GENETIC ANALYSIS OF YIELD AND RESISTANCE TO ANTHRACNOSE IN CHILLI (*Capsicum annuum* L.)

AJITH. P. M.

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

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2004

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

DECLARATION

I hereby declare that this thesis entitled "**Genetic Analysis of Yield and Resistance to Anthracnose in Chilli (*Capsicum annuum* L.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
14.9.04

AJITH. P. M
(01-21-23)

CERTIFICATE

Certified that this thesis entitled **"Genetic Analysis of Yield and Resistance to Anthracnose in Chilli (*Capsicum annuum* L.)"** is a record of research work done independently by Mr. Ajith P. M. (01-21-23) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Vellayani,
14.9.2004

Dr. P. Manju
(Chairman, Advisory Committee)
Associate Professor
Department of Plant Breeding and Genetics
College of Agriculture, Vellayani
Thiruvananthapuram.

APPROVED BY

CHAIRMAN

Dr. P. MANJU
Associate Professor,
Department of Plant Breeding and Genetics,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522.

14.9.2004.

MEMBERS

Dr. D. CHANDRAMONY
Professor and Head,
Department of Plant Breeding and Genetics,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

14/9/04

Dr. P. J. JOSEPH
Associate Professor,
Department of Plant Pathology,
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522.

14.9.04

Dr. SUMAM GEORGE
Associate Professor,
Department of Soil Science and
Agricultural Chemistry,
College of Agriculture, Vellayani.
Thiruvananthapuram- 695 522.

14.9.04

Dr. VIJAYARAGHAVA KUMAR
Associate Professor,
Department of Agricultural Statistics,
College of Agriculture, Vellayani.
Thiruvananthapuram-695 522.

14.09.04

EXTERNAL EXAMINER

19/1/05

Dr. Syed Moshin Ibrahim
Professor (Plant Breeding & Genetics)
Regional Research Station,
Kovilangulam, Aruppukotta

Every word of Truth

Dedicated forever

at the Lotus feet of

My Father, Mother

Gurudeva

Beloved God

ACKNOWLEDGEMENT

In every wisp of breath, thought, word and deed, let me be with my Beloved Mother Divine – I am Thine own forever and forever and Thou art eternally my own.

Words fall short to express my gratitude towards Dr. P. Manju, Chairperson of my Advisory Committee for her patient guidance, constant affection, support and care spread through three long years of my life. I shall be grateful to you forever.

I wish to express my deep sense of gratitude and indebtedness to:

Dr. D. Chandramony, Professor and Head, Department of Plant Breeding and Genetics and Member of Advisory Committee for her wise advice and critical scrutiny of the manuscript of the thesis.

Dr. P. J. Joseph, Associate Professor, Department of Plant Pathology for his sustained interest in my work and timely suggestions.

Dr. Suman George, Associate Professor, Department of Soil Science and Agricultural Chemistry for her encouragement and whole hearted help and suggestions.

Dr. P. Rajendran, Associate Professor, Department of Soil Science and Agricultural Chemistry for his critical suggestions and help during the project work.

Dr. Vijayaraghava Kumar, Associate Professor, Department of Agricultural Statistics for his expert advice during the project work and in refining the manuscript.

Jithesh, my friend, through whom untold happiness and help has always flowed to me. His sincere love, kindness and exemplary selfless service is gratefully acknowledged.

Suma Bai madam and Maya Devi madam for all the encouragement and well wishes.

Sri.. Ajith Kumar, Junior Programmer, Department of Agricultural Statistics for the help in statistical analysis of data.

Bini, my classmate and friend, for her love and prayers.

My classmates and friends Anu chechi and Lovely for their support.

All the teaching staff and students especially Sindhumole chechi, Radhika chechi, Vidya chechi and Jiju and Sri. Sulochanan for their help and support.

Sri. Premachandran and Sri. Divakaran for the help rendered in raising the crop.

Rajkumar, Sibychayan, Iswaraprasad, Santhoshji, Shyam, Manoj, Mani, Reji, Swami, Abhilash, Allan, Sunil, Vyasan, Pillai, Kandasamy, Muthuswami, Manickam, Shanmugavel, Manuel, Rateesh, Pravin, Selvakumar, Thamilvel, Palanikumar, Parthsarathy, Jagannathan, Shaiju, Madhu, Sekhar, Haridas, Suresh, Guruvbalan and Kavi for their help and support.

Nisha, Poornima, Manju, Ann, Priya Mohan, Ambily Paul, Shruti Pandey and Beena chechi and Geetha chechi for their well wishes.

Leaya, Deepthy Antony, Deepa, Padiyath, Jyothi, Anilas, Vidya, Luttappi, Lini, Sheron, Jisha, Prince, Shiraj, Joseph, Subunu, Shibu, Roopak, Mohan, Pattu and Joy annan for their love.

Sri. Kishore B. Nair and his family for helping me in every way for preparing the thesis.

Kerala Agricultural University for granting me the KAU Senior fellowship.

Beyond words is my gratitude to my Father, Mother, Sister, Brother-in-law and Thakkudu vava for their love and prayers which sustain me.

I thank every blade of grass, every moment of love and pain, every man and woman, every living creature and the non-living at my Vellanikkara campus and Vellayani campus for the wisdom and experience imparted to me through the long years of my sojourn there.

And obeisance to Thee my Goddess and Guru, for Thou art the end and Thou art the means of everything that I do.

AJITH

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INTRODUCTION

1. INTRODUCTION

Chilli is an indispensable condiment of every Indian cuisine. Apart from being a source of flavour and colour, it is a rich source of vitamins A, C and E. The quality of chilli powder is based on visual and extractable colour, pungency level and to a lesser degree the nutritive value (Bosland, 1993). The active principle of pungency in chilli is capsaicin, which is a mixture of 20 capsaicinoids. Chilli is a rich source of red pigments *viz.*, capsorubin, cryptoxanthin and related carotenoids which are esters of capsanthin. Oleoresin extracted from chilli is widely used in the west in food preparations for uniform quality, longer shelf life, taste and flavour. Chilli has cosmetic and medicinal values also

Chilli belongs to the genus *Capsicum* (Family Solanaceae). Chillies are known as capsicum, paprika, pimento, sweet pepper, hot pepper, red pepper and bird pepper. Five species of *Capsicum* are under cultivation, but in India only two species *viz.*, *Capsicum annuum* and *C. frutenscens* are well known and most of the cultivated varieties belong to the species *C. annuum*.

India is the largest producer, consumer and exporter of chillies in the world. In India, chilli is grown in an area of 9.65 lakh hectares with an annual production of 10.75 lakh tonnes (Peter *et al.* 2004). The major production comes from Andhra Pradesh, Karnataka, Orissa, Maharashtra, West Bengal, Tamil Nadu and Rajasthan. Andhra Pradesh alone accounts for 46 per cent of total production. Karnataka and Maharashtra are the other important states.

The productivity of chilli in India is 1.11 tonnes per hectare as against the world average of 2.0 tonnes per hectare. A conglomeration of reasons like poor genetic stock, lack of scientific package of agronomic practices, incidence of a large number of parasitic and non-

parasitic diseases have led to low level of productivity for chilli in India (Peter, 1998). Among the various diseases affecting chilli, anthracnose or die-back and fruit rot is a very destructive fungal disease. The disease affects well developed green fruits, ripe fruits turning red and may continue even after the fruits have been harvested. The disease also causes necrosis of tender twigs from the tip backwards and the entire top of the plant may wither away (Singh, 1987a). It is essential to identify the source of resistance to anthracnose disease and study the inheritance of resistance. However, the studies on the inheritance pattern of anthracnose resistance in chillies are very much limited.

Efficiency of selection for the improvement of both quantitative and qualitative traits depends upon the nature and interaction of the gene involved in the inheritance of a particular character. Generation mean analysis helps to understand the nature and magnitude of gene action using the means of different generations.

In the light of these facts, the present investigation was undertaken with the following objectives.

- To study the genetic basis and inheritance pattern of yield and related characters.
- To understand the inheritance of resistance to anthracnose in chilli through generation mean analysis.
- To formulate an appropriate breeding programme for developing high yielding anthracnose resistant varieties in chilli.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The literature available on various aspects of the present investigation is reviewed hereunder.

2.1 ORIGIN AND DISTRIBUTION

Capsicum is believed to be of new world origin. Mexico is the centre of diversity of *C. annuum* while Guatemala is the secondary centre. The genus *Capsicum* is clearly of South American origin.

Columbus in 1493 introduced capsicum into Spain. By the year 1545, cultivation of capsicum spread from the Mediterranean area to England. It reached Central Europe by the end of 16^{th} century. It was the Portuguese who brought capsicum to India from Brazil prior to 1585 for cultivation.

If the genus *Capsicum* is accepted to contain only the pungent taxa, then a clear centre of diversity is to be found ranging from southern Brazil to Bolivia (Mc Leod *et al.*, 1982; Eshbaugh *et al.* 1983 and Pickersgill, 1984). If the genus is reconstituted to include other non-pungent taxa, another centre of diversity may be recognized in Central America and Southern Mexico. Ultimately, the definition of the genus *Capsicum* and what species it includes will determine the view of its centre of origin and whether the genus is monophyletic or polyphyletic.

Mc Leod *et al.*, (1982) have speculatively hypothesized that Bolivia is a nuclear centre of the genus *Capsicum* and that the origin of the domesticated taxa can ultimately be traced back to this area. But this does not imply that each of the domesticated species arose in Bolivia. Clearly, evidence supports a Mexican origin of *C. annuum* while the other domesticated species arose in South America. Nonetheless the ancestry of domesticates can be traced to South America.

Evidence suggests that *C. annuum* originally occurred in northern Latin America and *C. chinense* in tropical Northern Amazonia.

(Pickersgill, 1971). *C. pubescens* and *C. baccatum* appear to be more prevalent in lower South America.

C. annuum has its centre of diversity in Mexico and Northern Central America with more recent distribution in parts of South America. Pickersgill *et al.* (1979) using karyotype analysis suggested that the origin of domesticated *C. annuum* is to be found in Southern Mexico.

2.2 TAXONOMY

One of the perplexing questions regarding the taxonomy of *Capsicum* is defining the genus (Hunziker, 1979). What taxa are ultimately included in *Capsicum* may change if the concept of the genus is broadened to include taxa with non-pungent fruits but with other common morphological and anatomical traits such as the nature of the anther, the structure of nectaries and the presence of giant cells on the inner surface of the fruit (Pickersgill, 1984).

Early works on the taxonomy of the genus *Capsicum* resulted in more than 100 species and botanical varieties. It belongs to the family Solanaceae. In the first edition of 'Species Plantarum', which appeared in 1753, Linnaeus recorded two species of *Capsicum*. Later in 1797, three additional species were added. The five species were *C. anomalum; C. pubescens* Ruiz and Pavan; *C. pendulum Willd; C. frutescens L. and C. annuum L., C. annuum and C. frutescens* are the most commonly cultivated types. Recognizing the extent of variability, modern taxonomists have divided *Capsicum* into the following five species.

C. annuum L.:syn. C. purpureum, C. grossum, C. cerasiformae,

C. frutescens L.: syn. C. minimum

C. chinense Jacq.:syn. C. luteum, C. umbilicatum, C. sinense

C. baccatum L.:syn. C. pendulum, C. microcarpum;, C. angulosum

C. pubescens R. and P.

Smith *et al.* (1987) classified chilli cultivars based on fruit shape, colour and usage.

I. Fruit large, smooth, thick fleshed

A. Bell group: Fruit large, 7.5 – 12.5 cm long, blocky, blunt, 3 – 4 lobed, square to rectangular or tapering in longitudinal section. Colour usually green when immature, red at maturity. Mostly non-pungent, although a few pungent forms are known.

(i) Non pungent

a. Green, turning red when ripe

b. Yellow, turning red when ripe

B. Pimento group: Fruit heart shaped but pointed, 3.75 – 12.5 cm, long, smooth, thick walled, non pungent.

II. Fruit broad, smooth, thin walled

A. Ancho group: Fruit 10 – 15 cm long, heart shaped but pointed, somewhat flattened, sweet to mildly pungent.

a. Dark green turning red at maturity

b. Turning brown at maturity

III. Pods long slender

A. Anaheim chilli group: (long green/long red chilli)

Fruit medium to dark green, smooth, 12.5 – 20 cm x 3.2 – 5 cm tapering to point, flesh medium thick, moderately pungent to sweet.

B. Cayenne group: Fruit slender, 12.5 – 25 x 1.9 – 2.5 cm, medium green, characteristically wrinkled and irregular in shape, thin walled and highly pungent. Mature fruit red in colour.

IV. Fruit elongated to 7.5 cm long, green when immature.

A. Jalapeno group: Fruit 3.75 – 5 cm wide, 5 – 7.5 cm long, rounded cylindrical shape, thick walled, dark green and smooth.

B. Serrano group: Fruit slender, cylindrical often slightly constricted near middle, tapering to abrupt point, highly pungent, 1.25 x 5 – 6.25 cm.

C. Small hot group: Fruit slender, medium to thin walled, less than 7.5 cm long, highly pungent.

V. Fruit small to 5 cm, globular to oblate, thick flesh.

A. Cherry group

1. Pungent 2.Non-Pungent

VI. Fruit yellow when immature.

A. Small wax group: Fruit 7.5 cm or less in length.

1. Pungent 2. Non-pungent

B. Long wax group: Fruit 8.8 cm or more in length, pointed or blunt.

1.Pungent 2. Non-pungent

VII. Fruit slender, yellow turning red at maturity, 2.5 – 3.75 cm long, highly pungent, of the species *C. frutescens.*

A. Tabasco group

2.3 REPRODUCTIVE BIOLOGY

Both self and cross pollination take place in chilli. Flower opening and anther dehiscence to a large extent depend on the weather conditions. Flower opening in chilli takes place between 5 and 6 AM. During cold as well as cloudy days, the opening is delayed. Flower remains open for 2 to 3 days. Anther dehisces half to 5 ½ hours after stigma becomes receptive. Anther dehiscence takes place from 9 to 11 AM. Maximum fruit setting occurs when pollination is done at the time of opening of flower (Padda and Singh, 1971). Bees and thrips are the pollinating agents.

2.4 GENETIC VARIABILITY

Forty-five genotypes were studied by Singh and Singh (1976). They found high variability for plant height, days to flowering, days to maturity, number of branches, fruit length, fruit thickness, number of fruits per plant and yield per plant.

Arya and Saini (1977) reported high phenotypic and genotypic variances for fruit yield per plant, number of seeds per fruit, number of fruits per plant, fruit size per plant and plant height. Hiremath and Mathapati (1977) evaluated 36 genotypes of chilli and found high

phenotypic variances for yield and number of fruits per plant. Elangovan *et al.* (1981) evaluated 30 cultivars of chilli and obtained high phenotypic and genotypic variances for plant height, plant spread, number of seeds per fruit and number of fruits per plant. In a study using 12 varieties of chilli, Ramakumar *et al.* (1981) found high variability for plant height, plant spread, fruit girth, number of seeds per fruit, number of fruits per plant and yield. High variability for number of primary and secondary branches, life span and number of seeds has been reported by Nair *et al.* (1984) in their study using 30 genotypes.

Ado *et al.* (1987) studied 16 cultivars and found the characters fruits per plant, branches per plant and fruit weight to be the most variable.

Bai *et al.* (1987) reported high variability for fresh fruit yield per plant and low variability for branches per plant and percentage of fruit setting. Gopalakrishnan *et al.* (1987a) found high variability for number of primary branches, number of secondary branches, life span and number of seeds in a study involving 38 chilli cultivars.

Adamu and Ado (1988) found high variability for fruits per plant, individual fruit weight and fresh fruit yield per plant in *C. annuum* and *C. frutescens*.

Vijayalakshmi *et al.* (1989) reported high genotypic and phenotypic variances for number of flowers, plant height and spread and low genotypic and phenotypic variances for number of primary branches, average fruit weight, fruit length and fruit girth.

In a study using 64 chilli genotypes, Ahmed *et al.* (1990) obtained low range of variability for days to first fruiting, plant height and plant spread. Das *et al.* (1990) observed significant differences among 30 chilli cultivars for six components of fruit yield.

Sahoo *et al.* (1990) studied F_2 progenies of 45 inter varietal crosses and found high variability for seeds per fruit, dry yield per plant, fruits

per plant and plant spread. Twelve cultivars were evaluated by Rajput *et al.* (1991) and they found wide variation for dry chilli yield and fruiting period. High variability for fruits per plant, yield per plant, fruit length and circumference and seeds per fruit was reported by Acharya *et al.* (1992) in their study using 19 chilli cultivars.

Pichaimuthu and Pappiah (1992) found very high variability for number of fruits, fresh and dry fruit weight and plant height in a study involving fourteen F_6 families produced from the F_5 generation of the cross ACC 1683 x K2

Singh *et al.* (1994) studied 20 genotypes and found high variability for weight of fresh red ripe fruits per plant.

Rani (1996a) studied 73 genotypes and found high variability for fruit length, fruit diameter, fruit weight and number of seeds per fruit. Seven principal components accounted for 85 per cent of the total variability of which six were significant. The first principal component which accounted for 25 per cent of variability was positively correlated with plant height and fruit diameter, fruit length and fruit weight and negatively correlated with number of primary branches per plant, number of secondary branches per plant and number of fruits per plant.

High variability for all the characters studied especially for fruit yield in 71 chilli genotypes was reported by Nayeema *et al.* (1998)

Verma *et al.* (1998) evaluated 119 accessions of chilli and found high degree of variability for plant height, density of branches, days to 50 per cent flowering, number of fruits per plant, fruit length, fruit width, green fruit weight per ten fruits and fruit dry weight per ten fruits.

In a study using 25 genotypes, Das and Chaudhary (1999b) reported high phenotypic and genotypic variances for fruit length. Devi and Arumugam (1999a) reported moderate variation for plant height, days to first flowering and dry fruit yield per plant and high variation for yield of fresh fruits per plant.

Dwivedi and Bhandari (1999) reported high variability for number of seeds per fruit, 1000-seed weight and days to maturity in a study involving 160 sweet pepper lines.

High variability for fruit yield has been reported by Jabeen *et al.* (1999) in a study involving 71 cultivars of chilli.

Munshi and Behera (2000) in a study involving 30 genotypes of chilli, found the existence of considerable genetic variability for all the characters studied except fruit girth.

Rathod *et al.* (2002) in an analysis of variance of eight yield components in 13 chilli cultivars found considerable variability among various components.

2.5 COEFFICIENT OF VARIATION

Arya and Saini (1976) studied seven bell pepper cultivars and reported high phenotypic (PCV) and genotypic coefficients of variation (GCV) for number of fruits per plant, fruit size and fruit yield per plant, while medium values were found for number of seeds per fruit and number of branches. Arya and Saini (1977) found that GCV ranged from 12.04 for days to flower to 223.33 for rind thickness in chilli.

In a study involving 36 cultivars of chilli, Hiremath and Mathapati (1977) found high coefficient of variation for number of branches and number of seeds per fruit.

Singh and Brar (1979) studied variability in 31 varieties of sweet pepper and reported high phenotypic and genotypic coefficients of variation for number of fruits and fruit yield, medium for fruit weight and low for all the other characters. Rajput *et al.* (1981) observed similar results for fruits per plant (GCV – 19.2) and yield (GCV – 18.28) in seven genotypes of chilli.

In a study on 45 F_1 and F_2 hybrids from a 10 x 10 diallel cross, Rao and Chhonkar (1981) observed low to medium phenotypic and genotypic coefficients of variation for several characters. Nair *et al.*

(1984) found high GCV among 25 cultivars for number of fruits (121.28), weight of fruit (100.65) and total yield (108.93).

Gopalakrishnan *et al.* (1985) observed great difference between PCV and GCV for number of branches per plant indicating greater influence of environment.

High GCV for fruit length (42.17), main stem length (44.61), fruit weight (29.70), fruits per plant (35.28) and fruit yield per plant (32.31) was reported by Goplakrishnan *et al.* (1987a) in a study involving 38 lines of chilli. In a study on F_2 generation of an inter-varietal cross, Ghai and Thakur (1987) found GCV to be ranging from 8.24 for number of fruits to 41.27 for fruit weight per plant.

Sahoo *et al.* (1989a) reported high values for GCV for dry yield per plant, plant spread, number of fruits per plant, weight of ten dry fruits and seed number per fruit in 45 crosses of a 10 x 10 diallel. Greater differences between PCV and GCV for plant height, plant spread, number of flowers, number of pods, total yield and total dry pod yield were reported by Vijayalakshmi *et al.* (1989).

Varalakshmi and Babu (1991), Rani *et al.* (1996) and Jabeen *et al.* (1999) reported that both PCV and GCV were high for fruit yield per plant, fruit number per plant, seed number per fruit and fruit weight.

Pichaimuthu and Pappiah (1992) found close association between the estimates of PCV and GCV for several characters in F_6 generation indicating low influence of environment. Nandi (1993) studied nine cultivars and found that length and weight of fruits and yield per plant had the highest GCV.

Devi and Arumugam (1999a) found moderate values of PCV and GCV for all the characters studied in F_2 generation, except days to first flower, dry fruit yield per plant and fruit girth for which it was low.

Chaim and Paran (2000) in a study on intra specific cross between a bell type 'Maor' and small-fruited pungent chilli line 'Perennial' found

low GCV for plant height, moderate GCV for fruit length and high GCV for fruit weight and fruit diameter.

In a study with 30 chilli genotypes, Munshi and Behera (2000) obtained GCV ranging from 5.32 per cent for days to first fruit harvest to 54.94 per cent for number of fruits per plant.

High PCV and GCV were observed for number of fruits per plant, fruit weight, fruit length, yield and leaf area (Sreelathakumary and Rajamony, 2002). High degree of PCV and GCV were observed for number of primary branches, fruit length, pericarp thickness, number of fruits per plant and green fruit yield per plant by Nandadevi and Hosamani (2003a).

2.6 HERITABILITY AND GENETIC ADVANCE

In a 10 x 10 diallel, Rao and Chhonkar (1981) found high heritability for number of branches, fruit length, fruit girth, seed content, fruits per plant, ripe fruit yield per plant and fruit weight. Singh *et al.* (1981) studied 35 chill genotypes and noticed high heritability for mean weight per fruit, fruits per plant and fresh fruit weight per plant.

In a study involving 25 genotypes of chilli, Bavaji and Murthy (1982) found high heritability coupled with high genetic advance for number of branches per plant, fruit length, 50 fruit weight and fruits per plant. High heritability with low genetic advance was reported for days to flowering, plant height, plant spread, number of primary branches and life span by Nair *et al.* (1984).

Chaudhary *et al.* (1985) studied 30 chilli lines and found a wide range of heritability from 27.81 (fruit girth) to 99.86 (number of seeds per fruit) and genetic advance from 0.33 (fruit girth) to 98.99 (yield per plant). Shah *et al.* (1986) found high heritability and expected genetic advance for plant height, number of primary branches, fruit length, fruit width and number of fruits per plant in a study using 12 chilli varieties.

In a population of parents, F_{1S}, F_{2S} and backcrosses, Ghai and Thakur (1987) found number of fruits and total yield to possess the lowest values of heritability in narrow sense. The expected genetic advance showed a wide range from 8.82 per cent for number of fruits per plant to 73.81 per cent for fruit weight. High heritability and high expected genetic advance for fruit length and days to first flowering were reported by Meshram (1987).

High heritability and genetic advance were reported for yield per plant, number of fruits per plant and weight of 10 dry fruits by Sahoo *et al.* (1989a) and Bhagyalakshmi *et al.* (1990).

Varalakshmi and Babu (1991) and Kumar *et al.* (1993) found high heritibility and genetic advance for fruits per plant and number of seeds per fruit. Singh *et al.* (1994) observed high heritibility for fruit length and fruit diameter in a study on 20 chilli varieties.

While evaluating fourteen F_6 families from the cross AC.1683 x K2, Pichaimuthu and Pappiah (1995) found high heritability and high genetic advance for fruit length, fruit girth and number of fruits per plant.

In a study involving 50 *C. annuum* and *C. frutescens* cultivars, Bhatt and Shah (1996) obtained high heritibility and genetic advance for average fruit weight and fruit diameter. High heritibility and genetic advance for fruits per plant, fruit weight and length and circumference of fruits has been reported by Ghildiyal *et al.* (1996) in a study involving 24 cultivars. Rani *et al.* (1996) found high heritibility coupled with high genetic advance for yield per plant, number of fruits per plant, mean fruit weight and dry matter production. High heritibility and genetic advance for fruit length has been reported by Rani and Singh (1996).

.Nayeema *et al.* (1998) found high heritability coupled with high genetic advance for fruit yield per plant, number of seeds per fruit, pericarp thickness and average fruit weight.

In a study involving 30 genotypes, Das and Chaudhary (1999b) found the highest estimates of heritability and genetic advance for yield per plant.

Devi and Arumugam (1999a) and Jabeen *et al.* (1999) found high heritibility and genetic advance for fruit yield per plant, fruit number per plant, seed number per fruit and pericarp thickness.

Chaim and Paran (2000) observed that days to first ripened fruit and total soluble solids had low (narrow sense) heritability, whereas nine other traits studied had moderate to high values. High heritability (broad sense) values for fruit weight, fruit diameter, fruit length and pericarp thickness and low heritability for plant height was also reported. Ibrahim *et al.* (2001) observed that the highest heritability was exhibited for plant height (98.12%) followed by fruit length (96.74%) and number of fruits per plant (96.18%).

High heritability coupled with high genetic advance for total yield per plant was reported by Acharyya *et al.* (2002). Rathod *et al.* (2002) found high heritability for days to fifty per cent flowering, plant height, number of primary branches, number of fruits per plant, fruit length, fruit diameter, 100 seed weight, harvest index and fresh red chilli yield per plant. High heritability coupled with high genetic advance was found for number of fruits per plant, fresh red chilli yield per plant and plant height. Sreelathakumary and Rajamony (2002) reported high heritability and genetic advance for number of fruits per plant, fruit weight, fruit length, fruit girth, fruit yield and leaf area.

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

2.7 CORRELATION

Pandian and Sivasubramanian (1978) reported that the total number of fruits harvested per plant had significant positive association

with flowers produced during 66-86 days. Positive correlation between yield and days to flowering has been reported by Sundaram and Ranganathan (1978).

Rao *et al.* (1981) found yield to be negatively correlated with days to flowering. Bavaji and Murty (1982) found significant positive association of number of fruits and number of branches with yield.

Chaudhary *et al.* (1985) reported positive correlation of yield per plant with fruit girth and weight of ten fruits, which in turn was positively associated with number of seeds per fruit. Gopalakrishnan *et al.* (1985) reported negative correlation of fruit girth with fruit yield per plant and positive correlation of fruit length with yield.

Yield was found to be significantly associated with fruit length, number of branches, number of fruits and plant spread in a study conducted by Ghai and Thakur (1987). Jayasankar *et al.* (1987) suggested that number of primary branches, fruit length, fruit girth and number of seeds per fruit could be considered as secondary yield determinants owing to their loose association with yield.

Fourteen parents and 24 F_{1S} were studied by Kaul and Sharma (1989) and reported a positive association of fruit yield with plant height, number of branches per plant, number of seeds per fruit and dry matter of fruit.

Bhagyalakshmi *et al.* (1990) reported negative correlation of yield with days to 50 per cent flowering and days taken for fruit set. In a study involving 30 chilli genotypes, Das *et al.* (1990) found that yield per plant was positively correlated with number of primary and secondary branches per plant and number of seeds per fruit.

Rani (1995) observed plant height, plant spread, number of primary branches per plant and number of secondary branches per plant to show significant positive correlation with yield.

Rani (1996 b) observed positive correlation between fruit seed weight and fruit seed number in chilli.

Ahmed *et al.* (1997b) reported that significant positive correlation existed between fruit number and branch number per plant, plant height and plant spread, plant height and fruit size, plant spread and fruit length, plant spread and average fruit weight, branch number and maturity, fruit length and fruit thickness, fruit length and average fruit weight, fruit thickness and average fruit weight and fruit thickness and pericarp thickness.

In a study involving 25 chilli genotypes, Das and Chaudhary (1999 b) found yield to show positive correlation with fruit weight, fruits per plant and primary branches per plant. Aliyu *et al.* (2000) reported significant positive correlation of fruit yield per plant with plant height, fruit number per plant and canopy width. In an F_2 population, Subashri and Natarajan (1999) found positive association of yield with branches per plant, fruits per plant, fruit weight and fruit length.

Chaim and Paran (2000) found high genotypic correlation between fruit weight and three characters, fruit diameter, pericarp thickness and pedicel diameter. But fruit weight had a low correlation coefficient with fruit length. Significant negative correlation between capsaicin content and yield was reported by Kohli and Chatterjee (2000).

Munshi *et al.* (2000) found that mean fruit weight showed significant negative correlation with number of fruits per plant and positive correlation with fruit length.

Ibrahim *et al.* (2001) in a study on 17 genotypes of chilli reported that dry fruit yield had significant positive correlation with number of fruits per plant, number of branches, fruit length, fruit width and plant height. Number of fruits per plant exhibited highly significant positive correlation with number of branches and plant height but negative correlation with fruit length. Negative association of individual fruit weight with number of fruits per plant was reported by Jose (2001). Also, crop duration was found to be positively correlated with number of branches, number of fruits per plant and fruit yield.

Rathod *et al.* (2002) reported significant positive association of fresh red chilli yield with number of fruits per plant, hundred seed weight and harvest index.

Mini (2003) reported negative association of days to first flowering with fruit length. Yield was positively correlated with individual fruit weight, number of fruits per plant and fruit length. Individual fruit weight was negatively associated with number of fruits per plant. Positive association of yield per plant with number of fruits per plant and pedicel length was reported by Nandadevi and Hosamani (2003a).

Muthuswamy (2004) reported negative association of days to first flowering with many of the characters studied and its positive association with fruit length. Fruits per plant was positively correlated with harvest index, capsaicin content and oleoresin content. Capsaicin content was positively correlated with number of primary branches, fruit weight, yield, fruit length, number of seeds per fruit, plant height, crop duration and harvest index.

2.8 PATH COEFFICIENT ANALYSIS

Sundaram and Ranganathan (1978) carried out path analysis in 50 varieties of chilli and found that number of fruits and fruit length showed positive direct effect on yield, whereas days to flowering and number of branches exerted small and negative direct effect on yield.

Rao *et al.* (1981) found that days to maturity and flowering, fruit setting ability in summer and fruits per plant were the most important factors affecting yield. Path analysis in a 10 x 10 diallel by Rao and Chhonkar (1981) revealed that number of fruits, fruit weight and dry yield had a direct effect on ripe fruit yield.

Nair *et al.* (1984) studied 30 varieties and reported that number of fruits, secondary branches, fruit weight, fruit circumference and duration had positive direct effect on yield.

Chouvey *et al.* (1986) observed positive direct effect for number of fruits per plant, 10-fruit weight, number of seeds per fruit and fruit circumference on yield. Number of fruits, plant height, number of primary branches per plant and fruit length were reported to have direct positive effect on yield by Solanki *et al.* (1986).

Kaul and Sharma (1989) studied 14 parents and 24 F_{1S} and found that number of fruits per plant, fruit diameter and number of branches per plant were the main contributors to yield.

Dahiya *et al.* (1991), Khurana *et al.* (1993) and Ahmed *et al.* (1997b) found that fruit yield exhibited highly significant positive correlation with number of fruits per plant, average fruit weight, plant height, plant spread and fruit length suggesting that these characters were the most important yield components and that effective yield improvement could be achieved through selection based on these component characters.

Twenty chilli genotypes were studied by Sarma and Roy (1995) who found that fruit diameter, fruit length and days to 50 per cent flowering were the main contributors to yield.

Deka and Shadeque (1997) reported high magnitude of positive direct effect of branches per plant, fruits per plant and fruit size on yield.

Fruits per plant and weight of fruits were reported to show the highest positive effect on yield (Das and Chaudhary, 1999 a). Dimova and Panayotov (1999) studied the relationship between five fruit characteristics in six pepper cultivars and reported that pericarp weight had higher direct effect on fruit weight (0.76 – 0.94), while the other fruit characteristics affected fruit weight mainly via pericarp.

Aliyu *et al.* (2000) reported that fruit diameter and number of seeds per plant exhibited large positive direct effect on yield, while plant height had a negative direct contribution to final yield.

Munshi *et al.* (2000) studied 30 chilli genotypes and reported direct positive effect of number of fruits per plant, fruit weight and fruit girth on yield per plant.

Jose (2001) reported the positive direct effect of number of fruits per plant, individual fruit weight and crop duration on yield.

Mini (2003) reported that number of fruits per plant and individual fruit weight had positive direct effect on yield, while number of branches had negative direct effect. There was positive indirect effect of number of branches through number of fruits per plant on yield.

2.9 GENETICS AND BREEDING FOR ANTHRACNOSE DISEASE RESISTANCE

Anthracnose is a major disease of chilli. It occurs world wide wherever chilli is grown under warm temperatures and overhead irrigation or rainfed conditions (AVRDC, 2000). Anthracnose is mainly a problem on mature fruits causing severe losses due to pre and post harvest fruit decay. Two significant causal pathogens found in tropical Asia are *Colletotrichum capsici (*Syd.) E. J. Butler and Bisby and *C. gloeosporioides* (Chang and Chung, 1985; Manandhar, *et al.,* 1995). *C. capsici* generally infects ripe red fruit, while *C. gloeosporioides* infects both green and ripe fruits. Suryawanshi and Deokar (2000), for the first time in India, reported *Aureobasidium pullulans* to cause fruit rot in chilli.

2.9.1 Symptomatology

The major symptoms are dieback and fruit rot (Singh, 1987a; Rajeswari, *et al.*, 2004).

i. Dieback

The fungus causes necrosis of tender twigs from the tip backwards and hence the disease is called dieback. Infection usually begins when

the crop is in flower. In diseased plant, flowers dry up. The drying up spreads from the flower stalk to the stem and the branches wither. The entire branch or the entire top of the plant may wither away. Partially affected plants bear fruits, which are few and are of low quality. The dead twigs are water soaked to brown becoming grayish white or straw coloured in advanced stage of the disease. A large number of black dots (acervuli) are seen scattered all over the necrotic surfaces of the affected twigs. Some times the necrotic areas are found separated from the healthy areas by a dark brown to black band. Dieback usually appears after the rains have stopped and when there is prolonged deposition of dew on the plants.

ii) Fruit rot

Ripe fruits turning red are affected. Green fruits are not spared once the disease starts in the field. A small, black, circular spot appears on the skin of the fruit and spreads in the direction of the long axis, thus becoming more or less elliptical. As the infection progresses, the spots get either diffused and black, greenish or dirty gray in colour or they are markedly delimited by the thick and sharp black outline enclosing a lighter black or straw coloured area. Badly diseased fruits turn straw coloured or pale white from normal red. On this discoloured area, numerous black acervuli are found scattered. When a diseased fruit is cut open the lower surface of the skin is found covered with minute, elevated, spherical, black stromatic masses or sclerotia of the fungus. In advanced stages, the seeds are covered by a mat of fungal hyphae. Such seeds turn rusty in colour. Affected fruits are deformed, white in colour and lose their pungency. In the fruit, the attacked parts turn black and become depressed or wrinkled. Ultimately the diseased fruits shrivel and dry up.

2.9.2 Etiology

Colletotrichum capsici (Syd.) Butler and Bisby is the causative agent. The mycelium of the fungus is septate and inter and

intracellular. Acervuli and stroma on the stem are hemispherical and 70 to 120 µm in diameter. Setae are scattered, dark brown, tips light brown, several septate and up to 15 µm long. Conidia in mass appear pinkish. They are borne singly at the tip of conidiophores. Individually, they are falcate, hyaline, unicellular curved with narrow ends and measure 17 to 29 x 3 to 4 µm (Rajeswari *et al.*, 2004).

2.9.3 Mode of Spread and Survival

The fungus is seed borne and the secondary spread is by air borne conidia and also through rain. The disease spreads rapidly by wind blown rains during rainy season.

2.9.4 Epidemiology

The optimum temperature for conidial germination is 30^{O}C. Maximum disease development takes place at 28^{O}C and 95.7 per cent relative humidity. The disease usually develops under high humid conditions when rain occurs after the fruits have started to ripen. The disease usually breaks out if rainy conditions prevail after the setting of fruits. Greatest disease development occurs at 28^{O}C (Rajeswari *et al.*, 2004).

2.9.5 Genetics of Anthracnose Resistance

According to Park *et al.* (1990 b) resistance to *Colletotrichum capsici* was likely to be controlled by a single dominant gene.

Inheritance of resistance to anthracnose caused by *Collectotrichum dematium* f. sp. *capsicum* and *C.gloeosporioides (Glomerella cingulata)* strain G was studied by Park *et al.* (1990a) using a six parent diallel. Detached green and red fruits were inoculated by pricking with a drop of spore suspension and lesion diameter was measured for index of resistance. Resistance to *C. dematium* (small lesions) was partially dominant to susceptibility (big lesions). Both broad and narrow sense heritabilities were high. Resistance of green fruits to *C. gloeosporioides* was found to be partially dominant or over

dominant. Broad sense heritability was high but narrow sense heritability was relatively low.

Ahmed *et al.* (1991) evaluated in the lab, 6 generations of a cross between susceptible capsicum cultivar 'Kolascai E-14' and resistant genotype 'Perennial' for their reaction to *C. capsici* and came to the conclusion that resistance to anthracnose was controlled by polygenes with a predominantly additive type of gene action and that the level of resistance could be improved through simple selection.

Qing *et al.* (2002) studied the inheritance of resistance to anthracnose in populations established from a cross between accession '83-168' and cultivar KAU Cluster and their progenies in F_{1S}, F_{2S} and BC_1s. The segregation of resistance to susceptibility appeared to be 3:1 in the F_{2S} and 1:1 in the BC_1 (F_1 x KAU cluster) which indicated that one dominant gene was responsible for the resistance in breeding line '83 – 168'.

2.9.6 Biochemical Basis of Anthracnose Resistance

Borua and Das (2000) suggested that higher levels of preformed phenolic compounds might be playing an important role in fruit rot resistance. They found increased activity of polyphenol oxidase and acid phosphatase in susceptible varieties after infection.

Gehlot and Purohit (2001) reported that total sugar and nitrogen contents were lower in resistant than in susceptible genotypes and the contents increased after infection. Total protein, free amino acids, phosphorus and phenols were higher in resistant genotypes and their contents decreased after infection. Also, specific activity of polyphenol oxidase and peroxidase was higher in resistant genotypes.

Higher levels of capsaicin and ascorbic acid and lower level of total sugars in resistant genotypes had been reported by Hegde and Anahosur (2001).

2.9.7 Breeding for Anthracnose Resistance

Ullasa *et al.* (1981) evaluated 298 genotypes and found that sixteen genotypes were resistant and six moderately resistant to *C. capsici*. Among the 23 cultivars of chilli studied by Pearson *et al.* (1984) the level of natural anthracnose infection rates ranged from zero to 17.2 per cent.

Among the 21 capsicum cultivars studied, Chang and Chung (1985) found that the cultivars Kumchang No.2, Bulamhouse, Pakistan and Hongilpum were resistant to fruit rot. Singh (1987b) observed that the chilli varieties K.Surkh, CH 107, Chamatkar, Saten Yellow and G 4 were moderately resistant to fruit rot. Sen (1989) reported variety Pant C-1 to be resistant to anthracnose.

Basak (1997) screened 10 cultivars of chilli against three major fruit rotting pathogens, *Colletotrichum capsici, C. gloeosporioides* and *Fusarium pallidoroseum*. Flood irrigation was given before spray inoculation to ensure high humidity. None of the cultivars was found to be immune. Cultivars C-011 and C-045 were susceptible to *G. cingulata* and *C. capsici,* C-123 to *C. capsici* and Chittagong local and Bogra local were susceptible to *F. pallidoroseum* and highly susceptible to *G. cingulata* and *C. capsici*. The remaining cultivars were moderately resistant.

Forty genotypes were studied by Jeyalakshmi and Seetharaman (1998) and found only one genotype CA 87-4 to be resistant to anthracnose.

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

Variety Phule Sai (GCH-8) was reported to be moderately resistant to anthracnose (Jadhav *et al.*, 2000) . Hegde and Anahosur

(2001) screened 52 genotypes against fruit rot and found the cultivars LCA-301, LCA-324, K-1 and Byadagi Kaddi to be resistant.

Variety Jiangshu No.4 was found to be resistant to fruit rot by Liu *et al.* (2001). Hybrid Xingla No.2 was reported to be resistant to fruit rot (Xiao *et al.*, 2001).

Varieties *viz.*, Pusa Deepti (KT-1), Punjab Lal, Musalwadi and Jawahar-218 are reported to be tolerant to fruit rot (Johny and Ravindran, 2004).

2.10 HETEROSIS

When four chilli lines Jwala, Pant C1, CA 33 and CA 23 were non-reciprocally crossed, Jwala x Pant C1 was the best hybrid. All the hybrids showed heterosis for earliness and three hybrids showed heterobeltiosis (Gopalakrishnan *et al.* 1987b).

Joshi (1987) opined that breeders should seek cross combinations which show high mean yield, high F_1 heterosis and good retention of heterosis in the F_2, while calculating heterosis retention as the percentage decrease in the F_2 over the F_1 for 10 quantitative characters. Inbreeding depression for yield was generally seen in any cross which exhibited inbreeding depression for any yield component.

All hybrids exceeded their mid parental value for yield as reported by Mak (1987), while studying five F_1 hybrids from crosses involving five varieties. Heterosis for yield was chiefly due to heterosis for number of fruits per plant. Despite producing fewer flowers than their parents, most hybrids showed high heterosis for per cent fruit set resulting in a greater number of fruits per plant.

Singh (1987b) while studying a batch of 33 F_1 hybrids produced using 11 male parents, found that MS 12 x S27 gave 235.7 per cent standard heterosis over Punjab Lal.

