crop is susceptible to several diseases and pests. Of these, Chilli leaf curl disease caused by Gemini virus and transmitted through the vector white fly is a serious production constraint of chilli. The infection starts at nursery stage and causes considerable yield loss up to 50 % (Meena *et al.*, 2006). Application of insecticides to control the insect vector does not always provide good control of the disease hence breeding chilli for resistance is more rational approach to protect the interest of farmers.

One of the ways to improve the production and productivity is to harness the potential of heterosis breeding. The importance of heterosis breeding has been recognized widely in many vegetable crops. The quantum jump in yield achieved through heterosis, has been reported for many of the economic attributes in chillies, especially for quantitative traits. To plan an appropriate breeding programme, the plant breeders must possess an adequate knowledge of combining ability and nature of gene action, character association patterns and the extent of contribution of each character to fruit yield.

It is, therefore, imperative to carry out genetic studies on gene action involved in the manifestation of important quantitative and qualitative traits for the improvement of yield and for breeding resistant cultivars. The most appropriate strategy to combine various desirable attributes *viz.*, high yield, resistance to diseases along with responsiveness to better management is the heterosis breeding.

The most essential step in this direction is identification of superior heterotic F_1 hybrids for yield, quality and disease resistance. Knowledge of

relative importance of general combining ability and specific combining ability for quantitative characters influencing yield and its components is very helpful in selecting parents for production of superior hybrids. Several biometrical methods are available for studying the combining ability, heterosis and gene action.

The diallel analysis which was first developed by Griffing (1956) is one such method. In the light of these, the present investigation is framed to study the inheritance of leaf curl virus resistance, yield, and yield related traits and also to determine biochemical composition of plant associated with the manifestation of LCV resistance in chilli through combining ability analysis and to identify high yielding leaf curl virus resistant chilli hybrids.

Based upon these considerations, the proposed investigation was planned to achieve the following objectives:

- To identify the best general combiners and specific combiners for developing superior cross combinations.
- To study the inheritance pattern of yield, yield attributes and qualitative traits and resistance to leaf curl virus disease.

Review of Literature

2. REVIEW OF LITERATURE

Hybridization is the most potent technique for breaking yield barrier in any crop species. Biometrical techniques – diallel analysis is one of the methods commonly used for the evaluation and selection of parents for hybridization. The parents are chosen on the basis of the measurement of heterosis and combining ability and the breeding procedure is decided on the basis of gene action involved in the expression of various quantitative characters. In this section an attempt has been made to review the up-to-date literature with respect to these aspects as follows.

2.1 HETEROSIS

Heterosis is the superiority of the F_1 hybrid over the mid-parent value (mid-parent heterosis / relative heterosis) or better parent (heterobeltiosis) or a check variety or hybrid (standard or economic or useful or true heterosis).

Shull (1908) referred this phenomena as 'special stimulus of heterozygous' and it is increased vigour, size, fruit fullness, speed of development, resistance to disease or insect pests manifested by outbreeding organism as compared with corresponding inbreds.

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

Heterosis of varying magnitude has been observed in almost all the crop plants. Genetic phenomena known to influence qualitative or quantitative characters is expected to influence heterosis but over the years dispersion of completely or incompletely dominant genes and over-dominance along with some

contribution of non-allelic interactions have been considered to be the main causes of heterosis.

The first report on heterosis in chilli came from Deshpande (1933) who observed it for earliness, plant height, fruit girth, fruits per plant and yield per plant.

In chilli hybrid seed production can be economical since the fruits contain large number of seeds and the natural cross-pollination is to the extent of 7 to 68 per cent (Sekar and Arumugam, 1985).

Heterosis for yield components in chillies was reported as early as by Deshpande (1933) and Pal (1945)

Bhagyalakshmi *et al.* (1991) observed negative standard heterosis in fourteen hybrids among fifteen for days to first flowering and relative heterosis for number of fruits and reported that LCA 208 × LCA 960, LCA 206 × LCA 1079, LCA 960 × X 235 and X 235 × G_4 exhibited greater heterosis value for fruit yield in chilli.

Singh *et al.* (1992) reported the highest of 122.86 per cent heterobeltiosis in the cross Tiwari × Jawahar-218 for number of fruits per plant and observed standard heterosis ranging from -36.85 per cent (Jull × Pusa Jwala) to 40.40 per cent (Jull × IC-851201) for fruit length.

Saraladevi (1994) recorded negative relative and standard heterosis for days to first flowering and positive heterosis for plant height, number of primary branches, fruit length, fruit girth and fruit yield per plant.

Joshi *et al.* (1995) observed that only one hybrid showed significant difference for plant height in a diallel cross involving 12 × 12 purelines and reported heterosis of 75 and 68.60 per cent over the check and best variety respectively for fruit yield per plant.

Heterosis was high for total yield and average fruit weight in the evaluation of sweet pepper cross Fimentao × Pip and their F_1, F_2 and backcross generations (Mohamed *et al.*1995).

Significant negative heterosis over better parent and the best parent was observed for plant height in the hybrid RHRC Clustered Pendent × CA59, where as in all other hybrids significant positive heterosis (Anandanayaki, 1997).

Ahmed *et al*. (1999) crossed six hot pepper cultivars viz., Elephant trunk, Pusa Jwala, Shalimar long, SPE-1, Punjab Lal and G-4 in all possible combinations without reciprocals and found that the high heterosis over better parent for yield and earliness in the crosses Shalimar long × Punjab Lal, Elephant trunk × Shalimar long and Shalimar long × SPE-1.

Doshi and Shukla (2000) observed negative heterosis over better parent for capsaicin in 43 hybrids whereas in only one hybrid positive heterosis over check.

Out of 15 hybrids obtained from 6 × 6 diallel. Cross four exhibited significant heterobeltiosis and 11 exhibited significant standard heterosis for dry fruit yield per plant (Gandhi *et al*. 2000). Hemavathy (2000) observed the highest positive relative heterosis of 245.65 per cent for number of fruits per plant in the cross CA 133 × CA 100.

Malathi (2001) observed highly significant positive heterosis over the mid, better and best parents for number of fruits per plant and plant height and revealed a significant heterosis over mid, better and best parents in the cross CA86-1 × CA84 for dry fruit weight and CA 86-2 × CA 84 for number of branches per plant.

Singh and Hundal (2001) found both positive and negative heterosis over the better parent for fruit yield per plant with the highest estimate of 108.17 per cent.

Sathiyamurthy (2002) reported significant negative heterosis in seven hybrids for plant height and relative heterosis in 13 crosses for number of branches per plant.

Muthuvel (2003) reported that the relative heterosis for plant height was highest in Arka Lohit × CHD 8 (14.67 per cent) and the lowest in Ujwala × CHD (-12.14 per cent) in summer season. The heterobeltiosis estimates ranged from -15.32 per cent in Arka Lohit × CHD 8 to 32.46 per cent in the Puhjab Lal × CC3 for fresh fruit weight. He found that the hybrid Ujwala × CHD8 exhibited positive heterosis over standard parent (75.66 per cent) for dry fruit yield. Relative heterosis for capsaicin was high (34.36 per cent).

Muthuswamy (2004) reported positive standard heterosis for number of branches per plant, fruit length, fruit girth, fruit yield per plant and recorded heterobeltiosis, relative and standard heterosis for capsaicin content.

In a line × tester analysis, Ajith (2004) reported positive heterosis for fruit girth and negative heterobeltiosis and standard heterosis for duration of the crop.

Philip (2004) reported significant positive heterosis for number of fruits and fruit yield per plant while Shankarnag *et al.* (2005) reported negative heterosis for number of fruits per plant.

Kumar *et al*. (2005) crossed six inbreds in a 6 × 6 diallel fashion and observed that for capsaicin content relative heterosis and heterobeltiosis ranged from -46.15 to 89.16 per cent from -55.30 to 72.52 per cent.

In a line × tester analysis involving ten lines and three testers, Adapawar *et al*. (2006) reported that among the 30 hybrids, three (CA-960 × GP-172, AK-8625 × GP-196 and AK-8625 × GP-198) consistently exhibited high heterosis for yield and yield component characters.

Durvesh *et al*. (2006) observed minimum plant height in Pusa Sadabahar x Pant C-1 which showed 30.7, 25.1 and 7.6% heteresis over better parent, mid parent and standard parent, respectively.

Shankarnag *et al.* (2006), in a line × tester analysis involving three cytoplasmic genetic male sterile (CGMS) lines and seven testers reported that the cross $L_5 \times T_{14}$ was the most heterotic one over check hybrids for early green fruit yield and followed by $L_3 \times T_{14.}$

Haridass (2007) studied 15 hybrids and their possible three way cross hybrids by triallel analysis and reported that the cross Jwalamukhi × Ujwala showed the highest standard heterosis for number of fruits per plant, fruits yield per plant and capsaicin content. The three way cross hybrid, Vellayani Athulya × Ujwala × Jwalamukhi had high relative heterosis and heterobeltiosis for fruit yield per plant.

Kamble and Mulge (2008b) studied heterosis for 45 hybrids from line × tester mating design and found that the crosses KCPO2 × CW and KCPO9 × BL were superior over the commercial check with respect to total yield per plant and number of fruits per plant respectively.

Patel *et al.* (2008) studied heterosis for fruit yield and quality in crosses made using five cyloplasmic male sterile (CMS) lines and eight testers and found that hybrid ACMS-2 × LCA-206 exhibited the greatest significant positive heterosis over mid parent and better parent values; while ACMS-4 × GVC-101 and ACMS-2 × GVC-101 exhibited the highest significant positive heterosis and heterobeltiosis for chlorophyll and capsaicin content, respectively.

Prasath and Ponnuswami (2008) found that heterosis over best parent ranged from 40.35 to 126.32 per cent for dry fruit yield per hectare. The hybrids Byadagi Kaddi × Arka Abir and MDUY × CO4 were superior with respect to total extractable colour, dry fruit yield and yield contributing characters.

In a line × tester analysis involving 10 lines and 4 testers, Reddy *et al*. (2008) observed standard heterosis for total yield per plant, seed weight per fruit and growth parameters in the cross SKAU-SC-1003 × Arka Lohit, while the hybrid SKAU-SC-965-5 × GPC-82 showed significant standard heterosis for plant spread, number of fruits per plant, fruit length, fruit width, average fruit weight, pedicel length, pericarp thickness and number of seeds per fruit. Standard heterosis in desirable direction was recorded in twenty crosses for number of fruits per plant (Chadchan, 2008).

Surendra *et al.*(2011) observed, hybrids of 5AVS7 × SP32, SP12 × SP38, 5AVS7 × SP45, CO1234 × SP32, KNU1015 × SP32, 5AVS7 × SP34, 5AVS8 × SP51 and SP27 × SP25 expressed the highest positive standard heterosis on fruit number and yield per plant whereas highest positive heterobeltiosis was exhibited by the cross 5AVS7 × SP32 (87.2%) and SP12 × SP38 (119.3%) for yield per plant.

Among 51 F1's studied, cross ACA1 x LCA334 exhibited significant heterosis over mid parent 493.44% as well as better parent 402.78%. The F1 hybrid JNA1 x BVC-37 registered significant standard heterosis (48.47%) for dry fruit weight per plant. (Tembhurne and Rao, 2012)

Alok Chaudhary *et al.* (2013) reported, crosses Pusa Jwala × VR-339, Pusa Jwala × DC-16 and Pant C-1 × VR-339 exhibited higher level of heterobeltiosis for most of the traits.

2.2 COMBINING ABILITY

Out of the 11 traits studied in a 11 × 11 half diallel cross by Khadi and Goud (1986), *gca* variances were found to be higher than *sca* variances for ten traits.

Joshi and Singh (1987) were of the opinion that *gca* estimates and per se performances are to be taken together when assessing the breeding value of a cultivar. Study in the F_1 and F_2 of a 9 × 9 diallel cross, they found *gca* to be

predominant in the case of yield and yield related traits and hence straight forward selection was suggested for their improvement.

Seven genotypes were crossed in all possible combinations by Gaddagimath *et al*. (1988) and reported that the parents Jwala and K34-35 exhibited significant *gca* effects for most of the characters. A few cross combinations showed significant *sca* effects as well as reciprocal effects for yield and its components.

Sahoo *et al.* (1989) noticed predominant *gca* effects for plant height and hundred seed weight in combining ability evaluation of 45 F_2 hybrids from a diallel set of crosses involving 10 varieties. Variety BR Red had the highest *gca* for yield traits.

In a half diallel cross of six chilli cultivars, Bhagyalakshmi *et al.* (1991) observed *gca* and *sca* effects with the latter predominating for days to 50 per cent flowering, fruit length, fruit girth, fresh fruit weight and 100 seed weight.

Mishra *et al.* (1991) crossed 10 chilli genotypes in diallel fashion without reciprocals and studied 45 F_1 hybrids along with parents. The best general combiners for most of the qualitative characters were J218 and BR Red. Pusa Jwala and Lam-x-235 were good general combiners for number of fruits per plant. Pusa Jwala × Sindhur exhibited significant *sca* effect for yield per plant.

In a line × tester analysis involving 20 lines and three testers, Jagadeesh (1995) observed high *gca* effects for number of branches and plant height while high *sca* effects 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 a line × tester fashion 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 significant

sca effect for number of branches and yield per plant, fruit length and capsaicin content.

Ahmed *et al.* (1997) studied six diverse sweet pepper lines viz., California Wonder, KSPS3, KSPA2, Arka Gaurav, World Peater and KSPS1 and their F_1 hybrids and reported that *gca* effects were more than *sca* effects for fruit length, fruit girth, seed number, fruit number and average fruit weight and hence these traits would respond favourably to direct selection. For plant height and fruit yield per plant *sca* effects were more than *gca* effects and heterosis breeding was suggested for their improvement.

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

Yield and plant height were found to possess significant *sca* effects in a 6 × 6 diallel analysis by Gandhi *et al.* (2000).

In a 10 x 10 diallel analysis, Lohithaswa *et al*. (2000) indicated that *gca* and *sca* effects were significant for days to flower initiation, fruit width and plant height while only *sca* effect was significant for yield per plant.

Jadhav *et al.* (2001) in a 6 × 2 line × tester analysis found significant *gca* and *sca* effects for number of fruits per plant, average green fruit weight, yield per plant and plant height.

Following a 6 × 6 diallel analysis, Nandadevi and Hosamani (2003) reported high *gca* and *sca* effects for days to 50 per cent flowering, number of fruits per plant, average fruit weight, seeds per fruit and yield per plant.

In a line × tester analysis involving five lines and three testers, Ajith (2004) observed high *gca* effects for fruit yield, number of seeds per fruit and number of fruits per plant while high *sca* effect was recorded for yield, number of seeds per fruit and percentage of leaf curl disease incidence.

Muthuswamy (2004) observed high *gca* effects for fruit yield, number of fruits per plant, average green fruit weight, fruit length, fruit girth, harvest index, capsaicin content and also for leaf curl incidence in chilli

In a line × tester analysis involving five lines and nine testers, Saritha *et al*. (2005) observed high *sca* 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 content and susceptibility to virus complex. High *gca* was also observed for all the characters except primary branches and number of seeds per fruit.

Srivastava *et al.* (2005) in 15 × 3 line × tester analysis found that among the three testers (Pusa Jwala, Pant Chilli-1 and Chanchal), Pant Chilli-1 exhibited high general combining ability effects for red ripe fruit yield per plant and several other characters, whereas Chanchal was identified as the best general combiner for capsaicin percentage. Among the 15 lines, 8803 Sel-12, Sel-7 and 399-5-2 were identified as good general combiners for red ripe fruit yield per plant and many other characters. The crosses Sel-7 × Pant Chilli-1 and Sel-12 × Pant Chilli-1 showed high specific combining ability effects for red ripe fruit yield per plant and several yield contributing traits.

Anand and Subbraman (2006) reported higher *sca* variances than *gca* variances for all the characters.

In an evaluation of 8 × 8 diallel full set comprising of 56 F_1 hybrids, Venkataramana *et al*. (2006) observed highly significant differences due to *gca*, *sca* and *rca* (reciprocal combining ability) effects for all the characters and suggested the choice of maternal parent for exploitation of appropriate gene effects.

Gondane and Deshmukh (2007) in a line × tester analysis found significant variation for *gca* for days to 50 per cent flowering, plant height, number of fruits per plant, ascorbic acid and wet red chilli yield per plant in

female parents [CA-960, Jwala and AKC-86-25] and for ascorbic acid content and wet red chilli yield in male parents [GP-313, GP-22, GP-90]. Four hybrids viz., Jwala × GP-90, Jwala × GP-22, CA-960 × GP-22 and AKC-86-25 × GP-313 were found to have significant *sca* effects.

In a 6 × 6 diallel analysis, Haridass (2007) noticed high values of *gca* effects for fruit yield per plant, number of fruits per plant and incidence of anthracnose at 45 DAT and 60 DAT. High *sca* effects were recorded for fruit yield per plant, number of fruits per plant and vitamin C content.

In a line × tester analysis with 9 lines and 2 testers, Shekhawat *et al.* (2007) found that the lines Sel-54, 7722-1 and Sel. 16 were good general combiners for red ripe and dry fruit yield per plant whereas, cross combinations, viz., 2003 × 7950, Sel. 54-7950, Sel 16 × Sel. A-4 were best specific combiners for red-ripe fruit yield and Sel. 54 × 7950, A-28 × Sel. A-4 and 7722-1 × 7950 were best specific combinations for dry fruit yield per plant and other yield contributing traits.

Kamble and Mulge (2008a) following a 18 × 3 line × tester analysis found that lines KCP04, KCP11, KCP13, KCP15 and testers were adjudged as superior performers for total yield per plant and fruit yield per hectare based on *gca* effects. The cross KCP01 × BL was found to be superior performer for total yield per plant and fruit yield per hectare based on *sca* effect.

In a line × tester analysis, Reddy *et al*. (2008) found that the parents Arka Lohit, SKAU-SC-965-5, GPC-82, SKAU-SC-1003 and SKAU-SC-304-1 were good general combiners for fruit yield per plant and GPC-82, SKAU-SC-618-2 and SKAU-SC-1005 for days to 50 per cent flowering. The hybrids SKAU-SC-1005 × Kiran, SKAU-SC-1003 × Arka Lohit, SKAU-SC-65-5 × Kiran, SKAU-SC-618-2 × GPC-82 and SKAU-SC-814-2 × GPC-82 were identified as good specific combiners for fruit yield per plant.

Chadchan (2008) found that both *gca* and *sca* effects were significant for primary branches, fruit width, stalk length, stalk width, ascorbic acid

content and per cent capsaicin from diallel analysis. Among six parents VN-2 and X-235 were good general combiners and Raichur local × VN-2, Raichur local × LAM-334, VN-2 × LAM-334 and X-235 × VN-2 were specific combiners.

In a diallel mating design involving six parental lines, Prasath and Ponnuswami (2008) found Byadagi Kaddi, MDUY and Arka Abir as good general combiners for yield and quality characters. The cross MDU × CO4 had desirable significant *sca* effect for fresh yield, dry yield and quality characters like, total extractable colour and capsaicin.

In a line × tester analysis, Khereba *et al*. (2008) reported that PI 166988 was the best parent for early yield and PI 166988 × PI 159236 was the best cross for plant height, number of days to flowering, average fruit weight, fruit length, fruit diameter and total yield.

Combining ability analysis by Jagadeesha and Wali (2008) indicated that the parents VN-2, B-Kaddi, Arka Lohit, Phule-5 and LCA-312 were good general combiners for fruit and seed characters.

Vandana *et al*. (2012) observed that variance due to general combining ability was significant for all the characters. The higher magnitude of gca variances compared to sca variances was higher inducing the predominance of additive type of gene action in the expression of all the characters. The estimation of gca effects showed that, parents SP-19 was good general combiner for fruit length and ascorbic acid content, DARL-71 for fruit width and fruit weight, SP-6 for number of fruits per plant, fruit yield per plant and fruit yield per plot and California Wonder for Total Chlorophyll.

Alok Chaudhary *et al*. (2013) observed higher specific combing ability (SCA) for fruit yield in crosses Kashi Sinduri × Punjab Lal followed by Pant C-1 × VR-339 and Pusa Jwala × VR-339.

Muhamad Syukur *et al.* (2013) reported that parent IPB C15 (0.112) had the highest general combining ability compared to other parents.

PAU Selection Long × Surajmukhi, LCA 436 × Pant C1, Chilli Sonal × Surajmukhi, Jawahar Mirch 283 × Anugraha and Pusa Sadabahar × Surajmukhi were the most promising crosses on the basis of SCA effects for yield and its related traits (Sharma and Munish, 2013).

2.3 GENE ACTION

Salazar and Vallejo (1990) observed significant difference between *gca* and *sca* effects and prominence of non-additive gene action in relation to yield per plant, fruit number and mean fruit weight in a diallel analysis consisting of seven parents.

Bhagyalakshmi *et al.* (1991) conducted a half diallel analysis using six chilli cultivars and inferred preponderance of non-additive gene action for days to 50 per cent flowering, fruit length, fruit girth and 100 seed weight .

Ahmed *et al*. (1997) reported predominance of additive gene action for days to fruit set, fruit length, seed number, fruit number and fruit weight while non-additive gene action was reported for plant height and fruit yield per plant.

Murthy and Desphande (1997) evaluated six generations of four F_1s for fruit number, fruit length and dry chilli yield and observed additive x dominance interaction but their degree differed with crosses.

Tavares *et al*. (1997) found that fruit number is controlled by non-additive gene action.

Sundaram and Irulappan (1998) reported additive gene action for fruit length, fruit girth and number of fruits.

Ahmed (1999) crossed six hot pepper cultivars in all possible combinations without reciprocals. Variances due to *gca* and *sca* were significant 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. Shalimar long and Elephant trunk recorded high *gca* effects for most of the characters, while Punjab Lal, G_4 and Pusa Jwala exhibited high *gca* effects for number of fruits per plant. Estimates of *sca* effects showed that Shalimar Long x Punjab Lal, Elephant trunk x Shalimar Long, Elephant trunk x Pusa Jwala and Shalimar Long x SPE-1 were promising cross combinations for yield and earliness.

Devi and Arumugam (1999) observed the role of additive and non-additive gene action in the control of 23 agronomic and quality characters. Among the parents, the pungent chilli K2 was found to be a good general combiner for three economic traits. In F_1 crosses, the hybrids with low × low, high × high, low × medium and high × medium *gca* parents exhibited high *sca* effects for nine characters indicating the role of additive and non-additive gene action.

In a 6 × 6 diallel analysis, Devi and Arumugam (1999) found that additive gene action was more important than non-additive gene action for all yield components except for fruit length.

Non-additive gene action for yield and days to flowering was reported by Echevervi *et al*. (1999).

Lohithaswa *et al.* (1999) reported both additive and dominance for all characters except days to initiation of flowering and yield per plant.

Shukla *et al.* (1999) evaluated 24 F_1s from L × T design and observed non-additive gene action for fruit length and fruit girth.

Gandhi *et al.* (2000) detected the involvement of both additive and non-additive gene action for expression of all characters.

Lohithaswa *et al*. (2001) in a diallel analysis excluding parents revealed preponderance of non-additive gene action for all the characters except fruit length and fruit diameter. Non-additive gene action was dominant over

additive gene action for plant height, fruit number, fruit weight and fruit yield. Rajender *et al*. (2001) observed additive gene action for capsaicin content.

From a 10 × 10 half diallel analysis, Pandey *et al*. (2002) inferred non additive gene action for fruit yield and number of fruits. Rathod *et al*. (2002) indicated the presence of additive gene action for the number of fruits per plant, fresh red chilli yield per plant and plant height.

Patel *et al*. (2002) observed the additive gene action in the inheritance of days to flower, plant height, fruit length, fruit girth and average fruit weight. Additive gene action was noticed for plant height, fruit length, fruit girth, individual green fruit weight, dry fruit weight and capsaicin content (Sathiyamurthy, 2002). Ahmed *et al*. (2003) indicated that fruit length and pericarp thickness were influenced by both additive and non-additive gene actions while plant height, number of branches, fruit girth, fruits per plant, fruit weight and yield per plant were influenced by non-additive gene action.

Doshi (2003) reported additive gene effects for plant height, fruit weight and capsaicin content and over dominance for days to flowering, number of primary branches, fruits per plant, fruit length, fruit girth and yield per plant.

Gouda (2003) observed both additive and non-additive components of genetic variance for plant height, number of secondary branches, plant spread and number of primary branches while high *gca* and *sca* was recorded for stem girth and height at first branching revealing the non-additive type of gene action.

Nandadevi and Hosamani (2003) observed preponderance of additive gene action for fruit length and seeds per fruit while predominance of non-additive gene action for days to 50 per cent flowering, fruit diameter, green fruit weight, number of fruits and green fruit yield per plant.

Pandey *et al*. (2003) noticed preponderance of non additive gene action for plant height, number of primary branches, secondary branches per plant, number of fruits per plant, fruit length, fruit width and yield per plant.

Sousa and Maluf (2003), in diallel cross of hot pepper lines observed non-additive gene action for yield, capsaicin content and seeds per fruit.

In a line × tester analysis of crosses involving four male sterile and twelve male parents, Patel *et al.* (2004) reported the existence of non additive gene action for the characters days to flowering, plant height, primary branches per plant, fruits per plant, fruit length, fruit weight, fruit girth and green fruit yield per plant.

Jagadeesha *et al*. (2004) estimated gene action using six generation mean analysis and found that, fruit quality traits like fruit length, fruit width, fruit weight, pericarp weight, ascorbic acid content and capsaicin content were under the control of additive type of gene action. While thrips and mite resistance was under the control of dominance, additive × additive and additive × dominance gene effects.

In a 7 × 7 half diallel cross, Philip (2004) observed the predominance of non-additive gene action for days to 50 per cent flowering, plant height, primary branches per plant, secondary branches per plant, fruits per plant, yield per plant and capsaicin content. The study also indicated the equal importance of additive and non-additive gene action for crop duration. Muthuswamy (2004) following generation mean analysis reported predominant contribution of dominance and epistatic interaction for yield and major yield contributing characters.

Srivastava *et al.* (2005) found that the non-additive gene action had greater role in the inheritance of most of the characters studied. For fruit length and red ripe fruit yield per plant, additive gene action played an important role.

