GENETIC IMPROVEMENT AND MOLECULAR CHARACTERIZATION OF PAPRIKA (*Capsicum annuum* L.) GENOTYPES

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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

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DECLARATION

I hereby declare that this thesis entitled '**Genetic improvement and molecular characterization of paprika (*Capsicum annuum* L.) genotypes**' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled '**Genetic improvement and molecular characterization of paprika (*Capsicum annuum* L.) genotypes**' is a record of research work done independently by Mrs. Bini Philip (2001-21-13) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Dedicated to

My Beloved Parents

ACKNOWLEDGEMENT

It is a pleasure and privilege for me to express my profound sense of gratitude to Dr. D. Wilson, Associate Professor, Department of Plant Breeding and Genetics and chairman of my advisory committee for his valuable guidance, constant encouragement and care rendered during the research period which gave me a sense of comfortness and enabled me to complete the thesis successfully.

My sincere thanks to Dr. D. Chandramony, Professor and Head, Department of Plant Breeding and Genetics and member of my advisory committee for her critical suggestions and timely help during the course of this research.

I wish to place on record my sincere thanks to Dr. Vijayaraghavakumar, Associate Professor, Department of Agricultural Statistics and member of my advisory committee for the kind help rendered during the statistical analysis and interpretation, valuable suggestions and thorough scrutiny of the manuscript.

My profound gratitude to Dr. K. Rajmohan, Associate Professor and Head, Department of Plant Biotechnology and member of my advisory committee for his critical suggestions and valuable advice.

My sincere thanks to Dr. I. Sreelathakumari, Assistant Professor, Department of Olericulture and member of my advisory committee for her sincere help and whole hearted co-operation.

I thank Dr. Philippose Joshua, Associate Professor and Head, Department of Processing Technology and Dr. Roy Stephen, Assistant Professor, Department of Plant Physiology for their kind help in providing the lab facilities.

I also thank all teaching and non-teaching staff of Department of Plant Breeding and Genetics for their co-operation all through the period of the study. My thanks to the labourers especially Sri Divakaran for their cooperation in carrying out the field work.

I express my profound gratitude to Dr. V.P. Potty of CTCRI, Ranjit, Anoop, Ganga, Pradeep, Satheesh and Anitha chechi for their timely and sincere help and support provided during the critical stages of my research work.

I find special pleasure in placing my wholehearted thanks to my classmates Lovely, Anuchechi and Ajith and all my senior and junior friends for their kind support and affection provided during the various stages of my work. Thanks are due to Deepu Mathew for his invaluable help from the very beginning of the research tenure.

My immense gratitude to my friends Dhanya, Praveena chechi, Ambily, Priya, Poornima, Nisha, Usha, Rini and Geetha for their loving involvement and care during the entire period of my work.

I express my affection and thanks to my beloved parents and family members for their support and care give to me at all times. Special thanks to Jo for his love and care.

I would like to express my heartfelt gratitude to Mr. C.E. Ajithkumar, Junior Programmer, Department of Agricultural Statistics for executing the statistical analysis for my study.

My sincere thanks to Mr. Biju for his patience and co-operation in neat execution of the manuscript.

I sincerely acknowledge CSIR, New Delhi for awarding the Junior Research Fellowship.

Above all, I thank God Almighty for being with me always.

Bini Philip

CONTENTS

LIST OF TABLES

LIST OF TABLES CONTINUED

LIST OF FIGURES

LIST OF PLATES

Introduction

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) is an important spice cum vegetable crop rich in vitamins, yielding capsaicin, oleoresin and extractable colour besides providing green and dry fruits. India is the largest producer of chillies in the world contributing about ten per cent of the total world production (Berry, 2003). In India, chilli is grown in an area of 9.65 lakh hectare with an annual production of 10.75 lakh tonnes (Peter *et al.*, 2004).

Belonging to the family solanaceae, chilli is indigenous to Central and South America. The term capsicum refers to the fruits of the plants of the genus *Capsicum* and include five domesticated species and many varieties making this one of the largest class in the vegetable kingdom.

Paprika, the term used by the international spice traders for non pungent red capsicum powder has a great commercial importance world wide. According to the American Spice Trade Association (ASTA), spice industry uses two species, *Capsicum annuum*, the milder and *Capsicum frutescens*, the fiery one and denote the whole hot peppers as chillies. International Standards Organization (ISO) recognizes only two types of capsicum, paprika and chillies, the former characterized by zero or mild pungency and the latter by strong pungency. In the pungency scale paprika finds a place in *C. annuum* and chillies in either of the two species.