Mishra *et al.* (1988) after analyzing 45 F_1 hybrids from crosses between 10 cultivars came to the conclusion that crosses between two

poor yielding parents usually showed the highest heterobeltiosis for yield and fruits per plant.

Thomas and Peter (1988) reported that intervarietal crosses involving bell pepper lines *viz.*, Yolo Wonder, Improved, Sweet Red Cherry Pickling, Early Calwonder, Cubanelle, 672 Hungarian Wax and Bell Boy and hot chilli line KAU cluster showed significant favourable heterosis for days to flowering, days to green fruit harvest, days to fruit ripening, plant height, fruit length, fruit perimeter, fruit weight and green fruit yield per plant. The best yielding cross was Bell Boy × KAU cluster and 672 Hungarian Wax × KAU cluster with a standard heterosis of 108.3 per cent over Pant C1 for yield.

Heterosis in 45 F_1 hybrids from a diallel set of crosses involving 10 varieties was studied by Mishra *et al.* (1989) who found the hybrid Pusa Jwala x Sindur showing heterobeltiosis for dry yield per plant.

Of the six F_1 hybrids and four parents evaluated by Ram and Lal (1989), NP46A x Kalyanpur Yellow showed the highest standard heterosis for yield per plant. Positive inbreeding depression was observed in F_2 populations of all hybrids for all yield related characters except days to flowering.

Sahoo and Mishra (1990) studied 10 cultivars and the 45 F_2 progenies from a half diallel cross and found residual heterosis for number of fruits per plant (72.6%) and dry fruit yield per plant (116.8%) in the cross J 218 x KCS1.

Bhagyalakshmi *et al.* (1991) reported that relative heterosis was the highest (160%) for number of branches per plant while examining six chilli cultivars crossed in a non reciprocal half diallel fashion.

Heterosis was high for total yield and average fruit weight during an evaluation of sweet pepper cross Fimentao x Pip and their F_1, F_2 and back cross generations (Mohamed *et al.*, 1995).

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 highest heterosis over better parent for yield and earliness were for the crosses Shalimar Long × Punjab Lal, Elephant trunk × Shalimar long and Shalimar Long × SPE-1.

Muthuswamy (2004) reported significantly high relative heterosis and standard heterosis for leaf curl incidence in chilli.

2.11 COMBINING ABILITY

Out of the 11 traits studied in an 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* performance are to be taken together when assessing the breeding value of a cultivar. After studying 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 data were recorded for plant height, primary branches per plant, fruits per plant, average fruit weight and dry fruit yield per plant. The parents Jwala and K34 – 35 exhibited significant gca effects for most characters. A few cross combinations showed significant sca effects as well as reciprocal effects for yield and its components.

Significant sca effects were noticed for number of fruits per plant and fruit yield per plant in 'California Wonder' by Kaul and Sharma (1988a).

In the opinion of Sahoo *et al.* (1989b) gca effects were predominant for plant height and hundred seed weight during a 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.

Information on combining ability was derived by Bhagyalakshmi *et al.* (1991) from the data on six chilli cultivars crossed in a non reciprocal half diallel in which both gca and sca effects were observed with the latter predominating for days to 50 per cent flowering, fruit length, fruit girth, fresh fruit weight and 100 seed weight. On the basis of absolute performance, sca effects and heterosis, hybrid LCA 206 × LCA 960 was found to be the best yielding followed by LCA 206 × LA 1079. Cultivars LCA 960, LCA 206 and G4 were the best general combiners for most of the characters and gave high gca effects for yield per plant and many of the yield related traits.

Mishra *et al.* (1991a) crossed 10 chilli genotypes in a diallel fashion without reciprocals and studied 45 F_1 hybrids along with parents. The best general combiners for most of the qualitative characters were J 218 and B.R. 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.

Mulge (1992) from a study involving 18 × 3 line × tester cross, reported significant sca variance for number of branches. Pandian and Shanmugavelu (1992) crossed 15 chilli lines and six testers in a line × tester fashion and found that there was close agreement between gca and *per se* performance for 10 agronomic traits and for hybrid selection, *per se* performance was a more reliable parameter than sca effect.

Jagadeesh (1995) reported significant sca effect for days to first flowering from a 20 × 3 line ×tester crossing programme.

Ahmed *et al.* (1997b) studied six diverse parental sweet pepper lines *viz.*, California Wonder, KSPS 3, KSPA 2, Arka Gaurav, World Peater and KSPS 1 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.

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. 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 Punbjab Lal, G 4 and Pusa Jwala exhibited high gca effects for fruit number. 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 the best cross combinations for yield and earliness.

Devi and Arumugam (1999 b) in their study on 30 F_1 hybrids and their six parents found the role of additive and non additive gene action in the control of 23 agronomic and quality traits. Among the parents, the pungent chilli K2 was found to be a good general combiner for three economic traits followed by PKM 1. 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.

Yield and plant height were found to possess significant sca effects in a 6 × 6 diallel cross as reported by Gandhi and Navale (2000).

Lohithaswa *et al.* (2000) in a 10 × 10 diallel cross reported 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.

Days to 50 per cent flowering, number of fruits per plant, average fruit weight, seeds per fruit and yield per plant were having significant gca and sca effects while fruit length was having only gca effect as significant according to Nandadevi and Hosamani (2003 b) from their study on 6 × 6 diallel cross.

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

2.12 GENE ACTION

Gene action in chilli with respect to various characters are presented in Table 1.

2.13 GENERATION MEAN ANALYSIS

F_1, F_2, BC_1 and BC_2 from an eight-parent diallel cross were examined by Thakur (1987) who found that non-additive gene effects predominated in the F_1. Dominance x dominance epistatic effects predominated over additive x dominance effects. High heritability for yield and the predominance of non-additive gene effects suggested straight forward selection and utilization of heterosis to improve yield.

Khereba *et al.* (1995) while studying the cross Fimentao x Pip and the resulting F_1, F_2 and backcross generations found that fruit length and fruit diameter were governed by multiple gene effects. Partial dominance was found towards the longer, wider and thicker fleshed fruits.

Six generations of chilli inter varietal crosses Jatilong x LCA 205 and Jatilong x Sampathy were evaluated by Sharma and Talukdar

Table 1. Gene action in chilli

Character	Additive	Non additive	Dominance	Additive x Additive	Additive x Dominance	Dominance X Dominance	Over Dominance
Days to first flowering	Singh and Singh (1977) Gopalakrishnan *et al.* (1987 b) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Lohithaswa *et al.* (2000)	Singh and Singh (1977) Gopalakrishnan *et al.* (1987 b) Bhagyalakshmi *et al.* (1991) Mulge (1992) Jagadeesh (1995) Shukla *et al.* (1999) Lohithaswa *et al.* (2000) Nandadevi and Hosamani (2003 b)	Anandanayaki and Natarajan (2000)				
Number of branches per plant	Bhat (1981) Khadi (1983) Joshi (1988) Patil (1990)	Joshi (1988) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Mulge (1992)					Anandanayaki and Natarajan (2000)

	Bhagyalakshmi *et al.* (1991) Anandanayaki and Natarajan (2000)	Pandian and Shanmugavelu (1992) Jagadeesh (1995) Patil (1997) Shukla *et al.* (1999) Ahmed *et al.* (2003)					
Number of fruits per plant	Lippert (1975) Pandey *et al.* (1981) Sontakke (1981) Gaddagimath *et al.* (1988) Joshi (1988) Sahoo *et al.* (1989 c) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Mulge (1992) Ahmed *et al.* (1994) Pichaimuthu and Pappiah (1995) Bal and Singh (1997) Lohitaswa (1997) Murthy and Deshpande (1997)	Khalf-Allah *et al.* (1975) Gopalakrishnan *et al.* (1987 b) Joshi (1988) Kaul and Sharma (1988 a) Sahoo *et al.* (1989 b) Patil (1990) Bhagyalakshmi *et al.* (1991) Mulge (199_) Pandian and Shanmugavelu (1992) Jagadeesh (1995) Lohithaswa (1997) Patil (1997) Ahmed *et al.* (1999) Shukla *et al.* (1999) Jadhav *et al.* (2001) Ibrahim *et al.* (2001)		Joshi (1990)		Joshi (1990)	

	Ahmed *et al.* (1999) Devi and Arumugam (1999 b) Doshi and Shukla (2000)	Ahmed *et al.* (2003) Nandadevi and Hosamani (2003b)	Ahmed *et al.* (1994) Jadhav and Dhumal (1994) Murthy and Deshpande (1997) Anandanayaki and Natarajan (2000)	Ahmed *et al.* (1994)	Ahmed *et al.* (1994)	Ahmed *et al.* (1994)	Doshi and Shukla (2000)
Average green fruit weight	Dolgikh and Sviridova (1983) Gopalakrishnan *et al.* (1987 b) Joshi (1988) Gaddagimath (1992) Ahmed *et al.* (1994) Lohithaswa (1997) Patil (1997) Ahmed *et al.* (1999) Devi and Arumugam (1999 b)	Khalf-Allah *et al.* (1975) Joshi (1988) Lohithaswa (1997) Patil (1997) Ahmed *et al.* (1999) Shukla *et al.* (1999) Jadhav *et al.* (2001) Ahmed *et al.* (2003)	Ahmed *et al.* (1994)	Ahmed *et al.* (1994)	Ahmed *et al.* (1994)	Ahmed *et al.* (1994)	

	Chaim and Paran (2000) Doshi and Shukla (2000)						
Fruit weight per plant	Lippert (1975) Pandey *et al.* (1981) Kaul and Sharma (1988 b) Gopalakrishnan *et al* (1987 b) Joshi (1988) Patil (1990) Bhagyalakshmi *et al.* (1991) Ahmed *et al.* (1994) Murthy and Deshpande (1997) Legesse (2000) Doshi and Shukla (2000) Ahmed *et al.* (1999) Rathod *et al.* (2002)	Khalf-Allah *et al.* (1975) Gaddagimath *et al.* (1988) Joshi (1988) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Pandian and Shanmugavelu (1992) Lohithaswa (1997) Patil (1997) Legesse (2000) Ahmed *et al.* (1999) Shukla *et al.* (1999) Jadhav *et al.* (2001) Lohithaswa *et al.* (2000) Ahmed *et al.* (2003) Nandadevi and Hosamani (2003 b)	Joshi (1988) Ahmed *et al.* (1994)	Joshi (1988) Ahmed *et al.* (1994)	Joshi (1988) Ahmed *et al.* (1994)	Joshi (1988) Ahmed *et al.* (1994)	

							Doshi and Shukla (2000)
Fruit length	Lippert (1975) Gopalakrishnan *et al.* (1987 b) Kaul and Sharma (1988 a) Patil (1990) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Ahmed *et al.* (1994) Jadhav and Dhumal (1994) Pichaimuthu and Pappiah (1995) Lohithaswa (1997) Murthy and Deshpande (1997) Sundaram and Irulappan (1998) Ahmed *et al.* (1999) Bal and Singh (1999)	Gopalakrishnan *et al.* (1987 b) Patil (1990) Bhagyalakshmi *et al.* (1991) Mulge (1992) Jagadeesh (1995) Lohithaswa (1997) Patil (1997) Ahmed *et al.* (1999) Bal and Singh (1999) Ibrahim *et al.* (2001) Jadhav *et al.* (2001) Ahmed *et al.* (2003)	Joshi (1988) Joshi (1990)	Joshi (1990)	Joshi (1990)		

	Shukla *et al.* (1999) Chaim and Paran (2000) Doshi and Shukla (2000) Ahmed *et al.* (2003) Nandadevi and Hosamani (2003 b)						Doshi and Shukla (2000)
Fruit girth	Jadhav and Dhumal (1994) Pichaimuthu and Pappiah (1995) Sundaram and Irulappan (1998) Shukla *et al.* (1999) Doshi and Shukla (2000)	Jadhav and Dhumal (1994) Ahmed *et al.* (2003)	Joshi (1988) Joshi (1990)	Joshi (1990)	Joshi (1990)	Joshi (1990)	Doshi and Shukla (2000)
Fruit width	Milkova (1979) Gopalakrishnan *et al.* (1987 b) Kaul and Sharma (1988 b) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992)	Lippert (1975) Patil (1990) Bhagyalakshmi *et al.* (1991) Jagadeesh (1995) Lohithaswa (1997) Patil (1997) Krishnamurthy and Deshpande (1997)	Murthy and Deshpande (1997)				

	Lohithaswa (1997) Murthy and Deshpande (1997) Patil (1997)						
Number of seeds per fruit	Martin and Lippert (1975) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992) Patil (1997) Lohithaswa (1997) Jabeen *et al.* (1999) Nandadevi and Hosamani (2003 b)	Singh and Singh (1982) Gaddagimath *et al.* (1988) Bhagyalakshmi *et al.* (1991) Pandian and Shanmugavelu (1992) Patil (1997) Lohithaswa (1997) Mishra *et al.* (1991 b)					
100- Seed weight	Lippert (1975) Mishra *et al.* (1991 b) Bhagyalakshmi *et al.* (1991) Gaddagimath (1992)	Mishra *et al.* (1991a) Bhagyalakshmi *et al.* (1991)					
Plant height	Pandey *et al.* (1981 b)	Ahmed *et al.* (1982)				Joshi (1990)	

	Ahmed *et al.* (1982) Joshi (1988) Sahoo *et al.* (1989b) Patil (1990) Bhagyalakshmi *et al.* (1991) Jadhav and Dhumal (1994) Patil (1997) Ahmed *et al.* (1999) Gandhi and Navale (2000) Lohithaswa *et al.* (2000) Doshi and Shukla (2000) Rathod *et al.* (2002)	Gaddagimath *et al.* (1988) Sahoo *et al.* (1989 c) Gaddagimath (1992) Patil (1997) Pandian and Shanmugavelu (1992) Jadhav and Dhumal (1994) Jagadeesh (1995) Ahmed *et al.* (1999) Shukla *et al.* (1999) Gandhi and Navale (2000) Lohithaswa *et al.* (2000) Anandanayaki and Natarajan (2000) Ibrahim *et al.* (2001) Jadhav *et al.* (2001) Ahmed *et al.* (2003)	Joshi (1988)				
Capsaicin content	Park and Takahashi (1980) Ahmed *et al.* (1982)						

	Lohithaswa (1997) Doshi and Shukla (2000)	Lohithaswa (1997) Patil (1997)					

(1998) for plant height, fruits per plant, fruit length, fruit diameter and fruit yield per plant and found that dominance and dominance x dominance interaction prevailed in the inheritance of these traits.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study was undertaken at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2002-2004 to study the genetic basis and inheritance pattern of important quantitative and qualitative characters including yield and anthracnose disease resistance in chilli. The details of materials used and methods adopted for the study are presented below.

3.1 MATERIALS

A germplasm collection of 76 chilli varieties / genotypes including a known anthracnose resistant variety, varieties released by Kerala Agricultural University and local collections from different parts of Kerala (Table 2) formed the materials for the study.

3.2 METHODS

3.2.1 Germplasm Evaluation

Two parallel experiments as detailed below for screening for anthracnose disease resistance and evaluation for yield traits were laid out using 76 genotypes of chilli during rabi 2002.

3.2.1.1 Screening for Anthracnose Resistance

An experiment using 76 genotypes of chilli was conducted during rabi 2002 to screen for anthracnose disease resistance. Randomised block design with two replications, at a spacing of 45 x 45 cm and ten plants per treatment per replication was used for evaluation. Cultural and manurial practices were followed as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002) without adopting any plant protection measure. Scoring for disease incidence was done following the standard procedures by Mayee and Datar (1986) and Sulochana *et al.* (1992) during three stages of the crop *viz.*, 30, 45 and 60 DAT (Days After Transplanting).

3.2.1.2 Evaluation for Yield Traits

The field experiment using 76 genotypes of chilli were laid out in randomized block design with two replications, at a spacing of 45 x 45 cm

Table 2. Germplasm collection of chilli

Treatments	Variety / genotype	Source
T_1	Jwalamukhi	Department of Plant Breeding and Genetics, College of Agriculture, Vellayani
T_2	Jwalasakhi	Department of Plant Breeding and Genetics, College of Agriculture, Vellayani
T_3	Neyyatinkara Local	Neyyatinkara, Thiruvananthapuram
T_4	Pathancote Local	Pathancote , Punjab
T_5	Yelahanka Local	Bangalore, Karnataka
T_6	Pettah Local-1	Pettah, Thiruvananthapuram
T_7	Pettah Local-2	Pettah, Thiruvananthapuram
T_8	Pettah Local-3	Pettah, Thiruvananthapuram
T_9	Adityapuram Local-1	Adityapuram, Kottayam
T_{10}	Kallara Local-1	Kallara, Kottayam
T_{11}	Kallara Local-2	Kallara, Kottayam
T_{12}	Ettumanoor Local-1	Ettumanoor, Kottayam
T_{13}	Ettumanoor Local-2	Ettumanoor, Kottayam
T_{14}	Ettumanoor Local-3	Ettumanoor, Kottayam
T_{15}	Parampuzha Local-1	Parampuzha,Kottayam
T_{16}	Samkranthi Local-1	Samkranthi, Kottayam
T_{17}	Samkranthi Local-2	Samkranthi, Kottayam
T_{18}	Mannanam Local-1	Mannanam, Kottayam
T_{19}	Mannanam Local-2	Mannanam, Kottayam
T_{20}	Kidangoor Local-1	Kidangoor, Kottayam
T_{21}	Pala Local	Pala, Kottayam
T_{22}	Kuruppanthara Local	Kuruppanthara, Kottayam
T_{23}	Muvattupuzha Local-1	Muvattupuzha, Ernakulam

T_{24}	Muvattupuzha Local-2	Muvattupuzha, Ernakulam
T_{25}	Parampuzha Local-2	Parampuzha, Kottayam
T_{26}	Kattachira Local-	Kattachira, Kottayam
T_{27}	Kozha Local-1	Kozha, Kottayam
T_{28}	Kozha Local-2	Kozha, Kottayam
T_{29}	Karithas Local	Karithas, Kottayam
T_{30}	Adichira Local-1	Adichira,Kottayam
T_{31}	Adichira Local-2	Adichira, Kottayam
T_{32}	Thiruvanjoor Local-1	Thiruvanjoor, Kottayam
T_{33}	Kanjikuzhi Local	Kanjikuzhi, Kottayam
T_{34}	Vaikom Local-1	Vaikom, Kottayam
T_{35}	Vaikom Local-2	Vaikom, Kottayam
T_{36}	Thiruvanjoor Local-2	Thiruvanjoor, Kottayam
T_{37}	Elikkuzhi Local-1	Elikkuzhi, Kottayam
T_{38}	Manjoor Local-1	Manjoor, Kottayam
T_{39}	Mitayikkunnu Local-1	Mitayikkunnu, Kottayam
T_{40}	Mitayikkunnu Local-2	Mitayikkunnu, Kottayam
T_{41}	Mitayikkunnu Local-3	Mitayikkunnu, Kottayam
T_{42}	Ujwala	College of Horticulture, Vellanikkara, Thrissur
T_{43}	Adityapuram Local-1	Adityapuram, Kottayam
T_{44}	Adityapuram Local-2	Adityapuram, Kottayam
T_{45}	Brahmapuram Local-1	Brahmapuram, Kottayam
T_{46}	Vellanikkara Local	Vellanikkara, Thrissur
T_{47}	Pudukkadu Local	Pudukkadu, Thrissur
T_{48}	Ollur Local	Ollur, Thrissur
T_{49}	Chalakudy Local	Chalakudy, Thrissur
T_{50}	Govindapuram Local	Govindapuram, Thrissur
T_{51}	Kunnamkulam Local	Kunnamkulam, Thrissur
T_{52}	Vengeri Local	Vengeri, Kozhikode

T_{53}	Omalloor Local	Omalloor, Pathanamthitta
T_{54}	Kanniyakumari Local	Kanniyakumari, Tamil Nadu
T_{55}	Kumaranalloor Local	Kumaranalloor, Kottayam
T_{56}	Malliyoor Local	Malliyoor, Kottayam
T_{57}	Panachikadu Local	Panachikadu, Kottayam
T_{58}	Harippadu Local	Harippadu, Alappuzha
T_{59}	Mannarassala Local	Mannarassala, Alappuzha
T_{60}	Kaduthuruthi Local	Kaduthurithi, Kottayam
T_{61}	Sankarankoil Local	Sankarankoil, Tamil Nadu
T_{62}	Muzhappilangad Local	Muzhappilangad, Kannur
T_{63}	Valiyakunnu Local	Valiyakunnu, Malappuram
T_{64}	Kothamangalam Local	Kothamangalam, Ernakulam
T_{65}	Koorkencherry Local	Koorkencherry, Thrissur
T_{66}	Vayapparapadi Local	Vayapparapadi, Malappuram
T_{67}	Areekode Local	Areekode, Malappuram
T_{68}	Kodungallur Local	Kodungallur, Thrissur
T_{69}	Cherpu Local	Cherpu, Thrissur
T_{70}	Purayar Local	Purayar, Ernakulam
T_{71}	Wadakkancherry Local	Wadakkancherry, Palakkadu
T_{72}	Eramalloor Local	Eramalloor, Alappuzha
T_{73}	Pallikkal Local	Pallikkal, Malappuram
T_{74}	Kavumpadi Local	Kavumpadi, Ernakulam
T_{75}	Keecheripadi Local	Keecheripadi, Ernakulam
T_{76}	Pant C1	G.B. Pant University of Agriculture and Technology, Pant Nagar, Uttar Pradesh

and ten plants per treatment per replication during rabi 2002 to evaluate the yield and yield attributes. Cultural and manurial practices were followed as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002). Observations on yield and yield attributes were recorded and biochemical traits were analysed.

3.2.2 Development of F_1s

Five high yielding anthracnose susceptible types and three resistant types, identified from the previous trials on evaluation and screening of germplasm, were selected as parental lines and testers respectively for developing F_1s. The five lines and three testers were raised in a Line x Tester (L x T) crossing block during summer 2003 and fifteen F_1 hybrids were produced. The technique of crossing done in chilli was as follows (Gopimony and Nair, 1983).

Mature flower buds of female parents, which would open on the following day were selected and emasculated in the evening. Emasculation was done by opening the corolla and removing the anthers by holding the filaments. The emasculated flower buds were covered with butter paper covers. The next morning, pollen from undehisced anthers of selected male parents were scooped out through the lateral sutures of anthers with a needle and transferred to the stigma of emasculated flowers of female parents. After pollination, the flowers were covered with small butter paper covers and properly labelled indicating the crosses. The labels were retained till the fruits ripened. The labelled mature fruits were harvested separately and F_1 seeds were extracted.

3.2.3 Evaluation of F_1s and Parents

The fifteen F_1 hybrids and their eight parents were planted in randomised block design with three replications, at a spacing of 45 x 45 cm and ten plants per treatment per replication during kharif 2003. Observations on yield and yield attributes and incidence of anthracnose disease were recorded from the hybrids and parents. Two superior F_1s with respect to yield and anthracnose resistance were selected.

3.2.4 Building up of Generations

The two selected F_1s were backcrossed to their respective parents to produce B_1 and B_2 generations during rabi 2003. Simultaneously, the F_1s were selfed to develop F_2 generation.

For selfing, mature flower buds that would open on the following day were covered with butter paper covers in the evening and labelled. Covers were retained till fruits set.

3.2.5 Evaluation of Generations

The six generations (P_1, P_2, F_1, F_2, B_1 and B_2) of each hybrid combination were evaluated during summer 2004 in a randomized block design with three replications. From every replication, five plants each were selected at random for recording observations in P_1 and P_2, ten plants in F_1, 25 plants in F_2 and 15 plants each in B_1 and B_2.

3.3 OBSERVATIONS

3.3.1 Biometric Observations on Yield Traits

For each genotype, five plants per replication were selected at random for taking the biometric observations and mean recorded.

a. Days to first flowering

Number of days from sowing to the blooming of first flower in each plant was recorded.

b. Number of branches

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

c. Number of fruits per plant

The total number of fruits harvested from each plant was counted and recorded.

d. Average green fruit weight (g)

Weight of five fruits from each plant was recorded and the mean single fruit weight calculated in grams.

e. Fruit weight per plant (g)

At each harvest, weight of fresh fruits from each observational plant was recorded. Total yield was calculated as the sum of fresh fruit weight per harvest and the mean worked out in grams.

f. Fruit length (cm)

Length of fruits from the base of the peduncle to the tip of the fruit for five fruits selected at random from the observational plants was recorded and the mean worked out and expressed in centimetre.

g. Fruit girth (cm)

The girths of those fruits used for recording length were measured at the broadest part of the fruit and the mean calculated and expressed in centimetre.

h. Number of seeds per fruit

Seeds were extracted from each of the five fruits, the total number counted, and mean recorded.

i. Hundred seed weight (g)

Seeds extracted from five ripe fruits chosen at random were dried and the weight of 100 fully developed seeds was recorded in grams.

j. Plant height (cm)

Plant height was measured from the base of the plant to the tip of the longest branch after the last harvest of fruits.

k. Duration of the crop

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

l. Harvest index

It was calculated as

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield}}{\text{Total biological yield}}$$

3.3.2 Biochemical Traits

a. Capsaicin content (%)

The capsaicin content of fruits of selected plants was estimated by Folin-Dennis method. The pungent principle in chilli reacted with Folin-Dennis reagent to give a bluish complex, which was estimated colorimetrically (Mathew *et al.*, 1971).

Reagents used included Folin-Dennis reagent and aqueous sodium carbonate solution (25 %).

For preparation of Folin-Dennis reagent, a solution containing 750 ml distilled water, 100 g sodium tungstate, 20 g phosphomolybdic acid

and 50 ml phosphoric acid were refluxed for two hours. It was cooled and diluted to 1000 ml with distilled water.

Procedure

Fruits harvested at red ripe stage were dried in a hot air oven at 50^0C and powdered finely. Five hundred milligrams of each sample was transferred into test tubes into which 10 ml acetone was added and kept overnight. From this, 1 ml aliquots were pipetted out into 100 ml conical flasks and 25 ml of Folin-Dennis reagent was added and allowed to stand for 30 minutes. Twenty-five millilitres of freshly prepared sodium carbonate solution was added to it and shaken vigorously. The volume was made up to 100 ml with distilled water and optical density read after 30 minutes at 725 nm against reagent blank using a UV spectrophotometer. The reagent blank contained 1 ml acetone, 25 ml Folin-Dennis reagent and 25 ml aqueous sodium carbonate-solution.

To determine the per cent value for pure capsaicin, a stock solution of standard capsaicin (200 mg l^{-1}) was prepared by dissolving 20 mg capsaicin in 100 ml acetone. From this stock solution, a series of solutions of different concentrations were prepared and their optical densities measured at 725 nm using a UV spectrophotometer. A standard graph was prepared from which capsaicin content in the samples was found out.

b. Oleoresin content (%)

Oleoresin was extracted in Soxhlet apparatus using the solvent acetone (Sadasivam and Manickam, 1992).

Procedure

Chilli fruits at red ripe stage were dried in a hot air oven at 50^0C and powdered finely. Two grams of powder was packed in a filter paper and placed in a Soxhlet apparatus. Two hundred millilitres of acetone was taken in the round bottom flask of the apparatus and heated in a water bath kept at the boiling point of acetone. After complete extraction, the solvent was evaporated to dryness under vacuum.

Yield of oleoresin on dry weight basis was calculated as

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

3.3.3 Incidence of Anthracnose

a. Per cent disease incidence

Five observational plants per treatment per replication were observed for characteristic symptoms on fruits. Per cent disease incidence in each observational plant was calculated using the formula

$$\text{Per cent disease incidence} = \frac{\text{Number of fruits affected by anthracnose in a plant}}{\text{Total number of fruits in that plant}} \times 100$$

b. Disease intensity (%)

The following rating scale was used for calculating disease intensity (Plate1).

Table 3. Anthracnose rating scale

Sl. No.	Percent fruit area affected	Grade	Rating scale
1	0	Highly resistant	0
2	1 – 10	Moderately resistant	1
3	10 – 20	Slightly resistant	2
4	20 – 40	Slightly susceptible	3
5	40 – 60	Moderately susceptible	4
6	> 60	Severely susceptible	5

Disease intensity (DI) was calculated using the formula

$$\text{DI} = \frac{\text{Sum of all scores for fruits in a plant}}{\text{Total number of fruits in that plant x Maximum score given}} \times 100$$

Disease intensity was calculated at the following stages of the crop

i. 30 days after transplanting (30 DAT)

ii. 45 days after transplanting (45 DAT)

iii. 60 days after transplanting (60 DAT)

Plate 1. Anthracnose rating scale

3.4 STATISTICAL ANALYSIS

3.4.1 Germplasm Evaluation

3.4.1.1 Screening for Anthracnose Disease Resistance

3.4.1.1.1 Analysis of Variance (ANOVA)

Analysis of variance was carried out for DI values corresponding to 30 DAT, 45 DAT and 60 DAT (Panse and Sukhatme, 1985)(Table 4.)

Table 4. ANOVA for each character

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

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

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

Where, t_{α} is the Student's t table value at error degrees of freedom and α is the level of significance (5% level).

3.4.1.2 Evaluation for Yield Traits

3.4.1.2.1 Analysis of Variance (ANOVA)

The biometric observations recorded were subjected to ANOVA (Panse and Sukhatme, 1985) for comparison among various treatments and to estimate variance components (Table 4).

3.4.1.2.2 Estimation of Genetic Parameters

a. Genetic components of variance

For each character, the phenotypic and genotypic components of variance were estimated by equating the expected value of mean squares (MS) to the respective variance components (Jain, 1982). Based on this, the following variance components were estimated.

i. Genotypic variance (V_G)

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

ii. Environmental variance (V_E)

$$V_E = MSE$$

iii. Phenotypic variance (V_P)

$$V_P = V_G + V_E$$

b. Coefficients of variation

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

i. Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sqrt{V_P}}{\bar{X}} \times 100$$

ii. Genotypic coefficient of variation (GCV)

$$GCV = \frac{\sqrt{V_G}}{\bar{X}} \times 100$$

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

c. Heritability

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

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

Heritability was categorised as :

< 30 %	→ low
31 – 60 %	→ moderate
>60 %	→ high

(Johnson *et al.*, 1955)

d. Genetic advance

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

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

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

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

Genetic advance was categorised as :

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

3.4.1.2.3 Association Analysis

a. Correlations

Phenotypic, genotypic and environmental correlation coefficients were calculated using the respective variances and co-variances of the characters.

Phenotypic correlation coefficient, $r_{Pxy} = \frac{Cov_P(x,y)}{\sqrt{V_P(x). V_P(y)}}$

Genotypic correlation coefficient, $r_{Gxy} = \frac{Cov_G(x,y)}{\sqrt{V_G(x). V_G(y)}}$

Environmental correlation coefficient, $r_{Exy} = \frac{Cov_E(x,y)}{\sqrt{V_E(x). V_E(y)}}$

Where, $Cov_P(x,y)$, $Cov_G(x,y)$ and $Cov_E(x,y)$ denote the phenotypic, genotypic and error co-variances between the two traits x and y respectively.

$V_P(x)$, $V_G(x)$ and $V_E(x)$ respectively are the phenotypic, genotypic and error variances for x, and $V_P(y)$, $V_G(y)$ and $V_E(y)$ respectively indicate the phenotypic, genotypic and error variances for y.

b. Path coefficients

The direct and indirect effects of component characters, which have high association with yield (fruit weight plant^{-1}) based on the genotypic correlations were estimated through path analysis technique (Dewey and Lu, 1959).

3.4.1.2.4 Selection Index

To discriminate the genotypes based on characters under study selection index developed by Smith (1936), using discriminant function of Fisher (1936), was employed.

The selection index is described by the function, $I = b_1x_1 + b_2x_2 +.....+ b_kx_k$ and the merit of a plant is described by the function, $H = a_1G_1 + a_2G_2 +.....+ a_kG_k$ where x_1, $x_2.....x_k$ are the phenotypic values and G_1, $G_2.....G_k$ are the genotypic values of the plants with respect to the characters x_1, $x_2.....x_k$, and H is the genetic worth of the plant. It is assumed that economic weight assigned to each character is equal to unity *ie.*, a_1, a_2,.....,a_k = 1 and b (regression) coefficients are determined such that correlation between H and I is maximum. The procedure will reduce to an equation of the form $b = P^{-1}Ga$ where P and G are the phenotypic and genotypic variance covariance matrices respectively from which the b_i values are estimated.

3.4.2 Line x Tester Analysis

3.4.2.1 Heterosis

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

estimating standard heterosis, Jwalamukhi and Pant C-1 (for anthracnose disease resistance only) were used as the standard varieties.

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

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

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

Where,

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

$\overline{MP}$ = Mid parental value

$\overline{SV}$ = Mean of standard variety

$\overline{BP}$ = Mean of better parent in that particular cross

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

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

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

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

Where,

MSE = estimate of error variance

r = number of replications

3.4.2.2 Combining Ability

Based on screening trials, five lines and three testers were identified and carried over for crossing programme. Following the L x T method (Kempthorne, 1957), the general combining ability effects (gca) of parents and the specific combining ability effects (sca) of hybrids were estimated. The mean squares due to various sources of variation and their genetic expectations were computed as per Table 5.

Table 5. ANOVA for line x tester analysis

Source	df	Mean square	Expected MS
Replication	(r – 1)		
Line	(l – 1)	M_1	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.) + rt (C_{OV} H.S.)
Tester	(t – 1)	M_2	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.) + rl (C_{OV} H.S)
Line x Tester	(l – 1) (t – 1)	M_3	MSE + r (C_{OV} F.S. – 2 C_{OV} H.S.)
Error	(r – 1) (lt – 1)	M_4	MSE
Total	(rlt – 1)		

Where,

r = number of replications

l = number of lines

t = number of testers

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

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

Where,

μ = Population mean

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

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

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

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

i = 1,2,.....l

j = 1,2,.....t

k = 1,2,.....r

The individual effects were estimated as follows :

$$\text{Mean} = \frac{X...}{r_{lt}}$$

i. *gca* effect of lines

$$g_i = \frac{X_{i..}}{r_t} - \frac{X...}{r_{lt}} \quad i=1,2,....,l$$

ii. *gca* effect of testers

$$g_j = \frac{X_{.j.}}{r_l} - \frac{X...}{r_{lt}} \quad j= 1,2...,t$$

iii. *sca* effect of hybrids

$$s_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{r_t} - \frac{X_{.j.}}{r_l} + \frac{X...}{r_{lt}}$$

Where,

X... = Total of all hybrids over 'r' number of replications

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

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

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

Significance of combining ability effects was tested as follows :

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

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

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

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

3.4.2.3 Proportional Contribution

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

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

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

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

3.4.3 Generation Mean Analysis

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

i. Development of scales

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

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

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

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

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

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

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

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

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

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

ii. Testing for epistasis

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

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

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

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

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

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

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

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

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

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

iii. Estimation of genetic components

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

$$m = \bar{F}_2$$

$$d = \bar{B}_1 - \bar{B}_2$$

$$h = \bar{F}_1 - 4\bar{F}_2 - \tfrac{1}{2}\bar{P}_1 - \tfrac{1}{2}\bar{P}_2 + 2\bar{B}_1 + 2\bar{B}_2$$

$$i = 2\bar{B}_1 + 2\bar{B}_2 - 4\bar{F}_2$$

$$j = (\bar{B}_1 - \tfrac{1}{2}\bar{P}_1) - (\bar{B}_2 - \tfrac{1}{2}\bar{P}_2) = \bar{B}_1 - \tfrac{1}{2}\bar{P}_1 - \bar{B}_2 + \tfrac{1}{2}\bar{P}_2$$

$$l = \bar{P}_1 + \bar{P}_2 + 2\bar{F}_1 + 4\bar{F}_2 - 4\bar{B}_1 - 4\bar{B}_2$$

Where,

m= mean

d= additive effect

h= dominance effect

i= additive x additive interaction

j= additive x dominance interaction

l= dominance x dominance interaction

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

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

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

$$V(h) = V(F_1) + 16V(F_2) + \tfrac{1}{4}V(P_1) + \tfrac{1}{4}V(P_2) + 4V(B_1) + 4V(B_2)$$

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

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

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

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

iv. Transgressive segregants (%)

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

RESULTS

4.RESULTS

The results obtained from various experiments of the present investigation are given below.

4.1 GERMPLASM EVALUATION

4.1.1 Screening for anthracnose disease resistance

4.1.1.1 Analysis of variance

Number of fruits affected by anthracnose as per cent of the total number of fruits produced in a plant and the scores obtained as per anthracnose rating scale (Plate 1; Table 3) for the 76 genotypes under study at three crop stages *viz.*, 30 DAT, 45 DAT and 60 DAT were subjected to ANOVA and the results are presented in Table 6.

Table 6. ANOVA for per cent disease incidence and anthracnose disease intensity

Crop stage	Varietal mean square (df = 75)	
	Per cent disease incidence	Disease intensity
30 DAT	2.11**	2.065**
45 DAT	25.01**	2.047**
60 DAT	1.87**	2.119**

4.1.1.1.1. Per cent disease incidence

The genotypes varied significantly for per cent disease incidence at 30 DAT, 45 DAT and 60 DAT.

The means of per cent disease incidence for the 76 genotypes are given in Table 7. Disease incidence during various crop stages is presented in Fig.1.