Ajith and Manju (2006) reported predominance of additive gene action for fruits per plant, average green fruit weight, fruit weight per plant, fruit length and fruit girth while evaluating the 76 genotypes of *Capsicum annuum*. Duntode *et al*. (2006) reported additive gene effects for green fruit yield, marketable yield of green fruits per plant, fruit length, ascorbic acid content, plant spread, diameter of the fruit and green fruits per plant.

In a line × tester analysis involving 14 parents and 45 F_1 hybrids, Anand and Subbaraman (2006) found the non-additive gene effects for yield and its component characters. Sood *et al*. (2007) observed additive effect for capsaicin and marketable fruit yield per plant while evaluating 25 genotypes of bell pepper.

In a generation mean analysis, Jagadeesha and Wali (2006) found that Leaf Curl Index (LCI) for thrips was predominantly under the control of non-additive gene action with duplicate type of gene interaction whereas non additive gene interaction in LCI for mites.

A Line × tester analysis done by Reddy *et al.* (2008) indicated that *sca* variance was higher than *gca* variance for yield and yield contributing characters which indicating the predominance of non-additive gene action. In 6 × 6 diallel analysis, Prasath and Ponnuswami (2008) revealed the preponderance of additive gene action for all yield and quality characters except for dry fruit yield per hectare and capsaicin.

From a diallel analysis, Chadchan (2008) found predominance of additive gene action for days to 50 per cent flowering, fruit length, fruit width, stalk length, stalk width, number of fruits per plant, green fruit yield per plant and ratio of fruit length to width.

Khereba *et al*. (2008) found that non-additive gene effect played major role in the inheritance of plant height, average fruit weight, fruit length, fruit diameter and total yield.

Jagadeesha and Wali (2008) observed higher proportion of additive gene effect for fruit related traits, while seed related traits were under the control of non-additive gene action.

The ratio of general combing ability (GCA) and specific combing ability (SCA) variance revealed preponderance of non-additive genetic variances for yield per plant (g) that is governed by additive gene action. (Alok Chaudhary, 2013)

The magnitude of non-additive gene action was predominant for majority of the traits with maximum contribution of lines in the expression of gene action as reported by Sharma and Munish (2013).

2.4 LEAF CURL VIRUS DISEASE

Leaf curl virus 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. 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.

Chilli leaf curl virus disease is characterized by stunting of the plants with upward and downward curling of leaves. The newly formed leaves exhibit chlorosis. The old, curled leaves become leathery and brittle. Shortening of internodes leads to dwarfing of the plant (Mishra *et al.,* 1963).

Dhanraj and Seth (1968) reported downward curling, dark green colour and oval to round shape of leaves, pronounced vien-thickening and leafy

outgrowths or enations on the under surface of leaves. The diseased plants produce fewer flowers and fruits.

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

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

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

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.

Brown *et al*. (1993) found that pepper plants infected by sinaloa tomato curl virus showed a splotchy green mottle on leaves.

Pepper mottle virus was reported to be involved in the leaf curl disease complex (Peter, 1998).

Infection by tomato leaf curl virus in *C. annuum* plants resulted in inter-veinal and marginal chlorosis and upward curling of the leaflet margin (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*).

Hussan (1932) reported that the leaf curl or leaf crinkle occurring on chillies was caused by *Bemisia tabaci* (*Bemisia gossypiperda*). Mishra *et al.* (1963), Muniyappa and Veeresh (1984) and Ravi (1991) reported the transmission of chilli leaf curl by means of whitefly (*Bemisia tabaci*). Inoculated chilli plants showed typical leaf curl symptoms after 2-6 weeks.

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 100 per cent infection was obtained in all genotypes (Dhanraj *et al.*, 1968).

Singh (1973) on screening 105 chilli varieties 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 (1977) found that four varieties *viz.*, Sel 4, 6, 7 and 15 obtained from advanced generations of the cross NP 46 A x Puri Red were superior and tolerant to the disease. 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 as compared to the susceptible variety NP 46A.

Konai and Nariani (1980) observed that 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.

Singh and Kaur (1986) found that Punjab Lal selected from Perennial x Long Red were 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).

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.

Sangar *et al.* (1988) screened ten varieties of *Capsicum annuum* for resistance to tobacco mosaic tobamovirus (TMV) and tobacco leaf curl gemini virus under natural field conditions at Chhindwara. The varieties JCA 248, JCA 218, Pant C-1, NP 46A, Pusa Jwala and JCA 196 were resistant to leaf curl virus. JCA 31A, Selection 3, JCA 154 and Pandurna exhibited different degrees of susceptibility. All varieties showed some symptoms of TMV among these 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.

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

The selection PSP 11, named ‘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).

In a study on genetic control of virus resistance against chilli mosaic and leaf curl viruses (most commonly tomato mosaic, tobamovirus, cucumber mosaic cucumo virus, potato virus Y 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 and recessive genes. The conventional method of back crossing was suitable for transferring resistant genes to commercial varieties with acceptable fruit size.

Among 35 cultivars of *Capsicum annuum* screened against tomato leaf curl bigemini virus causing leaf curl disease, five were found to be highly resistant (Gandhi *et al.,* 1995).

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

Munshi and Sharma (1996) screened 66 cultivars for resistance to leaf curl complex and 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 that no variety was free from infection. But Pusa Sadabahar, JM-218 and Pant C-2 showed only traces of infection.

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

Albejo (1999) evaluated 34 pepper cultivars for resistance to pepper leaf curl geminivirus and found that PCBO 67 was moderately resistant while 26 lines were moderately susceptible.

Screening of 33 chilli genotypes against leaf curl caused by thrips and mites showed that Sel 7-11-13-1 exhibited highest tolerance to leaf curl while the lowest incidence was recorded by Sel 4-1, followed by 7-11, 11-9 and 1-12 (Reddy *et al*., 2000).

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

Nandadevi and Hosamani (2003b) in a study on 6 x 6 diallel analysis 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 dominant variance was more than additive variance for resistance to leaf curl complex indicating the predominance of non-additive gene effects.

Sanap and Nawale (1987) observed the number of *Scirtothrips dorsalis* nymphs and *Polyphagotarsonemus latus* on 40 *Capsicum annuum* varieties and reported LIC 8 as resistant and Pant C1 and LEC 7 as moderately resistant to these pests.

In a field trial with several chilli varieties, Naitam *et al*. (1990) observed low leaf curl incidence by thrips and mites in Jwala and Pant CI. They also found that yield of these varieties were higher than the other varieties in the field trial.

Mallapur (2000) while evaluating 62 chilli genotypes for resistance to *Scirtothrips dorsalis* and yellow mite, observed that 13 varieties were showed lower percentage of leaf curl than local checks.

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

and LCA-312 were found to be promising sources of resistance against thrips and mites.

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

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

Echer *et al*. (2002) evaluated fifteen capsicum accessions, one hybrid and four pepper cultivars in greenhouse for resistance to the broad mite and ranked the accession BGH/UFV 1774 (*C. annuum*) and BGH/UFV 5086 (*C. frutescens*) as resistant and highly resistant respectively to *Polyphagotarsonemus latus* under severe testing conditions.

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

Leaya Jose *et al*. (2003) evaluated thirty seven genotypes of chilli to leaf curl virus under natural field conditions in Kerala. It was observed that the genotypes Alampady local-1, Nayattinkara local, Kottiyan local, Haripuram local, Pant C-1, Chandera local, Mangalapuram local and Kotti Kulam local were tolerant, 27 were susceptible and 2 were highly susceptible to the disease.

Desai *et al.* (2006) screened 21 chilli genotypes against yellow mite and ACG 77 found to be promising one on account of low pest population count and leaf curl intensity.

Ambika *et al*. (2008) screened sixteen cultivars in field condition for yellow mite resistance. Based on mean population count, intensity of leaf curling and grading index, cultivars Pusa Sadabahar and Pusa Jwala were identified as resistant to yellow mite.

Reddy *et al.* (2008) screened 50 genotypes to identify resistance source against chilli thrips and mites. Based on population count and damage intensity, genotype HS-HP154 and DCL-352 were found to be tolerant to chilli thrips and mite respectively whereas the genotype Poonkulam local was resistant to both chilli thrips and yellow mite.

Rishi *et al.* (2008) observed the increased quantity of phenolics in the infected plant leaves of the chilli being contributing to the resistance against pathogen (viral infection).

Chilli varieties Bhagyalakshmi (G_4), Kiran and Bhaskar were found to be tolerant to chilli thrips and yellow mite (www.ikisan.com).

Lekshmi S. L. (2012) reported in paprika (*Capsicum annuum* L.) that, bacterial wilt and leaf curl virus incidence among the 53 accessions studied, CA 33, CA 34, CA 35 and CA 47 recorded fewer incidences of both diseases.

Prathibha *et al.* (2013) observed, the quality parameters of chilli fruits such as capsaicin, oleoresin and phenol contents were reduced significantly in infected fruits as compared to healthy fruits. However, phenol content reduction was relatively high as compare to capsaicin and oleoresin. The extent of reduction of phenol content varied from 16 to 69 %, reduction in capsaicin varied from 20 to 60 % and oleoresin varied from 17 to 55 %.

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Heterosis and combining ability analysis to leaf curl virus in chilli" was carried out in the Department of Plant breeding and Genetics, College of Agriculture, Vellayani, during 2012-2014.

3.1 EXPERIMENTAL MATERIALS

High yielding varieties released by Kerala Agricultural University and leaf curl virus disease tolerant or resistant varieties from ICAR Institutes and NBPGR were collected and used as experimental materials.

3.2 METHODS

3.2.1 Experiment 1 (Pot culture)

3.2.1.1 *Establishment of Crossing Block*

a)Selfing

Seeds of ten parents were collected and used for raising plants for developing selfed seeds. For getting selfed seeds plants containing mature flower buds which would open on the next day were selected and these were protected with butter paper cover, labelled in the evening and these covers were retained till the end of fruit setting. At maturity labelled fruits were harvested and dried and seeds were extracted and stored properly to use it for the next experiment.

b) Crossing

Based on the performance, six parents – four high yielding, leaf curl virus susceptible varieties and two leaf curl virus resistant/tolerant types (Table 1) were raised and crossed in a diallel pattern and 30 F_1 combinations including reciprocals were produced. The crossing technique consisted of hand emasculation and artificial pollination. Selected proper sized and matured flower buds from new flush of both male and female parent plants. In the female parent, the selected mature flower buds

were emasculated and protected with butter paper cover. In the male parent, the selected mature flower buds were protected with butter paper cover in the evening between 4.00 pm to 6.00 pm. The emasculated flowers of the female parent plants were pollinated during the next day morning between 7.30 am to 9.00 am by brushing the pollen collected from selected male parent plant on the stigmatic surface of the emasculated flowers of female parent plant. Butter paper covers were used for protecting after pollination and the pedicel of each pollinated flower was tied with label bearing the information of name of female and male parents, date and time of crossing. At maturity, labelled and crossed fruits from the female parent plants were harvested and seeds were extracted and stored properly to use for the next experiment.

Table 1. Details of parents and their characteristics

Sl. No	Parent	Characters
1	Ujwala	High yielding, erect fruits, green fruits with high pungency and borne in clusters, average yield - 18t/ha. Released by KAU.
2	Anugraha	High yielding, fruits are medium long, medium pungent, pendulous and light green in colour, average yield - 27t/ha Released by KAU.
3	Vellayani Athulya	High yielding, early maturing, shade tolerant, green chilli variety with light green, medium pungent fruits having excellent quality, average yield - 32t/ha Released by KAU.
4	Jwalasakhi	Plants are dwarf, fruits are long, pendulous, succulent, and low pungent, average yield - 19.6t/ha Released by KAU.
5	Pant C 1	Plant is short stature with more primary branches. Fruits

		are erect and short, tolerant to leaf curl virus disease, average yield - 20t/ha. Released from G.B. Pant University of Agriculture and Technology.
6	Pusa Sadabahar	Fruit erect 6-8 cm in cluster, 6-14 per cluster, resistant to Chilli Mosaic Virus, Tobacco Mosaic Virus and leaf curl virus disease, yield - 30t/ha Released from IARI, Pusa, New Delhi.

3.2.2 Experiment 2 (Field experiment)

Field experiment to evaluate the performance of six parents and 30 F_1 diallel crosses (Table 2) with respect to various quantitative and qualitative characters together with natural screening for leaf curl virus disease resistance was carried out, during summer season.

3.2.2.1 *Raising of Seedlings*

The seedlings were raised in portrays by using potting mixture. Recommended plant protection measures were taken up before and after sowing the seeds.

3.2.2.2 *Field Preparation*

The experimental plots were ploughed, removed weeds and brought into the fine tilth. The FYM and recommended dose of fertilizers were incorporated into the soil

3.2.2.3 *Layout of the Experiment*

Design : RBD

Treatments : 36 (30 F1's and 6 parents)

Replications : 3

Table 2: List of cross combinations

Sl. No.	CROSS COMBINATIONS	
1	P1 X P2	Ujwala x Anugraha
2	P1 X P3	Ujwala x Vellayani Athulya
3	P1 X P4	Ujwala x Jwalasakhi
4	P1 X P5	Ujwala x Pant C 1
5	P1 X P6	Ujwala x Pusa Sadabahar
6	P2 X P1	Anugraha x Ujwala
7	P2 X P3	Anugraha x Vellayani Athulya
8	P2 X P4	Anugraha x Jwalasakhi
9	P2 X P5	Anugraha x Pant C 1
10	P2 X P6	Anugraha x Pusa Sadabahar
11	P3 X P1	Vellayani Athulya x Ujwala
12	P3 X P2	Vellayani Athulya x Anugraha
13	P3 X P4	Vellayani Athulya x Jwalasakhi
14	P3 X P5	Vellayani Athulya x Pusa Sadabahar
15	P3 X P6	Vellayani Athulya x Pant C1
16	P4 X P1	Jwalasakhi x Ujwala
17	P4 X P2	Jwalasakhi x Anugraha
18	P4 X P3	Jwalasakhi x Vellayani Athulya
19	P4 X P5	Jwalasakhi x Pusa Sadabahar
20	P4 X P6	Jwalasakhi x Pant C1
21	P5 X P1	Pant C1 x Ujwala
22	P5 X P2	Pant C1 x Anugraha
23	P5 X P3	Pant C1 x Vellayani Athulya
24	P5 X P4	Pant C1 x Jwalasakhi
25	P5 X P6	Pant C1 x Pusa Sadabahar
26	P6 X P1	Pusa Sadabahar x Ujwala
27	P6 X P2	Pusa Sadabahar x Anugraha
28	P6 X P3	Pusa Sadabahar x Vellayani Athulya
29	P6 X P4	Pusa Sadabahar x Jwalasakhi
30	P6 X P5	Pusa Sadabahar x Pant C1

Plate 1: Scoring scale based on severity of leaf curl virus disease

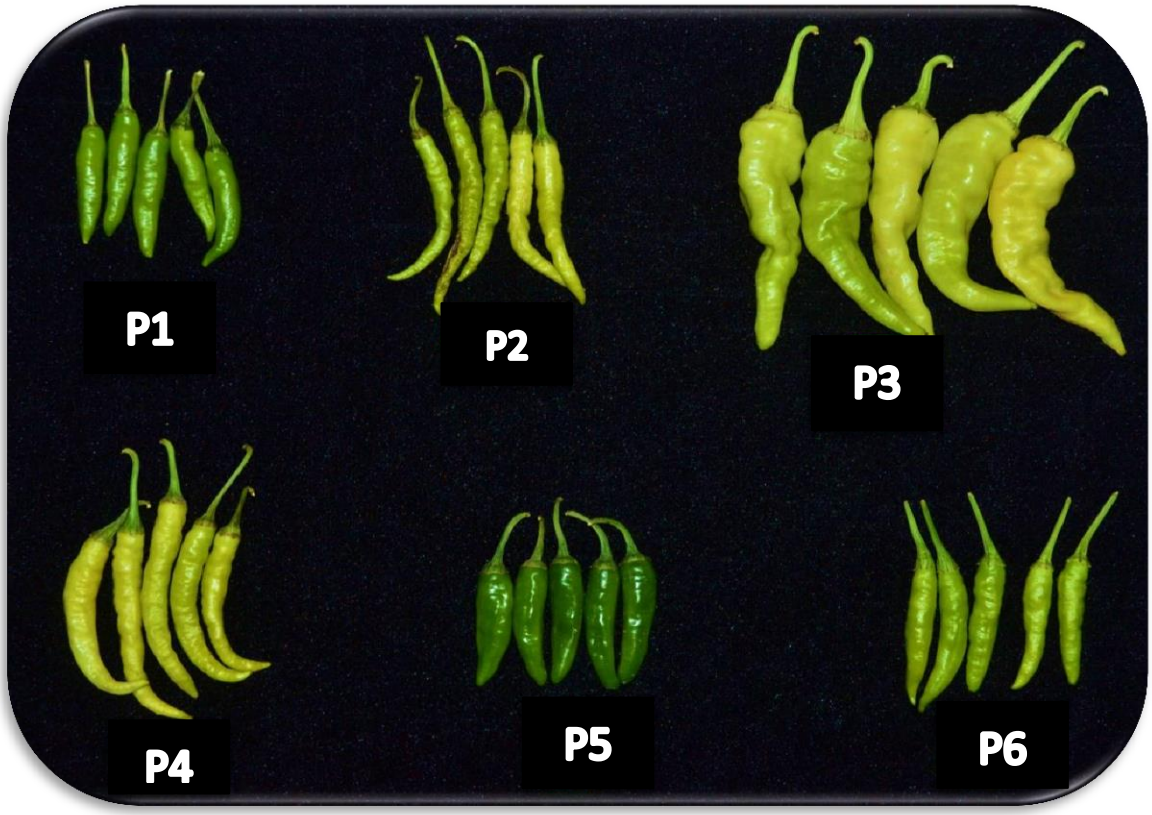

Plate 2: (a) Parents (fruits) used as experimental material

UJWALA (P1)

ANUGRAHA (P2)

VELLAYANI ATHULYA (P3)

JWALASAKHI (P4)

PANT C 1 (P5)

PUSA SADABAHAR (P6)

Plate 2: (b) Parents (Plants) used as experimental material

Plate 3: Experimental Field View

Spacing : 45 x 45 cm

Plot size : 4.5m^2

The crop management was followed as per package of practices recommendations of Kerala Agricultural University (KAU, 2011), without the application of plant protection chemicals.

Spraying of insecticides in the field was avoided.

3.2.2.4 *Biometrical Observations*

Five plants were randomly selected per treatment per replication for recording observations and the mean values are worked out. For recording observations on fruit characters, five fruits were selected at random from each treatment in each replication.

Observations on the following characters were recorded.

3.2.2.4.1 Plant Characters

a. Plant Height (cm)

Measured from the ground level to the tip of the plant at the time of final harvest using meter scale.

b. Number of Branches per Plant

Branches arising from the main stem were counted.

c. Number of Fruits per Plant

Total number of fruits produced per plant was recorded.

d. Average Fruit Length (cm)

Distance from the point of pedicel attachment to the fruit apex.

e. Average Fruit Girth (cm)

Measured using twine and scale at the position of maximum width of the fruit.

f. ***Fruit Weight (g)***

Average weight per plant in a treatment was estimated.

g. Yield per Plot (kg)

The total weight of fruits harvested from each plot was recorded.

3.2.2.4.2 ***Quality Characters***

a. Total Soluble Protein Content (mg/g)

The protein content of fresh leaf was estimated by the method developed by Lowry *et al.* (1951). 500 mg of leaf material was ground well with pestle and mortar in 10ml of buffer. 0.1 and 0.2 ml of supernatant was used for protein estimation and the residue was discarded. The volume was made up to 1ml and was allowed to stand for 10 minutes after adding 5 ml of alkaline copper solution. To this 0.5ml of Folin-Ciocalteau's reagent was added, mixed well and incubated at room temperature in dark for 30 minutes. The intensity of blue colour developed was read at 660 nm using spectrophotometer. Protein contents of different samples were calculated by referring to the standard curve which was prepared using bovine serum albumin and expressed as mg of protein per gram of sample.

b. ***Total Chlorophyll Content (mg/g)***

The total chlorophyll content of leaf was estimated by DMSO method. 500 mg of leaf material was cut into small bits and taken in a test tube into which 10ml of DMSO: 80% acetone mixture (1:1) was added and incubated overnight at room temperature. Coloured solution was decanted and by using measuring cylinder volume was made up to 25 ml by adding DMSO – acetone mixture. Absorbance was recorded at 645 and 663 nm using spectrophotometer. The amount of pigment was calculated by using the following formula and expressed as mg of chlorophyll per g of fresh leaf.

$$\text{mg of chlorophyll per g of fresh leaf} = [8.02(A_{663}) + 20.2(A_{645})] \frac{V}{1000 \times W}$$

Where,

A = absorbance at specific wavelengths

V = final volume of chlorophyll extract

and W = fresh weight of tissue extracted.

c. Phenol Content (µg/ml)

Phenol content was estimated using the Folin-ciocalteau reagent technique (Singelton *et al*., 1999). In this method 500 mg of dry chilli powder was added with ten times the volume of 80 per cent ethanol. The homogenate was centrifuged at 10,000 rpm for 20 minutes, the supernatant was saved and the residue re-extracted with five times the volume of 80 per cent ethanol, centrifuged and supernatant was dissolved. The supernatant was evaporated to dryness and the residue was dissolved in a known volume of distilled water. Different aliquots were pipetted out into test tubes and volume was made up to 3 ml in each tube with water. 0.5 ml of Folin-ciocalteau reagent was added and after 3 min, 2ml of 20 per cent Na_2CO_3 solution was added to each tube. The contents were mixed thoroughly and the tubes were placed in boiling water for one minute. After cooling, absorbance was measured at 650 nm against a blank reagent.

A standard curve was plotted using different concentrations of catechol. From standard curve, the concentration of phenol in the test sample was determined.

d. Epicuticular Wax Content (mg/g)

Fresh leaves were collected, made into bits of uniform size of $10cm^2$ and 3 bits were taken. In a beaker with 10ml of chloroform, leaf bits were dipped for 10 to 15 seconds, after removing leaf bits, chloroform was kept for evaporation. After some period of time the pre weighed Eppendorf tubes were taken and remaining

chloroform was transferred and kept for complete evaporation. Difference in the final and initial weights of Eppendorf tubes was estimated as the amount of wax present in sample.

e. Total Carbohydrate Content (mg glucose/100 g sample)

The total carbohydrate of fresh leaves was estimated by Anthrone method (Hedge and Hofreiter, 1962). 100mg of sample was weighed into a boiling tube. It was hydrolysed by keeping it in a boiling water bath for three hours with 5ml of 2.5 N HCl and cooled to room temperature. The volume was made up to 100ml after neutralizing it with solid sodium carbonate. 0.5 and 1ml of supernatant were used for estimation of carbohydrates. The volume was made up to 1ml and 4ml of anthrone reagent was added. After heating for 8 minutes, it was cooled rapidly and the optical density of the green to dark green colour was read in spectrophotometer at 630 nm. The amount of carbohydrate present in the sample was estimated using the standard curve prepared from standard glucose and amount of carbohydrate as mg per 100 g of sample was computed as:

$$\frac{\text{mg of glucose}}{\text{Volume of test sample}} \times 100$$

f. Poly Phenol Oxidase (activity/µg/minute)

Catechol activity was estimated by Esterbauer *et al*. (1977) method.

Reagents: Tris HCl (50 mM, pH 7.2) containing sorbitol (0.4 M) and NaCl (10 mM), Phosphate buffer (0.1 M, pH 6.5) and catechol solution (0.01M).

Procedure:

1. Preparation of enzyme extract

The enzyme extract was prepared by homogenizing 0.5 g of plant tissue in 2 ml containing Tris HCl, sorbitol and NaCl. The homogenate was centrifuged at 2000rpm for 10 minutes and supernatant was used for assay.

2. Assay

2.5 ml of phosphate buffer and 0.3 ml of catechol solution were added in the cuvette and read at 495 nm. The enzyme extract (0.2 ml) was added and change in absorbance was recorded for every 30 seconds upto 5 minutes in a spectrophotometer. One unit of catechol oxidase is defined as the amount of enzyme that transforms 1µ mole of dihydrophenol to 1µ mole of quinone per minute.

The activity was calculated by using the following formula,

Enzyme units in sample = K x ($\triangle$A / minute)

Where, K = catechol oxidase (0.272)

$\triangle$A = change in absorbance values

g. Membrane Integrity

Membrane integrity is assessed in terms of % leakage. Fully expanded leaves were excised with their petioles intact in water, allowed to regain turgidity by incubating in water for 45 minutes and then turgid weight was recorded. Allowed to wilt for 3 hours, after loss of 40 to 60 % of their fresh weight leaf punches of 1 cm diameter were taken and blotted on clean filter paper. Ten leaf punches were incubated in beaker with 20 ml distilled water for 3 hours. Leakage of solutes in the bathing medium was estimated by recording its absorbance at 273 nm and was noted as initial leakage of solutes. Further beakers were incubated in hot water bath of 100˚C for 15 minutes. Again absorbance was read at 273 nm and was noted as final absorbance of bathing medium.

$$\% \text{ leakage} = \frac{\text{Initial absorbance of bathing medium}}{\text{Final absorbance of bathing medium}} \times 100$$

h. Carotenoids Content (mg/g)

The carotenoids content of leaf was estimated by DMSO method. 500 mg of leaf material was cut into small bits and taken in a test tube into which 10ml of DMSO: 80% acetone mixture (1:1) was added and incubated overnight at room temperature. Coloured solution was decanted and by using measuring cylinder volume was made up to 25 ml by adding DMSO – acetone mixture. Absorbance was recorded at 480 and 510 nm using spectrophotometer. The amount of pigment was calculated by using the following formula and expressed as mg of carotenoids per g of fresh leaf.

$$\text{Carotenoids} = \frac{(7.6 \times A_{480}) - (1.49 \times A_{510}) \times V}{W \times 1000}$$

Where, A = absorbance at specific wavelengths

V = final volume of chlorophyll extract

and W = fresh weight of tissue extracted.

i. Capsaicin (%)

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

Reagents:

i) Folin-Dennis reagent

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

ii) 25% aqueous sodium carbonate solution

iii) Acetone

Procedure

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

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

j. Ascorbic Acid (mg per 100g fresh fruit weight)

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

Reagents:

1. Oxalic acid (4 %)

2. Ascorbic acid standard

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

3. 2, 6-dichlorophenol indophenol dye

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

4**.** Working standard

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

Procedure

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

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

Ascorbic acid content of the sample was calculated using the formula

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

k. Oleoresin (%)

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

Procedure

Chilli fruits harvested at red ripe stage were dried in a hot air oven at 50^{o}C and powdered finely in a mixer grinder. Weighed two grams of chilli powder and packed in filter paper and placed in Soxhlet's apparatus. 200 ml of acetone was taken in the

round bottom flask of the apparatus and heated in a water bath. The temperature was maintained at the boiling point of the solvent (around 60^{o}C). After complete extraction (4 - 5hours) the solvent was evaporated to dryness.