Paprika is defined in the United States as a sweet, dried red powder. This mild powder can be made from any type of *C. annuum* that is non-pungent and has brilliant red colour. Paprika may be pungent in Hungary, but is always non-pungent in international trade.

The quality of paprika product is based on visual and extractable red colour and mildness of flavour. The market value of paprika depends largely on its red colour, both surface hue and extractable colour. Its flavour quality is of secondary importance only. Oleoresin of paprika extracted from the ground pod is used to impart bright red colour to meat, sausage products, sauces and to other processed foods thus making the product more acceptable and pleasing to the eye. The most important pigments responsible for red colour are capsanthin and capsorubin. The colour value of paprika is expressed in ASTA units. The paprika colours are not metabolized in human body and hence is an ideal natural colour additive for food items.

Eventhough, India is a major producer and exporter of chilli, paprika is not commercially cultivated inspite of the fact that there is a clear price advantage for paprika compared to chilli. India has the potential to produce high quality paprika and there is tremendous scope for export also.

The increasing commercial importance world over for paprika as source of paprika powder and oleoresin resulted in establishing breeding programmes to develop varieties or hybrids to meet international demand. In order to make firm entry on the paprika trade, it is also necessary to identify suitable agroclimatic conditions and extend the cultivation of paprika. A few indigenous types of chillies which are similar to paprika with fruits having high colour and low pungency have been identified (Verma and Joshi, 2000). But the performance of the potential paprika types in Kerala condition is not known. Some local cultivars having low pungency and red colour are available in different parts of South India. however they have not been tested for their paprika quality.

Based on these facts, the present investigation was undertaken with the following objectives.

i) Collection and evaluation of different genotypes of *Capsicum annuum* for paprika quality and to exploit the variability present in them.

ii) Estimation of selection index and clustering of genotypes to facilitate selection of parents for hybridization

iii) Study of gene action for biochemical and quality characters for selecting appropriate breeding methods.

iv) Evaluation of F_1 progeny for fruit yield and quality characters on the basis of mean performance, combining ability and extent of heterosis to identify superior F_1's having good paprika quality.

v) Randomly Amplified Polymorphic DNA (RAPD) analysis to characterize selected parents and hybrids.

Review of Literature

2. REVIEW OF LITERATURE

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

2.1 VARIABILITY

Variability with respect to different characters is an essential requisite for the selection of superior genotypes from a population. Number of workers studied variability for different characters in chilli and are presented below.

Vijayalakshmi *et al.* (1989) observed significant genetic variation for nine fruit characters in four F_2 progenies and their five parental types.

Evaluation of 73 chilli genotypes revealed significant difference between entries for contents of capsanthin (0.126 – 0.407 per cent), ascorbic acid (58.73 – 193.1 mg 100 g^{-1}) and capsaicin (0.056 – 1.81 per cent) in the fruits (Rani, 1994).

Singh *et al.* (1994) studied variation for nine yield related traits in 20 chilli genotypes over two seasons and reported greatest variability for fresh red ripe fruits per plant. Kataria *et al.* (1997) reported high variability for fresh fruit weight per plant, number of fruits per plant and plant height among 54 genotypes of *Capsicum annuum*.

Das and Chaudhary (1999a) investigated genetic variability in 25 genotypes of chilli and observed significant variability for all the characters under study with maximum for fruit length.

Munshi and Behera (2000) observed existence of considerable amount of genetic variability for number of fruits per plant, fruit weight, fruit length and yield per plant in a study involving 30 chilli germplasm. High variability estimates for yield per plant, number of fruits per plant

and number of seeds per fruit among four F_2 chilli crosses was reported by Subashri and Natarajan (2000).

Mishra *et al.* (2001) evaluated nine genotypes of chilli for fruit characters and found considerable variability for fruits per plant and fruit length. Ibrahim *et al.* (2001) in their study using 17 genotypes of chilli reported high variability for fruit length followed by dry fruit weight and number of branches per plant.

The genetic variability among 52 chilli cultivars and lines with regard to yield and yield components was studied by Dipendra *et al.* (2002) and observed significant variation in all characters. Rathod *et al.* (2002b) observed considerable variability among 13 chilli cultivars with respect to eight yield components.

Khurana *et al.* (2003) reported highly significant variation among 46 *C. annuum* genotypes for fruit yield, fruit length, fruit thickness and number of fruits per plant. In a study involving 26 chilli genotypes, Nandadevi and Hosmani (2003b) observed high variability for number of primary branches, fruit length, number of fruits per plant and green fruit yield.

2.2 COEFFICIENT OF VARIATION

The variability in the genotypes for different characters was expressed using the coefficient of variation which is a unit free measurement.