Table 7. Percent disease incidence

Treat-ment Number	30 DAT		45 DAT		60 DAT	
	Means	Trans-formed means	Means	Trans-formed means	Means	Trans-formed means
T_1	63.79	7.99	57.62	7.59	54.14	7.36
T_2	78.05	8.83	76.44	8.74	64.24	8.02
T_3	30.04	5.48	31.11	5.58	37.98	6.16
T_4	18.68	4.32	25.89	5.09	34.11	5.84
T_5	34.21	5.84	36.81	6.07	32.14	5.67
T_6	58.65	7.65	58.96	7.68	60.10	7.75
T_7	33.43	5.78	20.11	4.49	20.19	4.49
T_8	31.99	5.66	31.99	5.06	31.57	5.62
T_9	29.98	5.48	31.24	5.59	30.45	5.52
T_{10}	19.38	4.40	17.57	4.19	24.79	4.98
T_{11}	37.93	6.16	35.10	5.92	34.81	5.90
T_{12}	36.25	6.02	38.61	6.21	34.19	5.85
T_{13}	32.42	5.69	28.71	5.36	29.18	5.40
T_{14}	42.16	6.49	38.97	6.24	43.71	6.61
T_{15}	23.57	4.86	25.43	5.04	24.89	4.99
T_{16}	49.61	7.04	51.33	7.16	52.71	7.26
T_{17}	24.09	4.91	27.24	5.22	26.49	5.15
T_{18}	27.67	5.26	28.27	5.32	31.08	5.58
T_{19}	36.93	6.08	29.33	5.42	31.80	5.64
T_{20}	6.63	2.57	8.43	2.90	9.88	3.14
T_{21}	30.04	5.48	25.05	5.00	25.34	5.03
T_{22}	25.77	5.08	22.22	4.71	27.85	5.28
T_{23}	59.42	7.71	59.08	7.69	68.51	8.28
T_{24}	32.31	5.68	24.21	4.92	20.10	4.48
T_{25}	31.01	5.57	29.35	5.47	26.48	5.15
T_{26}	16.58	4.07	18.72	4.32	23.77	4.88
T_{27}	29.03	5.39	25.89	5.09	31.51	5.61
T_{28}	18.36	4.28	20.86	4.57	22.05	4.69
T_{29}	18.54	4.31	18.09	4.25	19.82	4.45
T_{30}	33.25	5.77	29.22	5.41	28.84	5.37
T_{31}	28.47	5.34	27.76	5.27	24.39	4.94
T_{32}	27.18	5.21	26.02	5.10	31.71	5.63
T_{33}	21.41	4.63	24.71	4.97	26.69	5.17
T_{34}	23.08	4.80	20.66	4.55	30.16	5.49
T_{35}	48.23	6.95	57.31	7.57	62.64	7.91
T_{36}	27.59	5.25	24.78	4.98	24.44	4.94
T_{37}	24.47	4.95	17.43	4.18	25.76	5.08

T_{38}	23.98	4.89	26.60	5.16	21.67	4.65
T_{39}	32.22	5.68	32.19	5.67	27.66	5.26
T_{40}	26.31	5.13	27.59	5.25	26.83	5.18
T_{41}	26.41	5.14	27.31	5.23	29.82	5.46
T_{42}	7.70	2.78	6.55	2.56	8.46	2.91
T_{43}	25.62	5.06	29.48	5.43	22.99	4.79
T_{44}	23.61	4.86	23.59	4.86	21.80	4.67
T_{45}	28.12	5.30	29.02	5.39	26.29	5.12
T_{46}	31.92	5.65	32.93	5.74	35.66	5.97
T_{47}	25.44	5.04	28.32	5.32	20.02	4.47
T_{48}	24.76	4.98	26.88	5.18	29.52	5.43
T_{49}	22.56	4.75	9.79	3.13	20.33	4.51
T_{50}	32.41	5.69	22.68	4.76	32.21	5.68
T_{51}	16.39	4.05	21.17	4.60	15.81	3.97
T_{52}	21.54	4.64	26.27	5.13	27.33	5.23
T_{53}	28.02	5.29	24.94	4.99	20.72	4.55
T_{54}	27.75	5.27	28.55	5.34	16.97	4.12
T_{55}	28.82	5.37	29.59	5.44	26.52	5.15
T_{56}	20.99	4.58	22.79	4.77	23.53	4.85
T_{57}	25.99	5.09	26.59	5.16	33.66	5.80
T_{58}	26.83	5.18	28.26	5.32	27.33	5.22
T_{59}	26.98	5.19	26.33	5.13	24.00	4.89
T_{60}	28.11	5.30	27.81	5.27	26.65	5.16
T_{61}	25.49	5.05	26.28	5.13	23.23	4.82
T_{62}	27.78	5.27	26.05	5.10	27.43	5.24
T_{63}	19.68	4.44	31.85	5.64	20.19	4.49
T_{64}	25.41	5.04	26.06	5.10	26.47	5.14
T_{65}	18.91	4.35	26.39	5.14	23.29	4.83
T_{66}	31.82	5.64	29.46	5.43	31.06	5.57
T_{67}	18.81	4.34	20.34	4.51	28.12	5.30
T_{68}	21.07	4.59	28.85	5.37	23.07	4.80
T_{69}	28.57	5.35	26.51	5.15	30.94	5.56
T_{70}	26.49	5.15	29.99	5.48	33.28	5.77
T_{71}	21.25	4.61	25.23	5.02	23.37	4.83
T_{72}	28.93	5.38	25.46	5.05	28.23	5.31
T_{73}	22.45	4.74	27.63	5.26	29.57	5.44
T_{74}	25.07	5.01	23.83	4.88	23.81	4.88
T_{75}	25.63	5.06	22.56	4.75	26.90	5.19
T_{76}	5.07	2.52	6.33	2.52	8.48	2.91
Mean		5.24		5.49		5.29
SE		0.15		2.31		0.20
CD		0.42		6.54		0.57

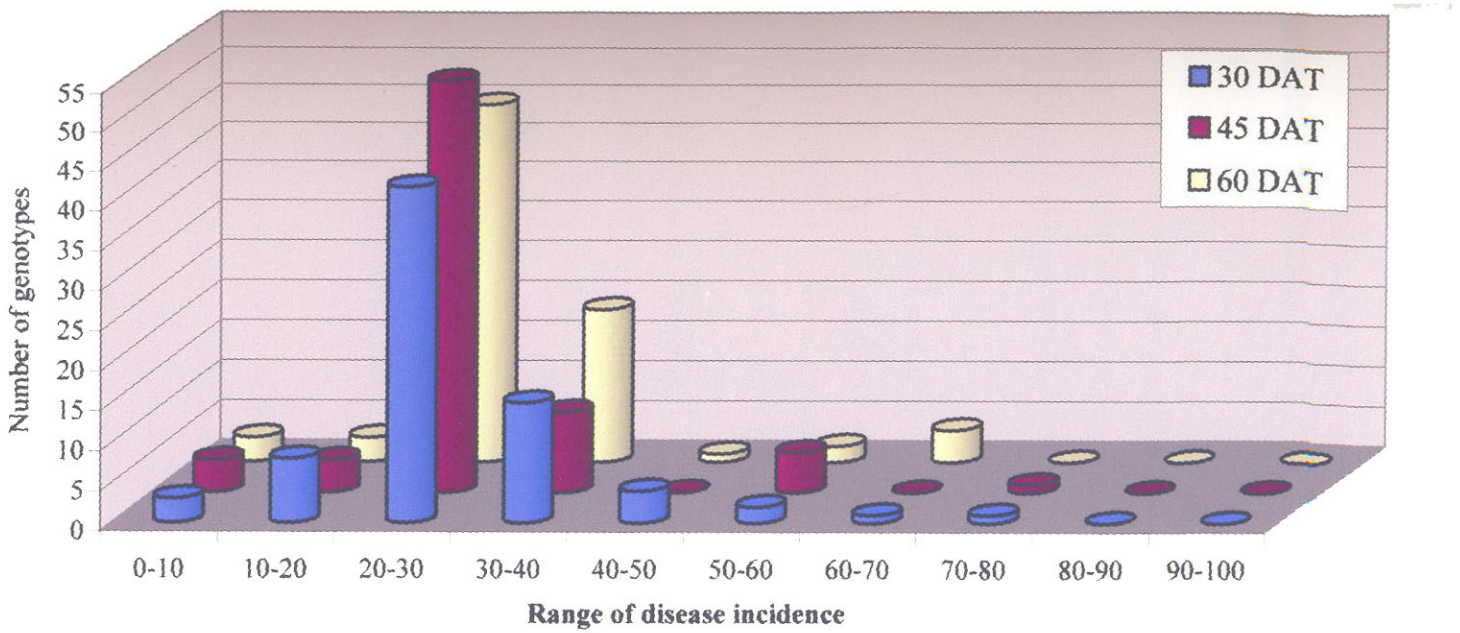


Fig. 1. Per cent disease incidence at three crop stages

a.30 DAT

Majority of the genotypes showed disease incidence between 20 and 30 per cent. T_{76}, T_{20} and T_{42} showed less than 10 per cent disease incidence. T_{76} and T_{20} were on par followed by T_{42}, T_{51}, T_{26}, T_{28}, T_{29}, T_4, T_{67}, T_{65}, T_{10} and T_{63} exhibited disease incidence between 10 and 20 per cent and were on par. T_2 showed the maximum incidence of 78.05 per cent. This was followed by T_1 (63.79 %). T_{23} and T_6 were on par with T_1.

b.45 DAT

There was significant difference between the genotypes for per cent disease incidence at all the three stages. However, T_{20}, T_{42}, T_{49} and T_{76} showed less than 10 per cent disease incidence.

c.60 DAT

Most of the genotypes showed disease incidence in the range 20 to 30 per cent. T_{42} showed the least incidence (8.46 %) followed by T_{76} and T_{20}, which were on par with T_{42}. T_{23} was the most affected genotype with disease incidence 68.51 per cent. T_2 and T_{35} were on par with T_{23}.

4.1.1.1.2 Anthracnose Disease Intensity

The genotypes varied significantly with respect to anthracnose disease intensity at 30 DAT, 45 DAT and 60 DAT.

The means of anthracnose disease index for the 76 genotypes are given in Table 8. Intensity of anthracnose incidence during various crop stages is presented in Fig. 2.

a. 30 DAT

Majority of the genotypes were slightly susceptible while three genotypes T_{20}, T_{42} and T_{76} were moderately resistant and were on par with each other. 13 genotypes were slightly resistant. T_2 was severely susceptible. T_6, T_{23}, T_{35} and T_1 were on par with T_2.

Table 8. Disease intensity (%)

Treatment Number	30 DAT		45 DAT		60 DAT	
	Means	Trans-formed means	Means	Trans-formed means	Means	Trans-formed means
T_1	54.95	7.36	58.41	7.64	52.27	7.23
T_2	62.06	8.02	68.64	7.99	56.46	7.51
T_3	32.82	6.16	34.72	5.89	26.99	5.19
T_4	22.97	5.84	22.22	4.71	23.78	4.88
T_5	25.24	5.67	24.07	4.91	23.54	4.85
T_6	59.21	7.75	57.34	7.57	54.79	7.40
T_7	28.67	4.49	25.49	5.05	23.12	4.81
T_8	26.84	5.62	30.08	5.48	36.92	6.08
T_9	25.48	5.52	34.66	5.89	27.13	5.21
T_{10}	22.04	4.98	20.74	4.55	25.81	5.08
T_{11}	29.09	5.90	30.39	5.51	35.59	5.97
T_{12}	24.41	5.85	25.67	5.07	27.80	5.27
T_{13}	24.04	5.40	31.45	5.61	26.89	5.19
T_{14}	26.59	6.61	30.53	5.53	37.63	6.13
T_{15}	23.59	4.99	30.37	5.51	26.19	5 12
T_{16}	43.43	7.26	40.87	6.39	32.27	5.68
T_{17}	20.00	5.15	19.91	4.46	27.39	5.23
T_{18}	31.02	5.58	29.57	5.44	35.29	5.94
T_{19}	32.46	5.64	30.17	5.49	36.34	6.03
T_{20}	4.52	3.14	7.69	2.77	4.27	2.07
T_{21}	25.38	5.03	23.85	4.88	22.59	4.75
T_{22}	19.22	5.28	23.54	4.85	25.28	5.03
T_{23}	57.32	8.28	61.05	7.81	65.90	8.12
T_{24}	33.04	4.48	31.73	5.63	36.20	6.02
T_{25}	25.91	5.15	21.92	4.68	23.11	4.81
T_{26}	13.85	4.88	18.35	4.28	19.68	4.44
T_{27}	27.16	5.61	24.61	4.96	26.34	5.13
T_{28}	17.66	4.69	17.37	4.17	20.29	4.50
T_{29}	20.10	4.45	23.81	4.88	32.79	5.73
T_{30}	34.92	5.37	27.95	5.29	39.47	6.28
T_{31}	25.13	4.94	19.72	4.44	21.30	4.62
T_{32}	28.39	5.63	24.13	4.91	22.52	4.75
T_{33}	18.93	5.17	22.91	4.79	19.87	4.46
T_{34}	19.70	5.49	23.38	4.83	25.38	5.04
T_{35}	55.04	7.91	63.08	7.94	63.02	7.94
T_{36}	25.88	4.94	26.87	5.18	29.27	5.41
T_{37}	24.53	5.08	24.44	4.94	31.99	5.66
T_{38}	21.68	4.65	22.80	4.78	21.49	4.63
T_{39}	30.66	5.26	28.05	5.29	29.74	5.45

T_{40}	21.74	5.18	21.83	4.67	21.48	4.63
T_{41}	23.41	5.46	19.17	4.38	18.33	4.28
T_{42}	6.08	2.91	4.39	2.09	4.51	2.12
T_{43}	19.76	4.79	21.10	4.59	15.97	3.99
T_{44}	19.21	4.67	18.59	4.31	18.01	4.24
T_{45}	26.54	5.12	28.42	5.33	26.24	5.12
T_{46}	26.52	5.97	38.11	6.17	37.97	6.16
T_{47}	29.46	4.47	30.28	5.50	31.66	5.63
T_{48}	24.89	5.43	39.00	6.25	41.10	6.41
T_{49}	32.38	4.51	18.19	4.26	23.36	4.83
T_{50}	25.18	5.68	22.62	4.75	29.28	5.41
T_{51}	18.69	3.97	17.73	4.21	22.98	4.79
T_{52}	15.98	5.23	18.17	4.26	26.45	5.14
T_{53}	27.28	4.55	26.59	5.16	35.67	5.97
T_{54}	28.43	4.12	25.98	5.09	17.86	4.23
T_{55}	30.96	5.15	22.44	4.74	28.81	5.37
T_{56}	24.57	4.85	25.39	5.04	36.56	6.05
T_{57}	21.32	5.80	24.31	4.93	29.57	5.44
T_{58}	28.38	5.22	28.69	5.36	22.67	4.76
T_{59}	29.67	4.89	27.19	5.21	23.01	4.79
T_{60}	25.01	5.16	28.43	5.33	25.91	5.09
T_{61}	21.87	4.82	28.03	5.29	28.55	5.34
T_{62}	39.51	5.24	34.53	5.87	28.27	5.32
T_{63}	19.69	4.49	27.86	5.28	35.36	5.95
T_{64}	23.84	5.14	23.81	4.88	32.83	5.73
T_{65}	20.91	4.83	29.09	5.39	37.31	6.11
T_{66}	24.10	5.57	21.59	4.65	28.38	5.33
T_{67}	19.44	5.30	25.67	5.06	27.38	5.23
T_{68}	21.92	4.80	24.07	4.90	23.78	4.88
T_{69}	26.65	5.56	25.06	5.01	27.07	5.20
T_{70}	30.82	5.77	25.44	5.04	29.80	5.46
T_{71}	22.50	4.83	21.47	4.63	30.56	5.53
T_{72}	28.35	5.31	33.06	5.75	29.39	5.42
T_{73}	23.02	5.44	26.51	5.15	27.74	5.27
T_{74}	18.68	4.88	19.46	4.41	30.19	5.49
T_{75}	28.09	5.19	25.04	5.00	23.60	4.86
T_{76}	2.75	2.91	4.45	2.10	4.48	212
Mean		5.06		5.13		5.28
SE		0.29		0.29		0.30
CD		0.85		0.81		0.86

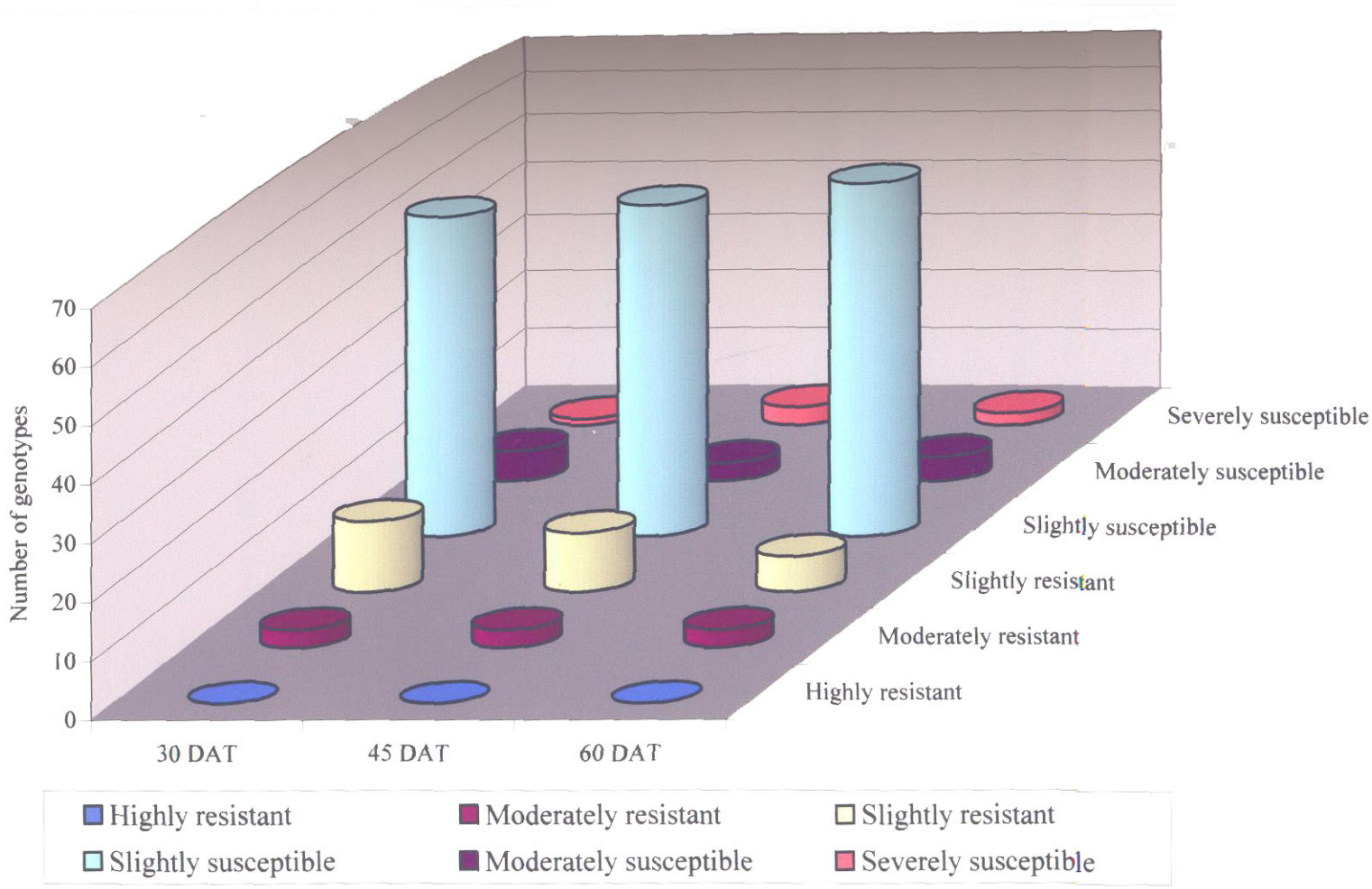


Fig. 2. Intensity of anthracnose at three crop stages

b. 45 DAT

Most of the genotypes were slightly susceptible. T_{20}, T_{76} and T_{42} were moderately resistant and on par. T_2, T_{35} and T_{23} were severely susceptible. T_1 and T_6 were on par with them.

c. 60 DAT

A large number of genotypes were slightly susceptible. T_{20}, T_{76} and T_{42} remained moderately resistant. T_{23} and T_{35} were severely susceptible. T_2, T_6 and T_1 were on par with T_{35}.

4.1.2 Evaluation for Yield Traits

4.1.2.1 Analysis of Variance

The results of the analysis of variance for 14 characters that were used to compare the performance of 76 chilli genotypes are presented in Table 9. The mean performance of genotypes with respect to various characters is furnished in Table 10. Genotypes superior for various traits are presented in Plate 2.

Significant differences were detected among the genotypes with respect to all the characters studied.

a. Days to first flowering

The mean performance of genotypes ranged from 48.0 (T_{65}) to 81.2 (T_{24}) days. T_{65} was the earliest to flower, which was homogeneous with 14 other treatments. T_{24} took the maximum number of days to produce the first flower. T_{26} and T_{41} were on par with it.

b. Number of branches

T_{24} recorded the lowest value (2.1), which was on par with 11 other genotypes. T_2 (7.2) possessed the largest number of branches. T_6, T_1, T_{35} and T_{74} were on par with it.

c. Number of fruits per plant

T_1 (138.4) ranked first for this character, while T_6 and T_2 were statistically on par with it. These were followed by T_{16} and T_{35}. T_{32} recorded the minimum number of fruits (17.6), which was on par with T_{38}.

Table 9. ANOVA for fourteen characters in chilli

Characters	Mean square	
	Treatment df=75	Error df = 75
1. Days to first flowering	191.64**	11.14
2. Number of branches	3.70**	0.15
3. Number of fruits per plant	1101.37**	29.93
4. Average green fruit weight (g)	2.95**	6.60
5. Fruit weight per plant (g)	10023.7**	55.14
6. Fruit length (cm)	6.21**	0.10
7. Fruit girth (cm)	2.27**	0.07
8. Number of seeds per fruit	2033.78**	69.67
9. Hundred seed weight (g)	0.03**	0.01
10. Plant height (cm)	461.36**	6.83
11. Duration of the crop	145.23**	16.42
12. Harvest index (HI)	0.02**	1.72
13. Capsaicin content (%)	0.01**	0.01
14. Oleoresin content (%)	3.97**	0.09

Table 10. Mean values of fourteen characters in chilli

Genotypes/ Treatments	Days to first flowering	No. of branches	No. of fruits per plant	Average green fruit weight (g)	Fruit weight per plant (g)	Fruit length (cm)	Fruit girth (cm)	No. of seeds per fruit	100-seed weight (g)	Plant height (cm)	Duration of the crop	Harvest index	Capsaicin content (%)	Oleoresin content (%)
T_1	48.1	7.0	138.4	5.4	379.2	9.9	6.1	52.3	0.631	42.1	162.3	0.90	0.14	13.35
T_2	56.2	7.2	129.3	5.8	358.4	9.7	5.7	60.3	0.633	44.3	160.6	0.90	0.15	13.35
T_3	62.5	3.5	68.0	2.5	198.3	5.3	3.6	130.6	0.425	76.4	136.3	0.79	0.22	8.53
T_4	56.5	4.4	67.1	3.4	126.3	5.3	3.7	129.5	0.620	67.3	147.4	0.59	0.25	8.19
T_5	71.1	5.2	74.6	2.7	138.5	4.2	3.9	128.2	0.446	42.1	150.3	0.68	0.32	9.17
T_6	50.5	7.1	131.0	4.2	216.2	6.7	7.3	100.6	0.541	45.1	141.3	0.78	0.14	10.19
T_7	60.2	3.0	68.0	4.0	150.2	3.7	8.0	96.1	0.340	42.7	138.7	0.72	0.26	10.37
T_8	58.4	4.1	63.0	3.1	168.0	7.7	4.7	90.1	0.463	71.3	139.5	0.66	0.14	9.25
T_9	67.3	5.4	70.3	2.3	114.3	4.5	4.7	100.1	0.529	49.5	140.3	0.54	0.14	11.19
T_{10}	62.5	4.0	57.5	2.7	131.5	7.1	5.6	62.5	0.443	60.5	140.4	0.51	0.22	11.00
T_{11}	51.4	4.1	68.4	5.3	181.7	7.6	3.5	48.5	0.606	78.3	153.4	0.75	0.15	9.36
T_{12}	76.0	2.6	69.5	2.3	265.2	3.5	4.9	79.1	0.450	46.5	160.3	0.83	0.22	12.17
T_{13}	70.1	3.1	65.7	5.4	291.5	3.9	4.7	62.4	0.511	51.5	150.6	0.84	0.26	9.96
T_{14}	62.1	4.1	63.9	4.3	199.1	6.0	3.2	128.2	0.532	86.1	137.3	0.76	0.15	9.17
T_{15}	58.5	4.3	97.5	6.3	268.3	4.2	5.0	126.0	0.421	80.3	148.1	0.78	0.17	10.11
T_{16}	48.4	3.1	114.6	4.6	302.2	5.9	4.4	120.5	0.627	93.1	140.2	0.74	0.14	8.89
T_{17}	49.6	4.1	69.6	7.8	298.4	6.9	4.8	61.5	0.382	62.5	136.3	0.86	0.22	9.25
T_{18}	56.1	3.2	67.2	2.7	210.7	7.2	5.1	102.1	0.563	44.7	125.3	0.77	0.14	8.89
T_{19}	51.2	4.3	63.9	4.8	228.5	4.9	4.9	61.2	0.434	65.3	136.5	0.77	0.29	10.16
T_{20}	72.0	5.1	56.6	4.2	168.2	10.7	4.7	63.4	0.462	83.4	130.5	0.86	0.41	14.14
T_{21}	73.3	2.6	39.4	3.1	200.3	8.3	5.6	51.5	0.502	59.2	146.3	0.79	0.23	10.12
T_{22}	49.1	3.5	31.9	4.1	138.0	4.2	3.1	56.1	0.225	83.1	140.5	0.75	0.12	8.24
T_{23}	69.2	6.8	105.2	5.1	360.4	6.8	5.3	92.1	0.197	46.4	161.4	0.65	0.15	8.19
T_{24}	81.2	2.1	49.2	2.5	62.3	9.1	5.2	107.5	0.349	43.6	130.3	0.34	0.17	11.16
T_{25}	75.2	4.7	72.7	4.4	146.1	3.8	2.9	63.1	0.426	62.2	138.5	0.68	0.20	12.15
T_{26}	80.1	3.0	40.5	2.9	118.2	4.8	4.8	75.5	0.530	42.3	131.3	0.69	0.22	10.88
T_{27}	49.1	2.3	44.0	1.8	55.3	5.9	3.7	148.5	0.618	67.3	129.3	0.53	0.24	9.99

T_{28}	48.0	2.6	.33.1	3.1	108.4	6.1	4.6	82,3	0.280	66.5	132.2	0.62	0,24	9.50
T_{29}	56.3	3.3	48.4	3.5	126.1	5.3	3.7	89.1	0.438	59.3	150.5	0.53	0.19	12.20
T_{30}	72.5	4.1	67.7	3.3	159.5	4.5	3.2	48.3	0.430	89.1	146.5	0.63	0.18	11.48
T_{31}	68.2	5.3	73.5	2.7	139.3	8.4	4.5	146.5	0.410	53.4	132.5	0.58	0.34	10.18
T_{32}	66.1	6.1	17.6	5.1	98.3	5.6	4.5	78.1	0.379	72.4	136.2	0.73	0.29	9.89
T_{33}	48.6	4.6	64.6	3.1	210.2	7.1	5.9	82.4	0.549	75.4	150.5	0.85	0.17	10.66
T_{34}	79.1	3.1	54.4	2.8	96.39	5.3	4.2	132.2	0.474	60.8	138.4	0.69	0.11	9.27
T_{35}	51.1	7.0	110.5	3.2	309.4	4.6	5.7	46.3	0.420	44.7	151.3	0.80	0.26	10.17
T_{36}	72.1	4.3	35.1	4.4	168.2	5.1	3.7	90.3	0.543	43.1	142.0	0.86	0.13	9.19
T_{37}	66.1	4.4	48.4	3.3	110.3	4.6	2.9	98.3	0.488	54.1	142.3	0.60	0.13	9.45
T_{38}	49.1	2.6	18.2	3.1	95.2	5.5	4.7	116.5	0.637	51.2	141.5	0.61	0.36	9.54
T_{39}	48.1	4.3	57.3	6.3	108.2	4.3	3.9	122.1	0.223	58.1	140.1	0.69	0.36	10.11
T_{40}	67.1	3.7	71.9	2.5	94.3	6.5	3.7	139.1	0.616	63.5	130.4	0.72	0.26	9.78
T_{41}	80.1	2.5	29.6	3.0	73.3	7.5	4.4	140.3	0.440	56.3	147.3	0.55	0.27	12.24
T_{42}	77.2	4.1	70.0	2.4	168.3	6.4	3.3	119.5	0.337	60.5	139.3	0.66	0.36	14.18
T_{43}	62.3	3.5	32.1	5.0	96.7	5.1	2.9	136.2	0.610	55.5	130.4	0.76	0.24	9.59
T_{44}	63.1	4.3	55.1	2.3	126.5	4.6	3.2	130.5	0.152	59.9	140.2	0.76	0.36	10.19
T_{45}	51.3	2.5	35.7	4.0	98.4	5.0	3.7	142.5	0.310	49.8	151.7	0.44	0.24	10.16
T_{46}	70.4	4.1	39.9	4.3	151.3	7.8	5.3	53.8	0.340	49.3	144.5	0.67	0.24	11.11
T_{47}	67.9	3.5	49.6	2.5	119.6	2.8	5.4	72.5	0.420	33.9	135.6	0.68	0.24	9.86
T_{48}	71.9	3.5	59.4	2.7	150.7	3.9	4.4	99.0	0.442	36.9	141.4	0.75	0.24	10.19
T_{49}	78.0	4.0	54.9	1.8	90.5	6.2	3.5	51.2	0.244	44.9	130.8	0.57	0.32	8.78
T_{50}	66.1	4.5	36.3	3.2	100.9	6.2	4.2	69.3	0.247	40.5	123.5	0.63	0.14	10.35
T_{51}	68.8	5.5	52.7	2.1	97.2	6.8	2.9	50.5	0.318	62.3	136.2	0.51	0.22	12.19
T_{52}	69.1	6.3	66.1	1.9	112.2	6.3	2.4	41.5	0.339	58.9	137.4	0.62	0.17	10.35
T_{53}	72.5	6.7	44.8	2.6	108.6	6.8	3.6	45.7	0.459	57.6	147.2	0.56	0.13	9.66
T_{54}	51.4	5.6	40.5	3.8	163.9	5.3	5.3	45.9	0.373	42.7	127.0	0.68	0.31	10.63
T_{55}	61.0	5.5	58.3	2.4	172.4	3.9	3.7	44.1	0.611	38.8	142.6	0.68	0.17	10.22
T_{56}	51.0	3.4	61.8	3.3	171.6	2.8	4.3	62.9	0.403	36.7	137.5	0.64	0.17	9.89

T_{57}	60.8	4.7	47.4	2.5	129.2	4.6	3.5	77.5	0.523	31.8	144.2	0.66	0.23	8.98
T_{58}	55.5	4.1	52.7	2.9	141.5	5.2	2.7	47.4	0.419	41.3	123.5	0.65	0.29	9.29
T_{59}	64.8	2.5	49.0	3.1	123.1	5.5	5.1	104.1	0.472	35.75	145.7	0.68	0.31	11.17
T_{60}	50.6	3.2	34.4	3.3	119.8	4.6	3.7	93.5	0.560	35.6	143.5	0.55	0.33	12.14
T_{61}	53.5	5.2	69.2	2.5	165.2	5.3	2.9	53.3	0.427	61.2	137.5	0.61	0.19	8.21
T_{62}	60.6	5.9	62.3	3.2	151.7	6.1	5.3	71.3	0.477	50.1	141.0	0.61	0.24	9.90
T_{63}	60.8	5.4	53.5	4.2	160.8	5.1	3.5	121.8	0.573	43.3	137.8	0.63	0.18	11.09
T_{64}	57.5	2.2	33.0	2.9	125.0	4.8	4.5	84.2	0.244	40.6	140.1	0.77	0.15	12.31
T_{65}	48.0	3.2	56.4	5.1	100.9	2.9	3.5	57.5	0.422	36.7	143.0	0.67	0.23	13.10
T_{66}	74.5	3.4	37.7	4.8	86.6	3.3	5.5	48.2	0.510	35.1	138.3	0.65	0.35	11.16
T_{67}	55.9	2.7	68.0	2.3	113.3	4.2	4.7	63.7	0.344	33.7	146.7	0.55	0.36	9.54
T_{68}	51.0	4.6	55.7	3.1	104.8	3.0	3.7	104.0	0.408	35.6	130.2	0.63	0.32	12.23
T_{69}	66.7	2.8	45.7	4.2	141.6	3.7	4.5	76.5	0.316	35.1	135.0	0.65	0.41	10.44
T_{70}	51.4	4.4	69.2	3.3	127.3	2.7	5.4	90.3	0.256	51.0	137.2	0.77	0.32	11.09
T_{71}	71.0	3.4	60.0	4.8	113.7	5.2	2.5	101.7	0.201	61.5	147.8	0.64	0.18	10.12
T_{72}	70.6	6.5	63.8	3.6	60.6	4.6	4.4	76.0	0.365	42.6	138.3	0.67	0.25	9.75
T_{73}	61.4	5.6	51.5	2.5	148.1	2.8	3.5	71.3	0.461	33.2	150.5	0.79	0.26	9.87
T_{74}	55.6	7.0	72.0	2.1	133.2	3.5	3.6	140.1	0.516	30.1	147.5	0.66	0.16	10.27
T_{75}	74.2	3.1	63.7	3.3	101.2	2.8	5.3	55.4	0.250	42.9	142.7	0.69	0.18	11.18
T_{76}	71.9	2.9	67.0	1.5	96.6	3.8	3.0	43.5	0.442	45.4	154.6	0.67	0.29	13.31
Mean	62.45	4.22	60.74	3.50	154.54	5.43	4.32	86.12	0.433	53.09	141.12	0.68	0.23	10.46
SE	2.36	0.27	3.87	0.18	5.25	0.23	0.18	5.90	0.016	1.85	2.87	0.03	0.01	0.31
CD	6.68	0.77	10.94	0.15	14.85	0.65	0.52	16.69	0.045	5.23	8.10	0.08	0.04	0.88

Plate 2. Superior genotypes

d. Average green fruit weight (g)

Average green fruit weight showed wide range of variation among the genotypes from 1.5g for T_{76} to 7.8g for T_{17}. Twenty-eight genotypes were on par with T_{76}. T_{17} was followed by T_{15} and T_{39} which were on par.

e. Fruit weight per plant (g)

T_1 (379.2g) was the highest yielder, followed by T_{23} (360.4g) and T_2 (358.4g) which were on par. T_{27} (55.3g) was the lowest yielder and vas on par with T_{72} and T_{24}.

f. Fruit length (cm)

Length of fruits exhibited wide range of variation among the various genotypes (Plate 3). The longest (10.7 cm) and shortest (2.7 cm) fruits were produced by T_{20} and T_{70} respectively. T_1 (9.9 cm) and T_2 (9.7 cm), which were on par, also had long fruits. T_{66}, T_{68}, T_{65}, T_{73}, T_{47}, T_{75} and T_{56} were on par with T_{70}.

g. Fruit girth (cm)

Fruits with maximum girth were produced by T_7 (8.0cm) followed by T_6 (7.3 cm). Girth of fruits was minimum for T_{52} (2.4 cm), which was on par with six other genotypes.

h. Number of seeds per fruit

Seeds per fruit varied from 148.5 in T_{27} to 41.5 in T_{52}. T_{31}, T_{45}, T_{41}, T_{74}, T_{40} and T_{43} were on par with T_{27}.

i. Hundred seed weight (g)

The highest value (0.637) was recorded by T_{38}, which was on par with T_1, T_2 and T_{16}. T_{44} showed the least value (0.152). T_{23} was on par with it.

j. Plant height (cm)

T_{16} was the tallest (93.1cm) followed by T_{30} and T_{14}, which were on par. T_{74} was the shortest (30.1cm) and six other genotypes were on par with it.

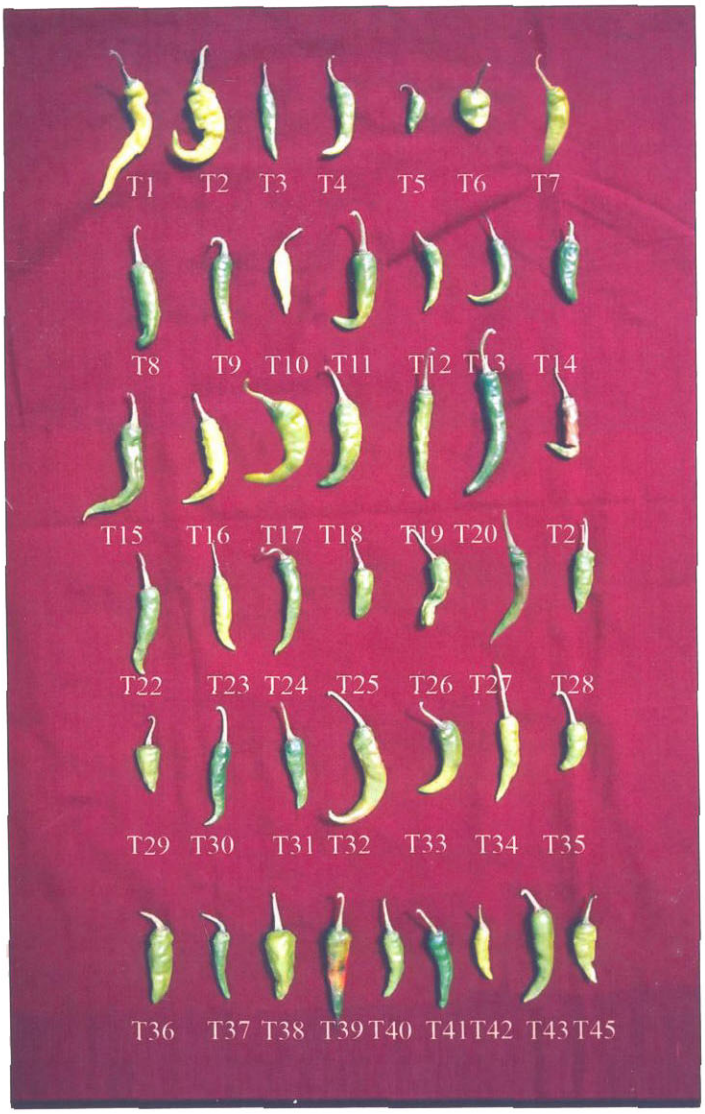


Plate 3. Variability in chilli fruits

k. Duration of the crop

Wide variation was observed among the genotypes under study for plant duration. The lowest (123.5 days) and the highest (162.3days) durations were exhibited by T_{50} and T_1 respectively. The duration of T_{23}, T_2 and T_{12} were found to be on par with T_1 while eleven other treatments belonged to the lowest duration category.

l. Harvest Index (HI)

The maximum value was recorded by T_1 and T_2 (0.90), while the minimum (0.34) was recorded by T_{24}. T_{20} ranked second with respect to harvest index. T_{36}, T_{17}, T_{33}, T_{13}, T_{12} and T_{35} were on par with T_{20}.

m. Capsaicin content (%)

T_{20} and T_{69} recorded the highest value (0.41%) for capsaicin content followed by T_{38} ,T_{39}, T_{42}, T_{44} and T_{67} (0.36%). The minimum value (0.11%) was recorded by T_{34}. Sixteen other treatments were on par with it.

n. Oleoresin content (%)

Oleoresin content was maximum for T_{42} (14.18 %) which was on par with T_1, T_2, T_{76} and T_{65}. T_4 showed the minimum value (8.19%). T_{23}, T_{61}, T_{22}, T_3, T_{49}, T_{16}, T_{18} and T_{57} were on par with T_4.

4.1.2.2 Genetic Parameters

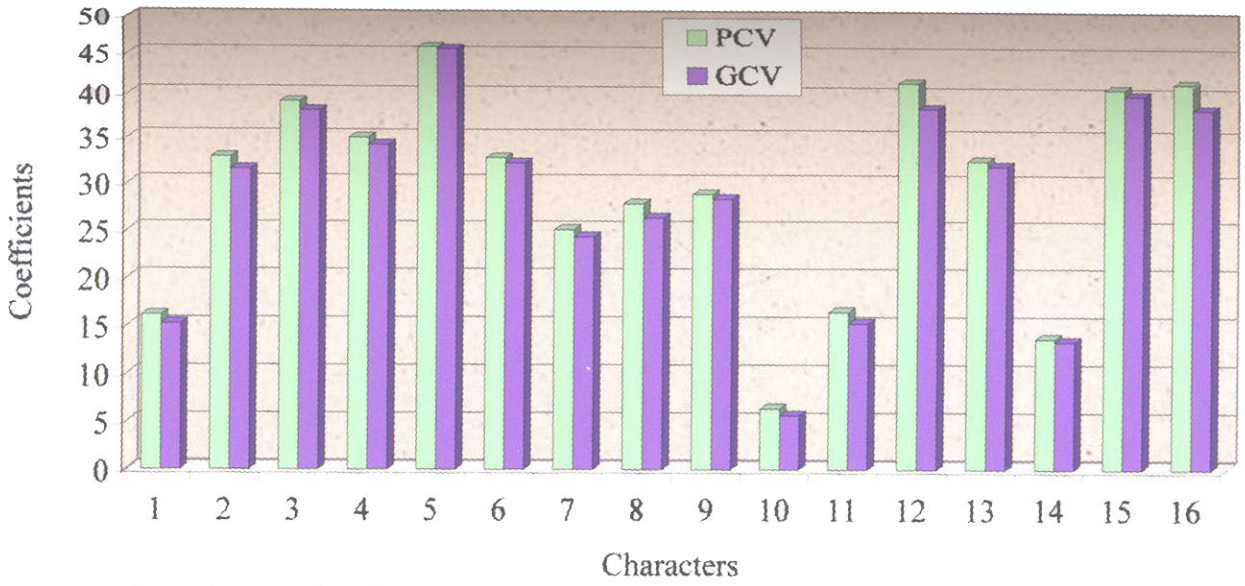
The genetic parameters *viz.*, phenotypic and genotypic coefficients of variation, heritability and genetic advance for each character under study were estimated and are presented in Table 11.

4.1.2.2.1 Coefficients of Variation

The highest values of phenotypic as well as genotypic coefficients of variation were observed for fruit weight per plant (45.93 and 45.68 respectively). Harvest index and disease intensity ranked second (41.48) for PCV, while per cent disease incidence was the second (40.05) with regard to GCV (Fig. 3).

Table 11. Genetic parameters of chilli

Characters	PCV	GCV	H^2 (%)	GA (% of mean)
1. Days to first flowering	16.12	15.21	89.01	29.56
2. Number of branches	32.86	31.56	92.30	62.56
3. Number of fruits per plant	39.15	38.10	94.70	76.39
4. Average green fruit weight (g)	35.02	34.24	95.62	69.14
5. Fruit weight per plant (g)	45.93	45.68	96.90	93.59
6. Fruit length (cm)	32.76	32.21	96.68	65.19
7. Fruit girth (cm)	25.04	24.30	94.21	48.38
8. No. of seeds per fruit	27.79	26.30	96.40	72.43
9. Hundred seed weight (g)	28.82	28.30	96.08	55.23
10. Plant height (cm)	6.37	5.63	79.68	57.62
11. Duration of the crop	16.41	15.22	86.12	10.46
12. Harvest index (HI)	41.48	38.41	85.75	29.11
13. Capsaicin content (%)	32.47	31.88	96.39	64.48
14. Oleoresin content (%)	13.63	13.31	95.26	26.75
15. Percent disease incidence	40.78	40.05	96.46	80.64
16. Disease intensity (%)	41.48	38.41	85.75	72.63



1	Days to first flowering	9	Hundred seed weight (g)
2	Number of branches	10	Plant height (cm)
3	Number of fruits/plant	11	Duration of the crop
4	Average green fruit weight (g)	12	Harvest index (HI)
5	Fruit weight / plant (g)	13	Capsaicin content
6	Fruit length (cm)	14	Oleoresin content
7	Fruit girth (cm)	15	Percent disease incidence
8	Number of seeds / fruit	16	Disease intensity

Fig. 3.Phenotypic and genotypic coefficients of variation

PCV and GCV were the least for plant height (6.37 and 5.63 respectively) followed by oleoresin content (13.63 and 13.31 respectively).

4.1.2.2.2 Heritability and Genetic Advance

High heritability (broad sense) was exhibited by all the characters studied (Fig. 4). Very high heritability was exhibited by fruit weight per plant (96.90), fruit length (96.68), per cent disease incidence (96.46), number of seeds per fruit (96.40) capsaicin content (96.39) and hundred seed weight (96.08).

Maximum genetic advance (% mean) was observed for fruit weight per plant (93.59). This was followed by per cent disease incidence (80.46), number of fruits per plant (76.39), disease intensity (72.63), number of seeds per fruit (72.43) and average green fruit weight (69.14). Genetic advance was the least (10.46) for duration of the crop.