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

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

L. Incidence of Leaf Curl Virus Disease

Leaf curl virus disease scoring was done at 30th, 60th and 90th days after planting (DAP) based on visual observations. The scoring was based on a scale of 0 to 4 as proposed by Rajamony *et al*., (1990) in melons with slight modifications (Table 3). This was done according to the characteristic symptom of each observational plant (Plate 1).

Table 3: Scoring index for chilli leaf curl virus disease symptom.

Score Index	Symptoms
0	No symptoms
1	Slight curling of terminal leaves
2	Curling of terminal and adjacent 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 work out the severity index or vulnerability index 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 bean (*Phaseolus vulgaris)* to beet curly top virus and later modified by Bos (1982).

$$\text{Vulnerability index (V.I)} = \frac{(0n_o+1n_1+2n_2+3n_3+4n_4) \times 100}{n_t\,(n_c-1)}$$

Where,

n_o, n_1, - - -, n_4 = number of plants in the category 0, 1, - - -, 4 respectively

n_t = total number of plants

n_c = total number of categories = 4

The genotypes were classified according to vulnerability index as,

V.I	**Category**
0.0	Resistant(R)
1.0- 25.00	Tolerant (T)
25.01- 50.00	Susceptible(S)
>50.00	Highly susceptible (HS)

j. Incidence of Thrips

Number of thrips from three leaves per plant, one each from top, middle and bottom regions of five plants selected at random was counted using stereo binocular microscope. Adults are swift in movement and fly away while counting. Therefore to avoid errors in thrips count only nymphs were considered for recording observations. The observation was taken at 30^{th}, 60^{th} and 90^{th} days after transplanting (DAT)

k. Incidence of Mites

Number of mites on six terminal leaves of five randomly selected plants in each plot was recorded using stereo binocular microscope. The observation was taken at 30^{th}, 60th and 90^{th} days after transplanting (DAT).

l. Incidence of Aphids

Number of aphids on six terminal leaves of five randomly selected plants in each plot was recorded. The observation was taken at 30^{th}, 60^{th} and 90^{th} days after transplanting (DAT)

3.2.2.5 Statistical Analysis

Data recorded from experimental plants were statistically analysed.

3.2.2.5.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) for individual character was carried out on the basis of mean value per treatment per replication in Randomized Block Design (RBD). The model of analysis of variance for RBD was as given below.

Sources of variation	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F ratio**
Replications	t-1	SSR	MSR	MSR/MSE
Treatment	r-1	SST	MST	MST/MSE
Error	(r-1)(t-1	SSE	MSE	
Total	rt-1			

Where,

r = number of replications t = number of treatments

MSR=mean squares for replication SSR=sum of squares for replications

MST=mean squares for treatments SSR=sum of squares for treatments

MSE=mean squares for error SSR=sum of squares for error

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

Where,

tα is the table value of students' t distribution at error degrees of freedom and α is the level of significance (5 % or 1%), (Panse and sukhatme, 1985)

3.2.2.5.2 Estimation of Heterosis

Per cent heterosis of the derived F_1 over mid parent (MP) – Relative heterosis, better parent (BP) - Heterobeltosis and standard commercial varieties – Standard heterosis was calculated as per the method of Turner (1953) and Hayes *et al.* (1956).

Parent Ujwala was considered as standard commercial variety for calculating standard heterosis for all the characters.

Heterosis for each trait was computed by using following formulae.

$$\text{Percent heterosis over mid parent (MP) (Relative heterosis)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{where mid parent} = \frac{\overline{P_1} + \overline{P_2}}{2}$$

$$\text{Percent heterosis over better parent (BP) (Heterobeltosis)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Percent heterosis over standard commercial variety(SH) (Standard heterosis)} = \frac{\overline{F_1} - \overline{SV}}{\overline{SV}} \times 100$$

Where,

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

BP= mean value of better parent of the particular cross.

SV= standard commercial variety.

Test of Significance: Test of significance was done by comparing the mean deviation with values of critical difference (CD) obtained separately for $\overline{MP}$, $\overline{BP}$ and $\overline{SV}$ by using the following formula.

$$\text{SE for Relative heterosis} = \sqrt{\frac{3 \times MSe}{2r}}$$

$$\text{SE for Heterobeltosis \& SH} = \sqrt{\frac{2 \times MSe}{r}}$$

Test of significance: 't' value for RH = $(F_1 - MP) / SE$

't' value for HB =$(F_1 - BP) / SE$

't' value for SH =$(F_1 - SV) / SE$

3.2.2.5.3 Analysis for Variance for Combining Ability

The mean of three replications computed for the hybrids and parents for ten characters was subjected to statistical analysis and variance due to different sources was worked out as per the method outlined by Griffing (1956) as follows.

Source	Degree of freedom	Mean sum of squares
Replication	(*r-1)*	MSR
Treatment	(t-*1)*	MST
Parents	(*p-1)*	MSP
Crosses	(*c-1)*	MSC
Parents Vs crosses	*1*	MSPC
Error	(r-*1)* (*t-1)*	MSE
Total	(*rt-1)*	

Where,

r = number of replications

t =number of treatments

p = number of parents

c = number of crosses

3.2.2.5.4 ANOVA for Combining Ability

The mean of each character for each entry was subjected to diallel analysis and the variance of general combining ability of parent and specific combining of different cross combinations was estimated by the procedure developed by Griffing (1956). The method and model of diallele analysis followed is explained below.

Method 1: It includes parents p^2, treatments and reciprocal crosses with full diallele analysis

Model 1: (Fixed effect model): the experimental material includes a set of fixed inbreds or varieties as parents.

The degrees of freedom and formulae followed to work out sum of squares due to various sources of variation for combining ability analysis with required to method 1 diallele analysis is as follows,

Method 1 ANOVA for combining ability

Source	**degree of freedom**	**Sum of Squares**	**Mean sum of squares**
gca	p-1	SSgca	Mg
sca	$\frac{p(p-1)}{2}$	SSsca	Ms
RCA	$\frac{p(p-1)}{2}$	SSRCA	Mr
Error		SSE	Me’
Total	p^2-1		

Me’= MSE / r = MSE taken from ANOVA table.

3.2.2.5.5 Genetic Component of Variance

Variance due to gca = $1 / (p-1) \sum gi^2 = (Mg – Me’) / 2p$

Variance due to sca = $2 / (p-1) \sum\sum Sij^2 = (Ms – Me’)$

Ratio of gca variance to sca variance and relative significance of additive as well as non-additive genetic variance were estimated.

Ratio of gca variance to sca variance, <1 = dominance gene action

Ratio of gca variance to sca variance, >1 = additive gene action

3.2.2.5.6 Combining Ability Effects

gca effect of parents (gi) = $1/ 2P (Yi. + Y.j) – Y../p^2$

sca effect of hybrids (sij) = $1/ 2 (Yij + Yji) – 1/2P(Yi. + Y.j + Y.i + Y j.) + Y../p^2$

Where,

Y.. = grand total of all hybrids

Yi. = row total of i^{th} parent

Y.i =column total of i^{th} parent

Y.j =column total of j^{th} parent

Yj. =row total of j^{th} parent

Yj. =row total of j^{th} parent

Yij =mean total of ij^{th} hybrid

Yji =reciprocal value of ij^{th} hybrid

p =number of parents involved

Significance of effects was estimated by ‘t’ test.

SE for gca effect of parents, (SE gi) $= \sqrt{\frac{(p-1)\, Me'}{2\, p^2}}$

SE for sca effect of hybrids, (SE Sij) $= \sqrt{\frac{(p^2-2p+2)\, Me'}{2\, p^2}}$

Significance of gca and sca effects was tested using the following formula,

t = effect / SE

t of gca effect = gi / SEgi

t of sca effect = Sij / SE Sij

Calculated 't' value was compared with the table value of 't' at error degrees of freedom.

Significant gca effect – parent is suitable to use in breeding programme.

Significant sca effect – hybrid is suitable for further breeding programme.

3.2.3 Experiment 3 – Pot culture

3.2.3.1 Materials

Leaf curl virus disease resistant hybrids selected from field experiment were subjected to vector transmission studies in insect proof house to confirm disease resistance through acquisition feeding.

Lay out

Season	summer
Design	CRD
Treatments	tolerant/resistant hybrids
Replications	3

3.2.3.2 Methods

3.2.3.2.1 Raising of Seedlings in Pots

The pot culture experiment was carried out in insect proof cage. After twenty days seedlings were transplanted to 30 cm earthen pots containing potting mixture prepared in 2:1:2 proportions of soil sand and compost.

3.2.3.2.2 Vector (whitefly) Transmission Method

An aspirator made with glass tube (30 cm long and 0.5 cm in diameter) was used for the collection of whiteflies. By turning the leaves slightly upward the whiteflies were sucked into the aspirator. The whiteflies were later transferred in to the cages for acquisition feeding. Source of vector collection from chilli plants showing symptoms in the field.

3.2.3.2.3 Acquisition Feeding

A 35 cm long plastic bottle with 7.5 diameters at one end and tapering towards narrow mouth was used to prepare cages for LCV acquisition. The bottom portion of bottle was removed with the help of knife or axel blade and was covered with muslin cloth. The LCV infected chilli branch was inserted in to the bottle and then closed with cotton plug. Acquisition access feeding from 24 hours period was given. After the acquisition access period, the viruliferous whiteflies were removed and allowed to feed on healthy seedlings, at the rate of 10 whiteflies per seedling

3.2.3.2.4 Inoculation of Seedlings

Plastic bottles of 15.0 cm long with 5.0 cm diameter were taken and the bottom and top portion was removed with the help of knife or blade. Muslin cloth was fixed to the removed top portion which helped to avoid accumulation of excess moisture inside the cage and also escape of whiteflies. The viruliferous whiteflies were released in to the cage and placed over the young seedling. For grownup seedlings/plants the bottom end of the cages were plugged with cotton after inserting the young leaflets in to the tube and the cages were tied to sticks with a rubber band.

3.2.3.2.5 Design

The design was CRD. Plants of 5 selected hybrids (treatments) were kept in 5 replication @ 2 plants per replication.

3.2.3.2.6 Observations

Genotypes were classified according to the calculation of vulnerability index as follows, (Rajamony *et al.*, 1990)

V.I	Category
0.0	Resistant(R)
1.0-25.00	Tolerant (T)
25.01- 50.00	Susceptible(S)
>50.00	Highly susceptible (HS)

3.2.3.2.7 ***Statistical Analysis***

3.2.3.2.7.1 Completely Randomized Design (CRD)

Completely Randomized Design was followed for laboratory screening experiment (Panse and Sukhatme, 1985).

ANOVA for Completely Randomized Design

Source	degree of freedom	Sum of Squares	Mean sum of squares	F -value
Between treatments	t-1	SST	MST	MST/MSE
Error	t(r-1)	SSE	MSE	
Total	rt-1			

Where,

r = number of replications

t = number of treatments

SST =sum of squares for treatments

SSE =sum of squares for errors

MST = mean squares for treatments

MSE = mean squares for errors.

$$\text{Critical difference, CD} = t\alpha\sqrt{\frac{2 \times MSE}{r}}$$

Where,

tα is the table value of students' t distribution at error degrees of freedom and α is the level of significance (5 % or 1%), (Panse and sukhatme, 1985)

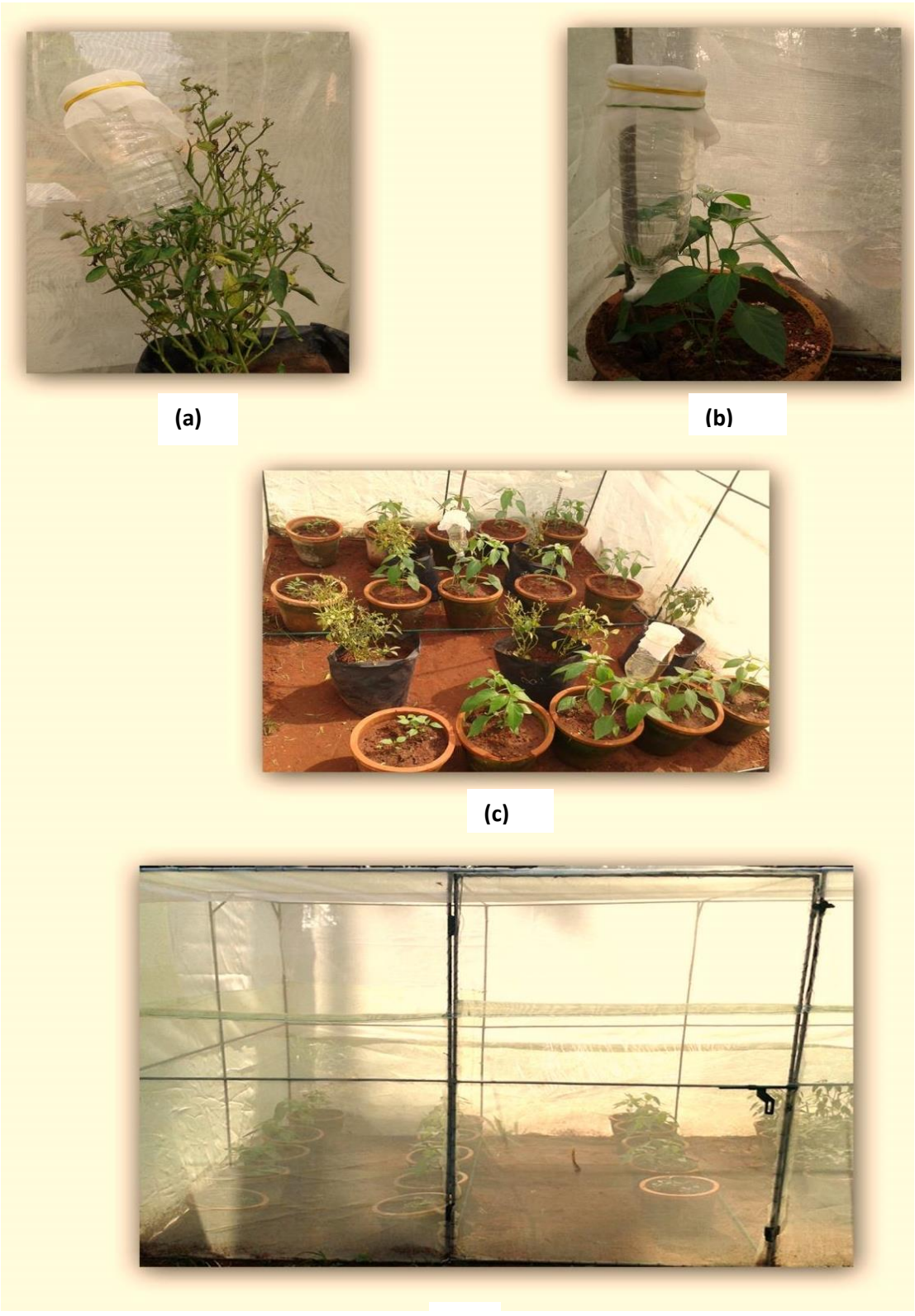

Plate 4: Artificial screening

(a) Acquisition of virus by whiteflies from diseased plant
(b) Inoculation of virus to chilli plant seedlings by release of whitefly
(c) & (d) General view of the experiment.

Results

4. RESULTS

In an experiment on combining ability analysis 6 parents were crossed in a diallel pattern and the resultant 30 F_1 hybrids and 6 parents were evaluated by following full diallel mating design to identify the best general combiners and specific combiners for developing superior cross combinations and to study the inheritance pattern of yield, yield attributes, qualitative traits and resistance to leaf curl virus disease.

The analysis of variance carried out for the yield and its component characters revealed that the variance due to treatments was found highly significant for all the characters studied. The parents and hybrids exhibited highly significant variation for all the characters. (Table 5)

4.1 HETEROSIS

The mean performance of parents and hybrids obtained for different traits were compared with the corresponding mid-parent (MP), better parent (BP) and standard variety Ujwala for the estimation of heterosis and the differences are being expressed as per cent heterosis (Table 4 & 6) and the results obtained are presented below.

4.1.1 Plant Height (cm)

The mean performance among parents ranged from 47.17 cm (P5) to 67.33 cm (P1) and among hybrids varied from 55.33 cm (P5 x P2) to 117.0 cm (P6 x P4).

The mid-parent heterosis (Relative heterosis) ranged from -5.33 per cent (P2 x P1) to 96.25 per cent (P6 x P4). 28 hybrids recorded positive heterosis of which, 22 hybrids recorded highly significant positive heterosis. The range of heterobeltiosis was from -16.83 per cent (P2 x P1) to 83.96 per cent (P6 x P4). A total of 26 hybrids

recorded positive heterosis of which, 16 hybrids recorded highly significant positive heterosis.

Many hybrids recorded heterosis in positive direction over the standard variety. The range of standard heterosis over the check variety was from -16.83 per cent (P2 x P1) to 73.76 per cent (P6 x P4).

4.1.2 Number of Branches per Plant

The mean performance among parents ranged from 3.33 (P1 and P2) to 5.33 (P4) and among hybrids ranged from 5.33 (P1 x P5) to 12.67 (P2 x P6).

The mid-parent heterosis was ranged from 26.67 per cent (P5 x P4) to 204.0 per cent (P2 x P6). All hybrids recorded positive heterosis of which, 27 hybrids recorded highly significant heterosis.

The maximum heterobeltiosis (153.33 per cent) was recorded by the cross P2 x P6 and minimum (6.67 percent) by the cross P6 x P1.

The positive heterosis over standard check was recorded by all 30 hybrids. Heterosis was ranged from 0 percent (P1 x P5 and P6 x P1) to 137.5 percent (P2 x P6). Out of 30 hybrids 16 hybrids exhibited significant heterosis. Cross P2 x P6 showed highest percent value in all types of heterosis.

4.1.3 Number of Fruits per Plant

The mean performance ranged from 21.74 (P4) to 57.48 (P1) among parents and 26.11 (P3 x P2) to 240.50 (P6 x P4) among hybrids.

Heterosis ranged from -29.19 (P3 x P5) to 383.69 per cent (P6 x P5) and -51.67 (P3 x P5) to 209.52 per cent (P6 x P4) over mid-parent and better parent

respectively and from -66.40 (P3 x P2) to 209.52 (P6 x P4) per cent over the standard variety Ujwala.

Among 30 hybrids, 24 exhibited significant positive heterosis over mid-parent, 18 over better parent and 10 over check variety.

4.1.4 Average Fruit Length (cm)

Among parents it varied from 4.9 cm (P1) to 9.1 cm (P3). However in hybrids it ranged from 5.3 cm (P1 xP3) to 14.6 cm (P4 x P5).

The extent of heterosis exhibited by the hybrids over their mid-parent ranged from -24.29 (P1 x P3) to 156.89 per cent (P4 x P5) and over better parent ranged from -41.70 (P1 xP3) to 135.48 per cent (P4 xP5). The standard heterosis was ranged from -41.76 (P1 x P3) to 60.44 per cent (P4 xP5).

Among 30 hybrids, 19 over mid-parent, 15 over better parent and 14 over commercial check exhibited significant positive heterosis.

4.1.5 Average Fruit Girth (cm)

It varied significantly among the parents and hybrids and ranged from 2.67 cm (P2) to 6.13 cm (P3) among the parents and 2.73 cm (P3 x P5) to 7.80 cm (P3 x P4) among the crosses.

The maximum positive heterosis over the mid-parent was observed in the cross P2 x P6 (106.15 per cent), over the better parent in the cross P4 x P5 (95.61 per cent) and over check in the cross P3 x P4 (27.17 per cent).

Out of 30 hybrids, 13 hybrids over mid-parent, 9 hybrids over better parent and 3 hybrids over check recorded significant positive heterosis.

4.1.6 Fruit Weight (g)

Among parents, maximum mean fruit weight was noticed in P3 (6.52 g) and minimum in P1 (2.14 g) while among hybrids, maximum in P3 x P6 (11.77 g) and minimum in P1 x P6 (1.99 g).

The magnitude of heterosis over mid-parent, better parent and standard variety was found highly significant and it was maximum and positive over mid-parent (177.59) and better parent (155.15) in the cross P2 xP1 and over standard variety (80.56) in the cross P3 xP6.

4.1.7 Yield per Plot (kg)

Mean performance for fruit yield per plot varied from 1.94 kg (P2) to 6.35 kg (P6) among the parents and from 2.77 kg (P4 x P2) to 52.60 kg (P3 x P6) among hybrids.

Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions. Maximum significant positive heterosis was observed in the cross P5 x P3 over mid-parent (1005.14 percent) and over better parent (951.91 percent) and in the cross P3 x P6 over commercial check (728.90 percent). Among 30 crosses, 25 crosses over check exhibited positive and significant heterosis.

4.1.8 Total Soluble Protein Content (mg/g)

Among the parents, maximum total soluble protein content was noticed in P6 (1.32 mg/g) and minimum in P2 (0.66 mg/g) while among hybrids, maximum in the cross P5 x P3 (1.84 mg/g) and minimum in the cross P2 x P4 (0.68 mg/g).

The magnitude of all the heterosis were found highly significant in both the directions. Maximum positive heterosis per cent over mid-parent (114.37), better parent (90.34) and check variety (39.75) was observed in the cross P5 x P3.

4.1.9 Total Chlorophyll Content (mg/g)

The parental values varied from 1.04 mg/g (P4) to 1.45 mg/g (P1). However, in the hybrids variation ranged from 0.83 mg/g (P4 x P1) to 1.72 mg/g (P3 x P6).

The magnitude of heterosis over mid-parent was ranged from -36.91 (P3 x P1) to 26.32 per cent (P3 x P6). Among 30 hybrids, 9 exhibited heterosis in highly significant and positive direction over mid-parent. The magnitude of heterosis over the better parent was ranged from -42.53 (P4 x P1) to 19.72 per cent (P3 x P6). Among 30 hybrids, 6 hybrids recorded highly significant positive heterosis over their respective better parent. The magnitude of heterosis over check was ranged from -42.53 (P4 x P1) to 18.62 per cent (P3 x P6).

4.1.10 Phenol Content (µg/ml)

The parental values had variation from 291.33 µg/ml (P2) to 622.67 µg/ml (P6). However, the hybrids had variation from 238.0 µg/ml (P4 x P1) to 736.0 µg/ml (P2 x P3).

Significant and maximum positive heterosis over the mid-parent, better parent and check variety was observed in the cross P2 x P3 (164.27, 152.63 and 18.20 per cent).

Significant and maximum negative heterosis over the mid-parent, better parent and check variety was observed in the cross P6 x P4 (-51.90, -61.78 and -61.78 per cent).

4.1.11 Epicuticular Wax Content (mg/g)

Among the parents variation was from 13.17 mg/g (P4) to 19.20 mg/g (P6). However among the hybrids the variation was from 5.53 mg/g (P5 x P6) to 22.40 mg/g (P2 x P4).

The significant and maximum positive heterosis over the mid-parent, better parent and check variety was observed in the cross P2 x P4 (69.06, 68.0 and 16.67 per cent).

The significant and maximum negative heterosis over the mid-parent, better parent and check variety was observed in the cross P5 x P6 (-64.90, -71.18 and -71.18 per cent).

4.1.12 Total CHO Content (mg glucose/100g)

Among the parents variation ranged from 59.53 mg/g (P1) to 98.39 mg/g (P6). However in hybrids the variation ranged from 39.22 mg/g (P3 x P5) to 110.50 mg/g (P6 x P4).

The significant and maximum positive heterosis over the mid-parent, better parent and check variety was observed in the cross P6 x P4 (38.75, 12.31 and 12.31 per cent).

The significant and maximum negative heterosis over the mid-parent, better parent and check variety was observed in the cross P3 x P5 (-47.56, -49.27 and -60.14 per cent).

4.1.13 Poly Phenol Oxidase (activity/µg/minute)

The parents had variation from 0.14 activity/µg/min. (P3) to 0.70 activity/µg/min. (P6). However, in the hybrids had variation from 0.20 activity/µg/min. (P4 x P2 and P4 x P3) to 0.88 activity/µg/min. (P6 x P4).

Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions. Maximum significant positive heterosis was observed in the cross P3 x P2 over mid-parent (133.66 per cent), better parent (82.01 per cent) and commercial check (25.33 per cent). Among 30 crosses, 9

crosses over mid-parent, 16 crosses over better parent and 21 crosses over check exhibited negative and significant heterosis.

4.1.14 Membrane Integrity

Membrane integrity is assessed in terms of % leakage. Higher the % leakage less will be the membrane integrity. The parental values varied from 36.26 percent (P6) to 66.65 percent (P2). However, in the hybrids values ranged from 31.30 percent (P6 x P4) to 70.97 percent (P3 x P4).

Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions. Maximum significant positive heterosis was observed in the cross P6 x P5 over mid-parent (44.74 per cent) and better parent (36.48 per cent) and in the cross P3 x P4 over commercial check (6.49 per cent). Among 30 crosses, 15 crosses over mid-parent, 10 crosses over better parent and 4 crosses over check exhibited positive and significant heterosis.

4.1.15 Carotenoids (mg/g)

Among the parents values varied from 0.42 mg/g (P1, P2, P3 and P6) to 0.43 mg/g (P4 and P5). However in hybrids the variation was ranged from 5.53 mg/g (P5 x P6) to 22.40 mg/g (P2 x P4).

The significant and maximum positive heterosis over the mid-parent, better parent and check variety was observed in the cross P3 x P1 (4.76, 4.76 and 2.33 percent).

The significant and maximum negative heterosis over the mid-parent, better parent and check variety was observed in the cross P3 x P6 (-3.17, -3.17 and -5.43 per cent).