Singh and Brar (1979) reported that phenotypic and genotypic coefficients of variation were high for fruit number and fruit yield and medium for fruit weight while conducting variability studies in 31 varieties of sweet pepper. Elangovan *et al.* (1981) observed high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for plant height, number of seeds per fruit and number of fruits per plant.

Gopalakrishnan *et al.* (1987b) obtained high GCV for fruit length, fruit weight, fruits per plant and fruit yield per plant in 38 lines of chilli. Evaluation of 73 genotypes including Pusa Jwala and G_4 revealed significant difference between genotypes for capsanthin, ascorbic acid and capsaicin content in the fruits (Rani, 1994). Upon evaluation of 79 genotypes for 19 traits Rani *et al.* (1996) reported high GCV and PCV for fruits per plant, fruit weight, yield per plant, fruit length and 100 seed weight.

Devi and Arumugam (1999) studied variability in 30 F_2 hybrids for 12 traits and reported moderate GCV and PCV for all the characters except days to flowering, dry fruit yield per plant and fruit girth for which it was low. According to Nayeema *et al.* (1999), GCV and PCV were high for fruit yield, fruit number, seeds per fruit, fruit weight and pericarp thickness among 71 chilli lines studied.

Munshi and Behera (2000) obtained genotypic coefficient of variation ranging from 5.32 per cent (days to first fruit set) to 54.94 per cent (number of fruits per plant) in a study with 30 chilli germplasm.

Ibrahim *et al.* (2001) observed high PCV and GCV for fruit length followed by dry fruit yield and number of branches per plant among 17 genotypes of *C. annuum*. Mishra *et al.* (2001) studied nine genotypes and reported high PCV and GCV for fruits per plant, fruit length, dry weight of fruit and red chilli yield.

High PCV and GCV for fresh as well as dry fruit yield per plant was reported by Dipendra *et al.* (2002), while Rathod *et al.* (2002b) reported high GCV estimates for number of fruits per plant, fresh and red chilli yield per plant and plant height.

Sreelathakumari and Rajamony (2002) observed high PCV and GCV for number of fruits per plant, fruit weight, fruit length, fruit girth and yield while evaluating 70 diverse chilli genotypes. High degree of

genotypic and phenotypic coefficients of variation was observed by Nandadevi and Hosamani (2003b) for number of primary branches, fruit length, pericarp thickness, number of fruits per plant and fruit yield per plant among 26 chilli genotypes.

Mini (2003) obtained high PCV and GCV estimates for fruit yield, number of fruits per plant, average fruit weight, 100 seed weight and fruit length while evaluating 25 wax type chilli genotypes.

2.3 HERITABILITY AND GENETIC ADVANCE

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

Choudhary *et al.* (1985) in their studies involving 30 genotypes obtained 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 weight) to 98.99 (yield per plant). Ado and Samarawira (1987) observed high heritability (broad sense) values for all characters studied except for days to maturity in 16 cultivars.

High heritability coupled with high genetic advance was reported by Vijayalakshmi *et al.* (1989) for number of fruits per plant, fruit weight, fruit length, fruit girth and number of seeds per fruit in a study involving 11 chilli genotypes.

Bhagyalakshmi *et al.* (1990) studied 15 F_1 hybrids and their parents and observed moderate heritability estimates for plant height, branches per plant, fruit weight, number of seeds per fruit and 100 seed weight while it was high for days to fifty per cent flowering, fruit length, fruit girth, number of fruits per plant and ascorbic acid content. High heritability estimates for fruit number and yield per plant was reported by Das *et al.* (1990).

Kumar *et al.* (1993) evaluated four F_2 progeny for nine fruit characters and observed high heritability and genetic advance for number of fruits per plant, number of seeds per fruit, ascorbic acid content and yield per plant.

Rani and Singh (1996) studied 21 traits in 73 *C. annuum* genotypes and reported high to moderate heritability for all characters except capsanthin content. Genetic advance was the highest for ascorbic acid content followed by number of fruits, plant height and fruit weight. High heritability and genetic advance observed for capsaicin content and fruit length.

High heritability and genetic advance for yield, fruit number, fruit weight and ascorbic acid was reported by Rani *et al.* (1996). Kataria *et al.* (1997) reported high heritability and genetic advance for fruit length, yield and average fruit weight, but according to Devi and Arumugam (1999) fruit length and yield had moderate heritability.

In a study on 71 genotypes over 12 traits Nayeema *et al.* (1999) observed high heritability coupled with high genetic advance for yield, fruit number, number of seeds, fruit weight and pericarp thickness. Das and Choudhary (1999a) obtained very high heritability (>80 per cent) for fruit length, fruit number, fruit weight and yield. Similar results were reported by Munshi and Behera (2000).