4.1.2.3 Association Analyses

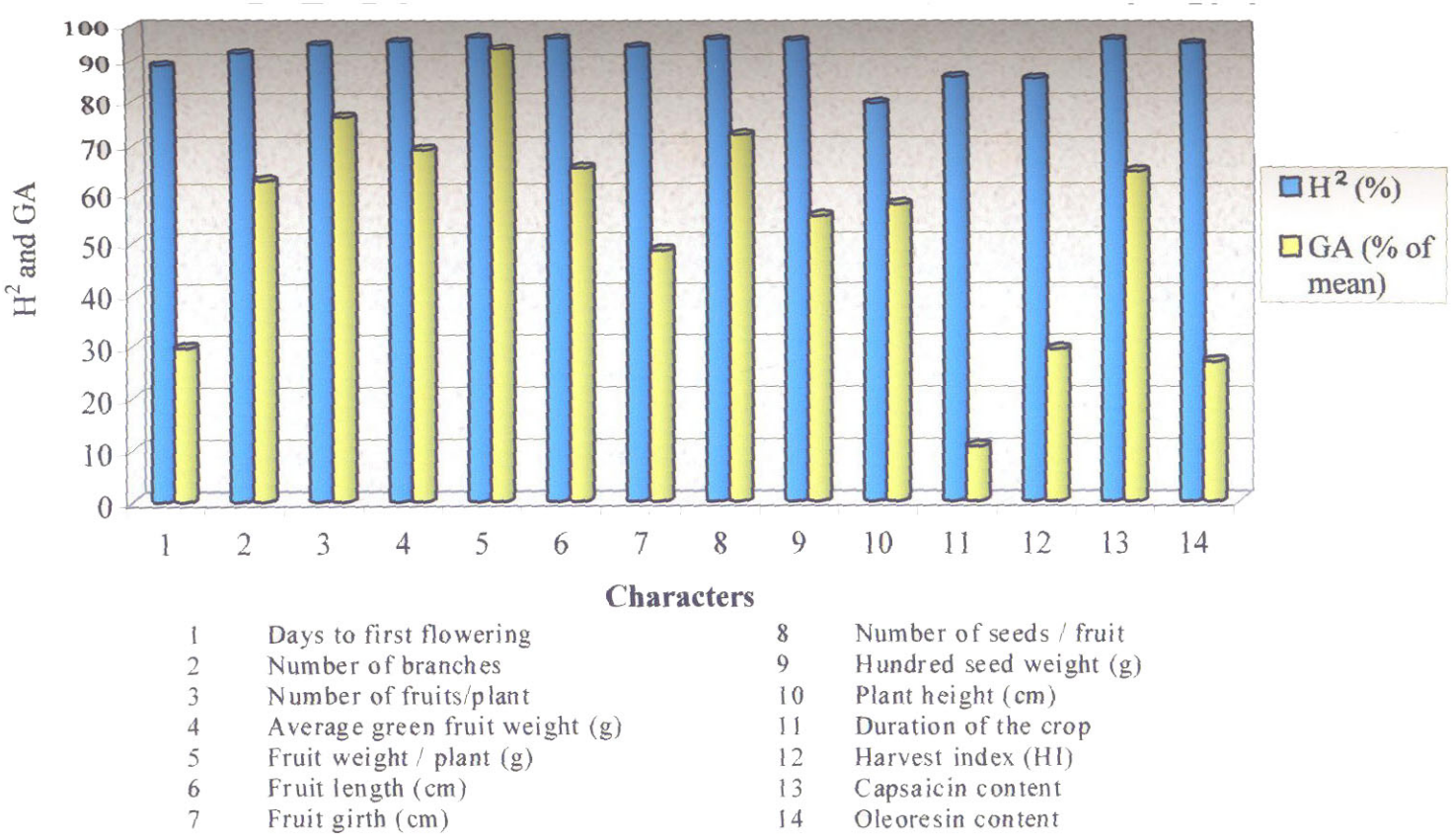
4.1.2.3.1 Correlations

a. Phenotypic Correlation

Phenotypic correlation coefficients estimated for the sixteen characters are furnished in Table 12. Days to first flowering was negatively associated with all the characters observed except fruit length and capsaicin content. Negatively significant association of days to first flowering was observed with average green fruit weight, fruit weight per plant and disease intensity. Number of branches showed significant positive correlation with number of fruits per plant, fruit weight per plant, capsaicin content, disease intensity and per cent disease incidence.

Number of fruits per plant was highly and positively correlated with average green fruit weight, fruit weight per plant, fruit girth, duration of the crop, harvest index, capsaicin content, oleoresin content, disease intensity and per cent disease incidence.

Average green fruit weight showed high positive correlation with fruit weight per plant, harvest index, capsaicin content, disease intensity and per cent disease incidence.



1	Days to first flowering	8	Number of seeds / fruit
2	Number of branches	9	Hundred seed weight (g)
3	Number of fruits/plant	10	Plant height (cm)
4	Average green fruit weight (g)	11	Duration of the crop
5	Fruit weight / plant (g)	12	Harvest index (HI)
6	Fruit length (cm)	13	Capsaicin content
7	Fruit girth (cm)	14	Oleoresin content

Fig. 4. Heritability and genetic advance

Table 12.Phenotypic correlation

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	-0.1011	1.0000														
X3	-0.1930	0.4969**	1.0000													
X4	-0.2668*	0.1100	0.2312*	1.0000												
X5	-0.2401*	0.3425**	0.7112**	0.4748**	1.0000											
X6	0.0642	0.1921	0.2043	0.1273	0.2727*	1.0000										
X7	-0.0992	0.0643	0.3114**	0.2165	0.3768**	0.2007	1.0000									
X8	-0.0517	-0.2065	-0.0191	-0.0668	-0.1878	0.0078	-0.0880	1.0000								
X9	-0.1428	0.0858	0.2133	0.0299	0.2230*	0.2006	0.0817	0.1115	1.0000							
X10	-0.0779	-0.0623	0.0672	0.2123	0.1544	0.3439	-0.1893	0.1417	0.0439	1.0000						
X11	-0.0285	0.1828	0.3744**	0.1901	0.4584**	-0.0002	0.1213	-0.1049	0.1236	-0.0328	1.0000					
X12	-0.1388	0.1847	0.3467**	0.4137**	0.6161**	0.0498	0.2612*	-0.1493	0.2139	0.1409	0.2221*	1.0000				
X13	0.0841	0.2647**	0.3624**	0.4268**	0.5318**	0.3089	0.1466	0.4228**	0.0024	0.3944**	0.2255*	0.4118**	1.0000			
X14	-0.1348	-0.1847	0.2412*	-0.1564	-0.0715	-0.1460	-0.0893	0.2041	0.3934	-0.0452	0.1449	-0.1718	-0.0527	1.0000		
X15	-0.2670*	0.4072**	0.6041**	0.3175**	0.6187**	0.1769	0.4364**	-0.0780	0.1801	-0.1204	0.3569**	0.2546*	-0.4322**	-0.0052	1.0000	
X16	-0.1911	0.3872**	0.6053**	0.3835**	0.6451**	0.2779	0.4199**	-0.0582	0.2194	-0.0219	-0.3541**	0.3176**	-0.3942**	-0.0116	0.8364**	1.0000

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

X1 = Days to first flowering
X2 = Number of branches
X3 = Number of fruits per plant
X4 = Average green fruit weight
X5 = Fruit weight per plant
X6 = Fruit length
X7 = Fruit girth
X8 = Number of seeds per fruit
X9 = Hundred seed weight
X10= Plant height
X11 = Duration of the crop
X12 = Harvest index
X13 = Capsaicin content
X14 = Oleoresin content
X15 = Disease intensity
X16 = Percent disease incidence

Fruit weight per plant showed high positive correlation with number of branches, number of fruits per plant, average green fruit weight, fruit length, fruit girth, hundred seed weight. duration of the crop, harvest index, capsaicin content, disease intensity and per cent disease incidence.

Positive correlation of fruit length was noticed with plant height, capsaicin content and per cent disease incidence, while fruit girth was positively correlated with harvest index, disease intensity and per cent disease incidence. Number of seeds per fruit was positively correlated with capsaicin content, while hundred seed weight was associated positively with oleoresin content.

Plant height was positively correlated with capsaicin content. Duration of the crop was associated positively with harvest index, capsaicin content, disease intensity and per cent disease incidence. Harvest index was positively correlated with capsaicin content, disease intensity and per cent disease incidence.

Association of capsaicin content was negative with disease intensity and per cent disease incidence. Oleoresin showed marked positive association only with fruit number per plant and hundred seed weight.

Disease intensity and per cent disease incidence displayed a similar pattern of association. Disease intensity and per cent disease incidence were highly correlated positively with each other.

b. Genotypic correlation

Genotypic correlation coefficients among the sixteen characters were estimated which are presented in Table 13.

Days to first flowering was negatively associated with all the characters except fruit length and capsaicin content. Correlation was significant with yield per plant, average green fruit weight and disease intensity. Number of branches showed high positive correlation with number of fruits per plant, yield per plant, duration of the crop, harvest index, capsaicin content, disease intensity and per cent disease incidence. It was negatively associated with number of seeds per fruit.

Number of fruits per plant was highly correlated with average green fruit weight, yield per plant, fruit girth, crop duration, harvest index,

Table 13. Genotypic correlation

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	-0.1109	1.0000														
X3	-0.2008	0.5309**	1.0000													
X4	-0.2850*	0.1162	0.2433*	1.0000												
X5	-0.2529*	0.3548**	0.7340**	0.4867**	1.0000											
X6	0.0683	0.2041	0.2063	0.1285	0.2790*	1.0000										
X7	-0.1043	0.0566	0.3269**	0.2205*	0.3861**	0.2017	1.0000									
X8	-0.0219	-0.2367*	-0.0257	-0.0678	-0.1957	-0.0114	-0.1023	1.0000								
X9	-0.1601	0.1020	0.2182	0.0309	0.2274*	0.2093	0.0841	0.1217	1.0000							
X10	-0.0680	-0.0571	0.0591	0.2275*	0.1520	0.3581**	-0.2005	0.1476	0.0471	1.0000						
X11	-0.0307	0.2277*	0.4506**	0.1869	0.4984**	0.0165	0.1558	-0.1182	0.1283	-0.0417	1.0000					
X12	-0.1570	0.2338*	0.3865**	0.4432**	0.6567**	0.0490	0.2795*	-0.1612	0.2147	0.1392	0.2270*	1.0000				
X13	0.0839	0.2562*	0.3908**	0.4231**	0.5411**	0.3188**	0.1497	0.4342**	0.0122	0.4021**	0.2527*	0.4184**	1.0000			
X14	-0.1416	-0.1213	0.4527*	-0.1867	-0.0592	-0.1497	-0.1052	0.1899	0.4142**	-0.0625	0.1568	-0.1891	-0.0529	1.000		
X15	-0.3020	0.4588**	0.6883**	0.3649**	0.6677**	0.1891	0.4777**	-0.1162	0.1974	-0.1274	0.4446	0.2832*	-0.4297**	0.0071	1.0000	
X16	-0.2065	0.4105**	0.6416**	0.3967**	0.6617**	0.2867*	0.4465**	-0.0569	0.2390	-0.0195	0.4144	0.3426**	-0.3841**	0.0098	0.9140**	1.0000

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

X1 = Days to first flowering
X2 = Number of branches
X3 = Number of fruits per plant
X4 = Average green fruit weight
X5 = Fruit weight per plant
X6 = Fruit length
X7 = Fruit girth
X8 = Number of seeds per fruit
X9 = Hundred seed weight
X10= Plant height
X11 = Duration of the crop
X12 = Harvest index
X13 = Capsaicin content
X14 = Oleoresin content
X15 = Disease intensity
X16 = Percent disease incidence

capsaicin and oleoresin content and disease intensity and per cent disease incidence. Average green fruit weight was positively correlated with yield per plant, fruit girth, plant height, harvest index, capsaicin content, disease intensity and per cent disease incidence.

Fruit weight per plant was significantly and positively correlated with fruit length, fruit girth, hundred seed weight, crop duration, harvest index, capsaicin content, disease intensity and per cent disease incidence.

Fruit length was positively associated with plant height, capsaicin content and per cent disease incidence while fruit girth was correlated positively with harvest index, disease intensity and per cent disease incidence.

Positive association of number of seeds per fruit was noticed with capsaicin content. Hundred seed weight showed positive correlation with oleoresin content and per cent disease incidence.

Plant height was positively correlated with capsaicin content. Duration of the crop was positively related with harvest index, capsaicin content, disease intensity and per cent disease incidence. Positive association of harvest index with capsaicin content, disease intensity and per cent disease incidence was noticed.

Capsaicin content was negatively correlated with disease intensity and per cent disease incidence. Disease intensity and per cent disease incidence were highly correlated positively with each other.

c. Environmental correlation

Environmental correlation coefficients were estimated for the sixteen characters and are presented in Table 14.

Days to first flowering was negatively and significantly correlated with number of seeds per fruit and plant height. Number of branches was negatively correlated with harvest index.

Number of fruits per plant was positively correlated with plant height and oleoresin content. Average green fruit weight was positively associated with crop duration.

Table 14. Environmental correlation

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	-0.0068	1.0000														
X3	-0.1132	0.0083	1.0000													
X4	-0.0547	0.0141	-0.0086	1.0000												
X5	-0.0813	0.1208	0.0342	0.0680	1.0000											
X6	0.0128	-0.0350	0.1530	0.0972	-0.0065	1.0000										
X7	-0.0464	0.1727	0.0481	0.1441	0.1634	0.1868	1.0000									
X8	-0.3725**	0.1859	0.0844	-0.0493	0.0088	0.0660	0.1285	1.0000								
X9	0.0890	-0.1998	0.1085	0.0075	0.0451	-0.0462	0.0341	-0.0831	1.0000							
X10	-0.2598*	-0.1738	0.2670*	-0.1935	0.3005**	-0.1001	0.0582	0.0268	-0.0529	1.0000						
X11	-0.0180	-0.1002	-0.1640	0.2861*	0.3386**	-0.1787	-0.1266	-0.0252	0.1311	0.0494	1.0000					
X12	-0.0114	-0.2301	-0.0277	0.1474	0.2562*	0.0745	0.1048	-0.0496	0.2600*	0.2137	0.2027	1.0000				
X13	0.0622	0.0101	0.0556	0.0062	-0.0833	0.1212	0.1912	0.0771	-0.0098	0.0213	-0.0675	-0.1377	1.0000			
X14	0.0161	-0.0492	0.3021**	0.1101	0.3628**	0.1541	0.2112	-0.0438	0.0191	-0.2524*	-0.0598	0.2782*	-0.3120**	1.0000		
X15	-0.0247	-0.0089	-0.1866	-0.1635	0.0959	0.0683	0.0780	0.2677*	0.0091	-0.0637	-0.0627	0.0793	-0.0291	0.1314	1.0000	
X16	0.0049	-0.0033	-0.1846	0.0621	-0.0619	0.0297	-0.1270	-0.0880	-0.3144**	-0.0943	-0.1081	0.0765	-0.0282	0.1432	0.0715	1.0000

X1 = Days to first flowering
X2 = Number of branches
X3 = Number of fruits per plant
X4 = Average green fruit weight
X5 = Fruit weight per plant
X6 = Fruit length
X7 = Fruit girth
X8 = Number of seeds per fruit
X9 = Hundred seed weight
X10= Plant height
X11 = Duration of the crop
X12 = Harvest index
X13 = Capsaicin content
X14 = Oleoresin content
X15 = Disease intensity
X16 = Percent disease incidence

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

Yield per plant was positively correlated with plant height, duration of the crop, harvest index and oleoresin content. Seeds per fruit was positively correlated with disease intensity.

Hundred seed weight was positively correlated with harvest index and negatively associated with per cent disease incidence. Plant height was negatively correlated with oleoresin content. Harvest index was positively correlated with oleoresin content. Capsaicin content was negatively associated with oleoresin content.

4.1.2.3.2 Path analysis

The characters that exhibited high genotypic correlation with fruit weight per plant (yield) were selected for path coefficient analysis. The direct and indirect effects of selected eight component characters on fruit yield were estimated and are presented in Table 15.

Number of branches had negative direct effect (-0.1531) on yield. The highest positive indirect effect was exerted through disease intensity (0.3675) followed by number of fruits per plant (0.1903). Negative indirect effect was through per cent disease incidence (-0.2233) and fruit girth (-0.0045).

Number of fruits per plant had positive direct effect (0.3584) on yield. Positive direct effect (0.1400) on yield was exerted by average green fruit weight. The highest positive indirect effect was through disease intensity (0.2566) followed by harvest index (0.2140), number of fruits per plant (0.0872) and duration of the crop (0.0401). Negative indirect effect was expressed through per cent disease incidence (-0.2158), number of branches (-0.0178) and fruit girth (-0.0175).

Fruit girth showed negative direct effect (-0.0793) on yield. Positive indirect effect was maximum through disease intensity (0.4006) and minimum through average green fruit weight (0.0309).

The direct effect on yield by duration of the crop was positive (0.2143). The highest positive indirect effect was exerted through disease intensity (0.2595) followed by number of fruits per plant (0.1615), harvest index (0.1096) and average green fruit weight (0.0262).

Harvest index exhibited positive direct effect (0.4828) on yield. Positive indirect effects were exerted through disease intensity (0.1690),

Table 15. Path analysis

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Total correlation coefficient
X_1	-0.1531	0.1903	0.0163	-0.0045	0.0488	0.1129	0.3675	-0.2233	0.355
X_2	-0.0813	0.3584	0.0341	-0.0259	0.0966	0.1866	0.5147	-0.3491	0.735
X_3	-0.0178	0.0872	0.1400	-0.0175	0.0401	0.2140	0.2566	-0.2158	0.486
X_4	-0.0087	0.1171	0.0309	-0.0793	0.0334	0.1350	0.4006	-0.2429	0.386
X_5	-0.0349	0.1615	0.0262	-0.0124	0.2143	0.1096	0.2595	-0.2255	0.497
X_6	-0.0358	0.1385	0.0620	-0.0222	0.0486	0.4828	0.1690	-0.1864	0.658
X_7	-0.0708	0.2319	0.0737	-0.0399	0.0984	0.1026	0.7953	-0.5228	0.668
X_8	-0.0629	0.2299	0.0555	-0.0354	0.0888	0.1654	0.7643	-0.5440	0.661

X_1-Number of branches
X_2-Number of fruits per plant
$R^2 = 0.2036$
X_3-Average green fruit weight
X_4-Fruit girth
X_5-Duration of the crop
X_6-Harvest index
X_7-Disease intensity
X_8-Per cent disease incidence

number of fruits per plant (0.1385), average green fruit weight (0.0620) and duration of the crop (0.0486).

The highest positive direct effect on yield (0.7953) was shown by disease intensity. The maximum positive indirect effect was exerted through number of fruits per plant (0.2319) followed by harvest index (0.1026), duration of the crop (0.0984) and average green fruit weight (0.0737). The direct effect manifested by per cent disease incidence on yield was in negative direction (-0.5440).

4.1.2.4 Selection Index

Selection indices were estimated for 76 genotypes (Table 16) based on yield (fruit weight per plant) and its component characters.

The important characters considered for formulating the selection index were days to first flowering, number of branches, number of fruits per plant, average green fruit weight, fruit weight per plant, fruit length, fruit girth, number of seeds per fruit, hundred seed weight, plant height, duration of the crop and harvest index.

Among the genotypes evaluated, T_1 (Jwalamukhi) ranked first with the highest index value (1597.62), followed by T_2 (Jwalasakhi),T_{23} (Muvattupuzha Local-1),T_{16} (Samkranthi Local-1) and T_{35} (Vaikom Local-2). The most inferior genotype with the lowest selection index value was T_{27} (661.24).

4.2 LINE X TESTER ANALYSIS

Based on selection indices, genotypes T_1(Jwalamukhi) , T_2 (Jwalasakhi), T_{23}(Muvattupuzha Local-1), T_{16} (Samkranthi Local-1) and T_{35} (Vaikom Local-2) (redesignated as lines L_1, L_2, L_3, L_4 and L_5 respectively) belonging to the high yielding and anthracnose susceptible category were selected as female parents (lines) and three genotypes T_{76} (Pant C^1), T_{20} (Kidangoor Local-1) and T_{42} (Ujwala) (redesignated as testers T_1, T_2 and T_3 respectively) which were moderately resistant to anthracnose were chosen as male parents (testers) for line x tester(L x T) analysis (Plate 4).The five selected lines and the three selected testers were crossed in the L x T fashion

Table 16. Selection indices for 76 genotypes

Rank	Treatments	Index value
1	T_1	1597.62
2	T_2	1563.64
3	T_{23}	1539.32
4	T_{16}	1403.19
5	T_{35}	1382.87
6	T_{15}	1293.53
7	T_{13}	1244.92
8	T_{17}	1225.12
9	T_6	1219.89
10	T_{12}	1191.89
11	T_{19}	1103.50
12	T_{14}	1081.51
13	T_{33}	1069.41
14	T_3	1066.19
15	T_{11}	1051.99
16	T_{30}	1037.74
17	T_{21}	1009.89
18	T_{18}	1005.54
19	T_8	989.13
20	T_{20}	981.38
21	T_{42}	967.77
22	T_{63}	963.86
23	T_{25}	957.15
24	T_{61}	955.58
25	T_{62}	934.59
26	T_5	919.91
27	T_{55}	919.02
28	T_{46}	917.77
29	T_{31}	914.84
30	T_{48}	912.96
31	T_7	900.22
32	T_{36}	899.63
33	T_4	896.19
34	T_{56}	894.70
35	T_{10}	880.25
36	T_9	876.98
37	T_{71}	868.64
38	T_{73}	852.02
39	T_{52}	850.90
40	T_{29}	850.29
41	T_{54}	848.40
42	T_{22}	847.62
43	T_{70}	844.42
44	T_{74}	843.99
45	T_{53}	842.93
46	T_{44}	842.02
47	T_{69}	827.12
48	T_{40}	821.96
49	T_{34}	820.71
50	T_{58}	819.99
51	T_{75}	814.00
52	T_{37}	813.29
53	T_{59}	811.89
54	T_{39}	809.65
55	T_{67}	804.92
56	T_{57}	800.89
57	T_{51}	800.44
58	T_{47}	794.75
59	T_{26}	789.68
60	T_{76}	786.79
61	T_{32}	763.64
62	T_{49}	761.73
63	T_{64}	757.71
64	T_{60}	751.67
65	T_{45}	751.53
66	T_{65}	750.89
67	T_{72}	744.99
68	T_{28}	740.05
69	T_{68}	733.47
70	T_{41}	732.74
71	T_{24}	731.72
72	T_{43}	726.56
73	T_{50}	719.15
74	T_{66}	717.62
75	T_{38}	681.99
76	T_{27}	661.24

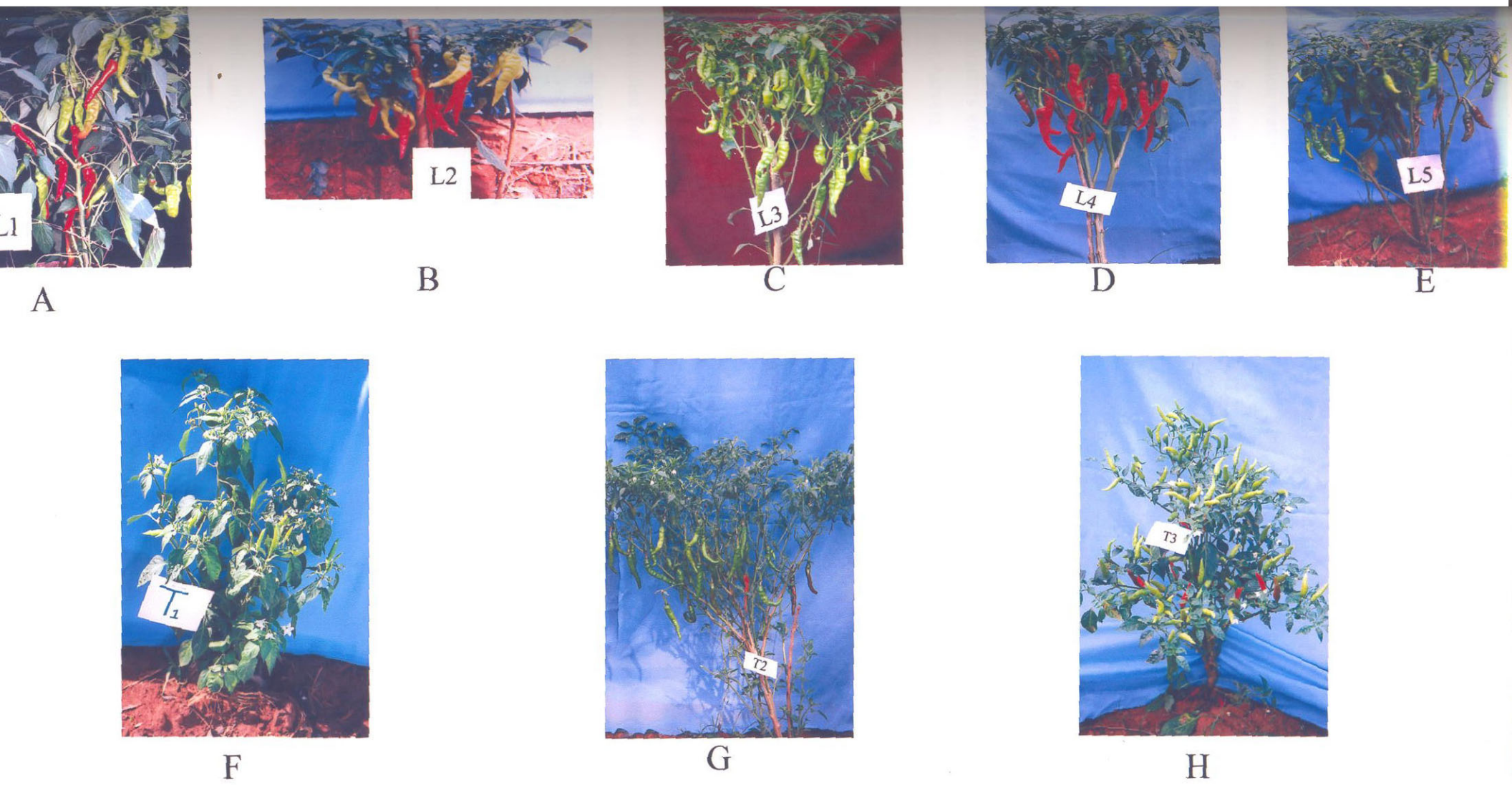


Plate 4. Selected lines and testers

) Jwalamukhi (B) Jwalasakhi (C) Muvattupuzha local-1(D) Samkranthi local-1 (E) Vaikom local-2 (F)Pant C1 (G)Kidangoor local-1(H) Ujwala

to produce 15 hybrids (Plate 5). Fruit characteristics of parents and hybrids are presented in Plate 6.

Results of line x tester analysis are presented in Table 17. Significant variation was observed among treatments for all the characters studied.

Parents also showed the same trend as that of treatments. Crosses had significant variation except for fruit girth. Interaction effects of parents and hybrids were significant for number of fruits per plant, fruit weight per plant, duration and disease intensity at 30 DAT, 45 DAT and 60 DAT.

Line x tester interaction mean square was significant for most of the characters. Non-significance was seen for number of branches, average green fruit weight, fruit length and fruit girth. Lines varied significantly for all the characters except average green fruit weight, fruit girth, hundred seed weight and harvest index while testers showed significant variation for all the characters except days to first flowering, number of branches, fruit girth, hundred seed weight and harvest index.

4.2.1 Heterosis

Relative heterosis, standard heterosis and heterobeltiosis were estimated for fifteen hybrids with respect to 14 characters under study and the results are furnished in the Table 18 to 31 and Fig. 5. Standard heterosis was calculated for each character based on the check variety Jwalamukhi. For per cent disease incidence and disease intensity, Pant C 1 was also used as a check variety.

a. Days to first flowering

The hybrids L_1T_1, L_1T_3, L_2T_1, L_2T_2, L_2T_3, L_4T_3 and L_5T_1 exhibited the desirable negative and significant heterosis over mid parent (Table 18). The maximum value was for L_2T_3 (-17.08 %) followed by L_1T_3 (-15.39 %). None of the hybrids showed negative standard heterosis while all of them except L_1T_1 and L_4T_1 displayed positive significant heterosis.

Twelve of the fifteen hybrids had positive and significant heterosis while only L_2T_3 (-2.25 %) had the desirable negative (but non-significant) heterosis.

Plate 5. Hybrids

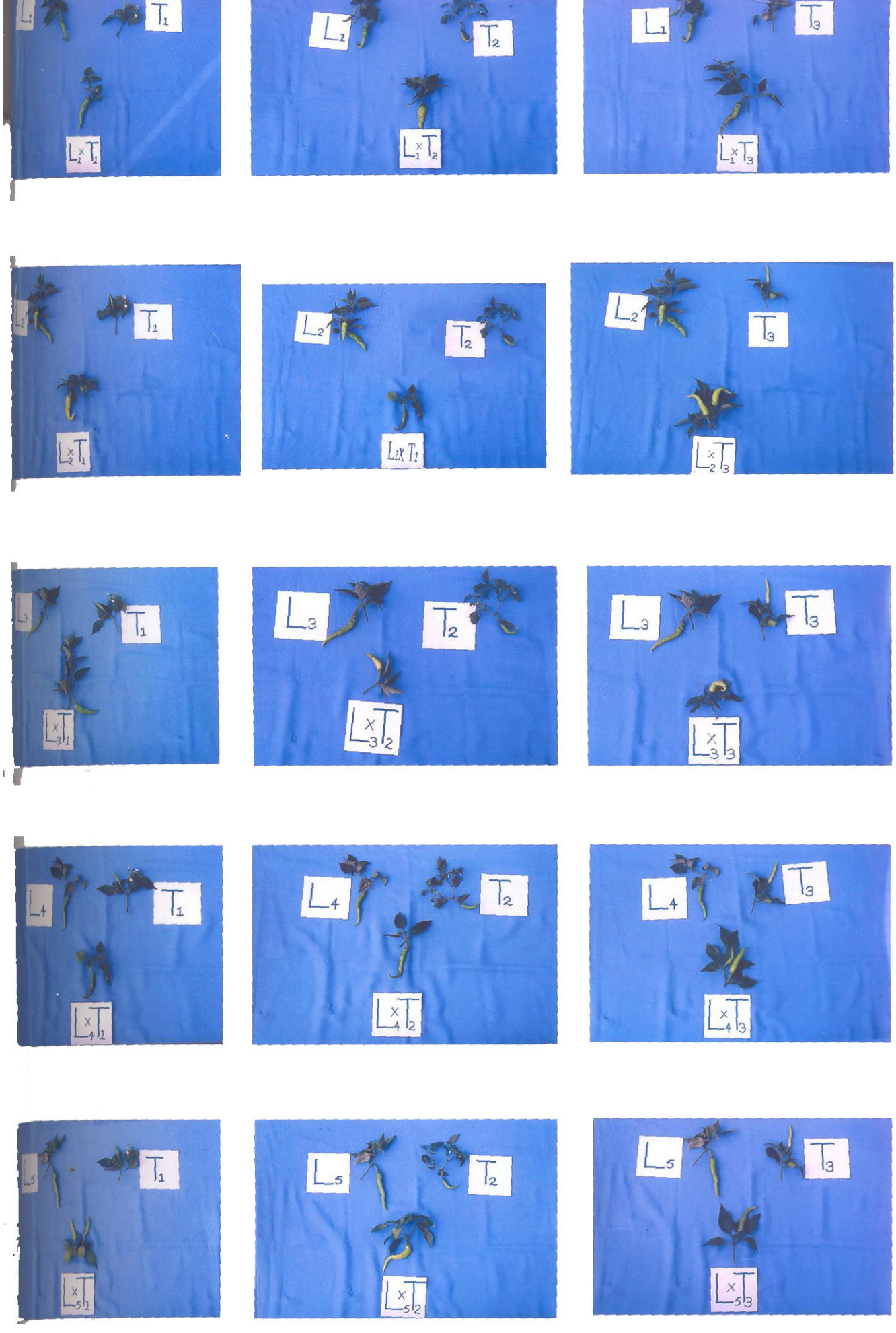


Plate 6. Fruit characteristics of parents and hybrids

Table 17. ANOVA (Varietal Mean Square) for line x tester analysis in chilli

Source	df	Days to first flowering	Number of branches	Number of fruits per plant	Average green fruit weight	Fruit weight per plant	Fruit length	Fruit girth	Number of seeds per fruit	100-seed weight
Replication	2	20.61*	0.07	205.13*	0.05	9.75	0.03	0.16	2.97	0.0005
Treatments	22	303.44**	6.04**	2054.69**	5.22**	26489.86**	17.44**	2.52**	2025.11**	0.04**
Parents	7	455.85**	9.39**	2919.29**	6.95**	34954.95**	19.39**	3.69*	3106.89**	0.07**
Crosses	14	248.84**	4.69**	1549.06**	4.48**	23890.75**	17.68**	2.06	1613.23**	0.03**
Parents x crosses	1	1.11	1.48	3081.49*	3.33	3621.88*	0.25	0.74	218.99	0.005
Lines	4	827.42**	12.86*	3388.89**	5.63	16270.25**	15.48**	2.75	1308.69**	0.05
Testers	2	18.53	2.77	2735.84**	19.72*	123399.10**	81.59*	8.45	5768.89**	0.08
Lines x Testers	8	17.12**	1.09	332.45**	0.10	2823.91**	2.81	0.11	471.58**	0.01**
Error	44	7.39	0.31	49.37**	0.08	82.58	0.04	0.02	6.03	0.0005

Source	Plant height	Duration	Harvest index	Disease intensity			% disease incidence		
				30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT
Replication	11.06	0.31	0.0002	1.00	0.43	21.47*	0.20	4.24	6.36
Treatments	712.50**	438.18**	0.03**	720.65**	771.26**	749.01**	820.19**	916.01**	928.19**
Parents	1213.85**	447.21**	0.04**	202.09**	228.31**	214.31**	1377.75**	1684.69**	1679.71**
Crosses	512.06**	392.99**	0.03**	303.87**	333.34**	318.07**	589.19**	596.41**	615.84**
Parents x crosses	9.34	1007.69*	0.004	10185.43**	10702.75**	10525.03**	151.14	9.79	40.38
Lines	340.04**	415.84**	0.08	219.62**	257.04**	194.41**	850.79**	855.10**	878.19**
Testers	2578.81**	845.13**	0.001**	1230.11**	1382.89**	1332.56**	766.34**	762.09**	795.59**
Lines x Testers	81.38**	268.53**	0.02	114.44**	109.09**	126.29**	414.11**	425.64**	439.74**
Error	1.04	2.06	0.0004	5.83	5.84	7.66	3.59	5.84	1.89

*Significant at 5% level

** Significant at 1% level

Table 18. Heterosis (%) for days to first flowering

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	-14.96**	7.20	7.20
$L_1 \times T_2$	-4.05	21.19**	21.19**
$L_1 \times T_3$	-15.39**	11.02*	11.02*
$L_2 \times T_1$	-9.67**	22.73**	92.58**
$L_2 \times T_2$	-6.41*	27.39**	6.48
$L_2 \times T_3$	-17.08**	16.95**	-2.25
$L_3 \times T_1$	6.55*	59.75**	8.13*
$L_3 \times T_2$	11.73**	67.79**	13.58**
$L_3 \times T_3$	8.19**	67.79**	13.58**
$L_4 \times T_1$	1.18	27.54	27.54**
$L_4 \times T_2$	-5.62	19.22**	19.22**
$L_4 \times T_3$	-7.21*	21 76**	21.76**
$L_5 \times T_1$	-6.47*	21.46**	12.85**
$L_5 \times T_2$	-3.18	25.99**	17.07**
$L_5 \times T_3$	-5.33	27.82**	18.76**

Table 19. Heterosis (%) for number of branches

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	6.12	-25.71**	-25.71**
$L_1 \times T_2$	8.19	-5.71	-5.71
$L_1 \times T_3$	27.27**	0	0
$L_2 \times T_1$	44.97**	2.86	0.93
$L_2 \times T_2$	13.51*	0	-1.87
$L_2 \times T_3$	32.93**	5.71	3.74
$L_3 \times T_1$	-8.03	-40.00	-33.68**
$L_3 \times T_2$	4.05	-14.29*	-5.26
$L_3 \times T_3$	-7.09	-31.43**	-24.21**
$L_4 \times T_1$	13.33	-51.43**	6.25
$L_4 \times T_2$	11.11	-33.29**	-10.26
$L_4 \times T_3$	14.82**	-41.00**	3.33
$L_5 \times T_1$	20.83**	-17.14*	-14.71*
$L_5 \times T_2$	-3.33	-17.14*	-14.71*
$L_5 \times T_3$	-6.79	-28.14**	-25.98**

b. Number of branches

Significant positive relative heterosis was exhibited by L_1T_3, L_2T_1, L_2T_2, L_2T_3, L_4T_3 and L_5T_1 (Table 19). The maximum was recorded by L_2T_1 (44.97 %) followed by L_2T_3 (32.93 %). Standard heterosis was negative and significant for nine hybrids while six hybrids showed negative and significant heterobeltiosis.

c. Number of fruits per plant

Significant positive relative heterosis was observed for eight hybrids while one hybrid (L_4T_2) (-11.04%) showed negative and significant value (Table 20). The maximum positive heterosis was possessed by L_1T_3 (46.60%) followed by L_2T_3 (42.88%).

Significant positive standard heterosis was shown by only one hybrid L_1T_3 (11.99%) while nine others displayed significant negative heterosis. Hetero beltiosis was positive and significant for L_1T_3 (11.99%) and L_2T_3 (11.57%) while it was negative and significant for five others.

d. Average green fruit weight

Relative heterosis was positively significant for ten hybrids (Table 21). Among these, the maximum value was noticed for L_5T_3 (68.76%) followed by L_1T_3 (67.69%) and L_2T_3 (54.85%) whereas the minimum heterosis was for L_3T_2 (2.26%). Four crosses *viz.*, L_4T_1, L_4T_2, L_5T_1 and L_5T_2 possessed negatively significant heterosis for this character.

Positively significant heterosis over standard variety was observed for L_1T_3 (20.44%) and L_2T_3 (16. 21%) only. Nine hybrids possessed negatively significant standard heterosis.

Heterobeltiosis was positive and significant for five hybrids while it was negative and significant for eight others. The maximum positive heterosis over better parent was shown by L_5T_3 (46.88%) followed by L_1T_3 (20.44%) and L_4T_3 (10.87%).

Table 20. Heterosis (%) for number of fruits per plant

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	27.69	-3.27	-3.27
$L_1 \times T_2$	41.48**	-0.09	-0.09
$L_1 \times T_3$	46.60**	11.99**	11.99**
$L_2 \times T_1$	23.68**	-10.04*	-4.25
$L_2 \times T_2$	37.27**	-7.21	-1.24
$L_2 \times T_3$	42.88**	4.82	11.57*
$L_3 \times T_1$	9.55	-29.29**	-8.86
$L_3 \times T_2$	12.47*	-33.19**	-13.88*
$L_3 \times T_3$	9.31	-28.75**	-8.17
$L_4 \times T_1$	0.36	-26.17**	-22.78**
$L_4 \times T_2$	-11.04*	-39.13**	-36.34**
$L_4 \times T_3$	38.46**	2.73	7.44
$L_5 \times T_1$	7.37	-28.61**	-12.38*
$L_5 \times T_2$	7.63	-33.97**	-18.96**
$L_5 \times T_3$	31.18**	-11.94**	8.07

Table 21. Heterosis (%) for average green fruit weight

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	25.67**	-19.52**	-19.46**
$L_1 \times T_2$	4.16**	-7.73	-7.73
$L_1 \times T_3$	67.69**	20.44**	20.44**
$L_2 \times T_1$	8.07**	-27.26**	-31.66**
$L_2 \times T_2$	0.50	7.73	-13.32**
$L_2 \times T_3$	54.85**	16.21**	9.17*
$L_3 \times T_1$	6.49**	-34.99**	-30.78**
$L_3 \times T_2$	2.26**	-12.52**	-6.86
$L_3 \times T_3$	49.93**	3.13	9.80*
$L_4 \times T_1$	-5.83**	-46.59**	-36.96**
$L_4 \times T_2$	-6.71**	-24.49**	-10.87*
$L_4 \times T_3$	46.34**	-6.08	10.87*
$L_5 \times T_1$	-14.02**	-62.61**	-36.46**
$L_5 \times T_2$	-8.25**	-37.57**	-19.09**
$L_5 \times T_3$	68.76**	-13.44**	46.88**

RH - Relative heterosis SH - Standard heterosis
HB - Heterobeltiosis

Fig. 5. Heterosis for various characters in fifteen hybrids

e. Fruit weight per plant

Ten hybrids possessed positively significant heterosis over mid parent for fruit weight per plant (Table 22). Among these, L_2T_3 (65.54%) was the most heterotic followed by L_1T_3 (61.19%), L_3T_3 (45.34%), L_5T_3 (36.02%) and L_4T_3 (33.49%). Negatively significant relative heterosis was observed for L_3T_2, L_4T_1, L_3T_1 and L_5T_1.

Only two hybrids, L_1T_3 (17.49%) and L_2T_3 (16.20%) exhibited positively significant standard heterosis.

Heterobeltiosis followed an almost similar pattern as that for standard heterosis. The maximum positively significant heterobeltiosis was possessed by L_2T_3 (22.81%) followed by L_1T_3 (17.49%). L_3T_3 and L_5T_3 also possessed positively significant heterobeltiosis.

f. Fruit length

Six hybrids possessed positively significant heterosis for fruit length over mid parent while five hybrids showed significant and negative heterosis (Table 23).

Positively significant heterosis over check variety was exhibited by three hybrids *viz.*, L_1T_3 (5.63%), L_2T_2 (5.22%) and L_2T_3 (6.35%) while eleven hybrids showed negatively significant standard heterosis.

Out of the thirteen hybrids which showed significant heterobeltiosis, only three crosses *viz.*, L_1T_3 (5.59%), L_2T_3 (6.85%) and L_3T_3 (14.77%) displayed positive heterosis.

g. Fruit girth

Seven hybrids showed positively significant relative heterosis while three others exhibited negatively significant relative heterosis (Table 24). The maximum positive value was for L_2T_3 (37.70%) followed by L_1T_3 (36.92%) and L_5T_3 (28.22%).

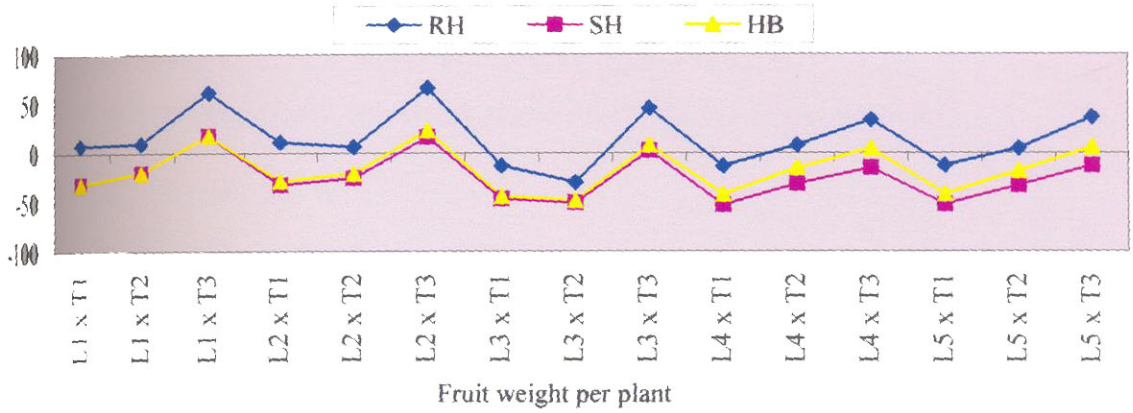
L_2T_1 (24.96%) and L_1T_3 (4.38%) were the only hybrids which possessed positively significant standard heterosis for fruit girth. Twelve hybrids showed negatively significant standard heterosis.