4.1.16 Capsaicin (%)

Among the parents it was ranged from 0.96 % (P2) to 1.85 % (P1). Among the hybrids variation was from 0.94 % (P2 x P3) to 1.92 % (P5 x P6). Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions.

The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P6 x P4 (50.20 and 33.80 per cent) and over check in the cross P5 x P6 (3.60 percent).

The significant and maximum negative heterosis over the mid-parent and better parent was observed in the cross P1 x P2 (-29.94 and -46.76 per cent) and over check in the cross P2 x P3 (-49.10 per cent).

4.1.17 Vitamin C (mg/100 g)

Among the parents variation was ranged from 96.53 mg/100g (P2) to 196.06 mg/100g (P6). However in hybrids the variation ranged from 92.23 mg/100g (P2 x P3) to 214.00 mg/100g (P5 x P3).

The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P4 x P3 (86.12 and 77.10 per cent) and over check in the cross P5 x P3 (9.15 per cent).

The significant and maximum negative heterosis over the mid-parent and better parent was observed in the cross P1 x P2 (-29.94 and -46.76 per cent) and over check in the cross P2 x P3 (-49.10 per cent).

4.1.18 Oleoresin (%)

Among the parents variation for oleoresin ranged from 9.68 % (P2) to 16.66 % (P6). However in hybrids the variation ranged from 9.01% (P4 x P2) to 18.08 % (P6 x P4).

The extent of heterosis exhibited by the hybrids over their mid-parent ranged from -15.50 (P2 x P6) to 37.04 per cent (P1 x P5) and over better parent ranged from -33.19 (P2 x P6) to 21.72 per cent (P1 x P5). The standard heterosis over the check was ranged from -45.90 per cent (P4 x P2) to 8.52 per cent (P6 xP4).

Among 30 hybrids, 18 over mid-parent, 15 over better parent and 6 over check variety exhibited significant positive heterosis.

4.1.19 Incidence of Leaf Curl Disease (Vulnerability Index - V.I)

Among the parents V.I**.** values ranged from zero (P6) to 49.29 (P4). However in hybrids V.I**.** values ranged from zero (P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4) to 53.33 (P4 x P5).

The significant and maximum negative heterosis over the mid-parent, better parent and check was -100.00 (P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4). The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P5 x P6 (555.54 and 227.77 per cent) and over check in the cross P3 x P2 (8.19 percent). Among 30 hybrids, 13 over mid-parent, 19 over better parent and 29 over check exhibited significant negative heterosis.

4.1.20 Incidence of Thrips

Incidence of thrips was found to be negligible.

4.1.21 Incidence of Mites

Incidence of mites was found to be negligible.

4.1.22 Incidence of Aphids

Incidence of aphids was found to be negligible.

Table 4: Mean performance of Parents and crosses for different characters

TREATMENT	Plant Height (cm)	Number of branches per Plant	Number of fruits per Plant	Average Fruit Length (cm)	Average Fruit Girth (cm)	Fruit Weight (g)	Yield per Plot (kg)	Total Soluble Protein Content (mg/g)	Total Chlorophyll Content (mg/g)	Phenol Content (µg/ml)
P1	67.33	3.33	57.48	4.90	3.27	2.14	2.74	0.92	1.45	516.00
P2	50.97	3.33	34.10	7.13	2.67	2.56	1.94	0.66	1.29	291.33
P3	62.90	4.00	24.70	9.10	6.13	6.52	3.59	0.75	1.29	265.67
P4	55.63	5.33	21.74	6.20	3.47	5.78	2.79	1.03	1.04	367.00
P5	47.17	4.67	67.67	5.17	3.80	2.16	3.24	0.97	1.15	613.33
P6	63.60	5.00	77.70	5.73	3.83	3.66	6.35	1.32	1.44	622.67
P1XP2	68.20	6.33	94.23	7.17	3.30	3.99	8.34	0.79	1.31	410.33
P1XP3	70.83	7.00	63.68	5.30	2.93	6.08	8.60	1.03	1.27	240.00
P1XP4	62.80	6.67	62.68	11.40	4.67	5.20	7.23	1.30	0.86	354.00
P1XP5	67.77	5.33	92.47	5.37	3.73	2.11	4.33	1.17	1.09	390.33
P1XP6	72.83	8.33	193.45	11.57	3.63	1.99	8.57	1.35	1.09	562.33
P2XP1	56.00	6.00	94.23	8.03	3.47	6.52	13.64	0.91	1.15	340.33
P2XP3	60.83	7.33	61.99	11.80	3.00	7.12	9.78	1.00	1.09	736.00
P2XP4	60.77	10.33	56.89	5.47	5.93	3.34	4.21	0.68	1.29	339.67
P2XP5	68.43	10.33	90.11	7.90	3.60	2.12	4.24	1.28	0.98	312.00
P2XP6	80.90	12.67	85.57	7.40	6.70	5.24	9.97	1.08	1.14	475.33
P3XP1	65.77	6.67	58.47	9.17	3.23	5.36	6.96	1.07	0.86	629.67
P3XP2	73.03	6.67	26.11	12.27	7.40	6.17	3.58	0.92	1.02	309.00
P3XP4	84.17	6.67	26.67	10.37	7.80	11.44	6.77	1.05	1.00	389.33
P3XP5	87.00	8.67	32.70	10.17	2.73	9.19	6.68	0.98	1.43	619.00
P3XP6	110.47	9.00	201.21	11.90	3.17	11.77	52.60	1.62	1.72	524.67

Table 4: Continued….

P4XP1	69.03	6.67	103.65	9.23	5.30	3.33	7.67	1.46	0.83	386.33
P4XP2	65.20	9.67	42.00	10.40	3.83	2.96	2.77	0.80	1.09	384.67
P4XP3	63.90	6.67	34.97	6.20	3.87	9.78	7.56	1.08	1.17	364.00
P4XP5	85.30	8.33	83.30	14.60	7.43	3.97	7.35	1.04	1.17	549.67
P4XP6	65.43	9.67	194.01	8.47	3.43	3.71	15.96	1.57	1.04	445.33
P5XP1	56.30	6.67	80.31	5.57	3.07	2.27	4.03	0.72	0.84	355.00
P5XP2	55.33	10.67	107.37	8.50	3.90	4.87	11.63	1.07	1.06	349.33
P5XP3	87.57	8.67	184.50	6.53	4.57	9.22	37.75	1.84	1.42	352.00
P5XP4	67.40	6.33	79.44	8.77	6.30	3.44	6.58	0.91	1.23	395.00
P5XP6	107.23	10.00	166.41	7.20	4.37	4.19	15.47	1.25	1.00	606.00
P6XP1	78.33	5.33	175.21	6.33	4.67	2.70	10.49	1.33	1.06	587.33
P6XP2	80.80	9.33	65.33	7.40	5.47	3.33	4.84	0.92	0.98	442.00
P6XP3	85.03	9.67	173.33	11.10	3.37	10.58	40.81	0.98	1.14	523.00
P6XP4	117.00	12.00	240.50	13.73	3.30	4.81	25.57	1.67	1.09	238.00
P6XP5	105.90	10.00	125.21	8.17	2.97	3.75	10.40	0.98	1.20	552.00
Mean	72.98	7.59	93.87	8.49	4.29	5.09	10.70	1.10	1.15	439.94
C.D. 1%	7.230	2.487	21.622	1.679	0.727	0.760	2.593	0.120	0.105	67.550

Table 4: Continued…..

TREATMENT	Epicuticular Wax Content (mg/g)	Total CHO Content (mg glucose/100 g)	Polyphenol Oxidasae Content (activity/µg/ min.)	Membrane Integrity	Carotenoids (mg/g)	Capsaicin (%)	Vitamin C (mg/100g)	Oleoresin (%)	Incidence of Leaf Curl Disease (Vulnerability Index)
P1	15.93	59.53	0.70	45.99	0.42	1.85	106.93	10.60	1.31
P2	13.33	60.56	0.26	66.65	0.42	0.96	96.53	9.68	35.22
P3	16.37	77.31	0.14	56.53	0.42	1.69	110.47	11.72	26.20
P4	13.17	60.89	0.37	60.22	0.43	1.42	99.76	10.82	49.29
P5	12.33	72.28	0.65	40.94	0.43	1.54	136.51	13.66	3.16
P6	19.20	98.39	0.60	36.26	0.42	1.11	196.06	16.66	0.00
P1XP2	7.70	58.21	0.56	45.97	0.42	0.99	108.73	10.93	42.01
P1XP3	7.83	66.36	0.28	44.89	0.43	1.76	99.57	13.20	40.80
P1XP4	13.63	44.14	0.38	58.36	0.43	1.75	92.33	13.12	17.90
P1XP5	5.70	53.48	0.65	59.22	0.43	1.80	94.47	16.62	8.57
P1XP6	16.53	56.57	0.70	40.26	0.43	1.77	95.33	16.88	3.14
P2XP1	17.53	64.21	0.54	52.36	0.43	1.60	95.50	9.94	40.63
P2XP3	16.63	55.29	0.34	58.56	0.43	0.94	92.23	9.84	19.66
P2XP4	22.40	53.32	0.54	60.75	0.42	1.56	109.72	9.68	21.72
P2XP5	20.10	52.65	0.32	47.55	0.43	1.64	204.19	11.17	24.69
P2XP6	8.47	74.47	0.21	68.04	0.43	1.06	175.56	11.13	26.24
P3XP1	12.23	56.98	0.35	50.14	0.44	1.88	113.93	11.12	27.44
P3XP2	17.37	53.78	0.47	60.66	0.43	1.63	117.01	11.45	53.33
P3XP4	17.53	53.87	0.36	70.97	0.43	1.82	107.29	11.97	37.35
P3XP5	17.37	39.22	0.44	40.43	0.42	1.72	207.49	14.51	17.57
P3XP6	16.00	59.65	0.75	53.46	0.41	1.37	153.94	13.16	0.00

Table 4: Continued……

P4XP1	14.30	56.09	0.43	45.12	0.43	1.35	97.29	10.88	8.33
P4XP2	15.03	41.00	0.20	46.16	0.43	1.06	99.96	9.01	36.81
P4XP3	20.93	43.76	0.20	60.09	0.42	1.64	195.64	9.94	26.73
P4XP5	18.73	40.00	0.45	64.65	0.43	1.45	113.33	13.65	12.75
P4XP6	15.03	99.61	0.86	38.79	0.43	1.35	116.08	16.65	0.00
P5XP1	19.37	47.69	0.70	50.00	0.44	1.67	145.96	14.29	2.36
P5XP2	18.03	40.36	0.43	52.81	0.43	1.24	200.02	12.52	17.03
P5XP3	14.73	84.57	0.77	36.34	0.42	1.91	214.00	16.15	0.00
P5XP4	17.67	56.23	0.52	67.45	0.43	1.61	100.98	13.62	13.00
P5XP6	5.53	57.44	0.71	51.55	0.43	1.92	175.55	14.74	10.35
P6XP1	22.37	52.86	0.83	39.51	0.43	1.30	94.65	17.55	0.00
P6XP2	6.63	55.05	0.50	63.33	0.43	1.46	206.27	11.17	37.30
P6XP3	13.37	66.57	0.61	60.31	0.43	1.18	173.50	13.13	10.93
P6XP4	13.53	110.50	0.88	31.30	0.43	1.90	200.08	18.08	0.00
P6XP5	6.43	63.00	0.74	55.87	0.43	1.81	168.08	14.96	8.33
Mean	14.70	60.72	0.51	52.26	0.43	1.52	136.53	12.89	18.89
C.D. 1%	0.289	10.122	0.056	2.297	0.004	0.158	0.806	0.261	8.013

Table 5: Analysis of variance (ANOVA) for various characters – RBD

Source	df	Mean Squares									
		Plant Height (cm)	No. of branches per Plant	No. of fruits per Plant	Average Fruit Length (cm)	Average Fruit Girth (cm)	Fruit Weight (g)	Yield per Plot (kg)	Total Soluble Protein Content (mg/g)	Total Chlorophyll Content (mg/g)	Phenol Content (µg/ml)
Replications	2	4.32	1.01	49.33	0.97	0.10	0.20	1.33	0.01	0.01	1046.37
Treatments	35	849.40**	16.67**	10491.46**	20.08**	6.25**	23.33**	380.60**	0.24**	0.11**	48974.57**
Error	70	11.18	1.32	100.02	0.60	0.11	0.12	1.44	0.00	0.00	976.20
Total	107	285.24	6.34	3498.14	6.98	2.12	7.71	125.46	0.08	0.04	16677.91

Source	df	Mean Squares								
		Epicuticular Wax Content (mg/g)	Total CHO Content (mg glucose/100g)	Polyphenol Oxidase Content (activity/µg/min.)	Membrane Integrity	Carotenoids (mg/g)	Capsaicin (%)	Vitamin C (mg/100g)	Oleoresin (%)	Incidence of Leaf Curl Disease (Vulnerability Index)
Replications	2	0.00009	34.14	0.0006	0.17	0.000004	0.01	0.05	0.01	5.13
Treatments	35	65.29**	820.30**	0.13**	322.46**	0.000124**	0.27**	5692.70**	19.55**	763.95**
Error	70	0.02	21.92	0.0006	1.13	0.000004	0.01	0.14	0.01	13.74
Total	107	21.37	283.30	0.04	106.22	0.000043	0.09	1862.19	6.40	258.97

* Significant at 5% level ** Significant at 1% level

Table 6: Heterosis (%) over mid-parent (RH), better-parent (HB) and standard commercial variety (SH) for various characters

PLANT HEIGHT(cm)				
CROSSES	Mean	Heterosis (%)		
		RH	HB	SH
P1 X P2	68.20	15.30**	1.29	1.29
P1 X P3	70.83	8.78	5.20	5.20
P1 X P4	62.80	2.14	-6.73	-6.73
P1 X P5	67.77	18.37**	0.64	0.64
P1 X P6	72.83	11.25**	8.17	8.17
P2 X P1	56.00	-5.33	-16.83**	-16.83**
P2 X P3	60.83	6.85	-3.29	-9.65
P2 X P4	60.77	14.01**	9.23	-9.75
P2 X P5	68.43	39.47**	34.27**	1.63
P2 X P6	80.90	41.23**	27.20**	20.15**
P3 X P1	65.77	1.00	-2.33	-2.33
P3 X P2	73.03	28.28**	16.11**	8.47
P3 X P4	84.17	42.01**	33.81**	25.00**
P3 X P5	87.00	58.09**	38.31**	29.21**
P3 X P6	110.47	74.65**	73.69**	64.06**
P4 X P1	69.03	12.28**	2.52	2.52
P4 X P2	65.20	22.33**	17.20**	-3.17
P4 X P3	63.90	7.82	1.59	-5.10
P4 X P5	85.30	65.95**	53.33**	26.68**
P4 X P6	65.43	9.76	2.88	-2.82
P5 X P1	56.30	-1.66	-16.39**	-16.39**
P5X P2	55.33	12.77**	8.57	-17.82**
P5 X P3	87.57	59.12**	39.22**	30.05**
P5 X P4	67.40	31.13**	21.15**	0.10
P5 X P6	107.23	93.62**	68.61**	59.26**
P6 X P1	78.33	19.65**	16.34**	16.34**
P6 X P2	80.80	41.05**	27.04**	20.00**
P6 X P3	85.03	34.44**	33.70**	26.29**
P6 X P4	117.00	96.25**	83.96**	73.76**
P6 X P5	105.90	91.21**	66.51**	57.28**
CD 1%		6.261	7.230	7.230
CD 5%		5.071	5.856	5.856

* - Significant at 5% ** - Significant at 1%

Table 6: Continued...

BRANCHES PER PLANT				
CROSSES	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	6.33	90.00**	90.00**	18.75
P1 X P3	7.00	90.91**	75.00**	31.25
P1 X P4	6.67	53.85**	25.00**	25.00
P1 X P5	5.33	33.33	14.29	0.00
P1 X P6	8.33	100.00**	66.67**	56.25**
P2 X P1	6.00	80.00**	80.00**	12.50
P2 X P3	7.33	100.00**	83.33**	37.50
P2 X P4	10.33	138.46**	93.75**	93.75**
P2 X P5	10.33	158.33**	121.43**	93.75**
P2 X P6	12.67	204.00**	153.33**	137.50**
P3 X P1	6.67	81.82**	66.67**	25.00
P3 X P2	6.67	81.82**	66.67**	25.00
P3 X P4	6.67	42.86**	25.00	25.00
P3 X P5	8.67	100.00**	85.71**	62.50**
P3 X P6	9.00	100.00**	80.00**	68.75**
P4 X P1	6.67	53.85**	25.00	25.00
P4 X P2	9.67	123.08**	81.25**	81.25**
P4 X P3	6.67	42.86**	25.00	25.00
P4 X P5	8.33	66.67**	56.25**	56.25**
P4 X P6	9.67	87.10**	81.25**	81.25**
P5 X P1	6.67	66.67**	42.86	25.00
P5X P2	10.67	166.67**	128.57**	100.00**
P5 X P3	8.67	100.00**	85.71**	62.50**
P5 X P4	6.33	26.67	18.75	18.75
P5 X P6	10.00	106.90**	100.00**	87.50**
P6 X P1	5.33	28.00	6.67	0.00
P6 X P2	9.33	124.00**	86.67**	75.00**
P6 X P3	9.67	114.81**	93.33**	81.25**
P6 X P4	12.00	132.26**	125.00**	125.00**
P6 X P5	10.00	106.90**	100.00**	87.50**
CD 1%		2.154	2.487	2.487
CD 5%		1.745	2.015	2.015

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

AVERAGE FRUIT LENGTH (cm)				
CROSSES	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	7.17	19.11	0.47	-21.25**
P1 X P3	5.30	-24.29**	-41.76**	-41.76**
P1 X P4	11.40	105.41**	83.87**	25.27**
P1 X P5	5.37	6.62	3.87	-41.03**
P1 X P6	11.57	117.55**	101.74**	27.11**
P2 X P1	8.03	33.52**	12.62	-11.72
P2 X P3	11.80	45.38**	29.67**	29.67**
P2 X P4	5.47	-18.00	-23.36	-39.93**
P2 X P5	7.90	28.46**	10.75	-13.19
P2 X P6	7.40	15.03	3.74	-18.68**
P3 X P1	9.17	30.95**	0.73	0.73
P3 X P2	12.27	51.13**	34.80**	34.80**
P3 X P4	10.37	35.51**	13.92	13.92
P3 X P5	10.17	42.52**	11.72	11.72
P3 X P6	11.90	60.45**	30.77**	30.77**
P4 X P1	9.23	66.37**	48.92**	1.47
P4 X P2	10.40	56.00**	45.79**	14.29
P4 X P3	6.20	-18.95*	-31.87**	-31.87**
P4 X P5	14.60	156.89**	135.48**	60.44**
P4 X P6	8.47	41.90**	36.56**	-6.96
P5 X P1	5.57	10.60	7.74	-38.83**
P5X P2	8.50	38.21	19.16*	-6.59
P5 X P3	6.53	-8.41	-28.21**	-28.21**
P5 X P4	8.77	54.25**	41.40**	-3.66
P5 X P6	7.20	32.11**	25.58*	-20.88**
P6 X P1	6.33	19.12	10.47	-30.40**
P6 X P2	7.40	15.03	3.74	-18.68**
P6 X P3	11.10	49.66**	21.98**	21.98**
P6 X P4	13.73	130.17**	121.51**	50.92**
P6 X P5	8.17	49.85**	42.44**	-10.26
CD 1%		1.454	1.679	1.679
CD 5%		1.178	1.360	1.360

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

AVERAGE FRUIT GIRTH (cm)				
CROSSES	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	3.30	11.24	1.02	-46.20**
P1 X P3	2.93	-37.59**	-52.17**	-52.17**
P1 X P4	4.67	38.61**	34.62**	-23.91**
P1 X P5	3.73	5.66	-1.75	-39.13**
P1 X P6	3.63	2.35	-5.22	-40.76**
P2 X P1	3.47	16.85	6.12	-43.48**
P2 X P3	3.00	-31.82**	-51.09**	-51.09**
P2 X P4	5.93	93.48**	71.15**	-3.26
P2 X P5	3.60	11.34	-5.26	-41.30**
P2 X P6	6.70	106.15**	74.78**	9.24
P3 X P1	3.23	-31.21**	-47.28**	-47.28**
P3 X P2	7.40	68.18**	20.65**	20.65**
P3 X P4	7.80	62.50**	27.17**	27.17**
P3 X P5	2.73	-44.97**	-55.43**	-55.43**
P3 X P6	3.17	-36.45**	-48.37**	-48.37**
P4 X P1	5.30	57.43**	52.88**	-13.59**
P4 X P2	3.83	25.00**	10.58	-37.50**
P4 X P3	3.87	-19.44**	-36.96**	-36.96**
P4 X P5	7.43	104.59**	95.61**	21.20**
P4 X P6	3.43	-5.94	-10.43	-44.02**
P5 X P1	3.07	-13.21	-19.30**	-50.00**
P5X P2	3.90	20.62**	2.63	-36.41**
P5 X P3	4.57	-8.05	-25.54**	-25.54**
P5 X P4	6.30	73.39**	65.79**	2.72
P5 X P6	4.37	14.41*	13.91	-28.80**
P6 X P1	4.67	31.46**	21.74**	-23.91**
P6 X P2	5.47	68.21**	42.61**	-10.87*
P6 X P3	3.37	-32.44**	-45.11**	-45.11**
P6 X P4	3.30	-9.59	-13.91	-46.20**
P6 X P5	2.97	-22.27**	-22.61**	-51.63**
CD 1%		0.629	0.727	0.727
CD 5%		0.510	0.589	0.589

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

FRUIT WEIGHT(g)				
CROSSES	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	3.99	69.93**	56.19**	-38.72**
P1 X P3	6.08	40.42**	-6.70	-6.70
P1 X P4	5.20	31.29**	-10.03	-20.15**
P1 X P5	2.11	-1.94	-2.31	-67.62**
P1 X P6	1.99	-31.53**	-45.72**	-69.51**
P2 X P1	6.52	177.59**	155.15**	0.10
P2 X P3	7.12	56.87**	9.21	9.21
P2 X P4	3.34	-19.98**	-42.31**	-48.80**
P2 X P5	2.12	-10.11	-17.08	-67.47**
P2 X P6	5.24	68.47**	43.08**	-19.64**
P3 X P1	5.36	23.79**	-17.75**	-17.75**
P3 X P2	6.17	35.93**	-5.37	-5.37
P3 X P4	11.44	86.02**	75.55**	75.55**
P3 X P5	9.19	111.76**	40.97**	40.97**
P3 X P6	11.77	131.25**	80.56**	80.56**
P4 X P1	3.33	-15.90*	-42.36**	-48.85**
P4 X P2	2.96	-28.94**	-48.76**	-54.53**
P4 X P3	9.78	59.02**	50.08**	50.08**
P4 X P5	3.97	0.04	-31.30**	-39.03**
P4 X P6	3.71	-21.43**	-35.85**	-43.07**
P5 X P1	2.27	5.34	4.94	-65.22**
P5X P2	4.87	106.50**	90.48**	-25.27**
P5 X P3	9.22	112.52**	41.48**	41.48**
P5 X P4	3.44	-13.39	-40.52**	-47.21**
P5 X P6	4.19	43.99**	14.48	-35.70**
P6 X P1	2.70	-6.84	-26.14**	-58.52**
P6 X P2	3.33	7.13	-9.02	-48.90**
P6 X P3	10.58	107.93**	62.35**	62.35**
P6 X P4	4.81	1.80	-16.89**	-26.24**
P6 X P5	3.75	28.75**	2.37	-42.51**
CD 1%		0.658	0.760	0.760
CD 5%		0.533	0.615	0.615

* - Significant at 5% ** - Significant at 1%

Table 6: Continued...

YIELD PER PLOT (kg)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	8.34	256.56**	204.65**	31.42
P1 X P3	8.60	172.03**	139.75**	35.60*
P1 X P4	7.23	161.77**	159.43**	13.95
P1 X P5	4.33	44.92	33.62	-31.71
P1 X P6	8.57	88.78**	35.11	35.11*
P2 X P1	13.64	483.19**	398.29**	114.96**
P2 X P3	9.78	253.85**	172.58**	54.17**
P2 X P4	4.21	78.31*	51.23	-33.58
P2 X P5	4.24	63.50	30.66	-33.22
P2 X P6	9.97	140.59**	57.08**	57.08
P3 X P1	6.96	120.13**	94.01**	9.73
P3 X P2	3.58	29.49	-0.25	-43.58**
P3 X P4	6.77	112.37**	88.64**	6.70
P3 X P5	6.68	95.43**	86.02**	5.21
P3 X P6	52.60	958.89**	728.90**	728.90**
P4 X P1	7.67	177.76**	175.28**	20.91
P4 X P2	2.77	17.07	-0.71	-56.39**
P4 X P3	7.56	137.04**	110.56**	19.09
P4 X P5	7.35	143.92*	126.76**	15.90
P4 X P6	15.96	249.55**	151.54**	151.54**
P5 X P1	4.03	34.78	24.27	-36.48*
P5X P2	11.63	348.83**	258.67**	83.32**
P5 X P3	37.75	1005.14**	951.91**	494.96**
P5 X P4	6.58	118.26**	102.90**	3.71
P5 X P6	15.47	222.60**	143.74**	143.74**
P6 X P1	10.49	130.95*	65.29**	65.29**
P6 X P2	4.84	16.85	-23.71	-23.71
P6 X P3	40.81	721.66**	543.19**	543.19**
P6 X P4	25.57	459.88**	302.90**	302.90**
P6 X P5	10.40	116.93	63.91**	63.91**
CD 1%		2.246	2.593	2.593
CD 5%		1.819	2.101	2.101

* - Significant at 5% ** - Significant at 1%

Table 6: Continued...