High heritability for plant height (98.12 per cent), fruit length (96.74 per cent) and fruit number (96.18 per cent) was reported by Ibrahim *et al.* (2001). Number of branches and dry fruit yield showed high genetic advance as per cent of mean.

Number of primary branches had low heritability, while fresh and dry fruit yield per plant and fruit length showed high heritability coupled with high genetic advance in a study involving 52 chilli genotypes (Dipendra *et al.*, 2002).

Rathod *et al.* (2002b) in their studies using 13 chilli cultivars observed high heritability for days to fifty per cent flowering, plant height, number of primary branches, fruit number, fruit length, 100 seed weight and fresh fruit yield. Among these, fruit number, fruit yield and plant height had high genetic advance also.

Doshi (2003) observed high heritability for capsaicin (95.2 per cent), fruit weight (82.2 per cent), fruits per plant (76.6 per cent) and plant height (67.10 per cent) while it was low for primary branches per plant (22.10 per cent).

High heritability coupled with high genetic advance was reported for number of primary branches, fruit length and green fruit yield per plant in 20 chilli genotypes. High heritability was observed for plant height (93.7 per cent), number of primary branches (91.7 per cent), fruit length (95.7 per cent) and green fruit yield (90.5 per cent) (Nandadevi and Hosamani, 2003b).

In a genetic diversity study involving 48 *C. annuum* genotypes high heritability was observed for fruit yield, number of fruits per plant, fruit length, fruit diameter and seeds per fruit. Capsaicin content and colouring matter showed high heritability value coupled with moderate level of genetic advance (Khurana *et al.*, 2003).

2.4 ASSOCIATION OF CHARACTERS

2.4.1 Correlation Coefficient Analysis

Nair *et al.* (1984) found positive correlation of fruit yield with fruits per plant, secondary branches per plant, fruit weight, fruit circumference and crop duration. Gopalakrishnan *et al.* (1985) observed positive correlation for fruit length with fruit yield while fruit girth showed negative correlation.

He *et al.* (1989) reported negative correlation of fruit yield with fruit length and the correlation between fruit weight and ascorbic acid was also negative.

Kaul and Sharma (1989) observed positive association between yield and plant height, number of branches, number of seeds as well as ascorbic acid content. Das *et al.* (1990) reported significant positive correlation of fruit yield with number of primary branches and number of seeds.

Bhagyalakshmi *et al.* (1990) observed negative correlation between fruit yield and days to fifty per cent flowering in chilli. Warade *et al.* (1996) also reported negative correlation of fruit yield with days to fifty per cent flowering and days to maturity.

Khurana *et al.* (1993) evaluated 10 *C. annuum* genotypes and found that fruit weight had maximum positive correlation with fruit yield followed by number of fruits, fruit length and number of branches.

According to Ali (1994) yield had positive correlation with number of fruits and number of seeds. He also found significant positive correlation between dry fruit weight and fresh fruit weight.

Fruit yield was positively and significantly correlated with number of fruits, number of branches, plant height and fruit length (Pawade *et al.*, 1995).

Ahmed *et al.* (1997b) reported that fruit yield was positively associated with number of fruits, fruit weight, plant height, fruit length and negatively associated with days to maturity. Rani (1997) found positive correlation between fruit yield and fruit number, number of primary and secondary branches, plant height and seed weight. Vallejo *et al.* (1997) reported that fruit number and fruit weight were negatively correlated.

Evaluation of 24 varieties of sweet pepper revealed strong positive correlation of yield per plant with fruit weight at genotypic and phenotypic levels. Number of fruits had positive and significant association with fruit weight, plant height and days to flowering (Mishra *et al.*, 1998).

Nawagatti *et al.* (1999) studied quality parameters of chilli cultivars, but could not observe definite relationship between quality parameters and yield.

Subashri and Natarajan (1999) obtained positive association of yield with number of branches, number of fruits, fruit weight and fruit length in F_2 population. Correlation studies in 25 genotypes revealed positive correlation of yield with fruit weight, number of fruits and number of primary branches (Das and Choudhary, 1999b). Dimova and Panaystov (1999) observed positive association between seed weight and fruit weight.

According to Aliyu *et al.* (2000) yield per plant was negatively correlated with plant height.

Munshi *et al.* (2000) observed positive association of yield with fruit weight and fruit number. Fruit weight had positive correlation with fruit length and negative correlation with fruit number.