Table 22. Heterosis (%) for fruit weight per plant

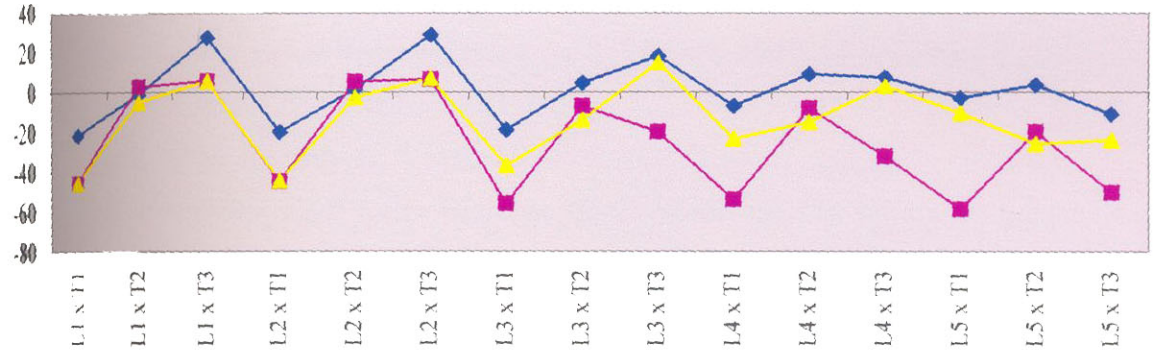
Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	7.42**	-31.59**	-31.59**
$L_1 \times T_2$	9.39**	-20.26**	-20.26**
$L_1 \times T_3$	61.19**	17.49**	17.49**
$L_2 \times T_1$	10.87**	-32.37**	-28.53**
$L_2 \times T_2$	6.21*	-25.44**	-21.19**
$L_2 \times T_3$	65.54**	16.20**	22.81**
$L_3 \times T_1$	-12.96**	-46.69**	-43.96**
$L_3 \times T_2$	-29.93**	-50.63**	-48.10**
$L_3 \times T_3$	45.34**	2.38	7.64**
$L_4 \times T_1$	-13.35**	-52.88**	-42.11**
$L_4 \times T_2$	7.91**	-31.38**	-15.69**
$L_4 \times T_3$	33.49**	-15.13**	4.27
$L_5 \times T_1$	-12.59**	-52.18**	-41.71**
$L_5 \times T_2$	4.65	-33.11**	-18.48**
$L_5 \times T_3$	36.02**	-13.07**	5.95*

Table 23. Heterosis (%) for fruit length

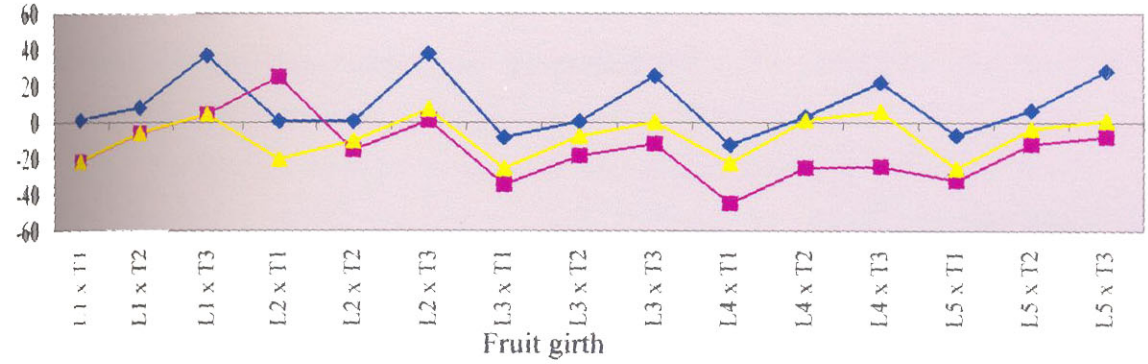
Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	-21.73**	-45.54**	-45.57**
$L_1 \times T_2$	-1.44	2.56	-5.11**
$L_1 \times T_3$	27.41**	5.63**	5.59**
$L_2 \times T_1$	-19.98**	-44.52**	-44.28**
$L_2 \times T_2$	1.35	5.22**	-2.65
$L_2 \times T_3$	28.68**	6.35**	6.85**
$L_3 \times T_1$	-18.99**	-55.89**	-36.79**
$L_3 \times T_2$	4.60**	-6.96**	-13.95**
$L_3 \times T_3$	18.13**	-19.95**	14.77**
$L_4 \times T_1$	-7.06*	-53.74**	-23.48**
$L_4 \times T_2$	8.99**	-8.19**	-15.03**
$L_4 \times T_3$	7.35**	-32.24**	3.01
$L_5 \times T_1$	-2.95	-58.54**	-10.59**
$L_5 \times T_2$	3.62	-19.95**	-25.95**
$L_5 \times T_3$	-11.07**	-50.15**	-24.17**



Fruit weight per plant



Fruit length



Fruit girth

Number of seeds per fruit

RH - Relative heterosis SH - Standard heterosis
HB - Heterobeltiosis

Fig. 5.Continued

L_1T_3 (4.43%), L_2T_3 (7.22%) and L_4T_3 (5.91%) possessed positively significant heterobeltiosis while L_1T_1, L_1T_2, L_2T_1, L_2T_2, L_3T_1, L_3T_2, L_4T_1 and L_5T_1 displayed negatively significant heterosis over the better parent.

h. Number of seeds per fruit

Seven hybrids exhibited positively significant relative heterosis, the maximum being shown by L_2T_1 (71.31%) followed by L_2T_3 (45.26%) and L_2T_2 (37.68%). Six hybrids displayed negatively significant relative heterosis (Table 25).

All the hybrids except L_3T_1 showed significant standard heterosis. The maximum positive value was possessed by L_2T_3 (136.80%) followed by L_5T_3 (97.11%), L_3T_3 (96.57%) and L_4T_2 (81.78%).

Only three hybrids L_2T_1 (60.43%), L_2T_2 (22.69%) and L_2T_3 (3.85%) displayed positively significant heterobeltiosis while all the others showed negative heterosis.

i. Hundred seed weight

Five hybrids showed positively significant relative heterosis while seven others displayed negatively significant relative heterosis (Table 26). The maximum positive value was possessed by L_3T_2 (40.42%) and the maximum negative value was displayed by L_5T_3 (-30.43%).

All the hybrids showed negatively significant standard heterosis, the highest value being –66.48 per cent for L_3T_3 followed by –58.01 per cent for L_5T_3.

Heterobeltiosis followed a similar pattern as that of standard heterosis except for two hybrids L_5T_1 and L_5T_2, which possessed positively significant heterobeltiosis.

j. Plant height

Seven hybrids possessed positively significant relative heterosis for the character while eight hybrids displayed negatively significant heterosis (Table 27). The maximum positive value was displayed by L_1T_3 (24.06%) closely followed by L_2T_3 (24.04%).

Table 24. Heterosis (%) for fruit girth

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	1.26	-21.72**	-21.62**
$L_1 \times T_2$	8.02**	-6.16**	-6.05**
$L_1 \times T_3$	36.92**	4.38*	4.43*
$L_2 \times T_1$	0.65	24.96**	-20.41**
$L_2 \times T_2$	0.77	-15.24**	-10.09**
$L_2 \times T_3$	37.70**	1.08	7.22**
$L_3 \times T_1$	-8.17**	-34.38**	-25.52**
$L_3 \times T_2$	0.60	-18.49**	-7.48**
$L_3 \times T_3$	25.59**	-11.68	0.25
$L_4 \times T_1$	-12.25**	-44.65**	-22.42**
$L_4 \times T_2$	3.12	-25.08**	1.31
$L_4 \times T_3$	21.99**	-24.43**	5.91*
$L_5 \times T_1$	-6.96**	-32.10**	-25.50**
$L_5 \times T_2$	6.61**	-12.00**	-3.44
$L_5 \times T_3$	28.22**	-7.89**	1.07

Table 25. Heterosis (%) for number of seeds per fruit

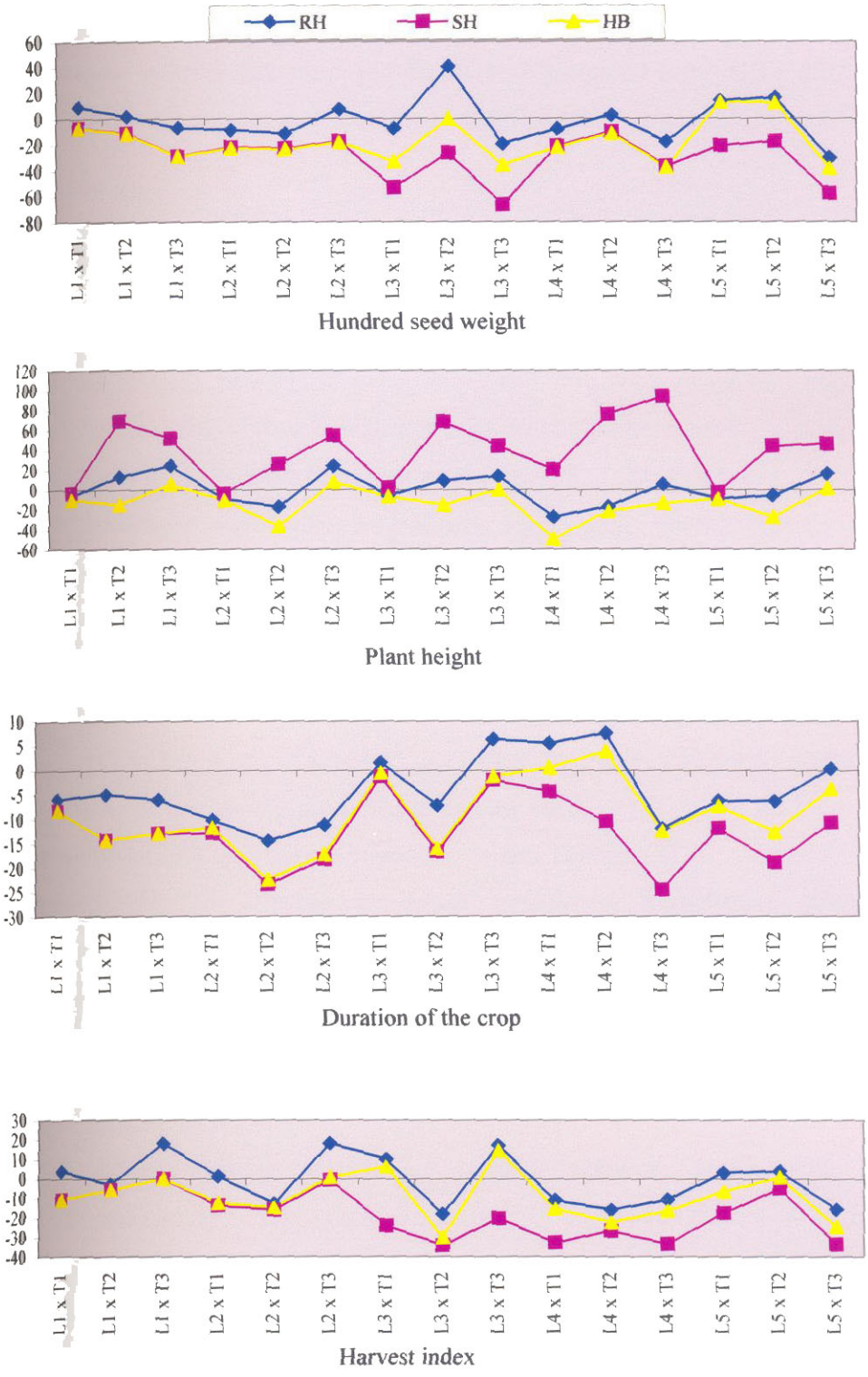
Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	-14.12**	-20.33**	-20.31**
$L_1 \times T_2$	6.11*	19.52**	-4.60
$L_1 \times T_3$	8.43**	77.84**	-22.01**
$L_2 \times T_1$	71.31**	57.26**	60.43**
$L_2 \times T_2$	37.68**	53.73**	22.69**
$L_2 \times T_3$	45.26**	136.80**	3.85*
$L_3 \times T_1$	-30.72**	-6 03	-49.40**
$L_3 \times T_2$	1.14	57.26**	-15.31**
$L_3 \times T_3$	-4.97**	96.57**	-13.79**
$L_4 \times T_1$	-6.99**	49.93**	-36.69**
$L_4 \times T_2$	0.39	81.78**	-23.24**
$L_4 \times T_3$	-27.83**	67.74**	-29.16**
$L_5 \times T_1$	-10.45**	-20.84**	-13.22**
$L_5 \times T_2$	10.29**	19.38**	-4.71
$L_5 \times T_3$	23.48**	97.11**	-13.56**

Table 26. Heterosis (%) for hundred seed weight

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	9.37**	-7.18*	-7.17*
$L_1 \times T_2$	1.92	-11.13**	-11.71**
$L_1 \times T_3$	-7.25*	-29.33**	-29.33**
$L_2 \times T_1$	-8 80**	-22.19**	-22.87**
$L_2 \times T_2$	-11.72**	-23.15**	-23.81**
$L_2 \times T_3$	7.35*	-17.73**	-18.44**
$L_3 \times T_1$	-7.65	-53.48**	-33.32**
$L_3 \times T_2$	40.42**	-26.84**	-0.09*
$L_3 \times T_3$	-19.55**	-66.46**	-35.99**
$L_4 \times T_1$	-8.05**	-21.35**	-22.37**
$L_4 \times T_2$	2.79	-10.28**	-11.44**
$L_4 \times T_3$	-18.08**	-37.04**	-37.86**
$L_5 \times T_1$	14.05**	-21.26**	12.89**
$L_5 \times T_2$	16.19**	-17.75**	12.30**
$L_5 \times T_3$	-30.43**	-58.01**	-38.55**

Table 27. Heterosis (%) for plant height

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	-6.76**	-3.28	-9.99**
$L_1 \times T_2$	12.99**	68.69**	-15.06**
$L_1 \times T_3$	24.06**	51.09**	5.22**
$L_2 \times T_1$	-9.44**	-3.88	-10.56**
$L_2 \times T_2$	-17.36**	25.37**	-36.88**
$L_2 \times T_3$	24.04**	54.04**	7.28**
$L_3 \times T_1$	-5.94**	2.11	-6.88**
$L_3 \times T_2$	8.94**	67.89**	-15.45**
$L_3 \times T_3$	13.33**	43.49**	-0.07
$L_4 \times T_1$	-27.54**	19.99**	-49.37**
$L_4 \times T_2$	-16.86**	75.57**	-21.53**
$L_4 \times T_3$	5.22**	93.26**	-13.63**
$L_5 \times T_1$	-9.39**	-2.76	-9.50**
$L_5 \times T_2$	-5.99**	43.73**	-27.63**
$L_5 \times T_3$	16.09**	45.58**	1.38



RH - Relative heterosis SH - Standard heterosis
HB - Heterobeltiosis

Fig. 5. continued

Only two hybrids exhibited negative standard heterosis while almost all others showed positively significant values, the maximum being possessed by L_4T_3 (93.26%) followed by L_4T_2 (75.57%).

Positively significant heterobeltiosis was possessed by L_1T_3 (5.22%) and L_2T_3 (7.28%) while eleven others possessed negatively significant values.

k. Duration of the crop

Relative heterosis was negative and significant for all the hybrids except L_3T_1 (1.59%), L_3T_3 (6.34%), L_4T_1 (5.48%), L_4T_2 (7.56%) and L_5T_3 (0.34%) (Table 28).

All the hybrids possessed significant and negative standard heterosis except L_3T_1 (-1.26) for which it was not significant. The maximum negative value was shown by L_4T_3 (-24.45%) followed by L_2T_2 (-23.39%).

The maximum value for negatively significant heterobeltiosis was possessed by L_2T_2 (-22.41%) followed by L_2T_3 (-17.25%). The minimum negatively significant value was shown by L_5T_3 (-3.82%).

l. Harvest index

L_1T_3 (17.95%), L_2T_3 (18.10%), L_3T_1 (9.95%), L_3T_3 (17.02%) and L_5T_2 (3.97%) displayed positively significant values while L_2T_2, L_3T_2, L_4T_1, L_4T_2, L_4T_3 and L_5T_3 showed significant negative values (Table 29).

Almost all the hybrids exhibited negatively significant standard heterosis for the character.

Positively significant heterobeltiosis were possessed by two hybrids L_3T_1 (6.06%) and L_3T_3 (14.58%).

m. Per cent disease incidence

Five hybrids showed significant negative relative heterosis for this character the maximum being displayed by L_2T_3 (-57.09 %) followed by L_1T_3 (-43.92 %) and L_4T_2 (-32.79 %) (Table 30).

Almost all the hybrids possessed negatively significant heterosis with respect to the standard variety Jwalamukhi and positively significant heterosis with reference to the standard variety Pant C 1. The maximum value with respect to Jwalamukhi was for L_2T_3 (-66.67%) closely followed by L_1T_3

Table 28. Heterosis (%) for duration of the crop

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	-5.95**	-8.23**	-8.23**
$L_1 \times T_2$	-4.93**	-14.30**	-14.30**
$L_1 \times T_3$	-5.99**	-12.96**	-12.96**
$L_2 \times T_1$	-10.13**	-12.88**	-11.76**
$L_2 \times T_2$	-14.41**	-23.39**	-22.41**
$L_2 \times T_3$	-11.15**	-18.29**	-17.25**
$L_3 \times T_1$	1.59*	-1 26	-0.49
$L_3 \times T_2$	-7.15**	-16.67**	-16.02**
$L_3 \times T_3$	6.34**	-1.96**	-1.19
$L_4 \times T_1$	5.48**	-4.36**	0.51
$L_4 \times T_2$	7.56**	-10.47**	3.88**
$L_4 \times T_3$	-11.82**	-24.45**	-12.34**
$L_5 \times T_1$	-6.19**	-11.82**	-7.32**
$L_5 \times T_2$	-6.24**	-18.83**	-12.59**
$L_5 \times T_3$	0.34	-10.68**	-3.82**

Table 29. Heterosis (%) for harvest index

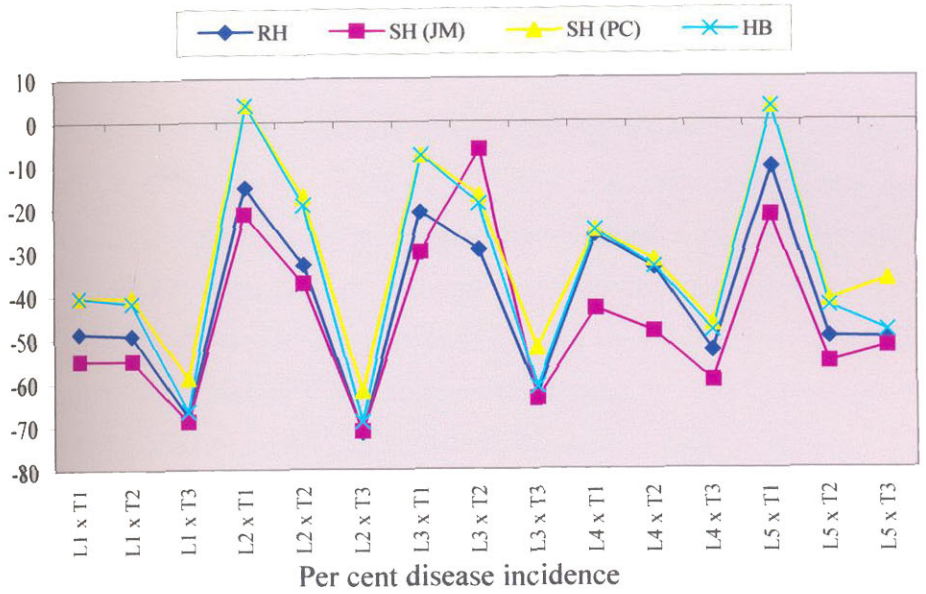
Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)	Heterobeltiosis (HB)
$L_1 \times T_1$	3.79	-10.87**	-10.87**
$L_1 \times T_2$	-2.99	-5.79**	-5.79**
$L_1 \times T_3$	17.95**	0.00	0.00
$L_2 \times T_1$	1.28	-13.77**	-12.50**
$L_2 \times T_2$	-12.78**	-15.94**	-14.71**
$L_2 \times T_3$	18.10**	-0.72	0.74
$L_3 \times T_1$	9.95**	-23.91**	6.06*
$L_3 \times T_2$	-18.01**	-34.06**	-30.00**
$L_3 \times T_3$	17.02**	-20.29**	14.58**
$L_4 \times T_1$	-11.00**	-32.61**	-15.45**
$L_4 \times T_2$	-15.83**	-26.81**	-22.31**
$L_4 \times T_3$	-10.68**	-33.33**	-16.36**
$L_5 \times T_1$	3.17	-17.39**	-6.56**
$L_5 \times T_2$	3.97*	-5.07**	0.77
$L_5 \times T_3$	-15.59**	-33.33**	-24.59**

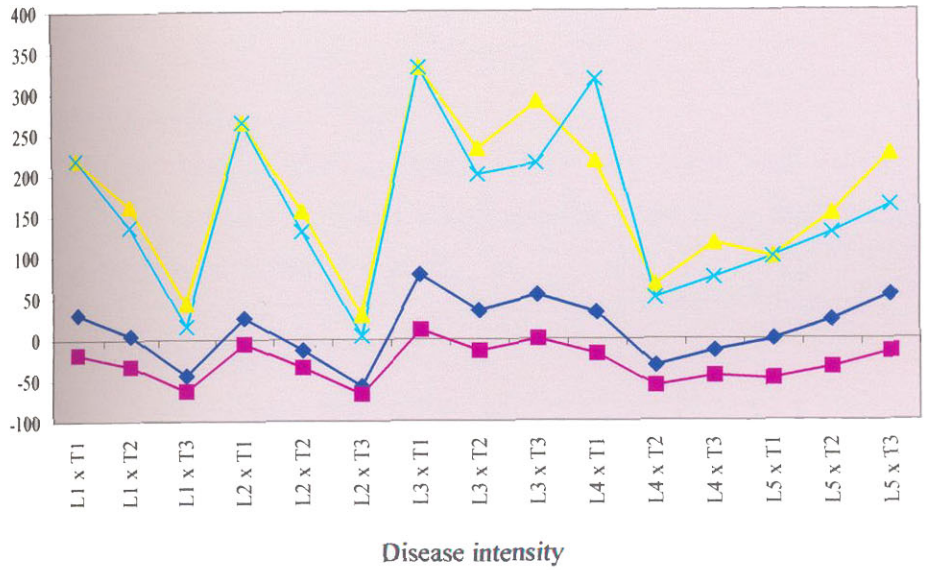
Table 30. Heterosis (%) for per cent disease incidence

Hybrids	Relative Heterosis (RH)	Standard Heterosis (SH)		Heterobeltiosis (HB)
		Jwalamukhi	Pant C-1	
$L_1 \times T_1$	30.64**	-17.85**	218.85*	218.86**
$L_1 \times T_2$	5.03*	-32.52**	161.90**	136.79**
$L_1 \times T_3$	-43.92**	-63.01**	43.56**	15.83**
$L_2 \times T_1$	25.96**	-5.53**	264.76**	264.76**
$L_2 \times T_2$	-13.48**	-34.27**	155.10**	130.65**
$L_2 \times T_3$	-57.09**	-66.67**	29.40**	4.40
$L_3 \times T_1$	78.04**	11.12**	331.30**	331.30**
$L_3 \times T_2$	34.08**	-14.48**	231.90*	200.11**
$L_3 \times T_3$	53.03**	0.00	289.02*	213.88**
$L_4 \times T_1$	32.03**	-18.42**	216.63*	316.64**
$L_4 \times T_2$	-32.79**	-57.55**	64.76**	48.97**
$L_4 \times T_3$	-14.43**	-45.38**	115.43**	73.82**
$L_5 \times T_1$	-0.83	-48.68**	99.17**	99.17**
$L_5 \times T_2$	22.21**	-35.09**	151.94**	127.78**
$L_5 \times T_3$	52.73**	-16.26**	225.02**	162.24**

Table 31. Heterosis (%) for disease intensity

Hybrids	Relative heterosis (RH)	Standard Heterosis (SH)		Heterobeltiosis (HB)
		Jwalamukhi	Pant C-1	
$L_1 \times T_1$	-48.64**	-54.86**	-40.41**	-40.41**
$L_1 \times T_2$	-49.13**	-54.85**	-40.39**	-41.73**
$L_1 \times T_3$	-67.75**	-68.88**	-58.92**	-66.51**
$L_2 \times T_1$	-15.14**	-21.37**	3.81	3.81
$L_2 \times T_2$	-33.04**	-37.38**	-17.33**	-19.18**
$L_2 \times T_3$	-71.48**	-71.13**	-61.89**	-68.94**
$L_3 \times T_1$	-20.81**	-30.09**	-7.71	-7.71
$L_3 \times T_2$	-29.55*	-6.53	-17.11**	-18.96**
$L_3 \times T_3$	-62.55**	-63.73**	-52.12**	-60.97**
$L_4 \times T_1$	-26.21**	-43.29**	-25.15*	-25.15**
$L_4 \times T_2$	-33.71**	-48.49**	-32.01**	-33.53**
$L_4 \times T_3$	-52.93**	-59.79**	-46.91**	-48.38**
$L_5 \times T_1$	-10.76**	-21.86**	3.16	3.16
$L_5 \times T_2$	-49.89**	-55.69**	-41.51*	-42.81**
$L_5 \times T_3$	-50.15**	-52.07**	-36.73*	-48.42**





RH - Relative heterosis SH - Standard heterosis
HB - Heterobeltiosis

JM - Jwalamukhi
PC - Pant C1

Fig. 5. continued

(-63.01 %) and L_4T_2 (-57.55%). With respect to Pant C 1, the values ranged from 29.40 per cent (L_2T_3) to 331.30 per cent (L_3T_1)

All the hybrids except L_2T_3 displayed positive and significant values for heterobeltiosis ranging from 15.83 per cent for L_1T_3 to 331.30 per cent for L_3T_1.

n. Disease intensity

Almost all the fifteen hybrids possessed significant negative heterosis over mid parent as well as the standard varieties *viz.*, Jwalamukhi and Pant C 1 (Table 31). For relative heterosis, the values ranged from -10.76 per cent (L_5T_1) to -71.48 per cent (L_2T_3) whereas standard heterosis with respect to Jwalamukhi ranged from -21.37 per cent (L_2T_1) to -71.13 per cent (L_2T_3). Negatively significant standard heterosis with respect to Pant C 1 ranged from –17.11 per cent (L_3T_2) to –61.89 per cent (L_2T_3)

Heterobeltiosis was negative and significant for all the hybrids except L_2T_1 and L_5T_1. The range was from -7.71 per cent (L_3T_1) to -68.94 per cent (L_2T_3).

L_2T_3 had the maximum relative heterosis, standard heterosis and heterobeltiosis.

4.2.2 Combining Ability

General combining ability (gca) effects of lines and testers are furnished in Table 32 and Fig. 6 and 7 and specific combining ability (sca) of hybrids are presented in Table 33 and Fig. 8.

a. Days to first flowering

Significant gca effects were observed for all the lines of which that of L_3 (16.71) was in positive direction while those of others were in negative direction. None of the testers exhibited significant gca effects.

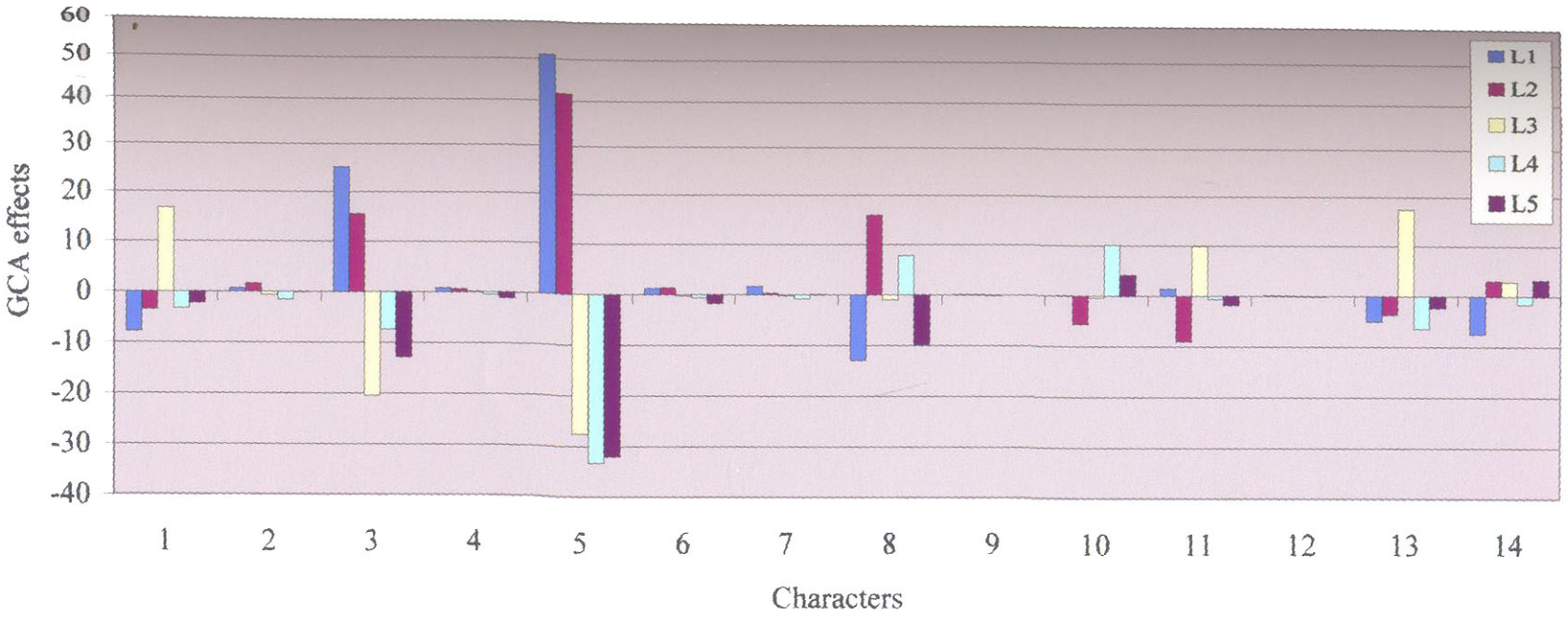
Significant sca effect was displayed by only one hybrid L_4T_1 (3.15).

b. Number of branches

Among the five lines L_1 (0.65) and L_2 (1.58) had positive values while L_3 (-0.62), L_4 (-1.55) and L_5 (-0.07) had negative values. In the tester group, T_1 (-0.46) and T_2 (0.39) had significant gca effects.

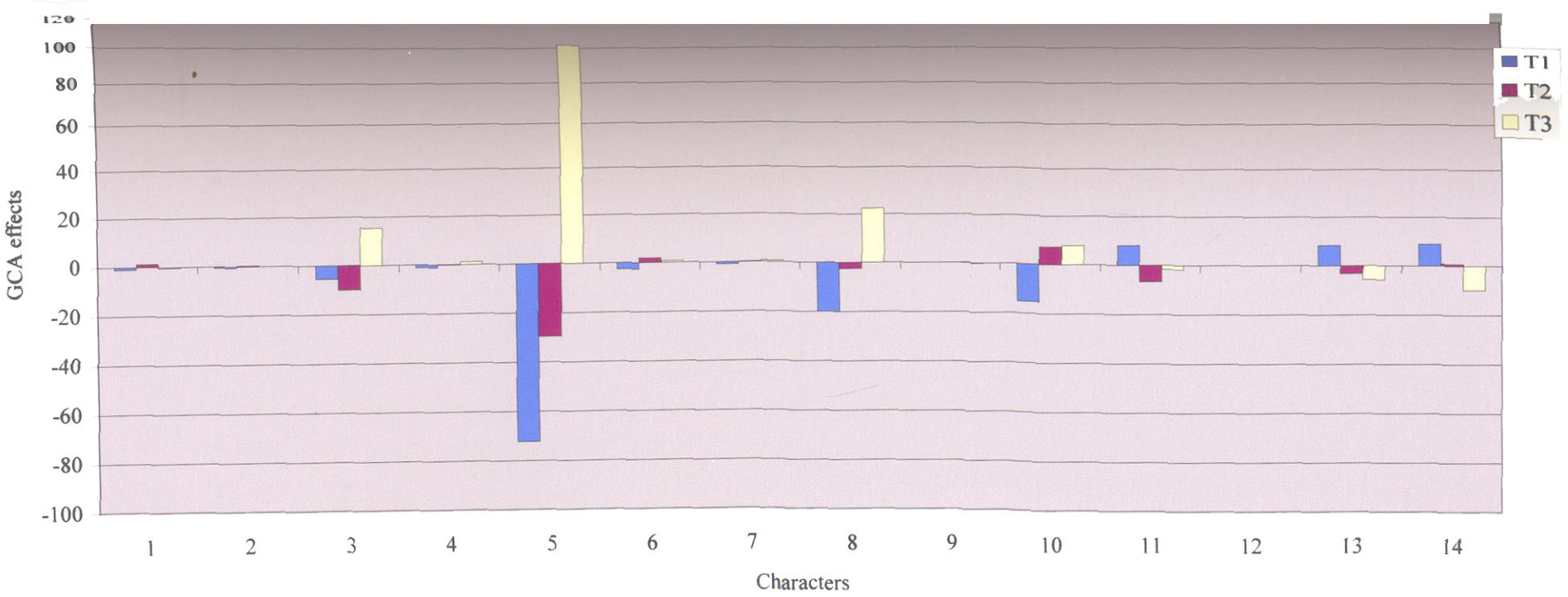
Table 32. General combining ability effects of parents for fourteen characters

Parents	Days to first flowering	Number of branches	Number of fruits per plant	Average green fruit weight	Fruit weight per plant	Fruit length	Fruit girth	Number of seeds per fruit	100-seed weight	Plant height	Duration	Harvest index	Disease intensity	% Disease incidence
Lines														
L_1	-7.82**	0.65**	25.10**	0.82**	51.08**	1.23**	1.64**	-12.97**	0.08**	0.04	1.43**	0.11**	-7.49**	-5.01**
L_2	-3.47**	1.58**	15.50**	0.60**	41.68**	1.38**	0.31**	15.98**	0.05**	-5.60**	-8.97**	0.07**	3.09**	-3.70**
L_3	16.71**	-0.62**	-20.43**	0.14	-27.52**	-0.25**	-0.20**	-0.97	-0.13**	-0.37	9.94**	-0.07**	2.85**	17.45**
L_4	-3.24**	-1.55**	-7.36**	-0.45**	-33.28**	-0.62**	-0.81**	7.78**	0.03**	10.10**	-0.64	-0.12**	-1.62*	-6.45**
L_5	-2.18**	-0.07**	-12.81**	-1.10**	-31.95**	-1.74**	0.05	-9.82**	-0.02**	4.12**	-1.75**	-0.003	3.16**	-2.29**
SE	0.91	0.19	2.34	0.09	3.02	0.07	0.06	0.82	0.008	0.34	0.48	0.007	0.92	0.46
CD	2.58	0.53	6.67	0.28	8.63	0 19	0.16	2.33	0.02	0.97	1.36	0.02	2.62	1.30
Testers														
T_1	-0.93	-0.46**	-5.47**	-1.13**	-72.25**	-2.59**	-0.82**	-19.93**	0.02**	-15.14**	8.17**	-0.001	8.96**	8.33**
T_2	1.23	0.39**	-9.91**	-0.03	-29.53**	1.91**	0.17**	-2.47**	0.06**	7.31**	-6.59**	0.007	0.86	-3.17**
T_3	-0.30	0.06	15.38**	1.16**	101.79**	0.68**	0.65**	22.40**	-0.08**	7.83**	-1.58**	0.007	-9.83**	-5.61**
SE	0.70	0.14	1.81	0.08	2.35	0.05	0.04	0.63	0.006	0.26	0.37	0.006	0.71	0.35
CD	2.00	0.41	5.17	0.22	6.68	0.15	0.12	1.80	0.02	0.75	1.05	0.02	2.03	1.01



1	Days to first flowering	8	Number of seeds per fruit
2	Number of branches	9	100-seed weight
3	Number of fruits per plant	10	Plant height
4	Average green fruit weight	11	Duration
5	Fruit weight per plant	12	Harvest index
6	Fruit length	13	Percentage disease incidence
7	Fruit girth	14	Disease intensity

Fig. 6. General combining ability effects of lines

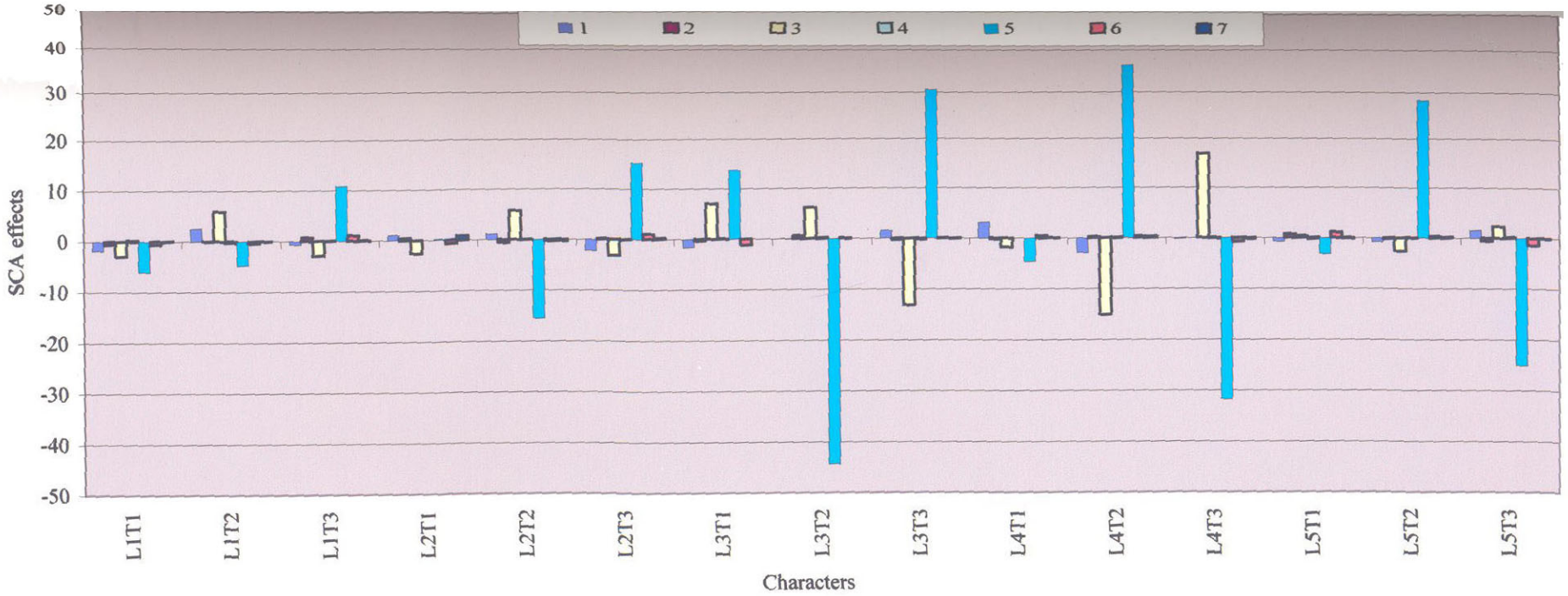


1	Days to first flowering	8	Number of seeds per fruit
2	Number of branches	9	100-seed weight
3	Number of fruits per plant	10	Plant height
4	Average green fruit weight	11	Duration
5	Fruit weight per plant	12	Harvest index
6	Fruit length	13	Percentage disease incidence
7	Fruit girth	14	Disease intensity