TOTAL SOLUBLE PROTEIN CONTENT (mg/g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	0.79	0.21	-13.77**	-39.75**
P1 X P3	1.03	22.95**	11.59*	-22.03**
P1 X P4	1.30	32.76**	25.48**	-1.52
P1 X P5	1.17	23.67**	20.69**	-11.39**
P1 X P6	1.35	20.42**	2.28	2.28
P2 X P1	0.91	15.37**	-0.72	-30.63**
P2 X P3	1.00	41.98**	33.78**	-23.80**
P2 X P4	0.68	-20.24**	-34.52**	-48.61**
P2 X P5	1.28	56.65**	32.07**	-3.04
P2 X P6	1.08	9.43	-17.72**	-17.72**
P3 X P1	1.07	28.54**	16.67**	-18.48**
P3 X P2	0.92	30.66**	23.11**	-29.87**
P3 X P4	1.05	18.13**	1.94	-20.00**
P3 X P5	0.98	14.17**	1.38	-25.57**
P3 X P6	1.62	56.77**	23.04**	23.04**
P4 X P1	1.46	49.15**	40.97**	10.63**
P4 X P2	0.80	-5.30	-22.26**	-38.99**
P4 X P3	1.08	20.75**	4.19	-18.23**
P4 X P5	1.04	4.00	0.65	-21.01**
P4 X P6	1.57	33.33**	18.99**	18.99**
P5 X P1	0.72	-23.67**	-25.52**	-45.32**
P5X P2	1.07	30.88**	10.34*	-18.99**
P5 X P3	1.84	114.37**	90.34**	39.75**
P5 X P4	0.91	-9.00*	-11.94**	-30.89**
P5 X P6	1.25	9.78**	-4.81	-4.81
P6 X P1	1.33	19.23**	1.27	1.27
P6 X P2	0.92	-7.07	-30.13**	-30.13**
P6 X P3	0.98	-5.16	-25.57**	-25.57**
P6 X P4	1.67	42.41**	27.09**	27.09**
P6 X P5	0.98	-14.45**	-25.82**	-25.82**
CD 1%		0.104	0.120	0.120
CD 5%		0.084	0.097	0.097

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

TOTAL CHLOROPHYLL CONTENT (mg/g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	1.31	-4.14	-9.43**	-9.43**
P1 X P3	1.27	-7.43**	-12.64**	-12.64**
P1 X P4	0.86	-30.83**	-40.69**	-40.69**
P1 X P5	1.09	-16.26**	-24.83**	-24.83**
P1 X P6	1.09	-24.71**	-25.06**	-25.06**
P2 X P1	1.15	-16.06**	-20.69**	-20.69**
P2 X P3	1.09	-15.14**	-15.25**	-24.60**
P2 X P4	1.29	10.60**	-0.26	-11.26**
P2 X P5	0.98	-19.51**	-23.77**	-32.18**
P2 X P6	1.14	-16.14**	-20.42**	-21.15**
P3 X P1	0.86	-36.91**	-40.46**	-40.46**
P3 X P2	1.02	-20.83**	-20.93**	-29.66**
P3 X P4	1.00	-14.20**	-22.54**	-31.26**
P3 X P5	1.43	17.21**	11.14**	-1.38
P3 X P6	1.72	26.32**	19.72**	18.62**
P4 X P1	0.83	-32.98**	-42.53**	-42.53**
P4 X P2	1.09	-6.02	-15.25**	-24.60**
P4 X P3	1.17	1.00	-8.81**	-19.08**
P4 X P5	1.17	7.15**	1.73	-19.08**
P4 X P6	1.04	-16.17**	-27.84**	-28.51**
P5 X P1	0.84	-35.72**	-42.30**	-42.30**
P5X P2	1.06	-13.23**	-17.83**	-26.90**
P5 X P3	1.42	16.12**	10.10**	-2.30
P5 X P4	1.23	12.02**	6.36	-15.40**
P5 X P6	1.00	-22.52**	-30.16**	-30.80**
P6 X P1	1.06	-26.56**	-26.90**	-26.90**
P6 X P2	0.98	-28.36**	-32.02**	-32.64**
P6 X P3	1.14	-16.03**	-20.42**	-21.15**
P6 X P4	1.09	-11.59**	-23.90**	-24.60**
P6 X P5	1.20	-7.34**	-16.47**	-17.24**
CD 1%		0.091	0.105	0.105
CD 5%		0.074	0.085	0.085

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

PHENOL CONTENT (µg/ml)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	410.33	1.65	-20.48**	-34.10**
P1 X P3	240.00	-38.59**	-53.49**	-61.46**
P1 X P4	354.00	-19.82**	-31.40**	-43.15**
P1 X P5	390.33	-30.87**	-36.36**	-37.31**
P1 X P6	562.33	-1.23	-9.69*	-9.69*
P2 X P1	340.33	-15.69**	-34.04**	-45.34**
P2 X P3	736.00	164.27**	152.63**	18.20**
P2 X P4	339.67	3.19	-7.45	-45.45**
P2 X P5	312.00	-31.02**	-49.13**	-49.89**
P2 X P6	475.33	4.01	-23.66**	-23.66**
P3 X P1	629.67	61.11**	22.03**	1.12
P3 X P2	309.00	10.95	6.06	-50.37**
P3 X P4	389.33	23.08**	6.09	-37.47**
P3 X P5	619.00	40.84**	0.92	-0.59
P3 X P6	524.67	18.12**	-15.74**	-15.74**
P4 X P1	386.33	-12.50*	-25.13**	-37.96**
P4 X P2	384.67	16.86*	4.81	-38.22**
P4 X P3	364.00	15.07*	-0.82	-41.54**
P4 X P5	549.67	12.14**	-10.38*	-11.72**
P4 X P6	445.33	-10.00*	-28.48**	-28.48**
P5 X P1	355.00	-37.13**	-42.12**	-42.99**
P5X P2	349.33	-22.77**	-43.04**	-43.90**
P5 X P3	352.00	-19.91**	-42.61**	-43.47**
P5 X P4	395.00	-19.42**	-35.60**	-36.56**
P5 X P6	606.00	-1.94	-2.68	-2.68
P6 X P1	587.33	3.16	-5.67	-5.67
P6 X P2	442.00	-3.28	-29.01**	-29.01**
P6 X P3	523.00	17.75**	-16.01**	-16.01**
P6 X P4	238.00	-51.90**	-61.78**	-61.78**
P6 X P5	552.00	-10.68**	-11.35**	-11.35**
CD 1%		58.500	67.550	67.550
CD 5%		47.385	54.715	54.715

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

EPICUTICULAR WAX CONTENT (mg/g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	7.70	-47.38**	-51.67**	-59.90**
P1 X P3	7.83	-51.50**	-52.14**	-59.20**
P1 X P4	13.63	-6.30**	-14.44**	-28.99**
P1 X P5	5.70	-59.67**	-64.23**	-70.31**
P1 X P6	16.53	-5.88**	-13.89**	-13.89**
P2 X P1	17.53	19.82**	10.04**	-8.68**
P2 X P3	16.63	12.01**	1.63*	-13.37**
P2 X P4	22.40	69.06**	68.00**	16.67**
P2 X P5	20.10	56.62**	50.75**	4.69**
P2 X P6	8.47	-47.95**	-55.90**	-55.90**
P3 X P1	12.23	-24.25**	-25.25**	-36.28**
P3 X P2	17.37	16.95**	6.11**	-9.55**
P3 X P4	17.53	18.74**	7.13**	-8.68**
P3 X P5	17.37	21.02**	6.11**	-9.55**
P3 X P6	16.00	-10.03**	-16.67**	-16.67**
P4 X P1	14.30	-1.72*	-10.25**	-25.52**
P4 X P2	15.03	13.46**	12.75**	-21.70**
P4 X P3	20.93	41.76**	27.90**	9.03**
P4 X P5	18.73	46.93**	42.28**	-2.43**
P4 X P6	15.03	-7.11**	-21.70**	-21.70**
P5 X P1	19.37	37.03**	21.55**	0.87
P5X P2	18.03	40.52**	35.25**	-6.08**
P5 X P3	14.73	2.67**	-9.98**	-23.26**
P5 X P4	17.67	38.56**	34.18**	-7.99**
P5 X P6	5.53	-64.90**	-71.18**	-71.18**
P6 X P1	22.37	27.32**	16.49**	16.49**
P6 X P2	6.63	-59.22**	-65.45**	-65.45**
P6 X P3	13.37	-24.84**	-30.38**	-30.38**
P6 X P4	13.53	-16.37**	-29.51**	-29.51**
P6 X P5	6.43	-59.20**	-66.49**	-66.49**
CD 1%		0.251	0.289	0.289
CD 5%		0.203	0.234	0.234

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

TOTAL CHO CONTENT (mg glucose/100g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	58.21	-3.06	-3.89	-40.84**
P1 X P3	66.36	-3.02	-14.17**	-32.56**
P1 X P4	44.14	-26.70**	-27.52**	-55.14**
P1 X P5	53.48	-18.85**	-26.01**	-45.64**
P1 X P6	56.57	-28.35**	-42.50**	-42.50**
P2 X P1	64.21	6.93	6.02	-34.74**
P2 X P3	55.29	-19.79**	-28.48**	-43.80**
P2 X P4	53.32	-12.20	-12.44	-45.81**
P2 X P5	52.65	-20.74**	-27.17**	-46.49**
P2 X P6	74.47	-6.30	-24.31**	-24.31**
P3 X P1	56.98	-16.72**	-26.29**	-42.08**
P3 X P2	53.78	-21.99**	-30.44**	-45.34**
P3 X P4	53.87	-22.05**	-30.32**	-45.25**
P3 X P5	39.22	-47.56**	-49.27**	-60.14**
P3 X P6	59.65	-32.10**	-39.38**	-39.38**
P4 X P1	56.09	-6.85	-7.89	-42.99**
P4 X P2	41.00	-32.48**	-32.66**	-58.32**
P4 X P3	43.76	-36.68**	-43.40**	-55.53**
P4 X P5	40.00	-39.93**	-44.67**	-59.35**
P4 X P6	99.61	25.08**	1.24	1.24
P5 X P1	47.69	-27.65**	-34.03**	-51.53**
P5X P2	40.36	-39.24**	-44.16**	-58.98**
P5 X P3	84.57	13.07**	9.40	-14.04**
P5 X P4	56.23	-15.55**	-22.20**	-42.84**
P5 X P6	57.44	-32.69**	-41.62**	-41.62**
P6 X P1	52.86	-33.06**	-46.28**	-46.28**
P6 X P2	55.05	-30.73**	-44.05**	-44.05**
P6 X P3	66.57	-24.22**	-32.34**	-32.34**
P6 X P4	110.50	38.75**	12.31**	12.31**
P6 X P5	63.00	-26.18**	-35.97**	-35.97**
CD 1%		8.766	10.122	10.122
CD 5%		7.100	8.199	8.199

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

POLY PHENOL OXIDASE CONTENT (activity /µg/min.)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	0.56	15.93**	-20.66**	-20.66**
P1 X P3	0.28	-35.14**	-60.90**	-60.90**
P1 X P4	0.38	-28.74**	-45.64**	-45.64**
P1 X P5	0.65	-4.77	-8.25**	-8.25**
P1 X P6	0.70	8.03**	0.14	0.14
P2 X P1	0.54	12.33**	-23.13**	-23.13**
P2 X P3	0.34	69.80**	32.26**	-51.23**
P2 X P4	0.54	72.76**	46.98**	-22.75**
P2 X P5	0.32	-29.33**	-50.61**	-54.22**
P2 X P6	0.21	-51.32**	-65.15**	-70.24**
P3 X P1	0.35	-16.51**	-49.67**	-49.67**
P3 X P2	0.47	133.66**	82.01**	-32.89**
P3 X P4	0.36	41.28**	-1.71	-48.34**
P3 X P5	0.44	9.96	-32.82**	-37.73**
P3 X P6	0.75	101.25**	24.86**	6.64
P4 X P1	0.43	-19.48**	-38.58**	-38.58**
P4 X P2	0.20	-35.24**	-44.91**	-71.04**
P4 X P3	0.20	-20.67**	-44.82**	-71.00**
P4 X P5	0.45	-12.37**	-31.34**	-36.35**
P4 X P6	0.86	78.15**	43.90**	22.89**
P5 X P1	0.70	3.98	0.19	0.19
P5X P2	0.43	-5.49	-33.95**	-38.77**
P5 X P3	0.77	94.06**	18.56**	9.91
P5 X P4	0.52	1.53	-20.45**	-26.26**
P5 X P6	0.71	13.84**	9.36	1.37
P6 X P1	0.83	26.84**	17.58**	17.58**
P6 X P2	0.50	15.19	-17.54**	-29.57**
P6 X P3	0.61	63.06**	1.17	-13.60
P6 X P4	0.88	82.27**	47.23**	25.73**
P6 X P5	0.74	18.31**	13.65**	5.36
CD 1%		0.048	0.056	0.056
CD 5%		0.039	0.045	0.045

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

MEMBRANE INTEGRITY				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	45.97	-18.37**	-31.02**	-31.02**
P1 X P3	44.89	-12.42**	-20.59**	-32.64**
P1 X P4	58.36	9.90**	-3.09	-12.43**
P1 X P5	59.22	36.27**	28.78**	-11.14**
P1 X P6	40.26	-2.11	-12.46**	-39.60**
P2 X P1	52.36	-7.02**	-21.43**	-21.43**
P2 X P3	58.56	-4.91**	-12.13**	-12.13**
P2 X P4	60.75	-4.23**	-8.84**	-8.84**
P2 X P5	47.55	-11.61**	-28.66**	-28.66**
P2 X P6	68.04	32.23**	2.09	2.09
P3 X P1	50.14	-2.17	-11.29**	-24.76**
P3 X P2	60.66	-1.50	-8.98**	-8.98**
P3 X P4	70.97	21.58**	17.85**	6.49**
P3 X P5	40.43	-17.04**	-28.48**	-39.34**
P3 X P6	53.46	15.24**	-5.42**	-19.78**
P4 X P1	45.12	-15.03**	-25.07**	-32.29**
P4 X P2	46.16	-27.24**	-30.74**	-30.74**
P4 X P3	60.09	2.93	-0.23	-9.84**
P4 X P5	64.65	27.82**	7.36**	-2.99
P4 X P6	38.79	-19.60**	-35.59**	-41.80**
P5 X P1	50.00	15.04**	8.72**	-24.98**
P5X P2	52.81	-1.82	-20.76**	-20.76**
P5 X P3	36.34	-25.42**	-35.71**	-45.47**
P5 X P4	67.45	33.35**	11.99**	1.20
P5 X P6	51.55	33.54**	25.92**	-22.66**
P6 X P1	39.51	-3.92	-14.08**	-40.71**
P6 X P2	63.33	23.08**	-4.97**	-4.97**
P6 X P3	60.31	30.00**	6.70**	-9.50**
P6 X P4	31.30	-35.11**	-48.02**	-53.03**
P6 X P5	55.87	44.74**	36.48**	-16.17**
CD 1%		1.989	2.297	2.297
CD 5%		1.611	1.861	1.861

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

CAROTENOIDS (mg/g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	0.42	0.00	0.00	-2.33**
P1 X P3	0.43	2.38**	2.38**	0.00
P1 X P4	0.43	1.18**	0.00	0.00
P1 X P5	0.43	1.18**	0.00	0.00
P1 X P6	0.43	2.38**	2.38**	0.00
P2 X P1	0.43	2.38**	2.38**	0.00
P2 X P3	0.43	1.59**	1.59**	-0.78
P2 X P4	0.42	-1.18**	-2.33**	-2.33**
P2 X P5	0.43	1.18**	0.00	0.00
P2 X P6	0.43	2.38**	2.38**	0.00
P3 X P1	0.44	4.76**	4.76**	2.33**
P3 X P2	0.43	2.38**	2.38**	0.00
P3 X P4	0.43	1.18**	0.00	0.00
P3 X P5	0.42	-1.18**	-2.33**	-2.33**
P3 X P6	0.41	-3.17**	-3.17**	-5.43**
P4 X P1	0.43	1.18**	0.00	0.00
P4 X P2	0.43	1.18	0.00	0.00
P4 X P3	0.42	-1.18	-2.33**	-2.33**
P4 X P5	0.43	0.00	0.00	0.00
P4 X P6	0.43	1.18**	0.00	0.00
P5 X P1	0.44	3.53**	2.33**	2.33**
P5X P2	0.43	1.18**	0.00	0.00
P5 X P3	0.42	-1.96**	-3.10**	-3.10**
P5 X P4	0.43	0.00	0.00	0.00
P5 X P6	0.43	1.18**	0.00	0.00
P6 X P1	0.43	2.38**	2.38**	0.00
P6 X P2	0.43	2.38**	2.38**	0.00
P6 X P3	0.43	1.59**	1.59**	-0.78
P6 X P4	0.43	1.18**	0.00	0.00
P6 X P5	0.43	1.18**	0.00	0.00
CD 1%		0.004	0.004	0.004
CD 5%		0.003	0.003	0.003

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

CAPSAICIN (%)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	0.99	-29.94**	-46.76**	-46.76**
P1 X P3	1.76	-0.85	-5.22	-5.22
P1 X P4	1.75	7.13	-5.40	-5.40
P1 X P5	1.80	6.18	-2.70	-2.70
P1 X P6	1.77	19.24**	-4.68	-4.68
P2 X P1	1.60	13.37**	-13.85**	-13.85**
P2 X P3	0.94	-28.89**	-44.18**	-49.10**
P2 X P4	1.56	31.19**	10.09	-15.65**
P2 X P5	1.64	31.12**	6.48	-11.33**
P2 X P6	1.06	1.93	-4.80	-42.99**
P3 X P1	1.88	5.93	1.26	1.26
P3 X P2	1.63	22.61**	-3.75	-12.23**
P3 X P4	1.82	17.04**	7.69	-1.80
P3 X P5	1.72	6.60	1.97	-7.01
P3 X P6	1.37	-2.38	-19.13**	-26.26**
P4 X P1	1.35	-17.72**	-27.34**	-27.34**
P4 X P2	1.06	-10.77	-25.12**	-42.63**
P4 X P3	1.64	5.47	-2.96	-11.51**
P4 X P5	1.45	-2.14	-6.05	-21.76**
P4 X P6	1.35	6.46	-5.16	-27.34**
P5 X P1	1.67	-1.86	-10.07**	-10.07**
P5X P2	1.24	-1.06	-19.65**	-33.09**
P5 X P3	1.91	17.94**	12.82**	2.88
P5 X P4	1.61	8.89	4.54	-12.95**
P5 X P6	1.92	44.72**	24.41**	3.60
P6 X P1	1.30	-12.26**	-29.86**	-29.86**
P6 X P2	1.46	41.16**	31.83**	-21.04**
P6 X P3	1.18	-15.95**	-30.37**	-36.51**
P6 X P4	1.90	50.20**	33.80**	2.52
P6 X P5	1.81	36.43**	17.28**	-2.34
CD 1%		0.137	0.158	0.158
CD 5%		0.111	0.128	0.128

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

VITAMIN C (mg/100g)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	108.73	6.88**	1.68**	-44.54**
P1 X P3	99.57	-8.40**	-9.87**	-49.22**
P1 X P4	92.33	-10.66**	-13.65**	-52.91**
P1 X P5	94.47	-22.39**	-30.80**	-51.82**
P1 X P6	95.33	-37.07**	-51.38**	-51.38**
P2 X P1	95.50	-6.13**	-10.69**	-51.29**
P2 X P3	92.23	-10.89**	-16.51**	-52.96**
P2 X P4	109.72	11.79**	9.98**	-44.04**
P2 X P5	204.19	75.25**	49.58**	4.15**
P2 X P6	175.56	20.00**	-10.46**	-10.46**
P3 X P1	113.93	4.81**	3.14**	-41.89**
P3 X P2	117.01	13.06**	5.92**	-40.32**
P3 X P4	107.29	2.07**	-2.88**	-45.28**
P3 X P5	207.49	68.03**	52.00**	5.83**
P3 X P6	153.94	0.44	-21.48**	-21.48**
P4 X P1	97.29	-5.86**	-9.02**	-50.38**
P4 X P2	99.96	1.85**	0.20	-49.01**
P4 X P3	195.64	86.12**	77.10**	-0.21**
P4 X P5	113.33	-4.07**	-16.98**	-42.20**
P4 X P6	116.08	-21.52**	-40.79**	-40.79**
P5 X P1	145.96	19.92**	6.93**	-25.55**
P5X P2	200.02	71.66**	46.53**	2.02**
P5 X P3	214.00	73.29**	56.77**	9.15**
P5 X P4	100.98	-14.52**	-26.02**	-48.49**
P5 X P6	175.55	5.57**	-10.46**	-10.46**
P6 X P1	94.65	-37.53**	-51.73**	-51.73**
P6 X P2	206.27	41.00**	5.21**	5.21**
P6 X P3	173.50	13.20**	-11.51**	-11.51**
P6 X P4	200.08	35.27**	2.05**	2.05**
P6 X P5	168.08	1.08**	-14.27**	-14.27**
CD 1%		0.698	0.806	0.806
CD 5%		0.566	0.653	0.653

* - Significant at 5% ** - Significant at 1%

Table 6: Continued…

OLEORESIN (%)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	10.93	7.79**	3.11**	-34.37**
P1 X P3	13.20	18.31**	12.69**	-20.75**
P1 X P4	13.12	22.47**	21.26**	-21.27**
P1 X P5	16.62	37.04**	21.72**	-0.22
P1 X P6	16.88	23.85**	1.34	1.34
P2 X P1	9.94	-2.04	-6.29**	-40.36**
P2 X P3	9.84	-8.01**	-15.99**	-40.92**
P2 X P4	9.68	-5.56**	-10.51**	-41.90**
P2 X P5	11.17	-4.26**	-18.18**	-32.93**
P2 X P6	11.13	-15.50**	-33.19**	-33.19**
P3 X P1	11.12	-0.39	-5.12**	-33.27**
P3 X P2	11.45	7.01**	-2.28**	-31.27**
P3 X P4	11.97	6.21**	2.13*	-28.17**
P3 X P5	14.51	14.37**	6.25**	-12.91**
P3 X P6	13.16	-7.25**	-21.01**	-21.01**
P4 X P1	10.88	1.62	0.62	-34.67**
P4 X P2	9.01	-12.07**	-16.67**	-45.90**
P4 X P3	9.94	-11.75**	-15.14**	-40.32**
P4 X P5	13.65	11.55**	-0.05	-18.07**
P4 X P6	16.65	21.19**	-0.06	-0.06
P5 X P1	14.29	17.81**	4.64**	-14.23**
P5X P2	12.52	7.28**	-8.32**	-24.85**
P5 X P3	16.15	27.33**	18.28**	-3.04**
P5 X P4	13.62	11.30**	-0.27	-18.25**
P5 X P6	14.74	-2.76**	-11.52**	-11.52**
P6 X P1	17.55	28.74**	5.34**	5.34**
P6 X P2	11.17	-15.22**	-32.97**	-32.97**
P6 X P3	13.13	-7.46**	-21.19**	-21.19**
P6 X P4	18.08	31.60**	8.52**	8.52**
P6 X P5	14.96	-1.33*	-10.22**	-10.22**
CD 1%		0.226	0.261	0.261
CD 5%		0.183	0.211	0.211

* - Significant at 5% ** - Significant at 1%

Table 6: Continued..

INCIDENCE OF LEAF CURL DISEASE (V.I.)				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	42.01	130.01**	19.27	-14.78
P1 X P3	40.80	196.63**	55.71**	-17.24**
P1 X P4	17.90	-29.26**	-63.69**	-63.69**
P1 X P5	8.57	284.02	171.49	-82.61**
P1 X P6	3.14	381.12	140.56	-93.62**
P2 X P1	40.63	122.45**	15.35**	-17.58**
P2 X P3	19.66	-35.99**	-44.19**	-60.12**
P2 X P4	21.72	-48.61**	-55.94**	-55.94**
P2 X P5	24.69	28.69	-29.89**	-49.91**
P2 X P6	26.24	49.01**	-25.50	-46.77**
P3 X P1	27.44	99.52**	4.73**	-44.33**
P3 X P2	53.33	73.66**	51.42**	8.19
P3 X P4	37.35	-1.04	-24.22**	-24.22**
P3 X P5	17.57	19.68	-32.95**	-64.36**
P3 X P6	0.00	-100.0**	-100.0**	-100.00**
P4 X P1	8.33	-67.08**	-83.10**	-83.10**
P4 X P2	36.81	-12.88	-25.32**	-25.32**
P4 X P3	26.73	-29.19**	-45.77**	-45.77**
P4 X P5	12.75	-51.37**	-74.13**	-74.13**
P4 X P6	0.00	-100.00**	-100.0**	-100.00**
P5 X P1	2.36	5.75	-25.24	-95.21**
P5X P2	17.03	-11.23	-51.64**	-65.44**
P5 X P3	0.00	-100.00**	-100.0**	-100.00**
P5 X P4	13.00	-50.42**	-73.62**	-73.62**
P5 X P6	10.35	555.54**	227.77	-79.01**
P6 X P1	0.00	-100.00	-100.00	-100.00**
P6 X P2	37.30	111.83**	5.92	-24.32**
P6 X P3	10.93	-16.59	-58.30**	-77.83**
P6 X P4	0.00	-100.00**	-100.0**	-100.00**
P6 X P5	8.33	427.77	163.89	-83.10**
CD 1%		6.940	8.013	8.013
CD 5%		5.621	6.491	6.491

* - Significant at 5% ** - Significant at 1%

Table 6: Continued…

NUMBER OF FRUITS PER PLANT				
CROSS	MEAN	Heterosis (%)		
		RH	HB	SH
P1 X P2	94.23	105.79**	63.95**	21.28
P1 X P3	63.68	54.98**	10.79	-18.04
P1 X P4	62.68	58.23**	9.05	-19.34
P1 X P5	92.47	47.78**	36.66**	19.01
P1 X P6	193.45	186.22**	148.97**	148.97**
P2 X P1	94.23	105.79**	63.95**	21.28
P2 X P3	61.99	110.84**	81.77**	-20.22
P2 X P4	56.89	103.74**	66.82**	-26.78*
P2 X P5	90.11	77.09**	33.17**	15.98
P2 X P6	85.57	53.07**	10.12	10.12
P3 X P1	58.47	42.30*	1.73	-24.75*
P3 X P2	26.11	-11.20	-23.44	-66.40**
P3 X P4	26.67	14.84	7.96	-65.68**
P3 X P5	32.70	-29.19	-51.67**	-57.91**
P3 X P6	201.21	292.99**	158.96**	158.96**
P4 X P1	103.65	161.68**	80.34**	33.40**
P4 X P2	42.00	50.41	23.16	-45.95**
P4 X P3	34.97	50.58	41.57	-55.00**
P4 X P5	83.30	86.33**	23.10	7.21
P4 X P6	194.01	290.19**	149.69**	149.69**
P5 X P1	80.31	28.35	18.69	3.36
P5X P2	107.37	111.00**	58.67**	38.18**
P5 X P3	184.50	299.49**	172.66**	137.45**
P5 X P4	79.44	77.71**	17.40	2.24
P5 X P6	166.41	128.95**	114.17**	114.17**
P6 X P1	175.21	159.24**	125.50**	125.50**
P6 X P2	65.33	16.87	-15.92	-15.92
P6 X P3	173.33	238.54**	123.08**	123.08**
P6 X P4	240.50	383.69**	209.52**	209.52**
P6 X P5	125.21	72.27**	61.15**	61.15**
CD 1%		18.725	21.622	21.622
CD 5%		15.167	17.514	17.514

* - Significant at 5% ** - Significant at 1%

4.2 COMBINING ABILITY

The analysis of variance for combining ability in a full diallel mating design revealed that the mean sum of squares was found highly significant for all the characters (Table 7).