Quantitative traits and their correlation in sweet paprika was studied by Wyrzykowska *et al.* (2000) and reported that fruit yield depended significantly on mean fruit weight and fruits per plant.

Fruit number had positive and significant association with number of branches and plant height while the association was negative with fruit length (Ibrahim *et al.*, 2001).

Fruit weight, pericarp thickness, number of seeds per fruit and 1000 seed weight showed positively significant association with fruit yield (Chatterjee *et al.*, 2001). Acharya *et al.* (2002) reported positive and

significant correlation of total fresh yield per plant with total dry yield per plant.

Jose and Khader (2002) reported positive correlation of yield with fruit weight, number of fruits, primary branches per plant, secondary branches per plant, plant height, 100 seed weight, fruit length, fruit girth and crop duration. Correlation was negative with days to flowering.

According to Todorova *et al.* (2003), correlation was unstable and expressed depending on the year of cultivation for some of the morphological characters in *C. annuum* cultivars.

Gadal *et al.* (2003) studied correlation between capsanthin content and other traits of *C. annuum* and found that it had significantly positive correlation with ascorbic acid content but no significant correlation with days to maturity, number of primary branches, fruit girth and seeds per fruit.

Fruit yield was positively correlated with number of fruits, fruit length, fruit diameter, plant height, capsaicin content and colouring matter but negatively correlated with number of days to flowering (Khurana *et al.*, 2003).

Sujatha *et al.* (2003) revealed the positive association of fruit yield with number of fruits, fruit length and fruit diameter.

2.5 SELECTION INDEX

Use of selection indices will increase the efficiency of selection to improve fruit yield in chilli.

Singh and Singh (1976) obtained maximum yield advance in F_2 when selection indices were based on the seven characters, plant height, number of branches, days to flowering, days to maturity, fruit length, fruit thickness and number of fruits per plant. The comparison of different

discriminant functions revealed that days to flowering, fruit length and number of fruits per plant were major yield components.

Singh and Singh (1977a) studied 45 strains of chilli and reported that discriminant function using seven characters at a time, plant height, number of branches, days to maturity, fruit length, fruit size and fruits per plant was more efficient than straight selection for yield.

Ramkumar *et al.* (1981) reported that selection based upon discriminant function involving fruit girth, number of fruits and plant spread may be more efficient than straight selection for yield.

Rani and Usha (1996) evaluated 73 *C. annuum* genotypes for fruit weight and related characters. Correlation and regression analysis were carried out to determine selection indices.

Vallejo *et al.* (1998) used selection index to evaluate individual genotypes and thereby to select best families from an F_2 generation of 19 hybrids obtained from a 7 x 7 half diallel cross. Mini (2003) constructed selection index based on 14 characters studied in 25 *C. annuum* genotypes. The genotypes were ranked based on this and observed high selection indices for high yielding types.

2.6 GENETIC DIVERGENCE

Genetic divergence is a basic requirement for effective selection within the existing population or a population arising out of hybridization.

Singh and Singh (1977a) grouped 45 genotypes of chilli into 10 clusters based on the similarities of their D^2 values. The clustering patterns of the strains did not follow the geographical distribution. Considerable diversity was noted between clusters. The characters contributing maximum towards total divergence were number of branches, fruit thickness, fruits per plant and yield per plant.

Gill *et al.* (1982) conducted a diversity study in six parents and their 15 hybrids of sweet pepper and the 21 genotypes were grouped into seven clusters.

Varalakshmi and Haribabu (1991) classified 32 geographically diverse chilli genotypes into 11 clusters based on D^2 values. Grouping of genotypes in different clusters was not related to their geographical origin. Considerable differences existed between clusters for all the characters. The number of fruits, leaf area index, fruit weight and total yield were reported to be the chief contributors towards genetic divergence.

Oliveira *et al.* (1999) used Mahalanobis D^2 values to evaluate the genetic diversity among six sweet pepper lines.

Forty *C. annuum* genotypes of indigenous and exotic origin were subjected to diversity analysis and based on D^2 values the genotypes were grouped into eight clusters. D^2 values ranged between 0.1032 and 8.7702. Fresh fruit weight and fruits per plant had the highest contribution towards divergence (Karad *et al.*, 2002).

Senapati *et al.* (2003) studied genetic divergence using Mahalanobis D^2 values, the genotypes were clustered in six groups with maximum divergence between clusters II and V. Fresh fruit weight, fruit girth, fruit length and fruits per plant were the chief contributors towards genetic divergence.

Mini (2003) conducted a genetic diversity study using D^2 statistic in 25 wax type chilli genotypes and the genotypes were grouped into nine clusters.