Fig. 7. General combining ability effects of testers

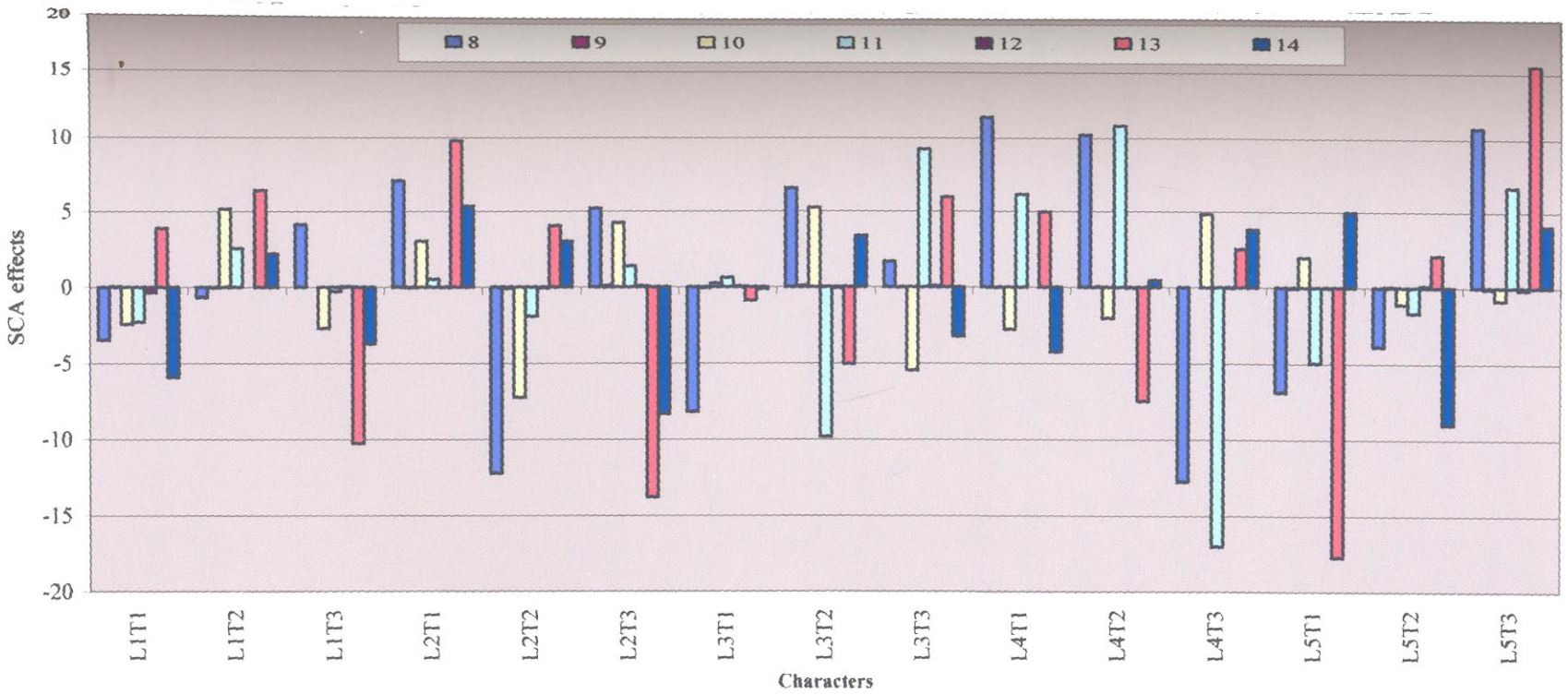
Table 33. Specific combining ability effects of fifteen hybrids for fourteen characters

Hybrids	Days to first flowering	Number of branches	Number of fruits per plant	Average green fruit weight	Fruit weight per plant	Fruit length	Fruit girth	Number of seeds per fruit	100-seed weight	Plant height	Duration	Harvest index	Disease intensity	% Disease incidence
L_1T_1	-1.87	-0.61	-2.93	0.19	-6.10	-0.64**	-0.03	-3.47*	0.04**	-2.43**	-2.28**	-0.36**	-5.92**	3.80**
L_1T_2	2.57	-0.06	5.84	-0.26	-4.76	-0.45**	-0.07	-0.67	-0.04**	5.14**	2.55**	-0.01	2.19	6.39**
L_1T_3	-0.69	0.68*	-2.92	0.07	10.86*	1.08**	0.10	4.13**	0.01	-2.71**	-0.27	0.04**	-3.73*	-10.26**
L_2T_1	1.11	0.46	-2.59	-0.01	0.23	-0.68**	0.80**	7.04**	-0.03**	3.02**	0.52	-0.02*	5.33**	9.78**
L_2T_2	1.15	-0.59	5.71	-0.04	-15.49**	-0.33**	-0.31**	-12.22**	-0.08**	-7.23**	-1.92**	-0.06**	2.99	4.02**
L_2T_3	-2.25	0.14	-3.12	0.06	15.26**	1.01**	0.22*	5.18**	0.10**	4.22**	1.39**	0.08**	-8.32**	-13.79**
L_3T_1	-1.60	-0.34	7.00	0.03	13.69*	-1.17**	0.02	-8.19**	-0.05**	0.23	0.61	0.03**	-0.11	-0.89
L_3T_2	0.04	0.60	6.11	0.16	-44.36**	0.10	0.01	6.53**	0.07**	5.23**	-9.83**	-0.08**	3.36*	-5.04**
L_3T_3	1.57	-0.26	-13.12**	-0.19	30.66**	0.06	-0.04	1.67	-0.02*	-5.47**	9.22**	0.05**	-3.24**	5.94**
L_4T_1	3.15*	-0.21	-1.79	-0.01	-4.61	0.41**	0.05	11.51**	-0.01	-2.77**	6.12**	-0.01	-4.25**	4.96**
L_4T_2	-2.94	0.20	-15.09**	0.10	36.33**	0.35**	0.21*	10.24**	0.02*	-2.04**	10.88**	-0.03**	0.46	-7.47**
L_4T_3	-0.21	-0.01	16.88**	-0.09	-31.72**	-0.77**	-0.22*	-12.76**	-0.01	4.81**	-17.00**	-0.03**	3.79*	2.51**
L_5T_1	-0.78	0.71*	0.32	-0.21	-3.21	1.07**	-0.09	-6.89**	-0.05**	1.96**	-4.97**	-0.02*	4.95**	-17.71**
L_5T_2	-0.81	-0.14	-2.58	0.05	28.27**	0.32**	0.15	-3.89**	0.03**	-1.10	-1.68**	0.12**	-9.00**	2.10**
L_5T_3	1.59	-0.57	2.26	0.16	-25.05**	-1.39**	-0.06	10.78**	-0.08**	-0.85	6.64**	-0.14**	4.05*	15.60**
SE	1.57	0.32	4.06	0.17	5.25	0.12	0.09	1.42	0.01	0.59	0.83	0.01	1.59	0.79
CD	4.48	0.92	11.56	0.49	14.95	0.34	0.28	4.04	0.03	1.68	2.36	0.03	4.55	2.26



1 Days to first flowering
2 Number of branches
3 Number of fruits per plant
4 Average green fruit weight
5 Fruit weight per plant
6 Fruit length
7 Fruit girth

Fig. 8. Speciific combining ability effects of hybrids



8	Number of seeds per fruit
9	100-seed weight
10	Plant height
11	Duration
12	Harvest index
13	Percentage disease incidence
14	Disease intensity

Fig. 8. Continued

Positive significant sca effects were displayed by L_1T_3 (0.68) and L_5T_1 (0.71).

c. Number of fruits per plant

L_1 (25.10) and L_2 (15.50) displayed significant positive gca effects while L_3, L_4 and L_5 showed significant negative gca effects. T_3 (15.38) showed positively significant gca effect whereas T_1 (-5.47) and T_2 (-9.91) displayed negative gca effects.

Among hybrids, L_3T_3 (-13.12), L_4T_2 (-15.09) and L_4T_3 (16.88) possessed significant sca effects.

d. Average green fruit weight

Among lines, L_1 (0.82) and L_2 (0.60) showed significant positive gca effects while L_4 (-0.45) and L_5 (-1.10) displayed negatively significant gca effects. T_1 (-1.13) and T_3 (1.16) showed significant gca effects.

None of the hybrids showed significant sca effects.

e. Fruit weight per plant

L_1 (51.08) and L_2 (41.68) exhibited significant positive gca effects while L_3 (-27.52), L_4 (-33.28) and L_5 (-31.95) displayed significant negative gca effects. Among testers, T_1 (-72.25) and T_2 (-29.53) exhibited negatively significant gca effects while T_3 (101.79) showed positive effects.

L_1T_3 (10.86), L_2T_3 (15.26), L_3T_1 (13.69), L_3T_3 (30.66), L_4T_2 (36.33) and L_5T_2 (28.27) possessed significant positive sca effects while L_2T_2 (-15.49), L_3T_2 (-44.36), L_4T_3 (-31.72) and L_5T_3 (-25.05) exhibited significant sca effects in the opposite direction.

f. Fruit length

L_1 (1.23) and L_2 (1.38) showed positively significant gca effects while L_3 (-0.25), L_4 (-0.62) and L_5 (-1.74) showed negative values. T_2 (1.91) and T_3 (0.68) possessed positively significant gca effects while T_1 (-2.59) showed gca effect in the opposite direction.

Among hybrids, L_1T_3 (1.08), L_2T_3 (1.01), L_4T_1 (0.41), L_4T_2 (0.35), L_5T_1 (1.07) and L_5T_2 (0.32) displayed positively significant sca effects while

L_1T_1 (-0.64), L_1T_2 (-0.45), L_2T_1 (-0.68), L_2T_2 (-0.33), L_3T_1 (-1.17), L_4T_3 (-0.77) and L_5T_3 (-1.39) showed significant negative sca effects.

g. Fruit girth

Among lines, L_1 (1.64) and L_2 (0.31) showed positively significant gca effects while L_3 (-0.20) and L_4 (-0.81) displayed negative and significant gca effects. T_1 (-0.82), T_2 (0.17) and T_3 (0.65) also showed significant gca effects.

L_2T_1 (0.80), L_2T_2 (-0.31), L_2T_3 (0.22), L_4T_2 (0.21) and L_4T_3 (-0.22) were the hybrids with significant sca effects.

h. Number of seeds per fruit

L_2 (15.98) and L_4 (7.78) showed positively significant gca effects while L_1 (-12.97) and L_5 (-9.82) displayed negatively significant effects. T_1 (-19.93), T_2 (-2.47) and T_3 (22.4) also showed significant gca effects.

Significant sca effects in the positive direction were shown by L_1T_3 (4.13), L_2T_1 (7.04), L_2T_3 (5.18), L_3T_2 (6.53), L_4T_1 (11.51), L_4T_2 (10.24) and L_5T_3 (10.78). L_1T_1 (-3.47), L_2T_2 (-12.22), L_3T_1 (-8.19), L_4T_3 (-12.76), L_5T_1 (-6.89) and L_5T_2 (-3.89) showed significant negative sca effects.

i. Hundred seed weight

All the lines exhibited significant gca effects; L_1 (0.08), L_2 (0.05) and L_4 (0.03) in the positive direction and L_3 (-0.13) and L_5 (-0.02) in the opposite direction. T_1 (0.02), T_2 (0.06) and T_3 (-0.08) also displayed significant gca effects.

All the hybrids except L_1T_3, L_4T_1 and L_4T_3 exhibited significant sca effects. Among these, L_1T_1 (0.04), L_2T_3 (0.10), L_3T_2 (0.07), L_4T_2 (0.02) and L_5T_2 (0.03) showed positive and significant sca effects while L_1T_2 (-0.04), L_2T_1 (-0.03), L_2T_2 (-0.08), L_3T_1 (-0.05), L_3T_3 (-0.02), L_5T_1 (-0.05) and L_5T_3 (-0.08) had significant negative effects.

j. Plant height

Three lines L_2 (-5.6), L_4 (10.10) and L_5 (4.12) and all the testers T_1 (-15.14), T_2 (7.31) and T_3 (7.83) possessed significant gca effects for plant height.

Specific combining ability effects were positive and significant for six hybrids, the maximum being displayed by L_3T_2 (5.23) closely followed by L_1T_2 (5.14) and the minimum value by L_5T_1 (1.96). Negatively significant values were shown by six hybrids. The maximum negative sca effect was for L_2T_2 (-7.23) and the minimum was for L_4T_2 (-2.04).

k. Duration of the crop

All the lines displayed significant gca effects of which only L_1 (1.43) and L_3 (9.94) had positive values whereas maximum and minimum negative values were noticed for L_2 (-8.97) and L_4 (-0.64). Among the testers, T_1 (8.17) exhibited positive value while T_2 (-6.59) and T_3 (-1.58) showed negative effects.

Six hybrids showed significant positive and significant negative sca effects. The maximum positive value was for L_4T_2 (10.88) closely followed by L_3T_2 (9.22). The maximum negative value was for L_4T_3 (-17.00) followed by L_3T_2 (-9.83) and L_5T_1 (-4.97).

l. Harvest index

L_1 (0.11) and L_2 (0.07) showed significant positive gca effects while L_3 (-0.07) and L_4 (-0.12) showed significant negative effects. None of the testers possessed significant gca effects.

Significant positive sca effects were displayed by five hybrids, the maximum being shown by L_5T_2 (0.12) followed by L_2T_3 (0.08). Significant negative sca effects were shown by eight hybrids. The maximum value was for L_1T_1 (-0.36) followed by L_5T_3 (-0.14).

m. Per cent disease incidence

L_3 (17.45) possessed significant positive gca effect while the other lines showed negatively significant effects, the maximum value being possessed by L_4 (-6.45) followed by L_1 (-5.01), L_2 (-3.70) and L_5 (-2.29). T_1 (8.33) showed significant positive gca effect whereas T_2 (-3.17) and T_3 (-5.61) displayed significant negative effects.

Nine hybrids exhibited significant positive sca effects. The maximum value was for L_5T_3 (15.60) followed by L_2T_1 (9.78) and L_1T_2 (6.39). Negatively significant effects belonged to five hybrids, the maximum value

being possessed by L_5T_1 (-17.71) followed by L_2T_3 (-13.79) and L_1T_3 (-10.26).

n. Disease intensity

Among the lines, L_2 (3.09), L_3 (2.85) and L_5 (3.16) possessed positively significant gca effects while L_1 (-7.49) and L_4 (-1.62) possessed negative effects. T_1 (8.96) and T_3 (-9.83) possessed significant gca effects but in the opposite direction.

Six hybrids showed significant positive sca effects, the maximum being displayed by L_2T_1 (5.33) followed by L_5T_1 (4.95) and L_5T_3 (4.05). Five hybrids exhibited significant negative sca effects. The maximum value was for L_5T_2 (-9.00) followed by L_2T_3 (-8.32) and L_1T_1 (-5.92).

4.2.3 *Per se* Performance of Parents and Hybrids

Per se performance of five lines, three testers and their fifteen hybrids with respect to fourteen characters are presented in Table 34 and Table 35.

a.Days to first flowering

The earliest flowering lines were L_1 and L_4 (47.20days) while the earliest flowering tester was T_1 (71.8 days) which was on par with T_2 (72.03 days). L_3 (69.73 days) and T_3 (76.67 days) took the maximum days for flowering within their respective groups. Among the hybrids, minimum number of days for flowering was observed for L_1T_1 (50.60 days) which was on par with L_1T_3 (52.40 days). The maximum days was observed for L_3T_2 and L_3T_3 (79.2 days).

b. Number of branches

L_2 (7.13) and L_4 (3.20) possessed the highest and the lowest number of branches respectively among the lines while these positions among testers were occupied by T_2 (5.20) and T_1 (2.80). Maximum value of this trait among hybrids was observed for L_2T_3 (7.40), which was on par with L_2T_1 (7.20), L_1T_3 (7.00) and L_2T_2 (7.00), whereas the minimum value was exhibited by L_4T_1 (3.40).

Table 34 Per se performance of parents for eighteen characters

Parents	Days to first flowering	Number of branches	Number of fruits per plant	Average green fruit weight (g)	Fruit weight per plant (g)	Fruit length(cm)	Fruit girth(cm)	Number of seeds per fruit	100-seed weight(g)
Lines									
L_1	47.20	7.0	136.80	5.43	389.20	9.77	6.17	50.87	0.627
L_2	56.47	7.13	128.53	5.78	368.27	9.73	5.81	49.87	0.633
L_3	69.73	6.33	106.13	5.10	370.20	6.81	5.43	94.47	0.194
L_4	47.20	3.20	130.80	4.60	316.80	5.91	4.40	120.47	0.635
L_5	50.80	6.80	111.47	3.20	319.33	4.53	5.62	46.40	0.429
Mean	54.28	6.09	122.75	4.82	352.76	7.35	5.49	72.42	0.504
SE	0.91	0.19	2.34	0.09	3.03	0.07	0.06	0.82	0.007
CD	1.84	0.38	4.73	0.18	6.12	0.14	0.12	1.66	0.014
Testers									
T_1	71.80	2.80	70.47	1.53	106.53	3.82	3.38	43.53	0.437
T_2	72.03	5.20	56.40	4.19	178.20	10.56	4.56	63.73	0.459
T_3	76.67	4.00	72.20	2.37	178.13	6.43	3.24	116.00	0.329
Mean	73.50	4.00	66.36	2.69	154.29	6.94	3.73	74.42	0.408
SE	0.70	0.14	1.81	0.08	2.35	0.05	0.04	0.63	0.006
CD	1.41	0.28	3.66	0.16	4.75	0.10	0.08	1.27	0.012
	S	NS	S	NS	S	NS	NS	S	S

S- Significant ; NS- Non significant

Table 34 Continued

Parents	Plant height	Duration	Harvest index	Disease intensity			% disease incidence		
				30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT
Lines									
L_1	41.71	163.60	0.92	54.91	60.14	65.20	50.89	56.14	61.13
L_2	43.71	161.53	0.91	61.22	66.60	71.43	64.18	69.42	75.46
L_3	45.73	162.33	0.61	54.78	60.43	65.71	50.54	51.22	60.55
L_4	93.33	141.00	0.73	40.28	45.47	50.80	50.09	54.69	59.79
L_5	44.71	151.93	0.81	54.41	59.21	64.78	37.25	41.90	47.51
Mean	53.84	156.08	0.79	53.12	58.37	64.05	50.59	54.67	60.89
SE	0.34	0.48	0.01	0.80	0.81	0.92	0.63	0.81	0.46
CD	0.69	0.97	0.01	1.62	1.64	1.86	1.27	1.64	0.93
Testers									
T_1	44.82	155.67	0.66	38.82	43.26	49.39	10.27	10.77	15.75
T_2	82.83	131.33	0.87	42.17	45.10	50.52	11.41	11.54	17.42
T_3	59.89	139.33	0.64	49.84	55.55	60.59	13.18	11.43	19.52
Mean	62.51	142.11	0.72	43.61	47.97	53.50	11.79	11.25	17.56
SE	0.26	0.37	0.01	0.62	0.62	0.71	0.49	0.62	0.35
CD	0.53	0.75	0.01	1.25	1.25	1.43	0.99	1.25	0.71
	S	S	NS	S	S	S	S	S	S

S- Significant ; NS- Non significant

Table 35. *Per se* performance of hybrids for fourteen characters

Hybrids	Days to first flowering	Number of branches	Numuer of fruits per plant	Average green fruit weight (g)	Fruit weight per plant(g)	Fruit length(cm)	Fruit girth(cm)	Number of seeds per fruit	100-seed weight(g)
L_1T_1	50.60	5.20	132.33	4.37	266.27	5.32	4.83	40.53	0.582
L_1T_2	57.20	6.60	136.67	5.01	310.33	10.02	5.79	60.80	0.554
L_1T_3	52.40	7.00	153.20	6.54	457.27	10.32	6.44	90.47	0.443
L_2T_1	57.93	7.20	123.07	3.95	263.20	5.42	4.63	80.00	0.488
L_2T_2	60.13	7.00	126.93	5.01	290.20	10.28	5.23	78.20	0.482
L_2T_3	55.20	7.40	143.40	6.31	452.27	10.39	6.23	120.47	0.516
L_3T_1	75.40	4.20	96.73	3.53	207.47	4.31	4.05	47.80	0.292
L_3T_2	79.20	6.00	91.40	4.75	192.13	9.09	5.03	80.00	0.459
L_3T_3	79.20	4.80	97.47	5.60	398.47	7.82	5.45	100.00	0.210
L_4T_1	60.20	3.40	101.00	2.90	183.40	4.52	3.41	76.27	0.498
L_4T_2	56.27	4.67	83.27	4.10	267.07	8.97	4.62	92.47	0.563
L_4T_3	57.47	4.13	140.53	5.10	330.33	6.62	4.66	85.33	0.395
L_5T_1	57.33	5.80	97.67	2.03	186.13	4.05	4.19	40.27	0.494
L_5T_2	59.47	5.80	90.33	3.39	260.33	7.82	5.43	60.73	0.516
L_5T_3	60.33	5.03	120.47	4.70	338.33	4.87	5.68	100.27	0.263
Mean	61.22	5.61	115.63	4.49	293.55	7.32	5.04	76.91	0.45
SE	1.57	0.32	4.06	0.17	5.25	0.12	0.10	1.42	0.01
CD	3.17	0.65	8.20	0.34	10.61	0.24	0.20	2.87	0.02

Table 35 continued

Hybrids	Plant height(cm)	Duration	Harvest index	Disease intensity (%)			% disease incidence		
				30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT
L_1T_1	40.34	150.13	0.82	19.84	24.94	29.43	40.21	45.03	50.22
L_1T_2	70.36	140.20	0.87	19.68	24.69	29.44	31.49	36.48	41.25
L_1T_3	63.02	142.40	0.92	11.21	11.00	20.29	12.44	16.81	22.61
L_2T_1	40.09	142.53	0.79	41.16	45.81	51.27	46.62	51.17	57.45
L_2T_2	52.29	125.33	0.77	30.92	35.94	40.83	30.13	35.02	40.18
L_2T_3	64.25	133.67	0.91	10.21	13.41	18.82	10.48	15.15	20.38
L_3T_1	42.59	161.53	0.70	35.69	40.84	45.58	57.03	61.77	67.93
L_3T_2	70.03	136.33	0.61	30.68	32.24	40.94	42.17	46.86	52.28
L_3T_3	59.85	160.40	0.73	15.88	21.37	23.65	50.78	55.64	61.27
L_4T_1	50.05	156.47	0.62	26.59	30.85	36.97	38.84	43.55	49.87
L_4T_2	73.23	146.47	0.67	22.95	27.69	33.58	15.68	19.85	25.95
L_4T_3	80.61	123.60	0.61	12.80	17.87	26.22	24.27	29.41	33.93
L_5T_1	40.56	144.27	0.76	40.71	45.48	50.95	22.48	27.28	31.37
L_5T_2	59.95	132.80	0.87	18.87	24.27	28.89	29.57	34.13	39.68
L_5T_3	60.72	146.13	0.61	23.47	28.34	31.25	40.84	45.87	51.19
Mean	57.86	140.81	0.75	24.04	28.32	33.87	32.87	37.59	43.04
SE	0.59	0.83	0.01	1.39	1.39	1.59	1.09	1.39	0.79
CD	1.19	1.68	0.02	2.81	2.81	3.21	2.20	2.81	1.59

c. Number of fruits per plant

Among lines, the highest and the lowest number of fruits per plant was noticed for L_1 (136.80) and L_3 (106.13) respectively. T_3 (72.20) which was on par with T_1 (70.47) produced the maximum and T_2 (56.40) the minimum number of fruits among testers. The best hybrid with respect to fruit production was L_1T_3 (153.2) whereas the lowest producer was L_4T_2 (83.27).

d. Average green fruit weight

Among the lines, L_2 (5.78 g) had the highest average green fruit weight while L_5 (3.20 g) had the lowest value. T_2 (4.19 g) and T_1 (1.53 g) respectively were the testers which possessed the maximum and minimum values within their group. Average green fruit weight among hybrids was maximum for L_1T_3 (6.54 g) which was on par with L_2T_3 (6.31 g) while it was minimum for L_5T_1 (2.03 g).

e. Fruit weight per plant

The best yielding line and tester were L_1 (389.20 g) and T_2 (178.20 g) respectively, while L_4 (316.80 g) on par with L_5 (319.33 g) among lines and T_1 (106.53 g) among testers were the lowest yielders. Fruit weight per plant among the hybrids was maximum for L_1T_3 (457.27) which was homogeneous with L_2T_3 (452.27) whereas the minimum yielding hybrid was L_4T_1 (183.40 g) which was on par with L_5T_1 (186.13 g) and L_3T_2 (192.13 g).

f. Fruit length

The lines which produced the longest and the shortest fruits were L_1 (9.77 cm) which was on par with L_2 (9.73 cm) and L_5 (4.53 cm) respectively, while among testers these positions were occupied by T_2 (10.56 cm) and T_1 (3.82 cm) respectively. Fruit length among the hybrids was maximum for L_2T_3 (10.39 cm) which was on par with L_1T_3 (10.32 cm) and L_2T_2 (10.28 cm) and minimum for L_5T_1 (4.05 cm).

g. Fruit girth

Fruit girth was maximum for line L_1 (6.17 cm) while the minimum value was for L_4 (4.40 cm). Among testers, T_2 (4.56 cm) and T_3 (3.24 cm) respectively possessed the highest and the lowest values. The hybrid with

maximum fruit girth was L_1T_3 (6.44 cm) while minimum fruit girth was displayed by L_4T_1 (3.41 cm).

h. Number of seeds per fruit

L_4 (120.47) and L_5 (46.40) were the lines with maximum and minimum number of seeds per fruit respectively, while among testers T_3 (116.00) and T_1 (43.53) had the highest and the lowest values in the respective order. Considering the hybrids, maximum number of seeds per fruit were produced by L_2T_3 (120. 47) whereas L_5T_1 (40.27) had the minimum.

i. Hundred seed weight

Maximum hundred seed weight was displayed by L_4 (0.635 g) among lines while L_3 (0.194 g) had the minimum weight. T_2 (0.459g) and T_3 (0.329g) occupied these positions respectively in the case of testers. Among the hybrids, maximum value was recorded for L_1T_1 (0.582 g), which was on par with L_4T_2 (0.563 g). The minimum value was for L_3T_3 (0.210 g).

j. Plant height

L_4 (93.33 cm) was the tallest and L_1 (41.71 cm) the shortest among lines while among testers, T_2 (82.83 cm) and T_1 (44.82cm) occupied these positions respectively. L_4T_3 (80.61 cm) was the tallest hybrid while the shortest was L_2T_1 (40.09 cm) which was homogeneous with L_1T_1 (40.34 cm) and L_5T_1 (40.56 cm).

k. Duration

Plant duration was the shortest and the longest for L_4 (141.00 days) and L_1 (163.60 days) among lines, T_2 (131.33 days) and T_1 (155.67 days) among testers and L_4T_3 (123.60 days) and L_3T_1 (161.53 days) among hybrids respectively.

l. Harvest index

Among lines, the maximum value was for L_1 (0.92) which was on par with L_2 (0.91) and the minimum for L_3 (0.61) while among testers, these positions were occupied by T_2 (0.87) and T_3 (0.64) respectively. L_1T_3 (0.92) had the maximum harvest index among hybrids, which was on par with L_2T_3

(0.91) while the minimum values were expressed by L_3T_2, L_4T_3 and L_5T_3 (0.61) which were on par with L_4T_1 (0.62).

m. Per cent disease incidence at 30 DAT

L_5 (37.25) recorded the minimum and L_2 (64.18) recorded the maximum values among lines while among testers, these positions were occupied by T_1 (10.27) and T_3 (13.18) respectively. Among hybrids, the minimum value was for L_2T_3 (10.48) which was on par with L_1T_3 (12.44) and the maximum was for L_3T_1 (57.03).

n. Per cent disease incidence at 45 DAT

Among lines, L_5 (41.90) showed the least disease incidence while L_2 (69.42) displayed the maximum incidence. Disease incidence was minimum for T_1 (10.77) and the two other testers were on par with it. Hybrid L_2T_3 (15.15) exhibited the least incidence and was on par with L_1T_3 (16.81) while the maximum incidence was for L_3T_1 (61.77).

o. Per cent disease incidence at 60 DAT

L_5 (47.51) was the least affected while L_2 (75.46) was the most affected among lines. Among testers T_1 (15.75) and T_3 (19.52) showed the minimum and maximum values respectively. L_2T_3 (20.38) was the hybrid, which showed the least incidence whereas L_3T_1 (67.93) showed the maximum incidence.

Per cent disease incidence among lines was the lowest for L_5 and the highest for L_2 at 30 DAT, 45 DAT and 60 DAT. Among testers, these positions were occupied by T_1 and T_3 at almost all the stages. L_2T_3 and L_3T_1 among hybrids recorded the minimum and the maximum values for per cent disease incidence at 30 DAT, 45 DAT and 60 DAT.

p. Disease intensity at 30 DAT

Among lines, the minimum and maximum values were recorded for L_4 (40.28) and L_2 (61.22) and among testers, T_1 (38.82) and T_3 (49.84) respectively. Among hybrids, the least value was for L_2T_3 (10.21), which was on par with L_1T_3 (11.21) and L_4T_3 (12.80) while the most susceptible one was L_2T_1 (41.16) which was homogeneous with L_5T_1 (40.71).

q. Disease intensity at 45 DAT

L_4 (45.47) showed the least disease intensity while L_2 (66.60) exhibited the maximum disease intensity among lines. Among testers, these positions were occupied by T_1 (43.26) and T_3 (55.55) respectively. Hybrid L_1T_3 (11.00) was the least affected by anthracnose and L_2T_3 (13.41) was on par with it. L_2T_1 (45.81) was the most susceptible and L_5T_1 (45.48) was on par with it.

r. Disease intensity at 60 DAT

Among lines L_4 (50.80) was the least affected whereas L_2 (71.43) was the most affected. T_1 (49.39) and T_3 (60.59) were the least and most affected respectively among testers. L_2T_3 (18.82) among hybrids, showed the least value for disease intensity and was on par with L_1T_3 (20.29). L_2T_1 (51.27) was the most affected and was on par with L_5T_1 (50.95).

Among lines, L_4 showed the least disease intensity while L_2 recorded the maximum disease intensity at 30 DAT, 45 DAT and 60 DAT. Among testers, the minimum and maximum disease intensity were recorded for T_1 and T_3 respectively at the three stages. Hybrid L_2T_3 showed the least disease intensity at 30 DAT and 60 DAT while L_2T_1 recorded the maximum disease intensity at the three stages.

4.2.4 Proportional Contribution of Parents and Hybrids

Proportional contribution of line, testers and hybrids to the total variation in each of the fourteen characters under study are presented in Table 36 and Fig. 9.

Lines contributed to most of the total variation in days to first flowering (95.00 %), number of branches (78.32 %), number of fruits per plant (62.51 %), hundred seed weight (45.06 %) and harvest index (65.05 %). Proportional contribution towards average green fruit weight (62.85 %), fruit weight per plant (73.79 %), fruit length (65.92 %), fruit girth (58.67 %), number of seeds per fruit (60.12 %), plant height (71.95 %) and disease intensity (59.85 %) was maximum by testers. With regard to duration of the crop (39.05 %) and per cent disease incidence (40.80 %) the maximum proportional contribution was expressed by hybrids.

Table 36. Proportional contribution of parents and hybrids

SL. No.	Characters	Proportional contribution		
		Lines	Testers	Hybrids
1	Days to first flowering	95.00	1.06	3.93
2	Number of branches	78.32	8.46	13.25
3	Number of fruits per plant	62.51	25.23	12.26
4	Average green fruit weight	35.85	62.85	1.30
5	Fruit weight per plant	19.46	73.79	6.75
6	Fruit length	25.01	65.92	9.07
7	Fruit girth	38.18	58.67	3.15
8	Number of seeds per fruit	23.18	60.12	16.70
9	100-seed weight	45.06	33.17	21.76
10	Plant height	18.97	71.95	9.08
11	Duration	30.23	30.72	39.05
12	Harvest index	65.05	0.76	34.19
13	Percentage disease incidence	40.74	18.46	40.80
14	Disease intensity	17.46	59.85	22.69

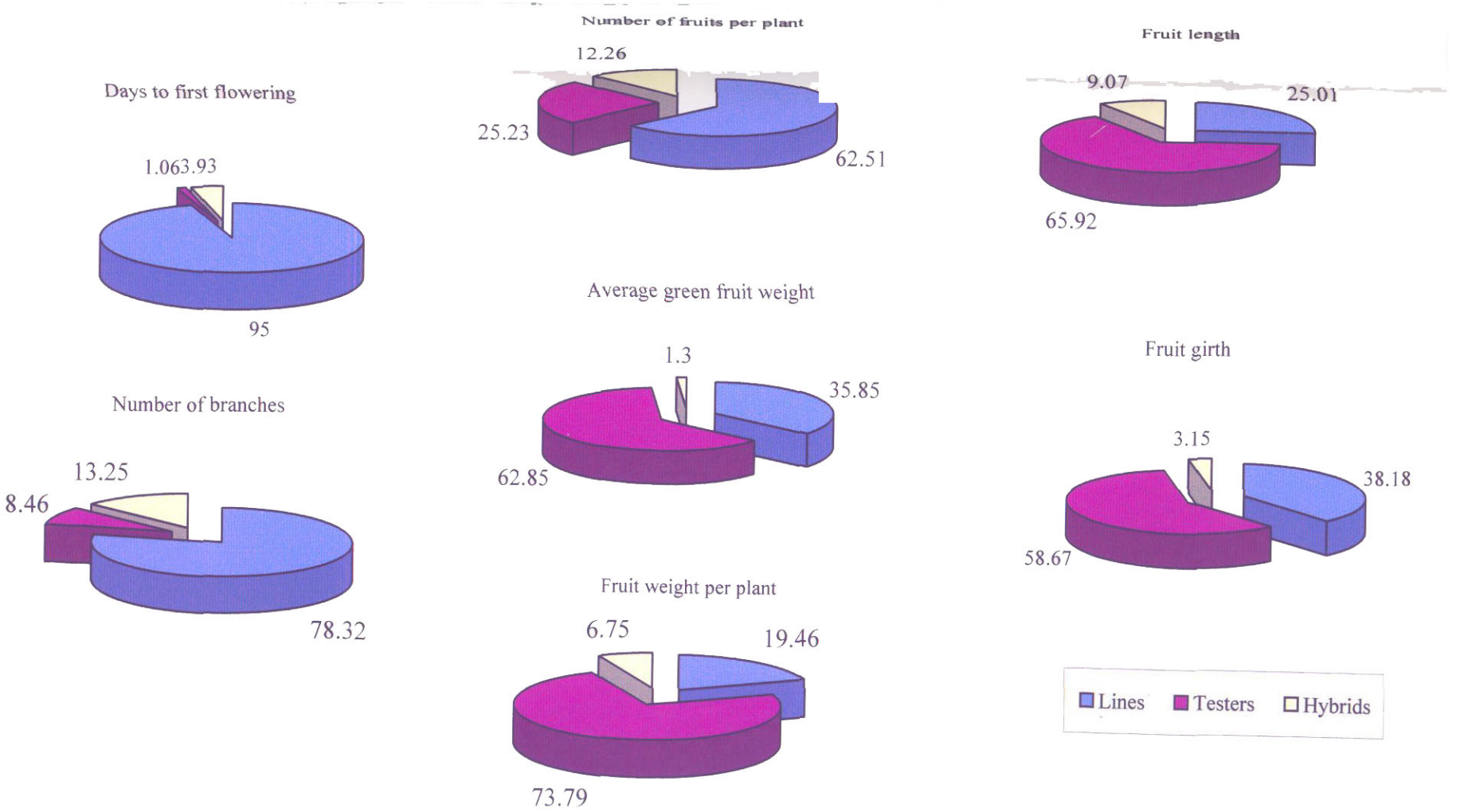


Fig. 9. Proportional contribution of parents and hybrids

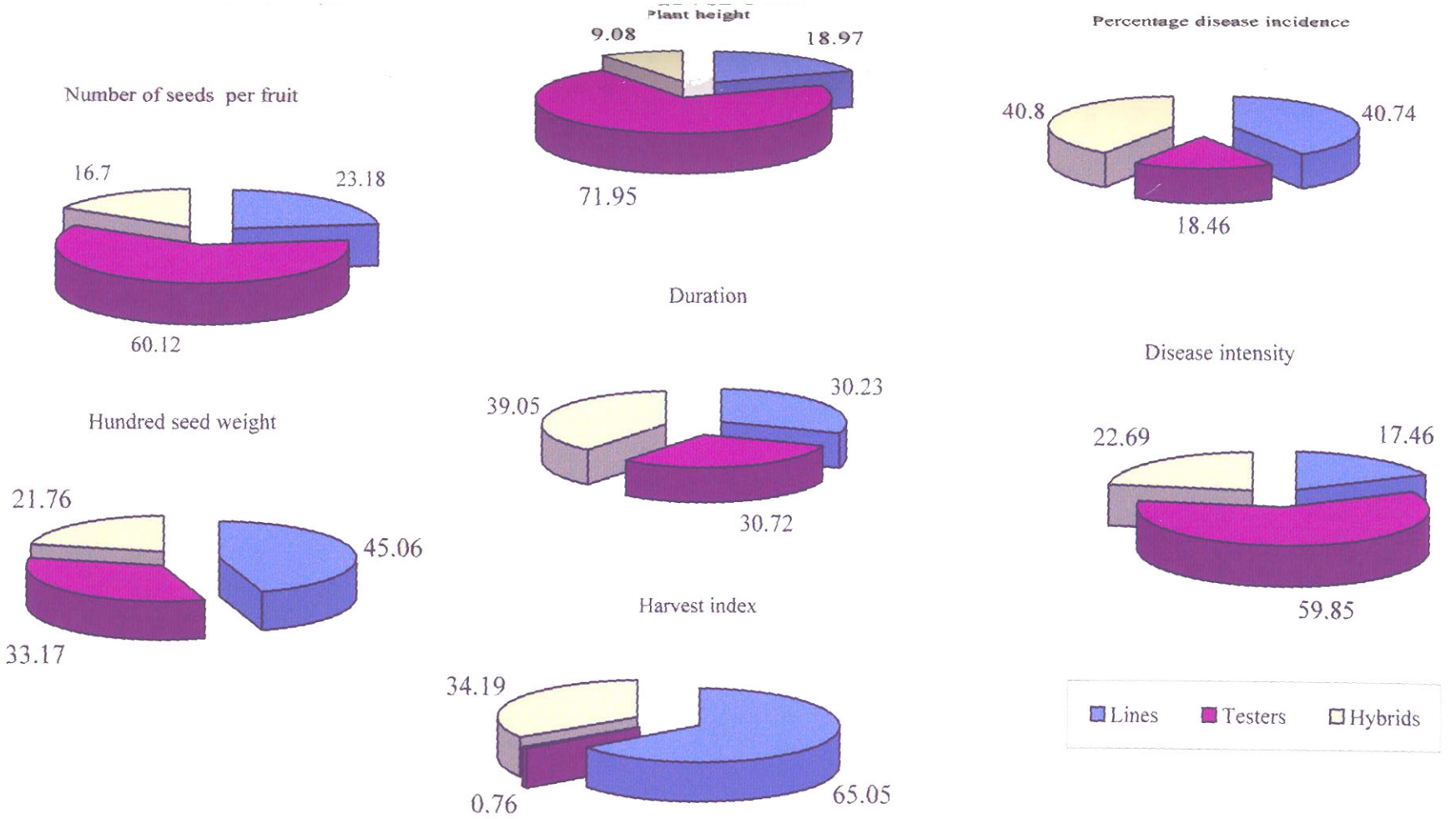


Fig. 9. Continued

4.3 GENERATION MEAN ANALYSIS

Generation mean analysis was done for the two selected crosses L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) (Plate 7) with respect to 16 characters. The results of generation mean analysis are presented in Table 37. The F_1, F_2, B_1 and B_2 generations of the selected crosses and their fruit characteristics are presented in Plates 8 and 9 respectively.

a. Days to first flowering

Among the generations, the lowest and the highest means were recorded by B_1 and P_2 in cross 1 and F_1 and B_2 in cross 2. The mean values of F_1 were less than those of F_2 in both the crosses.

Scale A was non significant in both the crosses while scale B was significant in cross 2 indicating the presence of non allelic interactions. Significance was observed for scale C and scale D in both the crosses.

Among the genetic components, m was significant and greater than all other effects in both the crosses. Negatively significant additive effect (d) and dominance effect (h) was observed in cross 1 and cross 2.

Among the interaction effects, additive x additive (i) and additive x dominance (j) effects were negative and significant in the two crosses. Dominance x dominance (l) effect was positive and significant in cross 1 only. Opposite signs of h and l indicated the duplicate nature of epistasis in both the crosses.

b. Number of branches

In both the crosses, number of branches was the highest for P_1 and the lowest for P_2.

Scales A and B were negative and significant in cross 2 while it was positive and significant with respect to scale D. None of the scales was significant in cross 1 indicating absence of epistatic effect. Scale C was non significant in both the crosses.