4.2.1 Combining Ability Variances

The mean sum of squares due to general combining ability (gca), specific combining ability (sca) and reciprocal combining ability (rca) were found highly significant for all the characters. (Table 8).

4.2.2 Combining Ability Effects

The estimate of general combining ability and specific combining ability effects for all traits in diallel mating design are presented in Tables (9 & 10) and respectively and the results are given below.

4.2.1.1 Plant Height (cm)

The mean sum of squares due to gca, sca and rca were found highly significant.

Of the six parents, P6 (12.95) recorded the highest significant positive gca effect and P2 (-8.69) recorded the highest significant negative gca effect. Out of 6 parents, 2 registered positive significant gca effects and 3 registered negative significant gca effects.

The sca effects ranged from -6.10 (P3 x P2) to 20.07(P5 x P6 and P6 x P5). The highest significant negative sca effect was observed in P3 x P2 (-6.10) followed

by P1 x P5 (-5.41). Among 30 hybrids, 17 exhibited significant sca effects towards positive direction.

4.2.1.2 Branches per Plant

The mean sum of squares due to gca, sca and rca were found highly significant.

Of the six parents, P6 (1.24) recorded the highest significant positive gca effect and P1 (-1.62) recorded the highest significant negative gca effect followed by P3 (-0.51). Out of 6 parents, 2 registered positive significant gca effects and 2 registered negative significant gca effects.

The sca effects ranged from -1.17 (P6 x P4) to 2.23 (P2 x P5). Among 30 hybrids, 11 exhibited significant sca effects towards positive direction.

4.2.1.3 Fruits per Plant

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P6 (54.10) recorded the maximum significant positive gca effect. Out of 6 parents, 3 registered negative significant gca effects and 2 registered positive significant gca effects.

The sca effects ranged from -44.65 (P2 x P6) to 82.52 (P4 x P6). Out of 30 hybrids, 15 hybrids recorded significant positive sca effects.

4.2.1.4 Average Fruit Length (cm)

The mean sum of squares due to gca, sca and rca were found highly significant.

Out of 6 parents, 3 exhibited significant positive gca effects while 3 parents exhibited significant negative gca effects. P3 (0.92) had the highest significant positive gca effect followed by P4 (0.76), while P1 (-1.08) exhibited the highest significant negative gca effect followed by P5 (-0.73).

Though 18 hybrids recorded positive sca effects only 10 were significant. The cross P4 x P5 (3.16) had the maximum sca effect. The sca effects ranged from -2.63 (P6 x P4) to 3.16 (P4 x P5).

4.2.1.5 Average Fruit Girth (cm)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P4 (0.61) recorded the maximum significant positive gca effect. Out of 6 parents, 2 registered negative significant gca effects and 2 registered positive significant gca effects.

The sca effects ranged from -2.20 (P3 x P2) to 2.06 (P4 x P5). Out of 30 hybrids, 10 recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects.

4.2.1.6 Fruit Weight (g)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among the parents, P3 (3.22) exhibited the maximum significant positive gca effect and P1 (-1.44) exhibited the maximum negative gca effect. Out of 6 parents, 4 registered negative gca effects and 2 registered positive gca effects.

The sca effects ranged from -1.38 (P5 x P2) to 3.01 (P3 x P6). Among hybrids, 11 recorded significant negative sca effects and 10 recorded significant positive effects

4.2.1.7 Yield per Plot (kg)

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -3.58 (P1) to 6.58 (P6). Out of 6 parents, 4 registered negative gca effects and 2 registered positive gca effects.

The sca effects ranged from -15.5 (P5 x P3) to 24.43 (P3 x P6). A total of 10 hybrids exhibited significant positive sca effects.

4.2.1.8 Total Soluble Protein Content (mg/g)

The mean sum of squares due to gca, sca and rca were found highly significant.

Out of 6 parents, P4 (0.04) and P6 (0.18) exhibited significant positive gca effects while P2 (-0.20) exhibited significant negative gca effect.

Though 15 hybrids recorded positive sca effects, only 12 were significant. The cross P3 x P5 (0.32) had maximum sca effect.

4.2.1.9 Total Chlorophyll Content (mg/g)

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -0.08 (P4) to 0.08 (P3). Out of 6 parents, 3 registered negative gca effects and 3 registered positive gca effects.

The sca effects ranged from -0.18 (P1 x P4) to 0.29 (P6 x P3). A total of 11 hybrids exhibited significant positive sca effects.

4.2.1.10 Phenol Content (µg/ml)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P6 (76.84) recorded the maximum significant positive gca effect. Out of 6 parents, 2 registered negative significant gca effects and 2 registered positive significant gca effects.

The sca effects ranged from -194.8 (P3 x P1) to 213.5 (P3 x P2). Out of 30 hybrids, 4 hybrids recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects.

4.2.1.11 Epicuticular Wax Content (mg/g)

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -0.67 (P5) to 1.56 (P4). Out of 6 parents, 3 registered negative significant gca effects and 2 registered positive significant gca effects.

The sca effects ranged from -6.87 (P5 x P6) to 6.53 (P1 x P6). Out of 30 hybrids, significant positive sca effects were observed for 15 crosses and significant negative effects for 15 crosses.

4.2.1.12 Total CHO Content (mg glucose/100g)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P6 (13.65) recorded the maximum significant positive gca effect. Out of 6 parents, 3 registered negative significant gca effects and only one registered positive significant gca effect.

The sca effects ranged from -22.68 (P5 x P3) to 31.37 (P4 x P6). Out of 30 hybrids, 13 hybrids recorded significant negative sca effects and 9 hybrids recorded significant positive sca effects.

4.2.1.13 Poly Phenol Oxidase Content (activity / µg / minute)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P6 (0.15) recorded the maximum significant positive gca effect. Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects.

The sca effects ranged from -0.19 (P2 x P6) to 0.26 (P4 x P6). Out of 30 hybrids, 14 hybrids recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects.

4.2.1.14 Membrane Integrity

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -4.35 (P6) to 5.19 (P2). Out of 6 parents, 3 registered negative significant gca effects and 2 registered positive significant gca effects.

The sca effects ranged from -15.94 (P4 x P6) to 12.58 (P2 x P6). Out of 30 hybrids, significant positive sca effects were observed for 13 crosses and significant negative effects for 14 crosses.

4.2.1.15 Carotenoids (mg/g)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P5 (0.002) and P1 (0.002) recorded maximum significant positive gca effect and P3 (-0.003) recorded maximum negative gca effect.

The sca effects ranged from -0.010 (P6 x P3) to 0.009 (P1 x P3). Out of 30 hybrids, 10 recorded significant positive sca effects.

4.2.1.16 Capsaicin (%)

The mean sum of squares due to gca, sca and rca were found highly significant.

Among parents, P5 (0.14) recorded maximum significant positive gca effect and P6 (-0.26) recorded maximum negative gca effect.

The sca effects ranged from -0.34 (P3 x P2) to 0.29 (P5 x P6). Out of 30 hybrids, 13 recorded significant positive sca effects.

4.2.1.17 Vitamin C (mg/100g)

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -32.22 (P1) to 26.07 (P6). Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects.

The sca effects ranged from -44.18 (P4 x P3) to 47.89 (P3 x P5). Out of 30 hybrids, significant positive sca effects were observed for 13 crosses and significant negative effects for 17 hybrids.

4.2.1.18 Oleoresin (%)

The mean sum of squares due to gca, sca and rca were found highly significant.

The gca effect was ranged from -2.38 (P2) to 2.17 (P6). Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects.

The sca effects ranged from -1.54 (P2 x P6) to 2.84 (P4 x P6). Out of 30 hybrids, significant positive sca effects were observed for 12 crosses and significant negative effects for 14 crosses.

4.2.1.19 Incidence of Leaf Curl Virus Disease

The mean sum of squares due to *gca, sca* and *rca* were found highly significant.

The gca effect was ranged from -10.87 (P6) to 13.60 (P2). Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects.

The sca effects ranged from -16.84 (P3 x P2) to 13.01(P1 x P3). Out of 30 hybrids, significant positive sca effects were observed for 11 hybrids and significant negative effects for 11 hybrids.

4.2.3 Gene action

The estimates of SCA variance were high for all characters than GCA variance. The proportion of variance due to GCA/SCA was found to be less than unity for all the characters, hence exhibited dominance / non additive gene action. (Table 8).

4.3 LEAF CURL VIRUS DISEASE INCIDENCE

Artificial screening was done in insect proof cage to confirm the leaf curl virus resistance among the high yielding and resistant hybrids selected from field experiment. Among hybrids P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4 recorded V.I value zero. These hybrids were used for the artificial screening. The experiment was conducted in CRD with 5 replications.

Leaf curl virus disease incidence scoring was done and vulnerability index (V.I.) was calculated and these values were used for statistical analysis. The results obtained are presented as follows. (Table 11)

Among the crosses P3 x P6 (4.11) recorded the lowest V.I. value. It was closely followed by the cross P4 x P6 (6.33), P5 x P3 (30.33). The highest V.I. value was recorded in the cross P6 x P4 (53.33).

Table 7: ANOVA for combining ability

SOURCE	gca	sca	rca	Error
df	5	15	15	70
Plant Height (cm)	707.97**	266.17**	158.48**	3.73
Number of branches per plant	11.30**	8.10**	1.10**	0.44
Number of fruits per plant	10111.43**	3717.39**	1072.15**	33.34
Average Fruit Length (cm)	7.70**	7.50**	5.55**	0.20
Average Fruit Girth (cm)	1.99**	2.55**	1.65**	0.04
Fruit Weight (g)	34.03**	5.83**	0.97**	0.04
Yield per plot (kg)	257.98**	164.03**	46.00**	0.48
Total Soluble Protein Content (mg/g)	0.18**	0.08**	0.05**	0.001
Total Chlorophyll Content(mg/g)	0.04**	0.05**	0.02**	0.0008
Phenol Content (µg/ml)	31391.42**	11351.65**	16275.88**	325.40
Epicuticular Wax Content (mg/g)	12.92**	32.16**	14.31**	0.01
Total CHO Content (mg glucose/100g)	595.06**	319.12**	120.54**	7.31
Polyphenol Oxidase Content (activity/µg/min.)	0.15**	0.03**	0.01**	0.0002
Membrane Integrity	187.67**	159.53**	28.71**	0.38
Carotenoids (mg/g)	0.000050**	0.000049**	0.000031**	0.000001
Capsaicin (%)	0.27**	0.04**	0.08**	0.0018
Vitamin C (mg/100g)	6023.33**	1745.74**	674.14**	0.05
Oleoresin (%)	30.01**	4.20**	1.00**	0.0048
Incidence of Leaf Curl Disease (vulnerability Index)	1026.52**	171.74**	80.27**	4.58

*Significant at 5% level ** Significant at 1% level

Table 8: Genetic components of variance

GENETIC COMPONENTS	gca/sca RATIO	GENE ACTION
Plant Height (cm)	0.224	DOMINANCE
Branches per Plant	0.118	DOMINANCE
Fruits per Plant	0.228	DOMINANCE
Fruit Length (cm)	0.086	DOMINANCE
Average Fruit Girth (cm)	0.065	DOMINANCE
Average Fruit Weight (g)	0.489	DOMINANCE
Yield/ per plot (kg)	0.131	DOMINANCE
Total Soluble Protein Content (mg/g)	0.202	DOMINANCE
Total Chlorophyll Content (mg/g)	0.065	DOMINANCE
Phenol Content (µg/ml)	0.235	DOMINANCE
Epicuticular Wax Content (mg/g)	0.033	DOMINANCE
Total CHO Content (mg/g)	0.157	DOMINANCE
Polyphenol Oxidase Content (activity/µg/min.)	0.368	DOMINANCE
Membrane Integrity	0.098	DOMINANCE
Carotenoids (mg/g)	0.085	DOMINANCE
Capsaicin (%)	0.521	DOMINANCE
Vitamin C (mg/100g)	0.288	DOMINANCE
Oleoresin (%)	0.595	DOMINANCE
Incidence of Leaf Curl Disease (Vulnerability Index)	0.509	DOMINANCE

Table 9: *gca* effect of parents for all the characters

TREATMENTS	P1	P2	P3	P4	P5	P6
Plant Height (cm)	-6.10**	-8.69**	3.22**	-1.95**	0.57	12.95**
Number of branches per plant	-1.62**	0.41*	-0.51**	0.21	0.27	1.24**
Fruits per plant	0.57	-27.87**	-17.79**	-13.24**	4.22**	54.10**
Average Fruit Length (cm)	-1.08**	-0.11	0.92**	0.76**	-0.73**	0.24*
Average Fruit Girth (cm)	-0.58**	0.04	0.24**	0.61**	-0.10	-0.22**
Fruit Weight (g)	-1.44**	-0.86**	3.22**	0.20**	-0.97**	-0.15**
Yield per Plot (kg)	-3.58**	-4.29**	4.99**	-2.59**	-1.12**	6.58**
Total Soluble Protein Content (mg/g)	-0.02	-0.20**	-0.01	0.04**	0.00	0.18**
Total Chlorophyll Content (mg/g)	-0.04**	-0.01	0.08**	-0.08**	0.00	0.05**
Phenol Content (µg/ml)	0.70	-49.82**	-5.10	-58.27**	35.65**	76.84**
Epicuticular Wax Content (mg/g)	-0.61**	0.02	0.86**	1.56**	-0.67**	-1.17**
Total CHO Content (mg glucose/100g)	-4.42**	-4.93**	0.50	-0.69	-4.12**	13.65**
Polyphenol Oxidase Content (activity/µg/min.)	0.06**	-0.13**	-0.11**	-0.05**	0.07**	0.15**
Membrane Integrity	-4.11**	5.19**	1.81**	3.08**	-1.62**	-4.35**
Carotenoids (mg/g)	0.002**	-0.001*	-0.003**	0.001**	0.002**	-0.001**
Capsaicin (%)	0.11**	-0.26**	0.08**	0.01	0.14**	-0.08**
Vitamin C (mg/100g)	-32.22**	-3.01**	4.77**	-17.17**	21.56**	26.07**
Oleoresin (%)	0.08**	-2.38**	-0.57**	-0.54**	1.23**	2.17**
Incidence of Leaf Curl Disease (vulnerability Index)	-2.74**	13.60**	4.96**	3.87**	-8.81**	-10.87**

*Significant at 5% ** Significant at 1%

Table 10: *sca* effect of crosses for all the characters.

CROSSES	Plant Height (cm)	No. of branches per Plant	Fruits per Plant	Average Fruit Length (cm)	Average Fruit Girth (cm)	Fruit Weight (g)	Yield per Plot (kg)	Total Soluble Protein Content (mg/g)	Total Chlorophyll Content (mg/g)	Phenol Content (µg/ml)
P1XP2	3.91**	-0.21	27.66**	0.30	-0.37**	2.47**	8.17**	-0.03	0.13**	-15.48
P1XP3	-1.80	1.37**	-15.58**	-1.10**	-0.87**	-1.15**	-4.32**	-0.02	-0.12**	-0.70
P1XP4	0.99	0.48	1.96	2.14**	0.66**	0.41**	2.93**	0.26**	-0.18**	-12.20
P1XP5	-5.41**	-0.24	-12.28**	-1.21**	-0.21	-0.49**	-1.81**	-0.14**	-0.14**	-103.6**
P1XP6	-4.25**	-0.38	35.79**	1.30**	0.66**	-1.16**	-4.17**	0.07**	-0.08**	57.35**
P2XP1	6.10**	0.17	0.00	-0.43	-0.08	-1.27**	-2.65**	-0.06**	0.08**	35.00**
P2XP3	-0.58	-0.49	-4.17	2.72**	0.63**	-0.81**	-4.72**	0.07**	-0.16**	137.49**
P2XP4	0.65	1.79**	-3.32	-1.21***	-0.06	-1.28**	-0.32	-0.20**	0.12**	30.32*
P2XP5	-2.97*	2.23**	28.51**	0.55	-0.48**	0.24	2.64**	0.27**	-0.12**	-95.09**
P2XP6	3.61**	1.76**	-44.65**	-1.22**	1.98**	0.20	-5.59**	-0.08**	-0.13**	-8.29
P3XP1	2.53*	0.17	2.60	-1.93**	-0.15	0.36**	0.82	-0.02	0.20**	-194.8**
P3XP2	-6.10**	0.33	17.94**	-0.23	-2.20**	0.48**	3.10**	0.04	0.04*	213.5**
P3XP4	-0.21	-0.63	-32.03**	-1.89**	0.69**	2.10**	-5.93**	-0.06**	-0.06**	0.10
P3XP5	10.51**	1.31**	28.29**	-0.33	-0.78**	1.87**	7.64**	0.32**	0.20**	15.02
P3XP6	8.60**	1.01**	57.09**	1.85**	-1.04**	3.01**	24.43**	0.03	0.16**	12.16

*Significant at 5% ** Significant at 1%

Table 10: Continued…..

CROSSES	Plant Height (cm)	No. of branches per Plant	Fruits per Plant	Average Fruit Length (cm)	Average Fruit Girth (cm)	Fruit Weight (g)	Yield per Plot (kg)	Total Soluble Protein Content (mg/g)	Total Chlorophyll Content (mg/g)	Phenol Content (µg/ml)
P4XP1	-3.12*	0.01	20.49**	1.08**	-0.32*	0.94**	-0.22	-0.08**	0.01	-16.17
P4XP2	-2.22	0.33	7.44*	-2.47**	1.05**	0.19	0.72	-0.06**	0.10**	-22.50
P4XP3	10.13**	0.01	-4.15	2.08**	1.97**	0.83**	-0.39	-0.01	-0.09**	12.67
P4XP5	4.76**	-0.74	-3.49	3.16**	2.06**	-0.62**	-2.73**	-0.16**	0.13**	55.02**
P4XP6	7.24**	1.79**	82.52**	1.61**	-1.31**	-0.89**	6.07**	0.30**	-0.05**	-116.8**
P5XP1	5.73**	-0.67	6.08	-0.10	0.33*	-0.08	0.15	0.22**	0.13**	17.67
P5XP2	6.55**	-0.17	-8.63*	-0.30	-0.15	-1.38**	-3.70**	0.10**	-0.04*	-18.67
P5XP3	-0.28	0.00	75.90**	1.82**	-0.92**	-0.02	-15.5**	-0.43**	0.01	133.5**
P5XP4	8.95**	1.00*	1.93	2.92**	0.57**	0.27*	0.39	0.06**	-0.03	77.33**
P5XP6	20.07**	0.90*	-6.38	-0.31	-0.30*	-0.01	-3.23**	-0.17**	-0.09**	26.57*
P6XP1	5.73**	1.50**	9.12*	2.62**	-0.52**	-0.36*	-0.96*	0.01	0.01	-12.50
P6XP2	6.55**	1.67**	10.12*	0.00	0.62**	0.95**	2.56**	0.08**	0.08**	16.67
P6XP3	-0.28	-0.33	13.94**	0.40	-0.10	0.59**	5.89**	0.32**	0.29**	0.83
P6XP4	8.95**	-1.17*	23.25**	-2.63**	0.07	-0.55**	-4.80**	-0.05*	-0.03	103.7**
P6XP5	20.07**	0.00	20.60**	-0.48	0.70**	0.22	2.53**	0.14**	-0.10**	27.00*

*Significant at 5% ** Significant at 1%

Table 10: Continued…..

CROSSES	Epicuticular Wax Content (mg/g)	Total CHO Content (mg glucose/100g)	Polyphenol Oxidase Content(activity/µg/min.)	Membrane Integrity	Carotenoids (mg/g)	Capsaicin (%)	Vitamin C (mg/100g)	Oleoresin (%)	Incidence of Leaf Curl Disease (vulnerability Index)
P1XP2	-1.49**	9.84**	0.11**	-4.18**	-0.003**	-0.08**	0.82**	-0.17**	11.57**
P1XP3	-4.92**	4.86**	-0.15**	-2.45**	0.009**	0.10**	-2.32**	-0.25**	13.01**
P1XP4	-1.69**	-5.50**	-0.11**	0.51	0.000	-0.09**	7.68**	-0.44**	-6.91**
P1XP5	-0.89**	-1.60	0.03**	8.08**	0.004**	-0.03	-5.65**	1.24**	-1.87
P1XP6	6.53**	-15.24**	0.04**	-3.91**	0.002*	-0.02	-35.38**	2.07**	-3.71*
P2XP1	-4.92**	-3.00	0.01	-3.20**	-0.005**	-0.31**	6.62**	0.50**	0.69
P2XP3	1.42**	-1.76	0.13**	0.34*	0.005**	-0.06*	-33.67**	0.70**	-0.95
P2XP4	2.44**	-7.93**	0.04**	-7.08**	-0.003**	0.05	-11.51**	-0.63**	-7.10**
P2XP5	5.02**	-5.17**	-0.08**	-5.66**	0.002*	0.05	47.02**	0.09*	-2.81*
P2XP6	-5.99**	-4.68*	-0.19**	12.58**	0.005**	0.08**	31.32**	-1.54**	10.15**
P3XP1	-2.20**	4.69*	-0.04**	-2.63**	-0.005**	-0.06*	-7.18**	1.04**	6.68**
P3XP2	-0.37**	0.76	-0.06**	-1.05*	-0.002*	-0.34**	-12.39**	-0.80**	-16.84**
P3XP4	2.11**	-11.72**	-0.07**	8.38**	0.000	0.12	27.34**	-0.83**	4.32**
P3XP5	1.16**	4.79**	0.13**	-14.07**	-0.007**	0.08**	47.89**	1.77**	-6.25**
P3XP6	0.29**	-11.77**	0.12**	7.16**	-0.006**	-0.25**	-3.64**	-1.35**	-7.52**

*Significant at 5% ** Significant at 1%

Table 10: Continued…..

CROSSES	Epicuticular Wax Content (mg/g)	Total CHO Content (mg glucose/100g)	Polyphenol Oxidase Content (activity/µg/min.)	Membrane Integrity	Carotenoids (mg/g)	Capsaicin (%)	Vitamin C (mg/100g)	Oleoresin (%)	Incidence of Leaf Curl Disease (vulnerability Index)
P4XP1	-0.33**	-5.98**	-0.02*	6.62**	0.000	0.20**	-2.48**	1.12**	4.78**
P4XP2	3.68**	6.16**	0.17**	7.30**	-0.005**	0.25**	4.88**	0.33**	-7.55**
P4XP3	-1.70**	5.05**	0.08**	5.44**	0.005**	0.09**	-44.18**	1.01**	5.31**
P4XP5	2.61**	-7.79**	-0.06**	12.33**	0.000	-0.13**	-33.76**	0.05	-1.07
P4XP6	-0.81**	31.37**	0.26**	-15.94**	0.003**	0.17**	12.66**	2.84**	-11.90**
P5XP1	-6.83**	2.90	-0.03**	4.61**	-0.005**	0.07*	-25.75**	1.17**	3.10*
P5XP2	1.03**	6.14**	-0.05**	-2.63**	0.000	0.20**	2.09**	-0.67**	3.83**
P5XP3	1.32**	-22.68**	-0.17**	2.04**	0.002*	-0.09**	-3.25**	-0.82**	8.78**
P5XP4	0.53**	-8.12**	-0.04**	-1.40**	0.000	-0.08**	6.17**	0.02	-0.13
P5XP6	-6.87**	-10.04**	-0.01	7.41**	0.002**	0.29**	-12.35**	-1.45**	10.13**
P6XP1	-2.92**	1.86	-0.06**	0.37	0.000	0.23**	0.34*	-0.33**	1.57
P6XP2	0.92**	9.71**	-0.14**	2.35**	0.000	-0.20**	-15.36**	-0.02	-5.53**
P6XP3	1.32**	-3.46	0.07**	-3.42**	-0.010**	0.10**	-9.78**	0.01	-5.46**
P6XP4	0.75**	-5.44**	-0.01	3.74**	0.000	-0.28**	-42.00**	-0.72**	0.00
P6XP5	-0.45**	-2.78	-0.01	-2.16**	0.000	0.06*	3.74**	-0.11*	1.01

*Significant at 5% ** Significant at 1%

Table 11: Analysis of variance – CRD (Experiment 3) - Leaf Curl Virus disease incidence – Artificial screening.

Source	d.f	Sum of squares	Mean sum of squares	F- value
Between treatments	4	23.72178	5.930446	0.013478*
Error	20	8800.218	440.0109	
Total	24	8823.94		

*Significant at 5% ** Significant at 1%

Jwalasakhi x Pusa Sadabahar (P4 x P6)

Vellayani Athulya x Pusa Sadabahar (P3 xP6)

Plate 5: Tolerant hybrids for LCV (Artificial screening)

Discussion

5. DISCUSSION

The objectives in crop improvement programme continue to be those which are of crucial importance in negating the world food crisis. The pressure of population and the consequent increase in demand for food on one hand and the depleting resources on the other hand has led to a ceiling in the crop yield improvement. Several parameters of selection have been developed in plant breeding research to achieve desirable genetic improvement for yield and other desirable quality components.