2.7 COMBINING ABILITY

Combining ability analysis of the crosses and their parents provides information on gene action, besides helping in evaluation of inbreds in terms of their breeding value for the development of an efficient hybridization programme.

The concept of combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). According to them general combining ability (*gca*) is the average performance of a genotype in a series of hybrid combinations and specific combining ability (*sca*) refers to those effects in specific combination which significantly departed from what would have been expected on the basis of average performance at the genotype involved. General combining ability is a measure of additive gene action and specific combining ability measures dominance gene action.

In a 9 x 9 diallel cross, Lippert (1975) found that additive effects were predominant in determining variation among hybrids for dry fruit weight per plant, fruit number, fruit length, fruit width and total carotenoid content.

Park and Takahashi (1980) reported that general combining ability played an important part in determining capsaicin content in chilli. According to Khadi (1984), ascorbic acid content in green fruits, fruit length, plant height and number of days to fruit ripening were controlled by additive and dominance effects.

Singh and Rai (1986) analysed data on fruit yield per plant and six related traits from an 8 x 8 half diallel cross in *C. annuum* and observed high specific combining ability variance and non additive gene action for all traits except for fruit length, fruits per plant and fruit yield per plant where, partial dominance was important.

Bhagyalakshmi *et al.* (1991) crossed six chilli cultivars in a half diallel fashion and found non additive gene action for days to fifty per cent flowering, fruit length, fruit girth and 100 seed weight among 13 characters studied.

When seven parents and their 21 F_1 hybrids from a diallel set of crosses without reciprocals were assessed for combining ability for yield

per plant and components of yield, Salazar and Vallejo (1990) found significant difference between GCA and SCA effects and prominence of non additive gene action in relation to yield per plant, fruit number and mean fruit weight.

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

Tavares *et al.* (1997) reported that fruit number is controlled by non additive gene action. Murthy and Deshpande (1997) evaluated six generations of four F_1s for fruit number, fruit length and dry chilli yield and observed additive dominance interaction, but their degree differed with crosses.

Sundaram and Irulappan (1998) reported additive gene action for fruit length, fruit girth and number of fruits. Shukla *et al.* (1999) evaluated 24 F_1's from L x T design and observed non additive gene action for days to flowering, plant height, number of primary branches, number of secondary branches, number of fruits and fruit yield per plant whereas, additive gene action for fruit length and fruit girth. Non-additive gene action for yield and days to flowering was reported by Echeverri *et al.* (1999).

A ten parent diallel analysis excluding reciprocals revealed preponderance of non additive gene action for all the characters except fruit length and fruit diameter (Lohithaswa *et al.*, 2001). Jadhav *et al.* (2001) studied combining ability and gene action among hybrids between six hot chilli cultivars and two paprika type chilli cultivars and found high SCA and GCA variances for plant height, number of fruits, fruit weight and fruit yield.

Rajinder *et al.* (2001) observed non-additive gene action for colouring matter and oleoresin and additive gene action for capsaicin content.

Pandey *et al.* (2002) evaluated 45 *C. annuum* hybrids and their parents from a 10 x 10 half diallel cross and observed non additive gene action for fruit yield, number of fruits and ascorbic acid content. According to Ahmed *et al.* (2003) plant height, number of branches, fruit girth, fruits per plant, fruit weight and yield per plant were more influenced by non additive gene action while for fruit length and pericarp thickness both additive and non additive gene actions were important.

Doshi (2003) reported additive gene effects for plant height, fruit weight and capsaicin content and over dominance for days to flowering, number of primary branches, fruits per plant, fruit length, fruit girth and yield per plant. Gouda *et al.* (2003) reported that specific combining ability effects of crosses can be predicted based on their performance for plant height, number of primary branches, number of secondary branches, days to first flowering, fruit length, fruit diameter, number of fruits, average fruit weight, green fruit yield per plant, dry fruit weight per plant and ascorbic acid content.

Nandadevi and Hosamani (2003a) reported that frequency of heterotic hybrids were comparatively high when one of the parents (female) involved in the crosses was of low combining ability status. They observed additive gene action for fruit length and seeds per fruit while predominance of non-additive gene action for days to fifty per cent flowering, fruit diameter, green fruit weight, number of fruits and green fruit yield per plant. Sousa and Maluf (2003) assessed combining ability in diallel crosses of hot pepper lines and observed non additive gene action for yield, capsaicin content and seeds per fruit.

2.8 HETEROSIS

Heterosis may be defined as the increased or decreased vigour of F_1 population over mid parent (relative heterosis), better parent (heterobeltiosis) or a standard parent (standard heterosis) with respect to any character in the direction of breeders desire (Mandal, 1991). To know the potential of hybrids, studies on the magnitude and direction of heterosis are very important.