Both the crosses exhibited positive significance of m and d effects. Additive x additive (i) effect was negative and significant while dominance x dominance (l) effect was positive and significant in cross 2 only. The h, i, j

A

B

(A) Jwalamukhi x Ujwala
(B) Jwalasakhi x Ujwala

Plate 7. Selected hybrids

Table 37. Generation means (± SE), scale values (± SE) and estimates of genetic components (± SE) in two selected crosses of chilli

	Days to first flowering		Number of branches		Number of fruits per plant		Average green fruit weight		Fruit weight per plant	
	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2
P_1	46.00 ±2.09	46.27 ±1.46	6.33 ±0.36	6.27 ±0.30	286.47 ±23.25	304.80 ±34.74	4.03 ±0.15	5.28 ±0.33	1075.33 ±90.80	1118.93 ±74.36
P_2	54.60 ±1.40	53.93 ±0.44	3.47 ±0.24	3.60 ±0.34	100.33 ±3.13	98.27 ±4.69	1.49 ±0.11	1.56 ±0.07	126.20 ±6.01	136.07 ±4.35
F_1	42.67 ±1.88	40.60 ±0.51	6.27 ±0.48	6.23 ±0.43	379.70 ±22.59	350.13 ±17.61	4.63 ±0.26	4.44 ±0.31	1413.53 ±61.05	1399.27 ±36.69
F_2	51.60 ±0.46	52.60 ±0.55	5.28 ±0.31	5.45 ±0.24	372.29 ±16.69	384.15 ±9.73	5.19 ±0.19	5.07 ±0.18	1601.17 ±45.31	1508.76 ±14.66
B_1	41.60 ±0.64	42.20 ±0.62	5.28 ±0.44	5.18 ±0.34	258.11 ±13.91	248.31 ±12.98	3.26 ±0.16	3.12 ±0.16	663.91 ±28.47	631.11 ±27.13
B_2	49.93 ±1.12	55.27 ±2.36	4.29 ±0.33	3.64 ±0.22	214.33 ±14.61	207.04 ±8.79	2.23 ±0.07	2.14 ±0.09	396.09 ±18.55	297.51 ±8.50
A	-5.47 ±3.09	-2.47 ±1.99	-0.96 ±1.06	-2.14* ±0.86	-149.94* ±42.72*	-158.31** ±46.81	-2.14** ±0.44	-3.49** ±0.56	-1161.04** ±123.35	-1255.97** ±99.09
B	2.60 ±3.24	16.00** ±4.76	-1.16 ±0.84	-2.54** ±0.71	-51.37 ±37.07	-34.31 ±25.32	-1.67** ±0.32	-1.72** ±0.36	-747.56** ±71.69	-940.31** ±40.67
C	20.47** ±4.89	29.00** ±2.87	-1.21 ±1.63	-0.52 ±1.38	342.97* ±83.97	433.25** ±63.13	5.99** ±0.94	4.52** ±1.00	2376.09** ±236.73	1981.51** ±119.89
D	11.67** ±1.58	7.73** ±2.68	0.45 ±0.83	2.08** ±0.64	272.14* ±39.01	312.94** ±24.99	4.90** ±11.69	4.87** ±0.39	2142.35** ±96.79	2088.89** ±40.85
m	51.60** ±0.46	52.60** ±0.55	5.28** ±0.31	5.45** ±0.24	372.29** ±16.69	384.15** ±9.73	5.19** ±0.19	5.07** ±0.18	1601.17** ±45.31	1578.06** ±14.66
d	-8.33** ±1.29	-13.07** ±2.44	1.53** ±0.55	1.53** ±0.40	43.78* ±20.18	41.27** ±15.67	1.03** ±0.17	0.98** ±0.18	267.82** ±33.98	333.60** ±28.43
h	-30.97** ±3.90	-24.97** ±5.43	0.47 ±1.74	-2.87* ±1.36	-357.99** ±82.06	-477.28** ±55.82	-7.93** ±0.88	-8.73** ±0.87	-3471.93** ±208.01	-3406.03** ±96.99
i	-23.33** ±3.18	-15.47** ±5.35	-0.89 ±1.66	-4.17** ±1.27	-544.28** ±78.02	-625.88** ±49.98	-9.80** ±0.84	-9.75** ±0.79	-4284.69** ±193.57	-4177.79** ±81.69
j	4.03** ±1.80	-9.23** ±2.55	0.10 ±0.59	0.20 ±0.46	-49.29* ±23.33	-62.00** ±23.51	-0.23 ±0.19	-0.89** ±0.25	206.74** ±56.79	-157.83** ±46.86
l	26.20** ±7.11	1.93 ±10.17	3.00 ±2.73	8.86** ±2.13	745.59** ±116.46	818.49** ±88.97	13.60** ±1.17	14.96** ±1.24	6193.29** ±272.97	6374.09** ±165.25
Epi	*D*	*D*	*C*	*D*	*D*	*D*	*D*	*D*	*D*	*D*

Table 37 continued

	Fruit length		Fruit girth		No. of seeds per fruit		100 seed weight		Plant height	
	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2
P_1	9.70 ±0.16	9.99 ±0.18	5.79 ±0.19	6.09 ±0.15	53.73 ±3.84	61.60 ±5.63	0.582 ±0.033	0.506 ±0.056	48.58 ±2.05	63.41 ±4.21
P_2	5.71 ±0.21	5.53 ±0.24	3.27 ±0.18	3.16 ±0.15	99.00 ±7.30	103.20 ±5.87	0.319 ±0.029	0.602 ±0.017	58.16 ±4.87	62.25 ±3.71
F_1	9.51 ±0.19	9.10 ±0.12	5.28 ±0.17	5.02 ±0.27	95.06 ±4.93	80.67 ±5.56	0.509 ±0.025	0.529 ±0.031	62.68 ±2.13	64.03 ±2.71
F_2	10.08 ±0.08	9.41 ±0.14	6.00 ±0.09	6.55 ±0.19	98.88 ±2.67	104.65 ±3.95	0.560 ±0.015	0.620 ±0.018	67.73 ±1.12	70.95 ±1.62
B_1	8.64 ±0.14	8.78 ±0.21	4.56 ±0.18	4.97 ±0.24	91.98 ±2.00	61.82 ±1.75	0.697 ±0.038	0.519 ±0.024	60.34 ±1.56	60.98 ±2.21
B_2	6.92 ±0.20	7.20 ±0.27	3.88 ±0.14	4.12 ±0.18	94.91 ±4.74	73.58 ±3.43	0.376 ±0.024	0.304 ±0.019	65.39 ±1.99	66.03 ±2.43
A	-1.94** ±0.37	-1.52** ±0.48	-1.96** ±0.45	-1.19* ±0.57	-24.84** ±7.43	-18.62* ±8.65	0.702 ±0.077	0.003 ±0.081	9.42* ±4.29	5.47 ±2.52
B	-1.39** ±0.49	-0.22 ±0.59	-0.79* ±0.38	0.05 ±0.47	-4.24 ±12.96	-36.71** 1±0.61	-0.076 ±0.053	-0.127* ±0.052	9.93 ±6.64	5.78 ±6.68
C	5.91** ±0.58	3.94* ±0.69	4.39** ±0.57	6.91** ±0.96	52.65** ±16.72	92.48** ±20.97	0.320** ±0.090	0.071 ±0.074	38.82** ±8.14	19.91 ±4.21
D	4.62** ±0.29	2.84* ±0.45	3.57** ±±0.29	4.02** ±0.48	40.87** ±7.42	73.91** ±8.79	-0.152 ±0.038	0.416** ±0.037	8.73** ±3.38	14.88** ±4.60
m	10.08** ±0.08	9.42** ±0.14	6.00** ±0.09	6.56** ±0.19	98.88** ±2.67	104.65 ±3.95	0.056** ±0.015	0.062** ±0.018	67.73** ±1.12	70.95 ±1.61
d	1.72 ±0.24	1.58** ±0.34	0.68** ±0.23	0.85 ±0.29	-32.93** ±5.15	-11.76** ±3.85	0.052 ±0.038	0.021** ±0.031	-5.05 ±2.53	-5.05 ±3.28
h	-7.43** ±0.64	-4.34** ±0.92	-6.38** ±0.64	-7.65** ±1.01	-63.04** ±16.18	-149.55 ±18.89	0.036 ±0.077	-0.066 ±0.074	-10.17 ±7. 57	-15.57 ±6.26
i	-9.24** ±0.59	-5.68** ±0.89	-7.14** ±0.59	-8.05** ±0.97	-81.74** ±14.85	-147.81** ±17.58	0.033 ±0.077	-0.083 ±0.074	-19.47** ±6.77	-29.77** ±9.21
j	-0.27 ±0.28	-0.65 ±0.37	-0.58* ±0.27	-0.62 ±0.31	-10.30 ±6.60	9.04 ±5.60	0.038 ±0.038	0.066 ±0.042	-0.26 ±3.66	-0.63 ±4.44
l	12.57** ±1.14	7.42** ±1.53	9.89** ±1.09	9.18** ±1.53	110.83** ±26.54	203.15** ±26.05	0.093 ±0.055	0.095 ±0.074	0.12 ±12.98	0.46 ±13.67
Epi	*D*	*D*	*D*	*D*	*D*	*D*	*C*	*D*	*D*	*D*

Table 37 continued

	Duration of the crop		Harvest Index		Capsaicin content		Oleoresin content		Per cent disease incidence 30 DAT	
	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2
P_1	155.06 ±3.52	148.53 ±2.51	0.79 ±0.01	0.75 ±0.03	0.15 ±0.01	0.15 ±0.01	13.18 ±0.26	12.52 ±0.44	50.87 ±1.23	54.33 ±2.13
P_2	133.13 ±1.69	122.27 ±2.11	0.59 ±0.03	0.52 ±0.02	0.33 ±0.02	0.34 ±0.02	10.09 ±0.42	10.50 ±0.61	31.37 ±.043	32.60 ±0.64
F_1	148.83 ±2.37	140.17 ±2.78	0.71 ±0.02	0.76 ±0.02	0.45 ±0.02	0.42 ±0.02	12.47 ±0.43	10.91 ±0.67	23.10 ±2.58	22.67 ±1.04
F_2	161.07 ±1.18	154.45 ±2.04	0.73 ±0.01	0.74 ±0.01	0.61 ±0.01	0.70 ±0.01	10.98 ±0.28	10.01 ±0.34	14.60 ±1.90	16.07 ±1.56
B_1	137.38 ±1.39	126.69 ±0.99	0.61 ±0.01	0.59 ±0.01	0.42 ±0.04	0.42 ±0.04	9.66 ±0.36	16.77 ±7.66	29.20 ±0.55	29.43 ±0.95
B_2	122.13 ±1.06	121.71 ±0.86	0.56 ±0.01	0.58 ±0.01	0.37 ±0.04	0.52 ±0.04	9.25 ±0.65	8.47 ±0.48	12.20 ±0.91	12.73 ±0.69
A	-29.14** ±5.07	-35.32** ±4.23	-0.28** ±0.03	-0.32** ±0.04	-0.03 ±0.05	0.27** ±0.08	-6.32** ±0.89	10.11 ±15.36	-15.57** ±3.06	-18.13** ±3.04
B	-37.70** ±3.59	-19.01** ±3.89	-0.18** ±0.04	-0.08** ±0.06	-0.08 ±0.06	0.29** ±0.08	-4.05** ±1.44	-4.48** ±1.33	-30.37** ±3.18	-29.80** ±1.85
C	58.40** ±7.75	66.68** ±10.38	0.13* ±0.07	0.97** ±0.13	0.97** ±0.13	1.47** ±0.06	-4.25** ±1.51	-4.80 ±1.97	-70.03** ±9.38	-68.00** ±6.96
D	62.02** ±2.94	60.51** ±4.28	0.30** ±0.02	0.51** ±0.07	0.54** ±0.07	0.45** ±0.06	3.06** ±0.93	-5.22 7.71	-12.20** 4.01	-10.03** ±3.34
m	161.07** ±1.18	154.45** ±2.03	0.73** ±0.01	0.74** ±0.01	0.62** ±0.03	0.70* ±0.01	10.98** ±0.02	10.01** ±1.93	14.60** ±1.93	16.07** ±1.56
d	15.24** ±1.74	4.98** ±1.31	0.05** ±0.01	0.02 ±0.01	-0.07 ±0.04	-0.10 ±0.05	0.40 ±0.74-	8.31 ±7.69	17.00** ±1.06	16.70** ±1.18
h	-120.51** ±6.63	-116.25** ±9.14	0.59** ±0.05	-0.49** ±0.05	-0.83** ±0.14	-0.73** ±0.12	-5.28** ±1.91	9.84 ±15.44	6.38 ±8.44	-0.73 ±6.85
i	-125.24** ±5.88	-121.01** ±8.55	0.61** ±0.04	-0.62** ±0.05	-1.09** ±0.14	-0.91** ±0.12	-6.12** ±1.87	10.44 ±15.42	24.40** ±8.01	20.07** ±6.68
j	4.28 ±2.62	-8.16** ±2.09	0.05* ±0.02	-0.10** ±0.02	0.03 ±0.03	0.01 ±0.06	-1.13 ±0.79	7.29 ±7.69	7.25** ±1.25	5.83** ±1.62
l	192.09** ±10.42	175.35 ±11.63	1.08** ±0.08	1.06** ±0.08	1.20** ±0.19	0.35 ±0.23	16.49** ±3.35	-16.08 ±30.80	21.23* ±10.29	27.87** ±8.40
Epi	*D*	*D*	*C*	*D*	*D*	*D*	*D*	*D*	*C*	*D*

Table 37 continued

	Per cent disease incidence 45 DAT		Per cent disease incidence 60 DAT		Disease intensity 30 DAT		Disease intensity 45 DAT		Disease intensity 60 DAT	
	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2	Cross 1	Cross 2
P_1	50.97 ±1.19	57.20 ±1.27	52.77 ±1.36	58.67 ±0.78	53.87 ±1.75	55.30 ±0.55	51.50 ±1.55	52.77 ±1.16	51.90 ±1.66	54.20 ±2.75
P_2	32.70 ±0.71	31.77 ±1.81	34.23 ±1.00	30.17 ±2.51	32.87 ±2.66	33.30 ±2.90	31.50 ±0.47	32.37 ±1.43	33.80 ±0.75	35.30 ±0.98
F_1	23.90 ±0.93	24.20 ±1.02	25.70 ±1.78	24.20 ±0.70	19.53 ±0.77	20.23 ±0.89	20.67 ±1.32	19.53 ±0.35	22.73 ±1.63	21.53 ±0.74
F_2	15.87 ±2.01	17.27 ±1.69	16.80 ±1.73	18.90 ±0.75	18.17 ±1.21	20.70 ±1.46	19.37 ±1.06	22.67 ±0.91	21.27 ±1.05	24.07 ±0.38
B_1	32.13 ±1.63	30.60 ±0.60	35.00 ±2.51	32.23 ±0.78	39.10 ±0.61	38.90 ±5.31	40.77 ±0.77	37.10 ±1.35	46.67 ±2.47	36.93 ±1.08
B_2	12.67 ±0.39	13.40 ±0.71	13.17 ±1.22	14.80 ±0.85	28.67 ±0.41	27.63 ±0.43	29.37 ±0.68	28.60 ±0.25	29.90 ±0.40	30.57 ±0.33
A	-10.60** ±3.59	-20.20** ±2.03	-8.47 ±5.49	-18.40** ±1.88	4.80* ±2.26	2.27 ±10.67	9.37** ±2.56	1.90 ±2.97	18.70** ±5.46	-1.87 ±3.58
B	-31.27** ±1.41	-29.17** ±2.52	-33.60** ±3.18	-24.77** ±3.12	4.93 ±2.89	1.73 ±3.16	6.57** ±1.96	5.30* ±1.55	3.27 ±1.97	4.30** ±1.39
C	-68.00** ±8.39	-68.30** ±7.42	-71.20** ±7.98	-61.63** ±4.23	-53.13** ±6.01	-46.27** ±6.78	-46.87** ±5.27	-33.53** ±4.15	-46.10** ±5.63	-36.30** ±3.62
D	-13.07** ±4.37	-9.47** ±3.52	-14.57** ±4.45	-9.23** ±1.89	-31.43** ±2.53	-25.13** ±6.07	-31.40** ±2.37	-20.37** ±2.29	-34.03** ±3.27	-19.37** ±1.37
m	15.87** ±20.2	17.27** ±1.69	16.80** ±1.73	18.90** ±0.75	18.17** ±1.21	20.70** ±1.46	19.37** ±1.06	22.67** ±0.91	21.27** ±1.05	24.07** ±0.38
d	19.47** ±1.67	17.20** ±0.93	21.83** ±2.79	17.43** ±1.15	10.43** ±0.73	11.27* ±5.33	11.40** ±1.03	8.50** ±1.37	16.77** ±2.50	6.37** ±1.13
h	8.20 ±8.81	-1.35 ±7.19	11.33 ±9.12	-1.75 ±4.07	39.03** ±5.37	26.20* ±12.27	41.97** ±4.98	17.70** ±4.67	47.95** ±6.80	15.52** ±3.19
i	26.13** ±8.73	18.93** ±7.03	29.13** ±8.90	18.47** ±3.79	62.87** ±5.07	50.27** ±12.15	62.80** ±4.74	40.73** ±4.57	68.07** ±6.53	38.73** ±2.74
j	10.33** ±1.81	4.48** ±1.44	12.57** ±2.92	3.18 ±1.75	-0.07 ±1.76	0.27 ±5.53	1.40 ±1.31	-1.70 ±1.66	7.71** ±2.66	-3.08 ±1.85
l	15.73 ±10.73	30.43** ±8.30	12.93 ±13.72	24.70** ±6.26	-72.60** ±6.68	-54.27* ±22.37	-78.73** ±6.70	-47.93** ±6.89	-90.03** ±11.49	-41.17** ±5.79
Epi	*C*	*D*	*C*	*D*	*D*	*D*	*D*	*D*	*D*	*D*

* Significant at 5% level

** Significant at 1% level

Cross 1

Cross 2

Plate 8. F_1, F_2, B_1 and B_2 generations of the two selected crosses

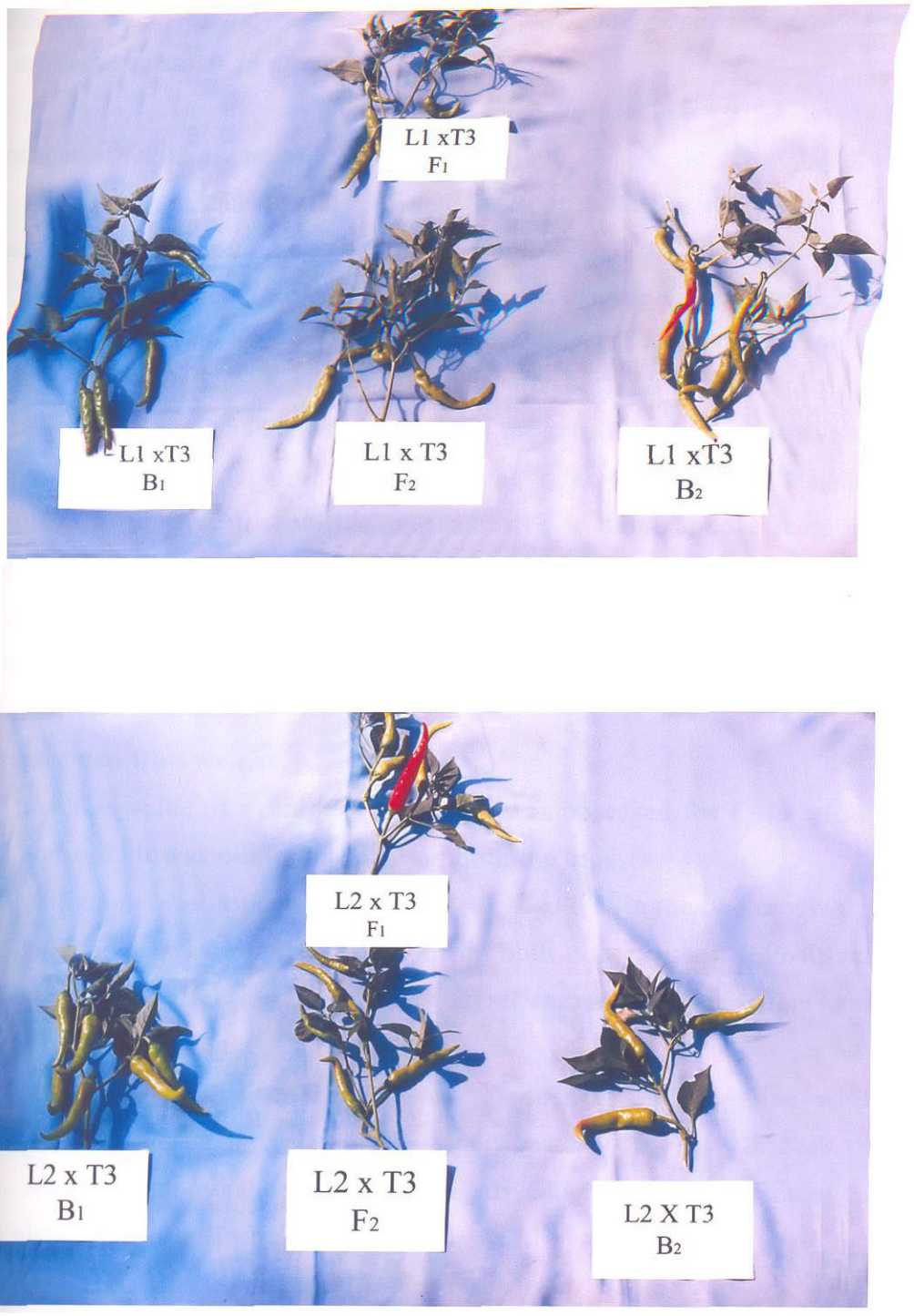


Plate 9. Fruit characteristics of F_1, F_2, B_1 and B_2 generations of the two selected crosses

and l effects were non significant for cross 1. Similar signs of h and l indicated complementary epitasis in cross 1 while their opposite signs showed the duplicate epistasis in cross 2.

c. Number of fruits per plant

The lowest means were recorded by P_2 in both the crosses while the highest mean was recorded by F_1 in cross 1 and F_2 in cross 2.

Scale A was negative and significant while scale C and scale D were positive and significant in both the crosses. None of the crosses exhibited significance for scale B.

The effect of m was significant in both the crosses. d was positive and significant while h was negative and significant in the two crosses. Negative and significant additive x additive and additive x dominance effects and positive and significant dominance x dominance effects were shown by cross 1 and cross 2. Opposite signs of h and l indicated the duplicate nature of epistasis in both the crosses.

d. Average green fruit weight

Maximum value of average fruit weight was observed for F_2 in cross 1 and P_1 in cross 2. It was minimum for P_2 in both the crosses.

Significance was noticed for scales A, B, C and D in the two crosses.

Significance was observed for m in both the crosses. Positively significant additive effect and negatively significant dominance effect were noticed in the two crosses.

Additive x additive interaction was significant and negative while dominance x dominance interaction was significant and positive in both the crosses. Additive x dominance effect was negative and significant in cross 2.

Epistasis was duplicate in the two crosses.

e. Fruit weight per plant

The highest and the lowest fruit weight per plant were exhibited by F_2 and P_2 in both the crosses.

Scales A, B, C and D were significant for the two crosses.

In both the crosses, m was significant. Positive and significant additive effect and negative and significant dominance effect were also observed for the two crosses.

Additive x additive and additive x dominance effects were negative and significant while dominance x dominance effect was positive and significant for both the crosses. Duplicate epistasis was evident for the two crosses.

f. Fruit length

The longest fruits were observed in F_2 and P_1 in crosses 1 and 2 respectively while the minimum fruit length was recorded for P_2 in both the crosses.

Significance for scales A, B, C and D were observed in cross 1 while all the scales except B was significant in cross 2.

m was significant in crosses 1 and 2. Additive effect (positive) and dominance effect (negative) were also noticed in the two crosses.

Negative and significant additive x additive and positive and significant dominance x dominance effects were observed in both the crosses while additive x dominance effect was significant in none of the crosses. Duplicate epistasis was also evident in the two crosses.

g. Fruit girth

Maximum and minimum values of fruit girth were observed for F_2 and P_2 respectively in both the crosses.

Scales A, B, C and D were significant in cross 1 while all the scales except scale B were significant in cross 2.

In the two crosses, m was found to be significant. Significant and positive additive effect and significant and negative dominance effect were observed. Cross 1 showed significance for i, j and l effects while cross 2 showed significance for i and l effects only. Duplicate epistasis was evident in the two crosses.

h. Number of seeds per fruit

Minimum number of seeds per fruit was observed for P_1 in both the crosses while the maximum value was recorded by P_2 for cross 1 and F_2 for cross 2.

Significance for scales A, C and D were observed for cross 1 while all the four scales were significant for cross 2.

m was significant for both the crosses. Additive effect, dominance effect and additive x additive effects were negative and significant while dominance x dominance effect was positive and significant for the two crosses. j effect was non significant for both the crosses. The epistasis for the crosses was duplicate in nature.

i. Hundred seed weight

The minimum hundred seed weight was exhibited by P_2 in both the crosses while the maximum was shown by B_1 in cross 1 and F_2 in cross 2.

Only scale C was significant in cross 1, while scales B and D were significant in cross 2.

m was significant in both the crosses. d was significant for cross 2 while all other effects were non significant for both the crosses. Epistasis was complementary in cross 1 while it was duplicate in cross 2.

j. Plant height

In both the crosses, plant height was maximum for F_2 while the minimum height was recorded for P_1 in cross 1 and B_1 in cross 2.

Scales A, C and D were significant for cross 1 while only scale D was significant for cross 2.

m was significant for both the crosses. Additive x additive effect was negative and significant for the two crosses while d, h, j and l effects were non significant. Presence of duplicate epistasis was also evident for the two crosses.

k. Duration of the crop

Plant duration was minimum for B_2 and maximum for F_2 in both the crosses.

All the four scales were significant for the two crosses.

Significance was observed for m, d, h, i and l in both the crosses while additive x dominance effect was significant and negative only in cross 2. Epistasis was duplicate for the crosses.

l. Harvest index

Maximum value was recorded by P_1 and F_1 in crosses 1 and 2 while the minimum value was recorded by B_2 and P_2 in crosses 1 and 2 respectively.

Scales A, B, C and D were significant for both the crosses.

m, h, i, j and l effects were significant for both the crosses while d effect was significant for cross 1 only. Epistasis was complementary for cross 1 and duplicate for cross 2.

m. Capsaicin content

The highest and the lowest values were recorded by F_2 and P_1 in both the crosses.

All the four scales were significant for cross 2 while only scales C and D were significant for cross 1.

Significance was observed for m in both the crosses. h and i effects were significant and negative in both the crosses while l was significant in cross 1 only. Duplicate epistasis for the two crosses was evident.

n. Oleoresin content

The minimum value was recorded by B_2 in both the crosses while the maximum value was recorded by P_1 in cross 1 and B_1 in cross 2.

All the four scales were significant for cross 1 while only scale B was significant for cross 2.

m was significant for both the crosses. h, i and l effects were significant for cross 1. Duplicate epistasis could be observed for the crosses.

o. Per cent disease incidence at 30 DAT

B_2 and P_1 generations exhibited the minimum and maximum values respectively for both the crosses.

Scales A, B, C and D were significant for the two crosses.

m was significant for the crosses. The effect d was positively significant for both the crosses. i, j and l effects were also positively significant for he two crosses. h was not significant in either of the crosses. Magnitude of i was the highest in cross 1 while the magnitude of l was the

highest in cross 2. Complimentary epistasis was noticed in cross 1 while duplicate epistasis was observed in cross 2.

p. Per cent disease incidence at 45 DAT

The lowest value was recorded by B_2 and the highest value was recorded by P_1 in both the crosses.

All the four scales were significant for the two crosses.

Among the genetic components, m, d, i, j and l were positive and significant for both the crosses while h was non significant for them.

Epistasis was complementary in cross 1 and duplicate in cross 2.

q. Per cent disease incidence at 60 DAT

B_2 recorded the minimum incidence while P_1 recorded the maximum incidence in both the crosses.

All the four scales were significant in cross 2 while scales B, C and D were significant in cross 1.

m and d effects were significant while h was non significant in both the crosses. i and j effects were significant for cross 1 while i and l effects were significant for cross 2.

Epistasis was complementary in cross 1 and duplicate in cross 2.

r. Disease intensity at 30 DAT

Generations F_2 and F_1 recorded the minimum scores in crosses 1 and 2 respectively while P_1 recorded the maximum score in both the crosses.

Scales A, C and D were significant in cross 1 while scales C and D were significant in cross 2.

m, d, h and i effects were positive and significant while l effect was negative and significant in both the crosses. Epistasis was duplicate in them.

s. Disease intensity at 45 DAT

Generations F_2 and F_1 recorded the minimum scores in cross 1 and cross 2 respectively while P_1 recorded the maximum score in both the crosses.

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

m, d, h and i effects were positive and significant while l effect was negative and significant in both the crosses. Duplicate epistasis was noticed in the two crosses.

t. Disease intensity at 60 DAT

The minimum score for cross 1 was recorded by F_2 while the minimum score for cross 2 was recorded by F_1.

Scales A, C and D in cross 1 and scales B, C and D in cross 2 were significant.

m, d, h, i, j, and l effects were significant in cross 1 while all of them except effect j were significant in cross 2. Duplicate epistasis was noticed in both the crosses.

4.3.1 Transgressive Segregants

Transgressive segregants were observed in the two crosses for almost all the characters except for days to first flowering in the two crosses and duration of the crop in cross 1 (Table 38). The highest value was observed for fruit weight per plant in cross 1 (92.00%) and in cross 2 (90.00%).

Minimum values of transgressive segregants were observed for oleoresin content (3.30%) in cross 1 and for duration of the crop in cross 2.

Table 38.Transgressive segregants in two crosses of chilli

Sl.No.	Characters	Transgressive segregants (%)	
		Cross 1	Cross 2
1.	Days to first flowering	Nil	Nil
2.	Number of branches	41.30	29.33
3.	Number of fruits per plant	74.67	76.00
4.	Average green fruit weight	66.67	46.67
5.	Fruit weight per plant	92.00	90.00
6.	Fruit length	62.67	32.00
7.	Fruit girth	57.30	49.00
8.	Number of seeds per fruit	46.60	51.00
9.	Hundred seed weight	50.67	77.33
10.	Plant height	81.33	61.33
11.	Duration of the crop	Nil	1.30
12.	Harvest index	30.67	38.67
13.	Capsaicin content	90.00	89.13
14.	Oleoresin content	3.30	13.30
15.	Percent disease incidence	30.31	32.17
16.	Disease intensity	29.00	31.12

DISCUSSION

5. DISCUSSION

The salient results gathered in the light of the present investigation are discussed hereunder.

5.1. GERMPLASM EVALUATION

Selection is the cardinal principle of plant breeding. It is the sorting out of desirable representatives from a group of genotypes thereby allowing only their progenies to perpetuate. Selection operates in all kinds of variability – whether existing or created – and it is the corner stone of all plant breeding practices (Sharma, 1994). The breeding procedure, efficiency of selection and final success depend on the germplasm chosen (Zelleke, 2000). Genetic improvement is dependent on the magnitude of genetic variability existing in a germplasm. So, as many genotypes as possible, from different ecogeographical situations, should be assembled and evaluated before adopting any particular breeding strategy.

Keeping this principle in mind, 76 genotypes of *Capsicum annuum* of diverse origin were brought together and evaluated for their resistance to anthracnose as well as yield potential.

5.1.1 Screening for Anthracnose Resistance

In order to develop new varieties resistant to anthracnose, identification of source of resistance forms the initial step. The 76 genotypes of chilli were screened for anthracnose resistance in the field under natural epiphytotic conditions during three crop stages *viz.*, 30 DAT, 45 DAT and 60 DAT. Large scale screening of chilli germplasm for anthracnose was attempted earlier by Ullasa *et al.* (1981), Jeyalakshmi and Seetharaman (1998) and Hegde and Anahosur (2001).

5.1.1.1 Per cent Disease Incidence

At 30 DAT, 45 DAT and 60 DAT, majority of the genotypes showed anthracnose disease incidence varying between 20 and 30 per cent. However, Pearson *et al.* (1984) while studying 23 cultivars, found anthracnose incidence rates ranging from 0 to 17.2 per cent.

T_{20} (Kidangoor Local-1), T_{42} (Ujwala) and T_{76} (Pant C 1) showed less than 10 per cent disease incidence at 30, 45 and 60 DAT. T_1, T_2, T_6 and T_{23} showed high incidence during all the stages.

5.1.1.2 Anthracnose Disease Intensity

In the current study, disease intensity gradually increased from 30 DAT to 60 DAT.

At 30 DAT, majority of the genotypes were found to be slightly susceptible while a few were severely affected by the disease. But three genotypes *viz.*, T_{20} (Kidangoor Local-1), T_{42} (Ujwala) and T_{76} (Pant C 1) were found moderately resistant.

The same trend continued during 45 DAT and 60 DAT with the number of slightly susceptible genotypes increasing as the number of days after transplanting increased. T_{20}, T_{42} and T_{76} remained moderately resistant throughout the crop period while T_1, T_2, T_6, T_{23} and T_{35} were severely susceptible.

Roy *et al.* (1998) evaluated 24 chilli genotypes and found some of the genotypes to be resistant. However, six were moderately resistant. Basak (1997) also could find only moderate resistance for anthracnose while evaluating ten chilli genotypes.

5.1.2 Evaluation for Yield Traits

A knowledge of the extent of variability available in a germplasm is of great importance as it acts as the key factor, which provides a clear practice of genetic advancement, that can be achieved through selection. In quantitative characters, phenotypes are unreliable indicators of genotype and so it is desirable to test the genetic value of individuals prior to selection. As the observed variability in a population is the sum

total of variation arising due to genotypic and environmental effects, knowledge on the nature and magnitude of genetic variation leading to gain under selection is essential (Allard, 1960). Analysis of variance partitions the total phenotypic variation into genotypic and environmental (error) components. This provides information on the breeding value of genotypes involved and also the nature and magnitude of variability in the expression of a particular character.

5.1.2.1 Analysis of Variance

ANOVA revealed remarkable variation for all the traits under study. Among the 76 genotypes, T_{65} was the earliest to flower. For number of fruits per plant, T_1 ranked first and was on par with T_6 and T_2. T_{17} was superior for average green fruit weight. T_1 was the highest yielder and it was followed by T_{23} and T_2 which were on par. The longest fruits were produced by T_{20}. T_1 and T_2 recorded the highest value for harvest index. Capsaicin content was the highest for T_{20} and T_{69} while oleoresin content was maximum for T_{42}.

Several findings are available dealing with varietal variations in chilli with respect to a large number of characters. Some of the important works on variability include those of Rani (1996a) for fruit weight, fruit length and number of seeds per fruit, Jabeen *et al.* (1999) for fruit yield, Verma *et al.* (1998) for number of branches, number of fruits per plant, and fruit girth and Devi and Arumugam (1999a) for plant height and days to first flowering.

Reports, which are contradictory to the present findings, could also be met with. Bai *et al.* (1987) reported low variability for number of branches per plant. Vijayalakshmi *et al.* (1989) found low genotypic and phenotypic variance for number of primary branches, average green fruit weight, fruit length and fruit girth. As pointed out by Munshi and Behera (2000), fruit length had no considerable variation.

Per se performance of 76 genotypes revealed some promising types, which were superior for various characters as listed in Table 39.

Table 39. Genotypes superior for various traits

Treatment No.	Genotype	Superior traits identified
T_1	Jwalamukhi	Number of fruits per plant, fruit weight per plant, number of branches, duration of the crop, harvest index and oleoresin content
T_2	Jwalasakhi	Number of fruits per plant, fruit weight per plant, number of branches, duration of the crop, harvest index and oleoresin content
T_7	Pettah Local-2	Fruit girth
T_{16}	Samkranthi Local-1	Days to first flowering, fruit weight per plant and plant height
T_{17}	Samkranthi Local-2	Days to first flowering, average green fruit weight, fruit weight per plant and harvest index
T_{20}	Kidangoor Local - 1	Fruit length, plant height, harvest index, capsaicin content, oleoresin content and anthracnose resistance
T_{26}	Kattachira Local	Anthracnose resistance
T_{31}	Adichira Local-2	Number of seeds per fruit
T_{38}	Manjoor Local-1	Capsaicin content
T_{39}	Mitayikunnu Local-1	Capsaicin content
T_{42}	Ujwala	Capsaicin content, oleoresin content and anthracnose resistance
T_{52}	Vengeri Local	Anthracnose resistance
T_{67}	Areekode Local	Capsaicin content
T_{76}	Pant C1	Oleoresin content and anthracnose resistance

5.1.2.2 Genetic Parameters

The genetic parameters like variance, coefficient of variation, heritability and genetic advance provide a clear insight into the extent of variability and the relative measure of efficiency of selection based on phenotype.

5.1.2.2.1 Coefficient of Variation

Being unit free, coefficient of variation is an ideal tool for comparing the characters measured in diverse units.

As phenotypic value is an aggregate of genotypic effect and environmental influence, selection solely based on external parameters may be misleading. Thus genotypic coefficient of variation (GCV) is a more precise indicator of genetic variability in a population compared to phenotypic coefficient of variation (PCV).

In the current study, high phenotypic and genotypic coefficients of variation were observed for most of the traits including green fruit yield and its components. There was close association between the estimates of PCV and GCV. Similar result was reported by Pichaimuthu and Pappiah (1992) where the highest values of PCV and GCV were observed for fruit weight per plant.

Singh and Brar (1979), Nair *et al.* (1984), Gopalakrishnan *et al.* (1987a), Nandi (1993), Jabeen *et al.* (1999), Sreelathakumary and Rajamony (2002) and Nandadevi and Hosamani (2003a) have reported similar findings. PCV and GCV were very low for plant height and days to first flowering. Low PCV and GCV for plant height were already reported by Chaim and Paran (2000). Arya and Saini (1977) and Devi and Arumugam (1999a) have found low PCV and GCV for days to first flowering as found in the present study.

5.1.2.2.2 Heritability

Selection acts on genetic differences and the benefits from selection for a particular trait depends on its heritability (Allard, 1960.)

So it is clear that GCV alone is not sufficient for successful selection. GCV along with heritability would provide precise idea regarding the amount of genetic gain achievable through selection.

The extent to which a crop is capable of transmitting its potential to the succeeding generation is termed as its breeding value. If a breeder chooses certain genotypes as parents according to their phenotypic performance, the success in manipulating the characteristics of population could be predicted from the degree of correspondence between phenotype and breeding value. Heritability estimates show the degree to which the phenotype reflects the respective genotype and thereby the effectiveness with which selection of genotype could be practiced based on their phenotypic performance.

Present investigation revealed high heritability for all the characters studied. Very high heritability was shown by fruit weight per plant, fruit length, hundred seed weight, number of seeds per fruit and capsaicin content.

This result is in conformity with the reports of many earlier workers *viz.*, Das *et al.* (1990) for fruit weight per plant, Pichaimuthu and Pappiah (1995) for fruit length, Nayeema *et al.* (1998) for fruit weight per plant and number of seeds per fruit, Ibrahim *et al.* (2001) for fruit length, Rathod *et al.* (2002) for fresh fruit yield, hundred seed weight and fruit length, Sreelathakumari and Rajamony (2002) and Nandadevi and Hosamani (2003a) for yield and fruit length. Ghai and Thakur (1987) found low heritability for total yield, which is in contradiction to the above result.

5.1.2.2.3 Genetic Advance

High heritability in broad sense does not necessarily indicate high response to selection as it includes non additive genetic variance too. According to Johnson *et al.* (1955), high heritability coupled with high genetic advance would be a more reliable criterion than simple heritability value alone in predicting the real effects of selection.

Genetic advance indicates the progress that could be expected as a result of practicing selection on a particular population. High value of genetic advance indicates better and definite progress on the mean value of population in the succeeding generation. Traits showing high magnitude of heritabiliy coupled with genetic advance are controlled by additive gene action and hence amenable to genetic improvement through selection.

In the present study, high genetic advance was observed for fruit weight per plant, per cent disease incidence, number of fruits per plant, disease intensity,average green fruit weight and number of seeds per fruit. For duration of the crop, genetic advance was moderate. High heritability for yield per plant indicates the additive gene action involved in this trait, which makes its selection highly effective. This is in conformity with the opinion of Nandadevi and Hosamani (2003a). High genetic advance for leaf curl incidence was reported by Muthuswami (2004).Other supporting evidences include those of Varalakshmi and Babu (1991) and Kumar *et al.* (1993) for number of fruits per plant and number of seeds per fruit, Devi and Arumugam (1999a) and Jabeen *et al.* (1999) for number of seeds per fruit, Das *et al.* (1990) for fruit yield, Pichaimuthu and Pappaih (1995) for fruits per plant, Nayeema *et al.* (1998) for fresh fruit yield per plant, individual fruit weight and seeds per fruit, Ibrahim *et al.* (2001) for number of fruits per plant and Sreelalthakumary and Rajamony (2002) for yield per plant, fruits per plant and average green fruit weight. However, Ghai and Thakur (1987) found low genetic advance for number of fruits per plant, which is in disagreement with the present findings.

High heritability coupled with high genetic advance (as % of mean) was shown by all the characters studied except duration of the crop for which genetic advance was moderate. Predominance of additive genetic effects for these characters is revealed suggesting selection to be rewarding. High values of both heritability and genetic advance were

put forth by several workers like Meshram (1987) for days to first flowering and fruit length, Jabeen *et al.* (1999) for number of seeds per fruit, fruit yield and number of fruits per plant, Pichaimuthu and Pappiah (1995) for fruit length and fruit girth, Rathod *et al.* (2002) for number of fruits per plant, yield per plant and plant height, Sreelathakumary and Rajamony (2002) for number of fruits per plant, fruit weight, fruit length, fruit girth and fruit yield and Nandadevi and Hosamani (2003a) for fruit length and fruit yield per plant.

High heritability with low genetic advance for days to first flowering, plant height and number of primary branches were reported by Nair *et al.* (1984).

5.1.2.3 Association Analyses

5.1.2.3.1 Correlation

Correlation analysis provides reliable estimates on the nature, extent and direction of selection. Estimates of correlation coefficient form a strong foundation for developing selection index.

Most of the character combinations exhibited an interesting trend in that genotypic correlation coefficients were of the highest magnitude, followed by the corresponding phenotypic correlation coefficients. This corroborates with the finding of Ahmed *et al.* (1997a). Environmental correlation coefficients were found to be the lowest.

Deviation from the general trend could be noticed for association of certain characters. Phenotypic correlation coefficient exceeded genotypic correlation coefficient for the association of capsaicin content with both disease intensity and per cent disease incidence indicating the low association between those characters.

Analysing genotypic correlation in detail, the most important trait green fruit weight per plant (yield) exhibited positively significant association with number of branches per plant, number of fruits per plant, average green fruit weight, fruit length, fruit girth, hundred seed weight, duration of the crop, harvest index, capsaicin content, disease

intensity and per cent disease incidence. Yield showed desirable negatively significant association with days to first flowering. Hence selection based on the above traits would lead to improvement in yield.

Some of the reports supporting this finding are: positive association of fruit yield with fruit length by Gopalakrishnan *et al.* (1985), fruit seed number by Rani (1996b) and fruit weight, number of fruits per plant and primary branches per plant by Das and Chaudhary (1999b). Aliyu *et al.* (2000) and Nandadevi and Hosamani (2003a) have mentioned number of fruits per plant to be positively associated with yield. Further more, positive correlation of fresh chilli yield with hundred seed weight, harvest index and number of fruits per plant was reported by Rathod *et al.* (2002). Rao *et al.* (1981) found yield to be negatively correlated with days to flowering.

There are a few reports contradictory to the present findings. Gopalakrishnan *et al.* (1985) found negative correlation between yield and fruit girth. Jayasankar *et al.* (1987) observed only a slight association of yield with number of primary branches, fruit length, fruit girth and number of seeds per fruit and hence he suggested them to be secondary yield determinants. Chaim and Paran (2000) noticed low correlation between yield and fruit length. Significant negative correlation between capsaicin content and yield was reported by Kohli and Chatterjee (2000) while positive association of yield with days to flowering was reported by Sundaram and Ranganathan (1978).