Chilli is one of the important vegetable crops of India. An ideal chilli hybrid should be vigorous, have good branching habit, short internodes, early flowering, prolonged production of flowers, high fruit weight and good plant height. It may be difficult to develop a hybrid having all these characters but it is reasonable to search or develop one, which can have maximum number of desirable characters keeping yield as a primary motto. The magnitude of heterosis depends on the genetic diversity existing between the parents.

For a systematic breeding programme, it is essential to identify the parents as well as crosses to bring about genetic improvement in economic characters. In a crop like chilli where there are increasing evidences for polygenic action in determining yield, yield components and disease, the choice of the parents must be based on refined biometrical techniques. The value of a genotype depends on its ability to produce superior hybrids in combination with other genotypes.

Genetic constitution of the parents involved in hybridization governs the nature of gene action in that hybrid. It is therefore necessary to assess the genetic potentialities of the parents in hybrid combination through systematic studies in relation to general and specific combining abilities which are due to additive and non-additive gene effects respectively.

In the present study, six parents were selected based on yield performance and resistance to LCV disease and they are crossed in a diallel fashion to produce

hybrids and to assess the potential of hybrids. The primary objective was to identify superior hybrid combinations and additionally combining ability and gene action of different trait of the parents would also be known. The materials generated were analyzed as per the full diallel experiment.

Diallel cross involved hybridization among six parents in all possible combinations generating 30 hybrids. The parents, F_1's and reciprocals were included as experimental materials in method 1 of Griffing (1956) numerical approach. All the possible matings in diallel cross are equal to P (P-1)/ 2 for direct or one way crosses and double of this, i.e., P (P-1) where reciprocals are included, where P is the number of parents.

With this background, the results obtained have been discussed as follows.

5.1 HETEROSIS

Heterosis is the superiority of F_1 over the mean of the two parents or over the mean of the better parent or the standard check (Hays *et al.*, 1956), with respect to agriculturally useful traits. The primary objective of heterosis breeding is to achieve a quantum jump in yield and quality aspects of crop plants.

In the present study parents formed the base material and in the following paragraphs, heterotic behaviour of hybrids for various traits is described. The range of heterosis over mid parent, better parent and standard checks and hybrids with their superior performance in respect of each of the characters are presented.

5.1.1. Plant Height (cm)

Plant height was reported to be an important yield component as it was significantly associated with fruit yield. In the present study, most of the hybrids recorded heterosis in positive direction. Out of 30 hybrids 22 hybrids recorded significant positive heterosis over mid parent, 16 hybrids over better parent and 12 hybrids over standard check. However, positive heterosis was realized over parents, indicating that the hybrids were taller than their parents and standard

check. Pusa Sadabahar x Jwalasakhi (P6 xP4) exhibited maximum and significant standard heterosis value (73.76) for this trait. Many workers have reported both positive and negative heterostic values for plant height. The predominance of tallness over dwarfness, indicated tallness as a dominant character as reported by Gaddagimath (1992), Patel *et al*. (1997), Jagadeesh (2000), Malathi (2001), Sathiyamurthy (2002), Nandadevi and Hosamani (2003), Durvesh *et al*.(2006), Kamble *et al.* (2009) and Surendra *et al.(*2011).

5.1.2. Number of Branches per Plant

Branches are the important growth trait contributing to productivity. The standard check had 3.33 branches per plant while the hybrids had the range of 5.33 to 12.67. 27 hybrids showed significant positive heterosis over mid parent and 24 hybrids showed significant positive heterosis over better parent and 16 hybrids over standard check. Similar results with significant positive heterosis for number of branches were reported by Das and Choudhary, 1999a, Ibrahim *et al*.(2001), Malathi (2001), Leaya Jose and Abdul Khader (2002), Mallikarjun *et al.* (2003), Nandadevi and Hosamani (2003), Prabhudeva (2003) and Kumari *et al.* (2011).

5.1.3 Number of Fruits Per Plant

Among parents and hybrids it ranged from 21.74 to 57.48 and 26.11 to 240.50 respectively. Pusa Sadabahar x Jwalasakhi (P6 xP4) exhibited maximum number of fruits per plant. Among 30 hybrids, 24 hybrids exhibited significant positive heterosis over mid-parent, 18 over better parent and 10 over check. The positive heterosis substantiated the fact that the hybrids had higher fruit number. These results are in agreement with the findings of Ghai and Thakur (1987), Ibrahim *et al*.(2001), Malathi (2001), Leaya Jose and Abdul Khader (2002), Mallikarjun *et al*. (2003), Nandadevi and Hosamani (2003), Prabhudeva (2003), Philip (2004), Reddy *et al*. (2008), Kamble and Mulge (2008b), Surendra *et al.(*2011) and Alok Chaudhary *et al.* (2013).

5.1.4 Average Fruit Length (cm)

Among hybrids Jwalasakhi x Pant C 1 (P4 x P5) had maximum value (14.60cm). Highest significant positive heterosis was recorded in the cross P4 x P5 over mid parent, P1 x P3 over better parent and P4 x P5 over the check. The positive heterosis substantiated the fact that the hybrids in general had longer fruits. Miranda *et al*. (1988b), Gupta and Singh (1992), Hiremath (1997), Subashri and Natarajan (1999), Ibrahim *et al*. (2001), Mallikarjun *et al*. (2003), Prabhudeva (2003), and Kumari *et al.* (2011) also observed similar results.

5.1.5 Average Fruit Girth (cm)

The average fruit girth varied significantly among the parents and hybrids and it ranged from 2.67 cm (P2) to 6.13 cm (P3) among the parents and 2.73 cm (P3 x P5) to 7.80 cm (P3 x P4) among the crosses.

The maximum positive heterosis over the mid-parent was observed in the cross P2 x P6, P4 x P5 over better parent and P3 x P4 over the check hybrid. Out of 30 hybrids, 13 hybrids over mid-parent, 9 hybrids over better parent and 3 hybrids over check recorded significant positive heterosis. The positive heterosis substantiated the fact that the hybrids had more girth. These results are in conformity with earlier findings of Deshpande (1933), Saraladevi (1994), Muthuswamy (2004), Ajith (2004) and Reddy *et al*. (2008),

5.1.6 Fruit Weight (g)

The fruit weight of a genotype serves as an indicator of fruit yield as it is an important character contributing to yield. Cross P3 x P6 had a maximum fruit weight (11.77g). In the present investigation, most of the hybrids recorded positive heterosis over mid parent, better parent and standard checks. Among 30 hybrids, cross P2 x P1 recorded significant positive heterosis over mid-parent, better parent and P3 x P6 over standard check. The positive heterosis substantiated the fact that the hybrids in general had higher fruit weight. Similar

results were obtained by Mohamed *et al.* (1995), Malathi (2001), Muthuvel (2003) and Alok Chaudhary *et al.* (2013).

5.1.7 Yield per Plot (kg)

The ultimate aim of any breeding programme is to increase the yield. Cross P3 x P6 had a maximum yield per plot (52.60 kg). All 30 hybrids recorded significant positive heterosis over mid parent which ranged from 16.85 to 1005.14 per cent, -23.71 to 951.91 percent over better parent and -56.39 to 728.90 percent over check. This suggests a strong influence of gene action in determining fruit yield per plant. It indicates that chances of the development of potential high yielding hybrids are more. Similar conclusions have been drawn by Deshpande (1933) and Pal (1945), Gaddagimath (1992), Saraladevi (1994), Jagadeesh (1995), Joshi *et al*. (1995), Shukla *et al*. (1999), Anandanayaki and Natarajan (2000), Ghandi *et al*. (2000), Singh and Hundal (2001), Narasimhaprasad *et al.* (2003), Muthuswamy (2004), Philip (2004), Adpawar *et al*. (2006), Haridass (2007), Kamble and Mulge (2008b), Reddy *et al*. (2008), Prasath and Ponnuswami (2008) and Surendra *et al*.(2011).

The superior performance of hybrids may be attributed to the favourable epistatic interaction of genes in the parental lines or due to buffering action of the gene combination against adverse environmental conditions, as these hybrids are characterized by highly homogeneous and heterozygous condition (Kide *et al.*, 1985).

5.1.8 Total Soluble Protein Content (mg/g)

The protein content of plants is considered as a better index for assessing the status of plants for its growth and development. Among the parents, maximum total soluble protein content was noticed in P6 (1.32 mg/g) and minimum was noticed in P2 (0.66 mg/g) while, the hybrid P5 x P3 (1.84 mg/g) exhibited maximum and P2 x P4 (0.68 mg/g) exhibited minimum. Maximum

positive heterosis percent over mid-parent, better parent and check was observed in P5 xP3. Similar results were observed by Devi and Arumugam (1999).

5.1.9 Total Chlorophyll Content (mg/g)

Chlorophyll content is an important trait. The parents had variation from 1.04 mg/g (P4) to 1.45 mg/g (P1). However, the variation in the hybrids ranged from 0.83 mg/g (P4 x P1) to 1.72 mg/g (P3 x P6). Loss of chlorophyll is always associated with the impairment of photosynthesis as reported by Aruyanark *et al*., (2008), Ladjal *et al.,* (2000), Tayebeh and Hassan, (2010), Zheng *et al.,* (2010) and Anjum *et al.,* (2012).

Among 30 hybrids, 21 exhibited heterosis in highly significant and negetive direction over mid-parent and 24 hybrids recorded highly significant negative heterosis over their respective better parents. (Patel *et al.* 2008)

5.1.10 Phenol Content (µg/ml)

Total phenol content was less in diseased plant as compared to healthy one. The parents had variation from 291.33 µg/ml (P2) to 622.67 µg/ml (P6). However, the variation in the hybrids ranged from 238.0 µg/ml (P4 x P1) to 736.0 µg/g (P2 x P3). Similar results were observed by Singh (2004), Ghosal *et al*, (2004), Devanathan *et al* (2005), and Parashar and Lodha (2007).

The significant and maximum positive heterosis over the mid-parent, better parent and check was observed in the cross P2 x P3. The significant and maximum negative heterosis over the mid-parent, better parent and check was observed in the cross P6 x P4.

5.1.11 Epicuticular Wax Content (mg/g)

Among the parents variation was ranged from 13.17 mg/g (P4) to 19.20 mg/g (P6). However in hybrids the variation ranged from 5.53 mg/g (P5 x P6) to 22.40 mg/g (P2 x P4). Percy and Baker (1987) observed the similar results.

The significant and maximum positive heterosis over the mid-parent, better parent and check was observed in the cross P2 x P4 (69.06, 68.0 and 16.67 per cent).

The significant and maximum negative heterosis over the mid-parent, better parent and check was observed in the cross P5 x P6 (-64.90, -71.18 and -71.18 per cent).

5.1.12 Total CHO Content (mg glucose/100g)

Among the parents variation was ranged from 59.53 mg glucose/100g (P1) to 98.39 mg glucose/100g (P6). However in hybrids the variation ranged from 39.22 mg glucose/100g (P3 x P5) to 110.50 mg glucose/100g (P6 x P4).

The significant and maximum positive and negative heterosis over the mid-parent, better parent and check was observed in the cross P6 x P4 and P3 x P5 respectively.

5.1.13 Poly Phenol Oxidase Content (activity/µg/minute)

Poly phenol oxidase catalyses the oxidation of monophenol and o-dihydroxy phenol (Jiang *et al.,* 2004). Polyphenol oxidase was known as tyrosinase, catechol oxidase and potato oxidase (Maheshwari *et al*, 2006). The parents had variation from 0.14 activity/µg/min. (P3) to 0.70 activity/µg/min. (P6). However, the variation in the hybrids ranged from 0.20 activity/µg/min. (P4 x P2 and P4 x P3) to 0.88 activity/µg/min. (P6 x P4) similar results were observed by Fatima (2007), Saraiva (2007) and Belcarz (2008)

Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions. Maximum significant positive heterosis was observed in the cross P3 x P2 over mid-parent, better parent and commercial check.

5.1.14 Membrane Integrity

Membrane ion leakage or % leakage is a measure of the loss of membrane integrity resulting from membrane damage. The parent P2 had the highest value (66.65 %) and P6 had the lowest value (36.26 %) comparatively. However, the variation in the hybrids ranged low in P4 x P2 and P4 x P3 and high in P6 x P4 as observed by Maalekuu *et al*. (2005).

Highly significant heterosis over mid-parent, better parent and commercial check was observed in both the directions. Among 30 crosses, 15 crosses over mid-parent, 20 crosses over better parent and 26 crosses over check exhibited negative and significant heterosis.

5.1.15 Carotenoids (mg/g)

Among the parents variation ranged from 0.42 mg/g (P1, P2, P3 and P6) to 0.43 mg/g (P4 and P5) only. However in hybrids the variation ranged from 5.53 mg/g (P5 x P6) to 22.40 mg/g (P2 x P4). Similar results were observed by Olaiya and Poloamina (2013). The significant and maximum positive and negative heterosis over the mid-parent, better parent and check was observed in the cross P3 x P1 and P3 x P6 respectively.

5.1.16 Capsaicin (%)

Capsaicin, the pungent principle in chilli is considered to be an important quality character. There existed a wide range of variation among the treatments. Among the parents it was ranged from 0.96 % (P2) to 1.85 % (P1) and among hybrids 0.94 % (P2 x P3) to 1.92 % (P5 x P6). Similar results were reported by Kumar *et al.* (2003), Chatterjee (2006), Prasanth *et al.* (2007), Jyothi *et al.* (2008), Chattopadhyay *et al.* (2011) and Ruiz-Lau *et al.,* (2011). Highly significant heterosis over mid-parent, better parent and commercial checks was observed in both the directions. The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P6 x P4 and over check in the cross P5 x P6 (Muthuvel, 2003, Kumar *et al*. 2005, Haridass, 2007 and Patel *et al*. 2008).

5.1.17 Vitamin C (mg/100 g)

P6 recorded maximum with 196.06 mg/100g. P5 x P3 with 214.00 mg/100g was found to be good source of trait. Similar results were observed by Manju (2001), Bini (2004), Choudhary and Samadia (2004), Shrisat *et al.* (2007) and Dandunayak (2008)

The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P4 x P3 (86.12 and 77.10 per cent) and over check in the cross P5 x P3 (9.15 percent).

The significant and maximum negative heterosis over the mid-parent and better parent was observed in the cross P1 x P2 (-29.94 and -46.76 per cent) and over check in the cross P2 x P3 (-49.10 percent).

5.1.18 Oleoresin (%)

Oleoresin represents the total flavor extract of ground spice. P6 with 16.66 % recorded the highest oleoresin content among the parents and P6 x P4 with 18.08 % among hybrids. The extent of heterosis exhibited by the hybrids was high in P1 x P5 over mid-parent and better parent and P6 x P4 over check. Similar variation was reported by Prasanth *et al.* (2007), Jyothi *et al.* (2008) and Chattopadhyay *et al.* (2011)

Among 30 hybrids tested, 16 hybrids over mid-parent, 11 over better parent, and 3 over check exhibited significant positive heterosis.

5.1.19 Leaf Curl Virus Disease Incidence (Vulnerability Index)

In the field experiment P6 has recorded zero and P4 recorded 49.29 V.I. values among the parents. However in hybrids V.I**.** values ranged from zero (P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4) to 53.33 (P4 x P5). Similar results were observed by Tewari and Ramanujam, 1974, Mathai *et al.* 1977 Kumar *et al*. 2009, Kumar *et al*. 2011 The significant and maximum negative heterosis over the

mid-parent, better parent and check was -100.00 percent (P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4). The significant and maximum positive heterosis over the mid-parent and better parent was observed in the cross P5 x P6 (555.54 and 227.77 per cent) and over check in the cross P3 x P2 (8.19 percent). Among 30 hybrids tested, 13 over mid-parent, 19 over better parent and 29 over check exhibited significant negative heterosis. Similar results were observed by Ajith (2004).

Measurement of heterosis revealed that standard heterosis was positive and significant in the combinations, Vellayani Athulya x Pusa Sadabahar (P3 x P6), Pusa Sadabahar x Vellayani Athulya (P6 x P3), Pusa Sadabahar x Jwalasakhi (P6 x P4) and Vellayani Athulya x Jwalasakhi (P6 x P4) for all the traits.

The crosses, Vellayani Athulya x Pusa Sadabahar (P3 x P6), Pusa Sadabahar x Ujwala (P6 x P1), Jwalasakhi x Pusa Sadabahar (P4 x P6) were exhibited positive and significant standard heterosis for yield and yield related traits. The cross Pant C1 x Vellayani Athulya (P5 x P3) exhibited negative and significant standard heterosis for incidence of leaf curl virus disease

5.2. COMBINING ABILITY AND GENE ACTION

The combining ability concept was first proposed by Sprague and Tatum (1942) in corn.

The combining ability analysis gives an indication of the variance due to gca and sca, which represent a relative measure of additive and non-additive gene action, respectively. It is an established fact that dominance is a component of non-additive genetic variance (breeding value). Breeders use these variance components to infer the gene action and to assess the genetic potentialities of the parents in hybrid combination.

5.2.1 Analysis of Variance

Analysis of variance in diallel design revealed that the mean sum of squares due to treatments were highly significant for all the traits. These results are in confirmity with the findings of Gouda *et al*. (2003) in chilli.

5.2.2 General Combining Ability Variance and Effects

The general combining ability (gca) is the comparative ability of the mean performance of all the cross involving a parent from over all mean.

A positive general combining ability (gca) indicates a parent that produced above average of different progenies, whereas parent with negative gca produced progeny that performs below average of the population.

Combining ability analysis showed significant *gca, sca* and reciprocal variances for all the traits. Moreover *gca/sca* variance ratio indicated preponderance of dominance gene action for the inheritance of all traits. Among parents, Pusa Sadabahar (P6) exhibited positive and significant *gca* effect for plant height, branches per plant, number of fruits per plant, yield per plot, total soluble protein, phenol content, total carbohydrate, poly phenol oxidase, vitamin C, oleoresin and negative and significant effect for incidence of leaf curl virus disease. Pant C 1 (P5) for carotenoids, Jwalasakhi (P4) for fruit girth and epicuticular wax content, Vellayani Athulya (P3) for fruit length, fruit weight, total chlorophyll and capsaicin, Anugraha (P2) for membrane integrity and incidence of leaf curl disease.

Since the parental performance is a good indicator of its *gca* effects, the lines with high fruit yield per plant and less disease incidence can be used in crossing programme.

5.2.3 Specific Combining Ability Variance and Effects

Specific combining ability (sca) was defined as the deviation in the performance of specific cross from the performance expected on the basis of general combining ability effects of parents involved in the crosses.

Specific combining ability (sca) can be either negative or positive and sca always refers to specific cross and never to particular parent by itself.

Among the total 30 crosses, cross exhibiting high *sca* effect was selected from each character and the *gca* status of the parents of each hybrids has been observed as either low or high and from the results it is clear that none of the hybrids combined higher *sca* effect for all the economic characters.

5.2.4 Gene Action

The estimates of sca variances were high as compared to gca and reciprocal variance for all the characters indicating the predominance of dominance/non additive gene action.

The estimate of *gca/sca* ratio (variance ratio) is less than unity indicated that a relatively higher proportion of *sca* was responsible for the expression of all the characters and hence the predominance of dominance gene action.

The magnitude of the ratio exhibited variation among the different traits.

5.2.3.1 Plant Height (cm)

The mean sum of squares due to gca, sca and reciprocal were found highly significant. P6 (12.95) recorded the highest significant positive gca effect and P2 (-8.69) recorded the highest significant negative gca effect.

The sca effect was positive and maximum in P5 x P6 and P6 x P5. Among 30 hybrids, 17 exhibited significant sca effects towards positive direction. Similar results are reported by Gaddagimath *et al*. (1988), Shoo *et al.* (1989), Ahmed (1999), Devi and Arumugam (1999), Muthuswamy (2004), Gondane *et al*. (2007), Khereba *et al.* (2008) and Muhamad syukur *et al.* (2013).

5.2.3.2 Branches per Plant

The mean sum of squares due to gca, sca and rca were found highly significant. Of the six parents, P6 (1.24) recorded the highest significant positive gca effect. Out of 6 parents, 2 registered positive significant gca effects and 2 registered negative significant gca effects.

The sca effects ranged from -1.17 (P6 x P4) to 2.23 (P2 x P5). Among 30 hybrids, 11 exhibited significant sca effects towards positive direction. Jagadeesh (1995), Patil (1997), Shukla *et al.* (1999), Saritha *et al.* (2005), Chadchan (2008) and Vandna *et al*. (2012) observed the similar results.

5.2.3.3 Fruits per Plant

Among parents, P6 (54.10) recorded the maximum significant positive gca effect. Out of 6 parents, 2 registered positive significant gca effects.

The sca effects ranged from -44.65 (P2 x P6) to 82.52 (P4 x P6). Out of 30 hybrids, 15 hybrids recorded significant positive sca effects. Similar finding were reported by Mishra *et al.* (1991), Jagadeesh (1995), Patil (1997), Jadhav *et al.* (2001), Nandadevi and Hosamani (2003), Ajith (2004), Gondane *et al*. (2007), Vandna *et al*. (2012) and Sharma and Munish (2013).

5.2.3.4 Average Fruit Length (cm)

Out of 6 parents, P3 (0.92) had the highest significant positive gca effect followed by P4 (0.76), Though 18 hybrids recorded positive sca effects only 10 were significant. The cross P4 x P5 (3.16) had the maximum sca effect. Vandna *et al*. (2012) and Sharma and Munish (2013) observed the similar results.

5.2.3.5 Average Fruit Girth (cm)

In accordance with earlier findings by Bhagyalakshmi *et al*. (1991), Ahmed *et al.* (1997), Muthuswamy, 2004, Chadchan (2008), Vandna *et al*. (2012), among parents, P4 (0.61) recorded the maximum significant positive gca

effect. Out of 6 parents, 2 registered negative significant gca effects and 2 registered positive significant gca effects.

Out of 30 hybrids, 10 recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects.

5.2.3.6 Fruit Weight (g)

Among the parents, P3 (3.22) exhibited the maximum significant positive gca effect and out of 6 parents, 4 registered negative gca effects and 2 registered positive gca effects.

The sca effects ranged from -1.38 (P5 x P2) to 3.01 (P3 x P6). Among hybrids, 11 recorded significant negative sca effects and 10 recorded significant positive effects. The resuts are supported by, Ahmed *et al.* (1997), Patil (1997), Jadhav *et al.* (2001), Muthuswamy, (2004), Khereba *et al*. (2008)

5.2.3.7 Yield Per Plot (kg)

The mean sum of squares due to gca, sca and rca were found highly significant. The gca effect was ranged from -3.58 (P1) to 6.58 (P6).

The sca effects ranged from -15.5 (P5 x P3) to 24.43 (P3 x P6). A total of 10 hybrids exhibited significant positive sca effects. Similar results were reported by Gaddagimath (1992), Pandian and Shanmugavelu, (1992), Jagadeesh (1995), Ahmed *et al*. (1997), Shukla *et al*. (1999), Ghandi *et al*. (2000), Nandadevi and Hosamani (2003), Srivastava *et al*. (2005), Prasath and Ponnuswami (2008) and Alok Chaudhary *et al*. (2013).

5.2.3.8 Total Soluble Protein Content (mg/g)

Out of 6 parents, P4 (0.04) and P6 (0.18) exhibited significant positive gca effects while P2 (-0.20) exhibited significant negative gca effect.

Though 15 hybrids recorded positive sca effects, only 12 were significant. The cross P3 x P5 (0.32) had maximum sca effect. Similar reports had observed by Devi and Arumugam (1999).

5.2.3.9 Total Chlorophyll Content (mg/g)

Out of 6 parents, 3 registered negative gca effects and 3 registered positive gca effects. The gca effect was ranged from -0.08 (P4) to 0.08 (P3). The sca effects ranged from -0.18 (P1 x P4) to 0.29 (P6 x P3). Aruyanark *et al*., (2008), Ladjal *et al.,* (2000), Tayebeh and Hassan, (2010), Zheng *et al.,* (2010) and Anjum *et al.,* (2012) observed the similar type of results.

5.2.3.10 Phenol Content (µg/ml)

The mean sum of squares due to gca, sca and rca were found highly significant. P6 (76.84) recorded the maximum significant positive gca effect.

The sca effects ranged from -194.8 (P3 x P1) to 213.5 (P3 x P2). Out of 30 hybrids, 4 hybrids recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects. Singh (2004), Ghosal *et al*, (2004), Devanathan *et al* (2005), Parashar and Lodha (2007) and Rishi *et al.* (2008) observed similar type of results.

5.2.1.11 Epicuticular Wax Content (mg/g)

The gca effect was ranged from -0.67 (P5) to 1.56 (P4). The sca effects ranged from -6.87 (P5 x P6) to 6.53 (P1 x P6). Out of 30 hybrids, significant positive sca effects were observed for 15 crosses and significant negative effects for 15 crosses. Percy and Baker (1987) observed the similar results

5.2.1.12 Total CHO Content (mg glucose/100g)

Among parents, P6 (13.65) recorded the maximum significant positive gca effect. The sca effects ranged from -22.68 (P5 x P3) to 31.37 (P4 x P6). Out of

30 hybrids, 13 hybrids recorded significant negative sca effects and 9 hybrids recorded significant positive sca effects.

5.2.1.13 Poly Phenol Oxidase Content (activity / µg / minute)

The mean sum of squares due to gca, sca and rca were found highly significant. Among parents, P6 (0.15) recorded the maximum significant positive gca effect. The sca effects ranged from -0.19 (P2 x P6) to 0.26 (P4 x P6). Out of 30 hybrids, 14 hybrids recorded significant negative sca effects and 11 hybrids recorded significant positive sca effects. Similar results were observed by Fatima (2007), Saraiva (2007) and Belcarz (2008).

5.2.1.14 Membrane Integrity

The gca effect was ranged from -4.35 (P6) to 5.19 (P2). The sca effects ranged from -15.94 (P4 x P6) to 12.58 (P2 x P6). Out of 30 hybrids, significant positive sca effects were observed for 13 crosses and significant negative effects for 14 crosses. Similar results were observed by Maalekuu *et al.* (2005).

5.2.1.15 Carotenoids (mg/g)

The mean sum of squares due to gca, sca and rca were found highly significant. Among parents, P5 (0.002) and P1 (0.002) recorded maximum significant positive gca effect and P3 (-0.003) recorded maximum negative gca effect. The sca effects ranged from -0.010 (P6 x P3) to 0.009 (P1 x P3). Out of 30 hybrids, 10 recorded significant positive sca effects. Similar results were observed by Olaiya and Poloamina (2013).