The first report on heterosis in chilli came from Deshpande (1933) who observed it for earliness, plant height, fruit girth, fruits per plant and yield per plant. In crosses between KAU cluster and bell pepper varieties, Pious and Peter (1986) observed heterosis for earliness, plant height, fruit length, fruit perimeter, average fruit weight and green fruit yield.

Gopalakrishnan *et al.* (1987a) observed heterosis for earliness in all the hybrids obtained by crossing four chilli lines non-reciprocally. According to Miranda and Costa (1988) positive heterosis was observed for yield per plant, fruits per plant and fruit weight among hybrids from a 6 x 6 half diallel cross. Mishra *et al.* (1988) studied heterosis for 14 traits in 45 hybrids derived from 10 x 10 half diallel cross and reported that poor yielding parents showed highest heterosis over the better parent for fruit yield per plant. Heterobeltiosis for dry fruit yield was 110.4 per cent. Bhagyalakshmi *et al.* (1991) reported that heterosis over mid parent was highest for branches per plant.

Zecevic and Stevanovic (1997) evaluated 15 hybrids of diallel crosses between three macrocarpum and three microcarpum varieties of paprika and reported heterosis for earliness, fruit length and fruit yield per plant.

The study of heterosis of 24 hybrids obtained from 3 x 8 Line x Tester indicated a pronounced hybrid vigour for fruit yield and most of the

yield components. Heterobeltiosis for yield was more than 20 per cent for most of the hybrids (Patel *et al.*, 1997).

Out of 15 hybrids obtained from a 6 x 6 half diallel, four exhibited significant heterobeltiosis and 11 exhibited standard heterosis for dry fruit yield per plant (Gandhi *et al.*, 2000).

Nayaki and Natarajan (2000) observed positive heterosis over better parent for plant height, number of branches, dry fruit yield and fruit length, while negative heterosis for days to fifty per cent flowering and fruit girth. Doshi *et al.* (2001) reported 77.9 per cent relative heterosis and 64.2 per cent heterobeltiosis for green fruit yield.

Mamedov and Pyshnaja (2001) evaluated six parental sweet pepper lines and their 15 hybrids for heterosis and observed heterosis for yield, fruit weight, number of fruits, fruit length, fruit girth and pericarp thickness.

Significant heterosis over mid parent, better parent and standard parent was observed for number of fruits, fresh and dry fruit yield per plant and seeds per fruit by Kumar and Lal (2001) in hybrids evolved from 8 × 8 half diallel. Rajinder *et al.* (2001) evaluated hybrids from 3 × 14 L × T cross of *Capsicum annuum* and observed relative heterosis for fruit length, fruit width, fruit weight, fruit length and yield.

Forty-five *Capsicum annuum* hybrids and their parents were evaluated for heterosis and the greatest average heterosis was recorded for fruit yield followed by number of fruits and ascorbic acid content (Pandey *et al.*, 2002).

In 9 × 9 half diallel crosses involving one bell pepper and eight hot pepper breeding lines, Prasad *et al.* (2003) observed heterosis for earliness, fruit length, fruit width, number of fruits and dry fruit yield per plant.

2.9 MOLECULAR CHARACTERIZATION

Detection of polymorphism at DNA level is used for estimation of genetic diversity, similarity and characterizing cultivars or for testing the purity of hybrid seeds. The random amplified polymorphic DNA (RAPD) technique (Williams *et al.*, 1990) based on the polymerase chain reaction (PCR) has resulted in a potentially useful tool for cultivar discrimination.

Prince *et al.* (1992) performed restriction fragment length polymorphism (RFLP) analysis on 25 accessions of *C. annuum*, *C. chinense* and *C. frutescens* from various regions of Mexico to estimate genetic distances among the accessions. Prince *et al.* (1995) examined interspecific variation among four *C. annuum* cultivars using both RFLPs and RAPDs and reported the effectiveness of both the methods for DNA fingerprinting and discrimination of closely related *C. annuum* genotypes.

Wang *et al.* (1996) surveyed 14 diverse *Capsicum* spp. by RAPD analysis and obtained high degree of polymorphism from four random decamer primers which produced 11 reproducible and effective amplification fragments useful for identification between species. Wang *et al.* (1997) evaluated genetic diversity within 44 *Capsicum* germplasm by RAPD markers and the accessions were divided into six groups.