Inter relationships of component characters were also analysed. Days to first flowering was negatively correlated with all the characters except with fruit length. Muthuswamy (2004) also found negative relationship for days to first flowering with many of the characters studied while noticing its positive correlation with fruit length similar to the present finding. But Mini (2003) observed negative association between days to first flowering and fruit length, which is in contrast to the present findings.

Number of branches was positively associated with number of fruits per plant. This is in accordance with the findings of Ahmed *et al.* (1997a) and Ibrahim *et al.* (2001). The positive correlation of number of branches with fruit yield and crop duration found in the present study is supported by the report of Jose (2001). The negative correlation of number of branches with seeds per fruit and the positive correlation with harvest index is in agreement with the findings of Muthuswamy (2004).

Present investigation revealed the positive association of number of fruits per plant with number of branches, average green fruit weight, fruit yield, crop duration, fruit girth, harvest index, capsaicin content and oleoresin content. Supporting evidences of the positive association of number of fruits per plant with number of branches (Bavaji and Murty, 1982), yield and crop duration (Jose 2001), fruit girth (Mini, 2003), harvest index, capsaicin content and oleoresin content (Muthuswamy, 2004) had been reported.

Average green fruit weight was found to be positively correlated with fruit yield, plant height, harvest index, capsaicin content and fruit girth in the present study. Positive association of average green fruit weight with yield and plant height (Mini, 2003) and harvest index and capsaicin content (Muthuswamy, 2004) had already been reported.

Fruit length was positively correlated with yield and plant height in the present study. This is supported by the findings of Mini (2003). Positive association of fruit length with capsaicin content as found in this study was observed by Muthuswamy (2004).

The positive association between number of seeds per fruit and capsaicin content noticed in this study is in accordance with the findings of Muthuswamy (2004). The positive correlation between hundred seed weight and yield found in the present investigation is supported by the findings of Jose (2001) while the positive association between hundred seed weight and oleoresin content by Muthuswamy (2004).

Positive association of harvest index with number of branches, number of fruits per plant, average green fruit weight, fruit yield per plant, fruit girth and crop duration was found in this study. Capsaicin content was found to be positively correlated with number of branches, number of fruits per plant, average green fruit weight, fruit yield per plant, plant height, crop duration and harvest index. These findings are in accordance with the reports of Muthuswamy (2004).

5.1.2.3.2 Path Analysis

Correlation coefficients reveal only the relation between yield and yield components but not the actual direct and indirect effects of the components on yield. Rate of crop improvement will be rapid if differential emphasis is given to the component characters during selection. The differential emphasis is to be given based on the degree of direct and indirect influence of the component characters on the economic character of interest as revealed by path coefficient analysis. Path analysis splits the genotypic coefficients into direct and indirect effects of the component characters on yield based on which crop improvement can be done more effectively.

The direct and indirect effects exerted on yield by the eight characters which had high genotypic correlation, were studied by path analysis.

Positive direct effect on yield was maximum for disease intensity followed by harvest index and number of fruits per plant. High direct effect in positive direction by disease index was pointed out by Xu *et al.* (1992). Positive direct effect of number of fruits per plant is in accordance with the findings of Deka and Shadeque (1997), Ahmed *et al.* (1997b), Munshi *et al.* (2000), Jose (2001) and Mini (2003).

Direct effect in the negative direction was the highest for per cent disease incidence followed by number of branches and fruit girth. Negative direct effect of number of branches was reported by Mini (2003).

Though the direct effect of number of branches was negative, its correlation with yield turned out to be positive mostly due to its positive indirect effect via disease intensity and number of fruits per plant. The positive indirect effect of number of branches through number of fruits per plant had been reported by Mini (2003).

The positive correlation of number of fruits per plant with yield was considerably enhanced due to its high indirect effect via disease intensity. The direct positive effect of average green fruit weight on yield was low but its indirect effect through harvest index and disease intensity were considerable which led to a high positive correlation with yield. Positive direct effect of average green fruit weight on yield was pointed out by Das and Chaudhary (1999 b), Jose (2001) and Mini (2003).

As against the reports of Sarma and Roy (1995), Deka and Shadeque (1997) and Munshi *et al.* (2000), fruit girth showed negative direct effect on yield in this study. But its correlation with yield turned out to be positive owing to its positive direct effect via disease intensity, harvest index and number of fruits per plant.

The positive direct effect of crop duration on yield was almost equal to its indirect effect via disease intensity resulting in a high positive correlation with yield. The positive direct effect of crop duration on yield was in accordance with the findings of Jose (2001).

The positive direct effect of harvest index was enhanced to a high correlation with yield due to its positive indirect effect through number of fruits per plant and disease intensity.

Very high positive direct effect of disease intensity with yield was decreased by its high indirect effect through per cent disease incidence in the opposite direction. High negative direct effect of per cent disease incidence was converted into high positive correlation by its positive indirect effect via disease intensity and number of fruits per plant.

5.1.2.4 Selection Index

Superior genotypes from a genetic stock can be selected by employing a suitable index with the help of discriminant function based on reliable characters. Selection index provides scope for greater efficiency in increasing the yield through selection for yield components.

Rani and Rani (1996) used a number of characters like fruit girth, pericarp weight, seed weight, pedicel weight, number of seeds per fruit and thousand seed weight for developing selection index in chilli.

Jose (2001) and Mini (2003) also used selection indices for the ranking of genotypes. In the present investigation, selection indices were formulated for the 76 genotypes, based on yield and its component characters.

In the present study, five genotypes T_1 (Jwalamukhi), T_2 (Jwalasakhi), T_{23} (Muvattupuzha Local-1), T_{16} (Samkranthi Local-1) and T_{35} (Vaikom Local-2) (redesignated as L_1, L_2, L_3, L_4 and L_5 respectively) belonging to the high yielding and anthracnose susceptible category were selected as female parents (lines) and three genotypes T_{76} (Pant C1), T_{20} (Kidangoor Local-1) and T_{42} (Ujwala) (redesignated as T_1, T_2 and T_3 respectively) which were moderately resistant to anthracnose were utilized as male parents (testers) for line x tester crossing programme.

5.2 LINE X TESTER ANALYSIS

Various biometrical methods can be used to direct the genetic make up of genotypes and also to evaluate effectively their combining ability, for developing a suitable breeding strategy. Line x tester analysis is a unique method, which allows the screening of a large number of genotypes at a time and is dependable in determining the relative ability of the males and females for making desirable hybrid combinations.

In the present study, line x tester analysis was undertaken to sort out the top ranking parents and crosses by examining their mean

performance, general combining ability of parents and specific combining ability and heterosis of hybrids. Significant variation existed for most of the traits as revealed by the ANOVA, which justifies the adequacy of genotypes chosen for hybridization. The salient results derived are discussed under three headings *viz.*, (i) heterosis (ii) combining ability and (iii) evaluation of parents and hybrids.

5.2.1 Heterosis

Exploitation of hybrid vigour is a method to break the yield ceiling. Commercial utilization of hybrid vigour is facilitated in chilli due to the high amount of natural cross-pollination, which leads to more fruit set after hybridization, and due to the production of large number of seeds by a single pollination. Magnitude of heterosis for yield is of utmost importance. Expression of even a small magnitude for individual component characters of yield is also a desirable factor (Hatchcock and Mc Daniel, 1973). Heterosis is the result of the gene effects *viz.*, additive, dominance and epistasis (additive x additive, additive x dominance and dominance x dominance interactions). The more the additive effect the greater the retention of hybrid vigour in the subsequent segregating generations. Joshi (1987) opined that a breeder should aim at cross combinations with high mean yield, high F_1 heterosis and good retention of heterosis in F_2.

Heterosis for various characters with respect to the respective mid, standard and better parents for fifteen hybrids were analysed.

Estimates of relative heterosis exhibited by the hybrids were high for per cent disease incidence and disease intensity. Standard heterosis recorded high values for days to first flowering, yield per plant, number of seeds per fruit, plant height, harvest index, per cent disease incidence and disease intensity. High standard heterosis for days to first flowering had already been reported by Gaddagimath (1992); for yield per plant by Thomas and Peter (1988), Ram and Lal (1989), Gaddagimath (1992) and

Lohithaswa (1997); for number of seeds per fruit by Lohithaswa (1997) and for plant height by Patil (1997).

Per cent disease incidence showed the highest value for heterobeltiosis followed by yield per plant. Muthuswamy (2004) found high values of heterobeltiosis for incidence of leaf curl disease in chilli. Heterobeltiosis for yield had been reported by Mishra *et al.* (1989) and Ahmed *et al.* (1999).

5.2.2 Combining Ability

Combining ability is the relative ability to transmit the desirable performance of a genotype to its crosses (Sprague and Tatum, 1942). General combining ability is the average performance of a strain in a series of crosses, which reflects the additive gene effects of parents. Specific combining ability indicates situations where certain crosses do relatively better or worse than would be expected on the basis of average performance of their respective parents. It is a measure of non-additive gene action (Rojas and Sprague, 1942).

On a relative assessment of the magnitude of general combining ability of both lines and testers it was observed that fruit yield showed highly significant values followed by number of seeds per fruit and number of fruits per plant. High gca effects were recorded for yield, number of seeds per fruit and number of fruits per plant by Nandadevi and Hosamani (2003 b). Legesse (2000) and Jadhav *et al.* (2001) had also reported high gca for fruit yield.

Highly significant sca effects also were noticed for yield followed by number of seeds per fruit and per cent disease incidence among crosses. High sca for yield is in accordance with the reports of Gandhi and Navale (2000) and Lohithaswa *et al.* (2000). Patil (1997) and Nandadevi and Hosamani (2003 b) reported high sca for number of seeds per fruit as observed in this study.

5.2.3 Evaluation of Parents and Hybrids

5.2.3.1 Parents

5.2.3.1.1 Per se Performance of Parents

L_1 was the best among the lines for fruit yield and yield attributes *viz.*, number of fruits per plant, fruit length, fruit girth, and harvest index. It was the earliest to flower. Being next to L_1, L_2 showed superiority for number of branches, number of fruits per plant, average green fruit weight, fruit length, fruit girth and harvest index. The best performance for number of seeds per fruit and hundred seed weight was recorded by L_4. L_4 also showed comparatively lesser disease intensity while L_5 showed lesser per cent disease incidence.

Among the testers, T_2 performed better for fruit yield, average green fruit weight, fruit length, fruit girth, hundred seed weight, number of branches, plant height and harvest index. T_3 had the largest number of fruits per plant and it closely followed T_2 for yield and yield attributes. T_1 was the earliest to flower and had high duration but showed the minimum per cent disease incidence and disease intensity.

5.2.3.1.2 General Combining Ability Effects of Parents

L_1 was a good general combiner for days to first flowering, number of fruits per plant, average green fruit weight, fruit yield, fruit girth, hundred seed weight, harvest index, disease intensity and per cent disease incidence. It showed moderate gca effect for number of branches and fruit length. Joshi and Singh (1987), Jadhav *et al.* (2001), Nandadevi and Hosamani (2003 b) and Muthuswamy (2004) had reported high gca for yield and yield contributing characters. Muthuswamy (2004) found high gca effect for leaf curl incidence. The line L_2 displayed significant gca effects for yield and its contributing characters and also for days to first flowering and per cent disease incidence.

T_3 showed the best general combining ability among the testers for yield and yield related attributes. It was the best with regard to gca effects for per cent disease incidence and disease intensity. T_2 exhibited

good general combining ability for number of branches, fruit length, fruit girth, plant height and per cent disease incidence. The performance of hybrids largely depends on the parental attributes. Yadav and Murthy (1966) emphasized that the appraisal of parents should be based on their *per se* performance along with general combining ability estimates, which indicate the genetic potential of a genotype. Judgments based on phenotypic performance may not always lead to better results. Also, if gca effects and mean performance are evaluated separately, it may lead to the projection of different individuals. So a combined assessment of parents using both these criteria at the same time would be beneficial (Joshi and Singh, 1987).

Combined appraisal of the per se performance and gca effects of both lines and testers revealed that the mean values of parents truly reflected the gca effects for most of the traits. This is in agreement with the opinion of Pandian and Shanmugavelu (1992) that there was close agreement between gca and *per se* performance.

Considering the overall performance, L_1 ranked first for excellent performance and high gca effects for many traits like fruit weight per plant, fruit length, fruit girth and harvest index. The second position was occupied by L_2.

Among the testers, T_3 could be considered as the best tester based on its gca effects and mean performance for yield and yield attributes like number of fruits per plant, average green fruit weight, fruit length and also for per cent disease incidence and disease intensity.

5.2.3.2 Hybrids

Per se performance, heterosis value and sca effects of the crosses must be considered for exploitation of hybrid vigour. As the mean values for various characters reflect the field performance, they should be given utmost importance. The sca effect alone may not be the criterion for assessing hybrid vigour as hybrids with high sca effects may sometimes possess low heterosis estimates and vice versa. Hence mean

performance, standard heterosis and sca effects should be used together for choosing the best cross combinations.

a. Days to first flowering

With respect to mean performance, L_1T_1 and L_1T_3 were superior. L_4T_2, L_2T_3 and L_1T_1 were found good with regard to sca effects. None of the hybrids showed favourable negative heterosis. L_1T_1 was a combination of good x good general combiners. High sca effect for days to first flower had been reported by Jagadeesh (1995) and Lohithaswa *et al.* (2000).

b. Number of branches.

The mean performance was superior for L_2T_1 and L_2T_3 but their standard heterosis values were not significant. L_5T_1 and L_1T_3 had better sca effects. Hence L_2T_1 (good x poor general combiners) could be regarded as a good hybrid for this trait. Gaddagimath (1992), Mulge (1992) and Pandian and Shanmugavelu (1992) found significant sca effects for number of branches.

c. Number of fruits per plant

L_1T_3, L_2T_3 and L_4T_3 showed high mean values and standard heterosis in the favourable direction. But only L_4T_3 had significant sca effect. So L_4T_3 (poor x good general combiners) could be selected as the top ranking cross for this character. The superiority of L_4T_3 indicates the involvement of both additive and non-additive factors. Jadhav *et al.* (2001) and Nandadevi and Hosamani (2003 b) indicated significant sca effects for number of fruits per plant.

d. Average green fruit weight

Mean performance and standard heterosis were high for L_1T_3 and L_2T_3 for average green fruit weight. Though sca effect was the highest for L_1T_1 (good x poor general combiners), correspondingly high values were not evident for mean values and standard heterosis. Other best specific combinations were L_3T_2, L_5T_3, L_4T_2, L_1T_3 and L_2T_3. Jadhav *et al.* (2001) and Nandadevi and Hosamani (2003 b) observed high sca

effects for average fruit weight. L_1T_3 and L_2T_3 had superior overall performance.

e. Fruit weight per plant

Hybrids L_1T_3 and L_2T_3 were the best for yield with respect to mean performance and standard heterosis. Sca effects were significant for L_4T_2, L_3T_3, L_5T_2, L_2T_3, L_3T_1 and L_1T_3. Gandhi and Navale (2000), Jadhav *et al.* (2000), Legesse (2000), Lohithaswa *et al.* (2000) and Nandadevi and Hosamani (2003 b) reported high sca effects for yield. Except L_3T_3, L_1T_3 and L_2T_3, the other crosses had low values for mean performance. Hence L_1T_3 and L_2T_3 stand out from the rest. In both these crosses, the parents were with good general combining ability and the interaction of additive factors lead to hybrid vigour fixable by selection and this also justifies comparatively low sca effects in them.

f. Fruit length

High mean values and standard heterosis for fruit length was observed for L_2T_3, L_2T_2 and L_1T_3. Significant sca effects were noticed for L_2T_3 and L_1T_3 along with the crosses L_5T_1, L_4T_2, L_4T_1 and L_5T_2. This agrees with the finding of Ahmed *et al.* (1999) and Nandadevi and Hosamani (2003 b). L_1T_3 and L_2T_3 were found to be superior. Both these had good general combiners as parents denoting additive x additive interaction.

g. Fruit girth

Mean values were high for L_1T_3, L_2T_3 and L_1T_2 while standard heterosis was significant for L_1T_3 and L_2T_1 and non significant for L_2T_3. Sca effects were significant for L_2T_1, L_2T_3 and L_4T_2. Hence L_2T_3 (good x good general combiners) projects out as a better hybrid with additive effects fixable through selection. Significant sca effect was noticed by Joshi (1988) for fruit girth in chilli.

h. Number of seeds per fruit

Mean values and standard heterosis were high for L_2T_3, L_3T_3 and L_5T_3 while sca effects were high for L_4T_1, L_5T_3, L_4T_2 and L_2T_1. Thus L_5T_3 (poor x good general combiners) with predominant non-additive effect stands out from the rest of the hybrids.

i. Hundred seed weight

Considering mean performance and sca effect, L_1T_1 (good x good general combiners) was found superior. None of the hybrids showed favourable standard heterosis. L_4T_2 also had high sca effect for the character.

j. Plant height

The crosses L_4T_3, L_4T_2 and L_1T_2 were superior for both mean performance and standard heterosis. High sca effects were noticed for L_3T_2, L_1T_2, L_4T_3, L_2T_3 and L_2T_1. Thus L_4T_3 (good x good general combiners) and L_1T_2 (average x good general combiners) could be projected as the better hybrids. Gandhi and Navale (2000), Lohithaswa *et al.* (2000) and Jadhav *et al.* (2001) reported significant sca effects for plant height.

k. Duration of the crop

Considering the overall performance, L_4T_3 was superior to the other crosses. High mean value along with good standard heterosis and sca effects were recorded for L_2T_2 and L_5T_2

l. Harvest index

L_5T_2, L_2T_3 and L_1T_3 stood out from the rest with regard to mean performance and sca effects. None of the hybrids displayed favourable standard heterosis.

m. Per cent disease incidence

L_1T_3 and L_2T_3 outperformed the other crosses when mean, standard heterosis and sca effects were considered together. Both were the products of parents with good general combining ability.

n. Disease intensity

L_2T_3, L_1T_3, L_4T_3 and L_3T_3 performed well with respect to mean values and standard heterosis. Among these only L_2T_3, L_1T_3 and L_3T_3 showed good sca effects.

From the foregoing discussion it was clear that L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) stood much above the other hybrids with regard to many traits like fruit yield, average green fruit weight, fruit length, harvest index and anthracnose resistance. L_4T_3 (Samkranthi Local-1 x Ujwala) performed well for number of fruits per plant, plant height and crop duration. It could be seen that T_3, a good general combiner for almost all the traits was a common parent in the above crosses.

5.2.4 Proportional Contribution of Parents and Hybrids

In the present study, testers contributed maximum variability towards majority of the traits studied *viz.*, average green fruit weight, fruit weight per plant, fruit length, fruit girth, number of seeds per fruit, plant height and disease intensity. Proportional contribution towards days to first flowering, number of branches, number of fruits per plant, hundred seed weight and harvest index was maximum by lines. For duration of the crop and percent disease incidence, the maximum proportional contribution was shown by hybrids.

5.3 GENERATION MEAN ANALYSIS

A sound knowledge of the genetic makeup of genotypes and their behaviour in differing genetic backgrounds is of utmost importance in formulating the most suited breeding strategy. Generation mean analysis is of great importance in this context as it derives additional knowledge on epistasis (additive x additive, additive x dominance and dominance x dominance interactions) also.

The concept of generation mean analysis was formulated by Hayman (1958). Of the different models available, six-parameter model in which six generations (P_1, P_2, F_1, F_2, B_1 and B_2) were utilized and

information on six parameters were derived. The hybrids utilized were cross 1 (Jwalamukhi x Ujwala) and cross 2 (Jwalasakhi x Ujwala). In all the crosses evaluated, high significance could be noticed for the parameter m indicating considerable variation among the six generations used. Prevalence of duplicate epistasis in majority of the cases could be observed.

a. Days to first flowering

Significance observed for scales C and D in cross 1 revealed the presence of dominance x dominance and additive x additive epistatic interactions of which only the additive x additive interaction was in the favourable negative direction. Additive and dominance effects were also significant and in the negative direction. Lohithaswa *et al.* (2000) reported additive gene action in inheritance of this character while Anandanayaki and Natarajan (2000) found dominance effect to play a part. Hence heterosis breeding and recombination breeding and isolation of desirable segregants in advanced generations would be useful for improvement of this trait.

In cross 2, significance was observed for the scales B, C and D indicating the role of all the three types of epistatic interactions. Further analysis showed the negative significance of additive, dominance, additive x additive and additive x dominance effects among which dominance effect had the highest magnitude.

Duplicate epistatis was seen in both the crosses.

b. Number of branches

None of the four scales was significant in cross 1 indicating the adequacy of the additive–dominance model. Additive effect showed significance in the positive direction. This was suggested earlier by Bhagyalakshmi *et al.* (1991) and Ananadanayaki and Natarajan (2000). Scales A, B and D were significant for cross 2 indicating the presence of all the three types of epistatic interactions but only dominance x

dominance effect was in the favourable positive direction. Additive effect was also significant and positive. Hence heterosis breeding and direct selection would improve number of branches.

Complementary epistasis was noticed in cross 1 while duplicate epistasis was found in cross 2.

c. Number of fruits per plant

Scales A, C and D were significant for both the crosses. Though additive, dominance and all the three types of interactions were significant, only additive and dominance x dominance effects were in the favourable positive direction. This suggested that hybridization followed by selection of genotypes would improve the character. The role of additive and dominance x dominance effects had been reported by Ahmed *et al.* (1994). Epistasis was found to be duplicate in both the crosses.

d. Average green fruit weight

All the four scales were significant for the two crosses suggesting all the three types of epistatic interactions. Though additive, dominance and almost all the three types of interactions were significant for both the crosses, only additive and dominance x dominance effects were of the favourable positive direction. Hence hybridization followed by selection could be resorted to improve this trait. Ahmed *et al.* (1994) had reported the significance of additive and dominance x dominance effects in controlling the inheritance of average green fruit weight. The epistasis was of duplicate nature in both the crosses.

e. Fruit weight per plant

All the four scales were significant for both the crosses. On further analysis, additive, dominance and all the three types of interactions were found to be significant for the two crosses. But only additive and dominance x dominance effects were in the positive direction. The highest magnitude was possessed by dominance x

dominance effect. Hence hybridization followed by selection would improve fruit weight per plant. Significance of additive and dominance x dominance effects were in accordance with earlier reports by Joshi(1988) and Ahmed *et al.* (1994). Doshi and Shukla (2000) had reported the role of additive gene action in the inheritance of this character as found in this study.

f. Fruit length

Scales A, B, C and D in cross 1 and scales A, C and D in cross 2 were found to be significant indicating the presence of three types of epistatic interactions. Additive, dominance, additive x additive and dominance x dominance effects were significant for the two crosses. But only additive and dominance x dominance effects were positive. Dominance x dominance effect had the maximum magnitude. Hence heterosis breeding and selection of superior genotypes in advanced generations would improve fruit length. Chaim and Paran (2000), Doshi and Shukla (2000), Ahmed *et al* (2003) and Nandadevi and Hosamani (2003 b) had found the role of additive gene action in inheritance of this character. The epistasis was found to be of duplicate nature in both the crosses.

g. Fruit girth

All the four scales in cross 1 and scales A, C and D in cross 2 were found to be significant. Additive x dominance, additive x additive and dominance x dominance interactions were significant in both the crosses. Additive x dominance effect was significant in cross 1 but in the negative direction. Only additive and dominance x dominance effects were in the favourable positive direction in the two crosses suggesting hybridization followed by selection to be a good method to improve the trait. Shukla *et al.* (1999) and Doshi and Shukla (2000) had found additive effect to play an important part in inheritance of this character. The epistasis was found to be of duplicate nature.

h. Number of seeds per fruit

All the four scales in cross 2 and scales A, C and D in cross 1 were significant indicating the presence of three types of epistatic interactions. Additive, dominance, additive x additive and dominance x dominance effects were significant in both the crosses. But only dominance x dominance effect was in the positive direction with the highest magnitude. Hence heterosis breeding would improve the number of seeds per fruit. Epistasis was found to be of duplicate nature.

i. Hundred seed weight

Scale C was significant in cross 1 but on further analysis dominance x dominance effect was not found to be significant. Scales B and D were significant in cross 2 but only additive effect was found to be positively significant suggesting direct selection as a method to improve the trait. Bhagyalakshmi *et al.* (1991), Mishra *et al.* (1991b) and Gaddagimath (1992) had found similar results. Epistasis was complementary in cross 1 and duplicate in cross 2.

j. Plant height

Scales A, C and D were significant in cross 1 while only scale D was significant in cross 2. On further analysis additive x additive effect was found to be significant for both the crosses but in the negative direction. Only dominance x dominance effect was in the positive direction but with smaller magnitude in the two crosses. Heterosis breeding might improve this trait. Joshi (1990) had found the role of dominance x dominance effect in inheritance of the character. This is contrary to the reports of Doshi and Shukla (2000), Lohithaswa *et al.* (2000) and Rathod *et. al.* (2002) that additive gene action played a role in inheritance of this trait. Epistasis was duplicate in nature.

k. Duration of the crop

All the four scales were significant for the two crosses. In cross 1, additive, dominance, additive x additive and dominance x dominance

effects were significant but only dominance and additive x additive interactions were in the desirable negative direction suggesting hybridization followed by selection of genotypes to be of use in improving the trait. Effects for cross 2 were similar to that in cross 1 with the addition of additive x dominance interaction in the favourble negative direction which indicated that recombination breeding would be useful. Epistasis was of dominant type in both the crosses.

l. Harvest index

Scales A, B, C and D were significant for both the crosses. In cross 1, all the different types of interactions along with additive and dominance effects were significant and positive with high magnitudes for dominance x dominance interaction, additive x additive interaction and dominance effect. Hence heterosis breeding and recombination breeding would be useful. In cross 2, only dominance x dominance interaction was in the desirable positive direction. Epistasis was complimentary in cross 1 and duplicate in cross 2.

m. Capsaicin content

In cross 1, scales C and D were significant suggesting the role of additive x additive and dominance x dominance effects. On further analysis, only dominance x dominance effect was found in the positive direction. Hence heterosis breeding could be adopted to increase the capsaicin content. In cross 2, all the four scales were significant but only dominance x dominance effect was in the positive direction but non significant. These are in contrast to the reports of Lohithaswa (1997) and Doshi and Shukla (2000) who found additive gene action to play an important role.

n. Oleoresin content

All the four scales were significant in cross 1. Dominance effect, additive x additive and dominance x dominance effects were significant but only dominance x dominance effect was in the positive direction and

with the highest magnitude suggesting that heterosis breeding would improve the trait. In cross 2, though scale B was significant, none of the epistatic interactions were found significant.

o. Per cent disease incidence

In cross 1 at 30 DAT, 45 DAT and 60 DAT, none of the effects was negatively significant. In cross 2, dominance effects were negative at the three crop stages but were not significant. Epistasis was found to be complimentary in cross 1 and duplicate in cross 2 at the three crop stages.

p. Disease intensity

At 30 DAT, 45 DAT and 60 DAT, additive, dominance, additive x additive and dominance x dominance effects were significant. But only dominance x dominance effect was negative and of the highest magnitude. Hence heterosis breeding would be ideal to decrease the disease intensity. Epistasis was found to be duplicate in all the cases.

Predominance of additive and dominance x dominance interaction in L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) for number of fruits per plant, average green fruit weight, fruit weight per plant, fruit length and fruit girth suggest their suitability for improvement through hybridization followed by selection. Anthracnose resistance in both the crosses could be improved through heterosis breeding due to the presence of negatively significant dominance x dominance components.

5.3.1 Transgressive Segregants

Estimates of transgressive segregants (%) were the highest for fruit weight per plant in both the crosses. This indicated the possibility for utilizing these desirable segregants to develop superior varieties. Moreover, number of fruits per plant also exhibited high degree of transgressive segregants in the two crosses. Cross 1 produced the highest level of transgressive segregants for number of branches, average

green fruit weight, fruit length, fruit girth and plant height. Cross 2 had the maximum transgressive segregants for number of seeds per fruit, hundred seed weight, harvest index, oleoresin content, per cent disease incidence and disease intensity.

The genetic analysis for yield and resistance to anthracnose brought to light genotypes which could be used as sources of resistance. Two superior crosses *viz.*, Jwalamukhi x Ujwala and Jwalasakhi x Ujwala with high yield potential and resistance to anthracnose were identified. The nature of gene actions underlying yield and yield attributes were found to be additive and dominance x dominance epistatic interaction which signifies the possibility of improvement through recombination breeding. For anthracnose resistance dominance x dominance interaction played a major role thereby suggesting heterosis breeding as the method of improvement.

SUMMARY

6. SUMMARY

Chilli is an important spice cum vegetable crop grown on a commercial scale in India. Though India is the largest producer, consumer and exporter of chillies in the world, productivity of chilli in India has remained low compared to the world average. One of the reasons for low productivity is the damage due to various diseases among which anthracnose or die-back and fruit rot is a serious one. Hence it is essential to evolve varieties resistant to anthracnose disease. The present investigation was undertaken in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2002-2004 to study the genetic basis and inheritance pattern of yield, yield attributes and anthracnose resistance through generation mean analysis in order to develop high yielding anthracnose disease resistant varieties in chilli.

Chilli germplasm consisting of 76 varieties/genotypes including a known anthracnose resistant variety, varieties released by Kerala Agricultural University and local collections from different parts of Kerala was evaluated simultaneously for anthracnose resistance and yield traits as two parallel experiments.

Screening for anthracnose resistance was carried out at three stages of the crop *viz.*, 30, 45 and 60 DAT (Days After Transplanting). ANOVA revealed significant variations among the genotypes during all the stages for percent disease incidence and disease intensity.

Majority of the genotypes showed disease incidence in the range of 20 to 30 per cent at 30, 45 and 60 DAT. Three genotypes T_{20}, T_{42} and T_{76} showed less than 10 per cent disease incidence at all the three stages. With regard to disease intensity, number of susceptible genotypes increased gradually from 30 DAT to 60 DAT with three genotypes T_{20}, T_{42} and T_{76} remaining moderately resistant at all the three stages.

Screening of germplasm (76 genotypes) for yield traits revealed significant variations among the genotypes with respect to all the 14 characters studied. Superior genotypes identified with respect to various characters were T_1, T_2, T_7, T_{16}, T_{17}, T_{20}, T_{26}, T_{31}, T_{38}, T_{39}, T_{42}, T_{52}, T_{67} and T_{76}.Genetic parameters *viz.*, phenotypic and genotypic coefficients of variation, heritability (broad sense) and genetic advance were estimated for each character. The maximum values of both phenotypic and genotypic coefficients of variation were observed for fruit weight per plant. Harvest index and disease intensity ranked second for phenotypic coefficient of variation while percent disease incidence was the second for genotypic coefficient of variation. High heritability was exhibited by all the characters studied. Maximum genetic advance was observed for fruit weight per plant followed by per cent disease incidence, number of fruits per plant, disease intensity, number of seeds per fruit and average green fruit weight.

Correlation analysis indicated that most of the character combinations had higher genotypic correlation coefficient than phenotypic, though both were in the same direction. Environmental correlation coefficients were the lowest. Fruit weight per plant was significantly and positively correlated with number of branches, number of fruits per plant, average green fruit weight, fruit length, fruit girth, hundred seed weight, crop duration, harvest index, capsaicin content, per cent disease incidence and disease intensity while it was negatively associated with days to first flowering.

The direct and indirect effects exerted on yield by eight characters, which had high association with fruit yield were estimated through path analysis. The maximum positive direct effect was exerted by disease intensity followed by harvest index and number of fruits per plant. The highest negative direct effect was exerted by per cent disease incidence.

Selection indices were computed based on yield and twelve component traits for 76 genotypes. Five genotypes *viz.*, Jwalamukhi (L_1), Jwalasakhi (L_2), Muvattupuzha Local-1 (L_3), Samkranthi Local-1 (L_4) and Vaikom Local-2 (L_5) belonging to high yielding and anthracnose susceptible category were utilized as lines and three genotypes *viz.*, Pant C1 (T_1), Kidgangoor Local-1 (T_2) and Ujwala (T_3), which were moderately resistant were employed as testers for the line x tester analysis.

Line x tester analysis was performed for fourteen characters. Line x tester interaction mean square was significant for all the characters except number of branches, average green fruit weight, fruit length, fruit girth and harvest index. Lines varied significantly for all the characters except average green fruit weight, fruit girth, hundred seed weight and harvest index while testers showed significant variation for all the traits except days to first flowering, number of branches, fruit girth, hundred seed weight and harvest index. High values of gca effects were noticed for fruit yield, number of seeds per fruit and number of fruits per plant. Highly significant sca effects were recorded for fruit yield, number of seeds per fruit and per cent disease incidence. Heterosis for the characters of 15 hybrids with respect to their mid, standard and better parents were estimated. Relative heterosis was high for per cent disease incidence and disease intensity whereas standard heterosis was high for days to first flowering followed by fruit yield per plant. The highest heterobeltiosis was observed for per cent disease incidence followed by yield per plant. High values for gca and sca effects were noticed for fruit yield per plant followed by number of seeds per fruit and number of fruits per plant. L_1 was the best among lines based on *per se* performance for fruit yield and other yield attributes *viz.*, number of fruits per plant, fruit length, fruit girth, crop duration and harvest index. Among the testers, T_2 was the best being superior for traits *viz.*, fruit yield per

plant, average green fruit weight, fruit length, fruit girth, hundred seed weight, number of branches, plant height and harvest index.

With respect to gca effects also, L_1 was the best being a good general combiner for days to first flowering, number of fruits per plant, average green fruit weight, fruit yield, fruit girth, hundred seed weight, harvest index, disease intensity and per cent disease incidence. T_3 showed the best gca for yield and yield attributes like number of fruits per plant, average green fruit, fruit length and also for per cent disease incidence and disease intensity.

Among the fifteen hybrids evaluated with respect to *per se* performance, standard heterosis and sca effects, L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) were superior with regard to days to first flowering, average green fruit weight, fruit weight per plant, fruit length, fruit girth, plant height and anthracnose resistance. T_3 a good general combiner for almost all the traits was a common parent in the two outstanding crosses.

The two superior crosses identified from line x tester analysis *viz.*, cross 1 (Jwalamukhi x Ujwala) and cross 2 (Jwalasakhi x Ujwala) were utilized for generation mean analysis. Six generations P_1, P_2, F_1, F_2, B_1, and B_2 were developed in the two selected crosses. The generation mean analysis was done to detect the gene action with respect to 16 characters. The generation means of the traits for the two crosses were computed and joint scaling test was conducted in order to detect the presence of epistasis followed by the estimation of additive x additive, additive x dominance and dominance x dominance interactions. In both the crosses, high significance could be noticed for 'm' indicting considerable variation among the different generations and duplicate epistasis was more prevalent than complementary type in majority of the cases.

For days to first flowering, additive, dominance and additive x additive interaction in cross 1 and additive, dominance, additive x additive and additive x dominance interactions in cross 2 were significant and negative suggesting suitability of recombination breeding and heterosis breeding.

None of the four scales was significant in cross 1 for number of branches, indicating the adequacy of the additive – dominance model. Positive significance of additive and dominance x dominance effects in cross 2 indicated that heterosis breeding and direct selection would improve the trait.

For number of fruits per plant, average green fruit weight and fruit weight per plant, additive and dominance x dominance effects were positively significant in both the crosses suggesting the suitability of hybridization followed by selection to improve these characters.

Among the positively significant additive and dominance x dominance interaction for fruit length in the two crosses, dominance x dominance effect had the highest magnitude indicating heterosis breeding and recombination breeding to be suitable.

For fruit girth, additive and dominance x dominance effects were in the favourable positive direction in the two crosses suggesting recombination breeding to be of use.

For capsaicin content and oleoresin content, significance was observed for dominance x dominance effects in cross 1 indicating heterosis breeding as a suitable method. In both the crosses, dominance x dominance interaction was negatively significant for disease intensity suggesting that heterosis breeding would be ideal to decrease the disease intensity.

Predominance of additive and dominance x dominance interaction in cross 1(Jwalamukhi x Ujwala) and cross 2 (Jwalasakhi x Ujwala) for number of fruits per plant, average green fruit weight, fruit weight per plant, fruit length and fruit girth suggests their suitability for

improvement by hybridization followed by selection. Anthracnose resistance in both the crosses could be improved through heterosis breeding due to the presence of negatively significant dominance x dominance effects.

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*Originals not seen

GENETIC ANALYSIS OF YIELD AND RESISTANCE TO ANTHRACNOSE IN CHILLI (*Capsicum annuum* L.)

AJITH. P. M.

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

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2004

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

ABSTRACT

Chilli (*Capsicum annuum* L) is an important spice cum vegetable crop, grown on a commercial scale in India. It is an important constituent of many foods since it adds flavour, colour, vitamin C and pungency. Productivity of the crop remains low mostly due to destructive diseases. One of the most dreaded diseases affecting chilli is anthracnose, which is also called dieback and fruit rot.

The best way to tackle this disease is to grow resistant varieties. Hence it is essential to identify the sources of anthracnose resistance and study the inheritance of resistance to develop high yielding anthracnose resistant varieties of chilli. Therefore, an investigation was undertaken to reveal the genetic variability and to identify the resistant genotypes in a collection of germplasm, to estimate the combining ability and heterosis by line x tester analysis and to assess the inheritance pattern of anthracnose resistance and yield using generation mean analysis in order to formulate an appropriate breeding programme for improving the economic characters.

Chilli germplasm consisting of 76 genotypes was evaluated simultaneously for anthracnose resistance and yield traits as two parallel field experiments in RBD with two replications during rabi 2002. Screening of germplasm for anthracnose resistance was carried out by recording per cent disease incidence and disease intensity at 30 DAT, 45 DAT and 60 DAT (Days After Transplanting).

Majority of the genotypes showed disease incidence in the range of 20 to 30 per cent at 30 DAT, 45 DAT and 60 DAT. Three genotypes showed less than 10 per cent disease incidence at all the three stages. With regard to disease intensity, number of susceptible genotypes

increased gradually from 30 DAT to 60 DAT with three genotypes remaining moderately resistant at all the three stages.

Evaluation for yield traits revealed significant variations among the genotypes for 14 traits *viz*., days to first flowering, number of branches, number of fruits per plant, average green fruit weight, fruit weight per plant (yield), fruit length, fruit girth, number of seeds per fruit, hundred seed weight, plant height, duration of the crop, harvest index, capsaicin content and oleoresin content.

The maximum values of both phenotypic and genotypic coefficients of variation were noticed for fruit weight per plant. All the traits possessed high heritability especially fruit weight per plant, fruit length, number of seeds per fruit, capsaicin content and hundred seed weight. Maximum genetic advance (% of mean) was observed for fruit weight per plant followed by number of fruits per plant, number of seeds per fruit and average green fruit weight.

Correlation analysis indicated that most of the character combinations had higher genotypic correlation coefficients than phenotypic correlations. Fruit yield displayed positive genotypic association with number of branches per plant, number of fruits per plant, average green fruit weight, fruit length, fruit girth, hundred seed weight, duration of the crop, harvest index, capsaicin content, percent disease incidence and disease intensity and negative correlation with days to first flowering.

Among the eight component traits, which had high association with fruit yield, the maximum positive direct effect was exerted by disease intensity followed by harvest index and number of fruits per plant. The highest negative direct effect was exerted by per cent disease incidence.

Selection indices were computed utilizing fruit yield and its 13 component characters. Based on the selection indices, five high yielding anthracnose susceptible types *viz*., Jwalamukhi (L_1), Jwalasakhi (L_2),

Muvattupuzha Local-1 (L_3), Samkranthi Local-1 (L_4) and Vaikom Local-2 (L_5) were used as lines and three anthracnose resistant types *viz.* Pant C-1 (T_1), Kidangoor Local-1 (T_2) and Ujwala (T_3) were used as testers for the line x tester analysis.

From line x tester analysis high values of *gca* effects were noticed for fruit yield, number of seeds per fruit and number of fruits per plant. High values of *sca* effects were recorded for yield, number of seeds per fruit and per cent disease incidence. L_1 was the most superior line which excelled with respect to mean performance and general combining ability for days to first flowering, number of fruits per plant, average green fruit weight, fruit yield, fruit girth, hundred seed weight, harvest index, per cent disease incidence and disease intensity. Among the testers, T_2 was the best with respect to mean performance for fruit yield, average green fruit weight, fruit length, hundred seed weight, number of branches, plant height and harvest index. T_3 showed the best general combining ability for yield and yield related attributes, per cent disease incidence and disease intensity.

Among the fifteen hybrids evaluated with respect to *per se* performance, standard heterosis and *sca* effects, L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) were superior with regard to days to first flowering, average green fruit weight, fruit weight per plant, fruit length, fruit girth, plant height and anthracnose resistance. T_3 a good general combiner for almost all the traits was a common parent in the two outstanding crosses.

The two superior crosses *viz.* L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) were utilized for generation mean analysis in order to detect the gene action with regard to the various traits. Presence of epistasis was tested and subsequently interaction effects *viz.* additive x additive, additive x dominance and dominance x dominance effects were computed.

Predominance of additive and dominance x dominance interaction in L_1T_3 (Jwalamukhi x Ujwala) and L_2T_3 (Jwalasakhi x Ujwala) for number of fruits per plant, average green fruit weight, fruit weight per plant, fruit length and fruit girth suggests their suitability for hybridization followed by selection. Anthracnose resistance in both the crosses could be improved through heterosis breeding due to the presence of negatively significant dominance x dominance components.

The genetic analysis for yield and resistance to anthracnose brought to light genotypes which could be used as sources of resistance. Two superior crosses with high yield potential and resistance to anthracnose were identified. The nature of gene actions underlying yield and yield attributes were found to be additive and dominance x dominance epistatic interaction which signifies the possibility of improvement through recombination breeding and selection has to be postponed to later generations. For anthracnose resistance, dominance x dominance interaction played a major role thereby suggesting heterosis breeding as the method of improvement.