5.2.1.16 Capsaicin (%)

Among parents, P5 (0.14) recorded maximum significant positive gca effect and P6 (-0.26) recorded maximum negative gca effect.

The sca effects ranged from -0.34 (P3 x P2) to 0.29 (P5 x P6). Out of 30 hybrids, 13 recorded significant positive sca effects. Patil (1997), Muthuswamy

(2004), Srivastava *et al.* (2005), Chadchan (2008), Prasath and Ponnuswami (2008) and Prathibha *et al.* (2013) observed similar results.

5.2.1.17 Vitamin C (mg/100g)

The gca effect was ranged from -32.22 (P1) to 26.07 (P6). The sca effects ranged from -44.18 (P4 x P3) to 47.89 (P3 x P5). Out of 30 hybrids, significant positive sca effects were observed for 13 crosses and significant negative effects for 17 hybrids. Manju (2001), Bini (2004), Choudhary and Samadia (2004), Shrisat *et al.* (2007) and Dandunayak (2008) observed similar results.

5.2.1.18 Oleoresin (%)

The mean sum of squares due to gca, sca and rca were found highly significant. The gca effect was ranged from -2.38 (P2) to 2.17 (P6). Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects.

The sca effects ranged from -1.54 (P2 x P6) to 2.84 (P4 x P6). Out of 30 hybrids, significant positive sca effects were observed for 12 crosses and significant negative effects for 14 crosses. These results are in conformity as reported by Prasanth *et al.* (2007), Jyothi *et al.* (2008), Chattopadhyay *et al.* (2011) and Prathibha *et al.* (2013).

5.2.1.19 Incidence of Leaf Curl Virus Disease

Out of 6 parents, the gca effect ranged from -10.87 (P6) to 13.60 (P2). Out of 6 parents, 3 registered negative significant gca effects and 3 registered positive significant gca effects. The sca effects ranged from -16.84 (P3 x P2) to 13.01(P1 x P3). Memane *et al.* (1987), Ajith (2004) Desai *et al*. (2006), Kumar *et al*. 2009 and Kumar *et al.* 2011 observed similar results.

For quality parameters among 30 hybrids, maximum *sca* effect was recorded for P3 x P5 for total soluble protein content, P6 x P3 for total chlorophyll

content, P3 x P2 for phenol content, P1 x P6 for epicuticular wax content, P4 x P6 for total CHO content, poly phenol oxidase content and oleoresin content, P2 x P6 for membrane integrity, P1 x P3 for carotenoids, P5 x P6 for capsaicin, P3 x P5 for vitamin C, and P1 x P3 for incidence of leaf curl disease

5.3. LEAF CURL VIRUS DISEASE INCIDENCE

Plant possess their own networks of defense system that include a vast assay of protein and other organic molecules that are produced prior to infection or during pathogen attack. Plants can also acquire enhanced resistance to pathogens by acquiring systemic resistance. Induced resistance in plants involves various biochemical interactions occurring between host and the pathogen. The plant resistance is an effect of combination of physical and chemical barriers that are induced only after infection. These include mainly proteins, phyto alexins, proteinase inhibitors, *etc.*

The in-depth knowledge in the relationship of resistant genes on induction with pathogen will allow exporting the potential of resistant crops to overcome the menace posed by the pathogen and insects in agricultural and horticultural crops.

The relationship between leaf curl virus disease incidence in terms of vulnerability index and various biochemical constraints in plants revealed that V.I. value is positively associated with membrane integrity in terms of % leakage, which clearly indicating that as % leakage increases degree of susceptibility also increases. whereas V.I. negatively associated with total soluble protein content, phenol content, total CHO content, poly phenol oxidase content, vitamin C and oleoresin content.

In the field experiment conducted for the evaluation of parents and their cross combinations for yield performance and natural screening for the leaf curl virus disease incidence in diallel mating design, most of the hybrids were superior to check variety for leaf curl virus disease incidence score. Among hybrids, P3 x P6, P4 x P6, P5 x P3, P6 x P1 and P6 x P4 exhibited zero V.I. value and P3 x P2

recorded the highest V.I. value and it was highly susceptible. The hybrids recorded the lowest V.I. value zero were subjected to artificial screening to confirm the disease resistance level and the V.I. values were recorded. Of which, P3 x P6 (4.11) and P4 x P6 (6.33) are classified as tolerant, P5 x P3 (30.33) and P6 x P1 (36.97) as susceptible and P6 x P4 (53.33) as highly susceptible hybrids as per the scoring method developed by Rajmony *et al.* (1990).

Coefficient of infection was significantly and negatively correlated with phenol content, peroxidase activity, and polyphenol oxidase activity in the leaves, suggesting that least susceptible genotypes had high phenol content and enhanced peroxidase and polyphenol oxidase activity in the leaves. Reports of earlier workers suggested that the resistance to diseases caused by pathogen was attributed to the presence of high amount of phenol in the leaf. (Jain and Yadav, 2003; Kushwaha and Narain, 2005; Parashan and Lodha, 2007). A positive correlation between host resistance and the amount of phenol and increased activity of peroxidase and polyphenol oxidase has been recorded in chilli by Jabeen *et al.* (2009). High total phenol content and higher activity of peroxidase and polyphenol oxidase in the leaves of 60 days old plants emerged as the dependable biochemical determinant of resistance in the host plant for chilli leaf curl virus disease which can be used for early identification of resistant genotypes during population screening.

Hence an in-depth knowledge in the relationship of disease incidence and biochemical components will be useful to carry out breeding for resistant varieties to overcome the menace posed by pathogen in host plants.

Table 12: Overall comparison of parents and hybrids by standard heterosis, gca effect and sca effect for various traits.

Character	Standard Heterosis	gca effect	sca effect
Plant Height (cm)	P6 x P4	P6	P6 x P5, P5 x P6
Number of branches per plant	P2 x P6	P6	P2 x P5
Number of fruits per plant	P6 x P4	P6	P4 x P6
Average Fruit Length (cm)	P4 x P5	P3	P4 x P5
Average Fruit Girth (cm)	P3 x P4	P4	P4 x P5
Fruit Weight (g)	P3 x P6	P3	P3 x P6
Yield per plot (kg)	P3 x P6	P6	P3 x P6
Total Soluble Protein Content (mg/g)	P5 x P3	P6	P3 x P5
Total Chlorophyll Content(mg/g)	P3 x P6	P3	P6 x P3
Phenol Content (µg/ml)	P2 x P3	P6	P3 x P2
Epicuticular Wax Content (mg/g)	P2 x P4	P4	P1 x P6
Total CHO Content (mg glucose/100g)	P6 x P4	P6	P4 x P6
Polyphenol Oxidase Content (activity/µg/min.)	P6 x P4	P6	P4 x P6
Membrane Integrity	P3 x P4	P2	P2 x P6
Carotenoids (mg/g)	P3 x P1, P5 x P1	P5	P1 x P3
Capsaicin (%)	P5 x P6	P3	P5 x P6
Vitamin C (mg/100g)	P5 x P3	P6	P3 x P5
Oleoresin (%)	P6 x P4	P6	P4 x P6
Incidence of Leaf Curl Disease (vulnerability Index)	P3 x P2	P2	P1 x P3

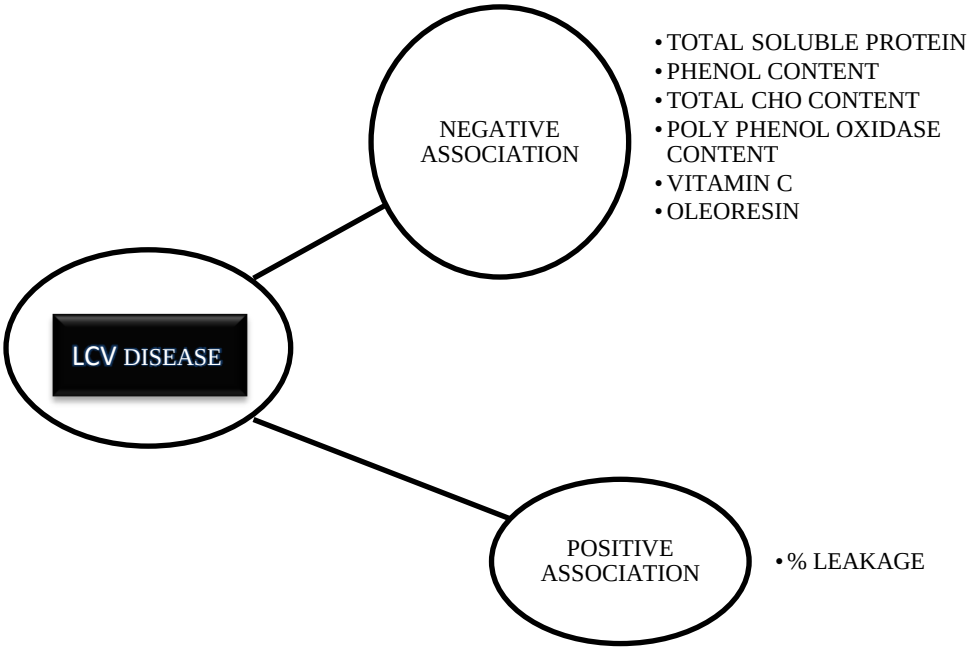

Fig. 1. Association of Leaf Curl Virus disease with various quality characters

Summary

6. SUMMARY

Chilli is one of the important vegetable crops of India. For a systematic breeding programme, it is essential to identify the parents, as well as crosses which could be exploited in order to bring about further genetic improvement in economic characters.

The experiment was carried out in a diallel model at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2012-14. Thirty crosses were developed by crossing 6 parents. All the crosses were evaluated along with the parents in randomized block design with three replications.

Analysis of variance indicated highly significant differences among the treatments (genotypes) for all the characters.

Heterosis studies revealed that standard heterosis was highly significant and positive in Pusa Sadabahar x Jwalasakhi (P6 x P4) for plant height, number of fruits per plant, total CHO content, poly phenol oxidase content and oleoresin, Anugraha x Pusa Sadabahar (P2 x P6) for number of branches per plant, Jwalasakhi x Pant C 1 (P4 x P5) for average fruit length, Vellayani Athulya x Jwalasakhi (P3 x P4) for average fruit girth, Vellayani Athlya x Pusa Sadabahar (P3 x P6) for fruit weight, yield per plot and total chlorophyll content, Pant C 1 x Vellayani Athulya (P5 x P3) for total soluble protein content and vitamin C, Anugraha x Vellayani Athulya (P2 xP3) for phenol content, Anugraha x Jwalasakhi (P2 x P4) for epicuticular wax content, Vellayani Athulya x Jwalasakhi (P3 x P4) for membrane integrity, Pant C 1 x Ujwala (P5 x P1) and Vellayani Athulya x Ujwala (P3 x P1) for carotenoids, Pant C 1 x Pusa Sadabahar (P5 x P6) for capsaicin, Vellayani Athulya x Anugraha (P3 x P2) for incidence of leaf curl disease.

The estimate of sca variance was high as compared to gca and reciprocal variance for all the characters indicates the predominance of dominance or non-additive gene action.

Among parents, Pusa Sadabahar (P6) exhibited positive and significant *gca* effect for plant height, branches per plant, number of fruits per plant, yield per plot, total soluble protein, phenol content, total carbohydrate, poly phenol oxidase, vitamin C, oleoresin and negative and significant effect for incidence of leaf curl virus disease. Pant C 1 (P5) for carotenoids, Jwalasakhi (P4) for fruit girth and epicuticular wax content, Vellayani Athulya (P3) for fruit length, fruit weight, total chlorophyll and capsaicin, Anugraha (P2) for membrane integrity and incidence of leaf curl disease.

Among crosses, Pant C 1 x pusa Sadabahar (P5 x P6) exhibited positive and significant sca effect for plant height, Anugraha x Pant C1 (P2 xP5) for branches per plant, Jwalasakhi x Pusa Sadabahar (P4 x P6) for fruits per plant, total CHO content, poly phenol oxidase content and oleoresin, Jwalasakhi x Pant C 1 (P4 x P5) for fruit length and fruit girth, Vellayani Athulya x Pusa Sadabhar (P3 x P6) exhibited positive and significant sca effect for fruit weight and yield per plot, Vellayani Athulya x Pant C 1 (P3 x P5) for total soluble protein content and vitamin C, Pusa Sadabahar x Vellayani Athulya (P6 x P3) for total soluble protein and chlorophyll content, Vellayani Athulya x Anugraha (P3 x P2) exhibited positive and significant *sca* effect for phenol content and negative and significant for incidence of leaf curl disease, whereas; Ujwala x Vellayani Athulya (P1 x P3) exhibited positive and significant sca effect for leaf curl virus disease incidence. Ujwala x Pusa Sadabahar (P1 x P6) exhibited positive and significant sca effect for epicuticular wax content, Ujwala x Vellayani Athulya (P1 x P3) for carotenoids, Jwalasakhi x Anugraha (P4 x P2) for capsaicin and Anugraha x Pusa Sadabahar (P2 xP6) for membrane integrity.

Among the hybrids subjected to artificial screening, Vellayani Athulya x Pusa Sadabahar (P3 x P6) and Jwalasakhi x Pusa Sadabahar (P4 x P6) are classified as tolerant, Pant C1 x Vellayani Athulya (P5 x P3) and Pusa Sadabahar

x Ujwala (P6 x P1) as susceptible and Pusa Sadabahar x Jwalasakhi (P6 x P4) as highly susceptible as per V.I. values.

The above mentioned promising hybrids can be directly popularised as hybrids after yield trails or can be carried forward to evolve high yielding and leaf curl virus disease resistant varieties.

Future line of work

1) F_2 and later segregating population from cross combinations involving parents with high gca effects can be used for participating selection.

2) The parents other than P6 (Pusa Sadabahar) can be further tried with new parental combination for realizing higher magnitude of heterosis.

3) Yield parameters like number of fruits per plant and average fruit weight were predominantly controlled by non-additive gene action and hence these traits can be exploited through heterosis breeding or recombination breeding.

4) Evaluation of promising hybrids *viz.*, P3 x P6 (Vellayani Athulya x Pusa Sadabahar), P4 x P6 (Jwalasakhi x Pusa Sadabahar), P5 x P3 (Pant C 1 x Vellayani Athulya), P6 x P1 (Pusa Sadabahar x Ujwala) and P6 x P4 (Pusa Sadabahar x Jwalasakhi) would be essential for reliable conclusion towards their commercial exploitation or these can be used for further breeding programme.

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Heterosis and Combining Ability Analysis to Leaf Curl Virus in Chilli

by

DARSHAN S.

(2012-11-176)

ABSTRACT

of the thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

2014

ABSTRACT

An experiment on “Heterosis and combining ability analysis to leaf curl virus in chilli” was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Kerala Agricultural University during the period 2012-2014 to identify the best general combiners and specific combiners for developing superior cross combinations, the inheritance pattern of yield, yield attributes and qualitative traits and resistance to leaf curl virus disease.

Six parents *viz*, Ujwala, Anugraha, Vellayani Athulya, Jwalasakhi, Pant C1 and Pusa Sadabahar were crossed in a diallel pattern and the resultant 30 hybrids were evaluated in full diallel fashion. The field experiment was laid out in randomized block design (RBD) with three replications.

Analysis of variance revealed significant differences among the genotypes for all the traits. Measurement of heterosis was carried out considering parent Ujwala (P1) as check and results revealed that standard heterosis was positive and significant in the combinations, Vellayani Athulya x Pusa Sadabahar (P3 x P6), Pusa Sadabahar x Vellayani Athulya (P6 x P3), Pusa Sadabahar x Jwalasakhi (P6 x P4) and Vellayani Athulya x Jwalasakhi (P3 x P4) for all the traits. The crosses, Vellayani Athulya x Pusa Sadabahar (P3 x P6), Pusa Sadabahar x Ujwala (P6 x P1), Jwalasakhi x Pusa Sadabahar (P4 x P6) were exhibited positive and significant standard heterosis for yield and yield related traits. The cross Pant C1 x Vellayani Athulya (P5 x P3) exhibited negative and significant standard heterosis for incidence of leaf curl virus disease.

Combining ability analysis showed significant *gca, sca , rca* variances and *gca, sca* effects for all the traits. Moreover *gca/sca* variance ratio indicated preponderance of dominance / non-additive gene action for the inheritance of all traits. Among parents, Pusa Sadabahar exhibited positive and significant *gca* effect for plant height, branches per plant, number of fruits per plant, yield per plot, total soluble protein, total carbohydrate, poly phenol oxidase, vitamin C, oleoresin and negative and significant effect for incidence of leaf curl virus

disease. Among crosses, Vellayani Athulya x Pusa Sadabhar (P3 x P6) exhibited positive and significant sca effect for fruit weight and yield per plot whereas; Ujwala x Vellayani Athulya (P1 x P3) exhibited negative and significant sca effect for leaf curl virus disease incidence.

Among the biochemical parameters studied, membrane integrity in terms of % leakage had positive association with LCV disease. Total soluble protein content, phenol content, total CHO content, poly phenol oxidase, vitamin C and oleoresin had negative association with LCV disease.

Artificial screening was carried out in insect proof cage to confirm the resistance/tolerance to leaf curl virus disease among the superior crosses identified in the field experiment. Crosses Vellayani Athulya x Pusa Sadabahar (P3 x P6) and Pant C1 x Vellayani Athulya (P5 x P3) were exhibited tolerance for leaf curl disease incidence.

From the present study Vellayani Athulya x Pusa Sadabahar (P3 x P6), Pusa Sadabahar x Vellayani Athulya (P6 x P3) and Pant C1 x Vellayani Athulya (P5 x P3) were identified as superior crosses and these can be used for improving yield and quality trait like resistance to leaf curl virus disease in future breeding programme.

സംഗ്രഹം

വെള്ളായണി, കാർഷിക കോളേജിൽ സസ്യ പ്രജനന വിഭാഗത്തിൽ 2012-2014 വർഷത്തിൽ, വിളവിലും വിളവിനെ ബാധിക്കുന്ന മറ്റ് സ്വഭാവ സവിശേഷതകളിലും കൂടാതെ വൈറസ് മുഖേനയുണ്ടാകുന്ന ഇലചുരുൾ എന്ന രോഗ രോധ ശേഷിയിലും മെച്ചപ്പെട്ട ഇനങ്ങളെ ജനകങ്ങളായി ഉപയോഗിച്ച് സങ്കരണം നടത്തി ഉല്പാദിപ്പിക്കുന്ന സങ്കരണ സന്തതികളിലുള്ള ജനിതക വീലുവ്യതിയാന പഠനത്തെ ലക്ഷ്യമാക്കി "ഹെറ്ററോസിസ് ആന്റ് കമ്പയിനിംഗ് എബിലിറ്റി അനാലിസിസ് റ്റു ലീഫ് കേൾ വൈറസ് ഇൻ ചില്ലി" എന്ന ഒരു പരീക്ഷണം നടത്തുകയുണ്ടായി.

ഉജ്ജ്വല, അനുഗ്രഹ, വെള്ളായണി അതുല്യ, ജ്വാലാസഖി, പന്ത് സി-1, പൂസാ സദാബാഹർ എന്നീ ആറു ജനകങ്ങൾ തെരെഞ്ഞെടുത്ത് അവ പരസ്പരം മാതൃസസ്യയിനമായും, പിതൃസസ്യയിനമായും സങ്കരണം നടത്തി ലഭിച്ച മുപ്പത് സങ്കര സന്തതികൾ ഒന്നാം തലമുറയിലെ ജനിതക സ്വഭാവ വ്യതിയാനങ്ങൾ വിലയിരുത്തുന്നതിനായി കൃഷി സ്ഥലത്ത് നടുകയുണ്ടായി.

എല്ലാ സങ്കരസന്തതികളിലും പഠനവിധേയമാക്കിയ സ്വഭാവ സവിശേഷതകളിൽ വ്യത്യാസങ്ങൾ കാണിക്കുകയുണ്ടായി. സങ്കര വീര്യനേട്ടം കണക്കാക്കുവാൻ ഉജ്ജ്വല ഇനത്തെ അടിസ്ഥാന ഇനമായി തെരെഞ്ഞെടുത്തു.

വെള്ളായണി അതുല്യയും പൂസാ സദാബാഹറും (P3xP6), പൂസാ സദാബാഹറും വെള്ളായണി അതുല്യയും (P6xP3), പൂസാ സദാബാഹറും ജ്വാലാസഖിയും (P6xP4), വെള്ളായണി അതുല്യയും ജ്വാലാസഖിയും (P3xP4), തമ്മിൽ സങ്കരണം നടത്തിയതിൽ ഉജ്ജ്വലയിനത്തേക്കാൾ ജനിതക സ്വഭാവങ്ങളിൽ മെച്ചപ്പെട്ട സങ്കര വീര്യം നിലനിർത്തുന്നതായി തെളിഞ്ഞു. ഇവയിൽ വെള്ളായണി അതുല്യയും പൂസാ സദാബാഹറും, പൂസാ സദാബാഹറും ഉജ്ജ്വലയും , ജ്വാലാസഖിയും പൂസാ സദാബാഹറും തമ്മിൽ സങ്കരണം നടത്തി ലഭിച്ച സങ്കര സന്തതികൾ വിളവിലും വിളവിനെ അനുകൂലമായി ബാധിക്കുന്ന മറ്റ് സ്വഭാവ സവിശേഷതകളിലും മെച്ചപ്പെട്ടവയായി കാണപ്പെട്ടു.

പന്ത് സി-1 ഒം വെള്ളായണി അതുല്യയും തമ്മിലുള്ള സങ്കരണത്തിൽ ലഭിച്ച സങ്കര സന്തതികൾ ഇലചുരുൾ വൈറസ് രോഗ രോധ ശേഷിയിൽ മെച്ചപ്പെട്ട സങ്കരണ വിത്യ വ്യതിയാനം കാണിച്ചിട്ടുണ്ട്.

ജനകങ്ങളുടെ പൊതു സങ്കലന ക്ഷമത (gca), സങ്കരയിനങ്ങളിലുള്ള സവിശേഷ സങ്കലന ക്ഷമത (sca), ജീനുകളുടെ പ്രഭാവവും പ്രവർത്തനവും എന്നീ വിവിധ പഠനങ്ങളിൽ, ആറിനങ്ങളിൽ പൂസാ സദാബാർ എന്നയിനം നല്ല ജനകമായി തെളിഞ്ഞു. ഈ ഇനം ഉയരം , ശിഖരങ്ങളുടെ എണ്ണം, കായ്കളുടെ എണ്ണം, വിളവ്, ജൈവരാസ സ്വഭാവ സവിശേഷതകളായ പ്രോട്ടീൻ, അന്നജം, ഫിനോൾ, വൈറ്റമിൻ - സി, ഒളിയോറെസിൻ എന്നിവയിൽ മെച്ചപ്പെട്ടതായികണ്ടു. കൂടാതെ ഇലച്ചുരുൾ രോഗ രോധ ശേഷിയുള്ളതായും തെളിഞ്ഞു.

സങ്കര സന്തതികളിൽ വെള്ളായണി അതുല്യയും പൂസാ സദാബാഹറും തമ്മിലുള്ള സങ്കരണം നടത്തി ലഭിച്ച, സന്തതികൾ കായുടെ തൂക്കത്തിലും വിളവിലും മുൻതൂക്കം കാണിക്കുകയുണ്ടായി. പക്ഷേ, ഉജ്ജ്വലയും വെള്ളായണി അതുല്യയും സങ്കരണം നടത്തി ലഭിച്ച സന്തതികൾ ഇലച്ചുരുൾ രോഗത്തെ അതിജീവിക്കുവാൻ കഴിവുള്ളവതായി തെളിഞ്ഞു.

ജൈവിക രാസ സ്വഭാവ വ്യതിയാനങ്ങളുടെ പഠനത്തിൽ നിന്നും 'മെബ്രയിൻ ഇൻറഗ്രിറ്റി' എന്ന ഘടകം ഇലചുരുളിനു അനുകൂല സഹബന്ധം കാണിക്കുന്നതായും എന്നാൽ പ്രോട്ടീൻ, ഫീനോൾ, കാർബോ ഹൈഡ്രേറ്റ്, പോളി ഫീനോൾ ഓക്സിഡൈസ്, വൈറ്റമിൻ-സി, ഒളിയോറെസിൻ എന്നിവയ്ക്ക് പ്രതികൂല സഹബന്ധം കാണിക്കുന്നതായും തെളിഞ്ഞു.

രോഗ രോധത്തിന് കൃത്രിമ നിർദ്ധാരണം ചെയ്യുന്ന പരീക്ഷണത്തിൽ വെള്ളായണി അതുല്യയും പൂസാ സദാബാഹറും, പന്ത് സി-1 ഉം വെള്ളായണി അതുല്യയും തമ്മിൽ സങ്കരണം നടത്തി ലഭിച്ച സങ്കരസന്തതികൾ ഇലച്ചുരുൾ രോഗത്തെ അതിജീവിക്കുവാൻ കഴിവുള്ളവയാണെന്നും തെളിഞ്ഞു.

ചുരുക്കത്തിൽ വെള്ളായണി അതുല്യയും പൂസാ സദാബാഹറും, പൂസാ സദാബാഹറും വെള്ളായണി അതുല്യയും പന്ത് സി-1 ഉം വെള്ളായണി അതുല്യയും തമ്മിൽ സങ്കരണം നടത്തി ലഭിച്ച സങ്കരസന്തതികൾ തമ്മിൽ സങ്കരണം നടത്തി ലഭിച്ച സങ്കരസന്തതികൾ മെച്ചപ്പെട്ടവയായി തെരെഞ്ഞെടുക്കാൻ സാധിച്ചിട്ടുണ്ട്. ഇവയുടെ ജനിതക സ്വഭാവ സവിശേഷതകൾ തുടർന്നുള്ള തലമുറകളിൽ വിലയിരുത്തി മെച്ചപ്പെട്ട ജനിതകയിനങ്ങൾ വികസിപ്പിച്ചെടുക്കാനുള്ള പ്രജനന രീതികൾ ഭാവിയിൽ അവലംബിക്കാനുതകുന്നതാണെന്നു പ്രസ്തുത പരീക്ഷണം തെളിയിക്കുന്നു.