Random amplified polymorphic DNA analysis was widely used to evaluate genetic distance among accessions within and between different species of *Capsicum* and of diverse geographic origin (Kang *et al.*, 1997; Rodriguez *et al.*, 1999; Votava and Bosland, 2001; Fan *et al.*, 2001 and Lanteri *et al.*, 2003).

Paran *et al.* (1998) examined genetic relationship among 34 pepper cultivars using RAPD and AFLP (amplified fragment length polymorphism). A dendrogram based on RAPD markers separated the large fruited sweet cultivars from the small fruited pungent peppers.

Wang and Fan (1998) used microsatellite DNA (inter simple sequence repeat, ISSR) and RAPD markers to compare 90 accessions of *C. annuum* from 16 different countries and observed that both ISSR and RAPD markers in addition to being simple and time efficient, allowed rapid identification of polymorphism within *C. annuum*. Lefebvre *et al.* (2001) evaluated concordance of AFLP and RAPD markers for estimating genetic distance of 47 *C. annuum* inbred lines belonging to five varietal types. Genetic distance and multidimensional scaling results showed a general agreement between AFLP and RAPD markers.

Pandey *et al.* (1986) studied seed protein electrophoresis to establish phylogenetic relationship in chili. Indira (1994) used polyacrylamide gel electrophoresis (PAGE) to study variation in peroxidase and esterase for assessing genetic diversity in chilli genotypes. Anu and Peter (2003) used PAGE to study the soluble protein pattern in 29 accessions of *C. annuum* and found high seed protein content and clustering pattern for paprika genotypes.

Ballester and Vincento. (1998) tested purity of F_1 chilli (*C. annuum* L.) hybrids and their parents using RAPD markers and proved that despite the dominant inheritance, these markers could be an efficient complement in the process of quality testing of hybrid seeds. Chao *et al.* (1998) performed cultivar identification and seed purity test by RAPDs. Eleven primers produced 16 polymorphic bands with sizes in the range of 330-1150 base pairs.

Huang *et al.* (2001) established a simple and efficient RAPD assay protcol in *C. annuum* cv. Zhonjiao to screen RAPD markers for genetic purity testing of hybrid cultivars and a total of 12 stable and strong RAPDs were identified to distinguish the hybrids from their parental lines.

F_1 hybrid seed purity of hot pepper variety Yuejiao No. 1 was tested using RAPD markers (Wang *et al.*, 2002). Ilbi (2003) evaluated the potential of RAPD markers in varietal identification and genetic purity

test of hybrid varieties of *C. annuum*. Five Jalapeno hybrid varieties and their corresponding parents were screened for polymorphic RAPD markers with 12 arbitrary 10 mer primers and six primers generated useful RAPD markers to determine seed purity of all tested hybrid varieties. Among a total of 177 bands observed, 14 bands contributed by nine primers were polymorphic in the five pepper varieties.

Garcia *et al.* (2002) used RAPD to study the relationship between genetic distance among parental lines of green pepper and the heterosis observed as yield of their F_1 hybrids.

Single nucleotide polymorphism (SNP) was studied by Acquadro *et al.* (2003) in 17 *C. annuum* accessions by polymerase chain reaction. Single strand conformation polymorphism among three SNPs detected, one SNP was positioned at the base 512 of the capsanthin-capsorubin synthase gene whereas two SNPs were detected at 5182 and 5252 base positions respectively.

Ma *et al.* (2003) studied the genetic relationship among 46 chilli germplasm accessions by RAPD and genetic polymorphism was observed in 88.68 per cent of the amplified bands from nine primers selected from a total of 160 primers. The accessions were classified into six groups by cluster analysis and the results of RAPD were similar to those obtained using traditional methods of genetic analysis.

2.10 GENETIC IMPROVEMENT FOR PAPRIKA QUALITY

Quality parameters of dried red chilli and paprika are red fruit colour, vitamin content and pungency (Bosland, 1993). Red chilli is the mature red fruit of pungent capsicum whereas international spices traders use the term paprika for non pungent (sweet, red) capsicum powder.

The colour is genetically controlled and four different genes (Y, C_1, C_2, C_1C_2) with epistatic interaction have been reported for the development of colour in mature fruits (Hurtado-Hernandez and Smith, 1985; Todorov *et al.*,

1989 and Shifriss and Pilovsky, 1992). The major red colour in capsicum comes from capsanthin and capsorubin and is measured spectrophotometrically in ASTA (American Spice Trade Association) units.

Generally, there is a decrease in pungency from chillies to paprika and a parallel increase in colour pigment and an increase in size and fleshy nature of pericarp. According to Govindarajan (1985) the group paprika contains less than 0.1 per cent of capsaicinoids, the best grade of Spanish paprika having 0 to 0.003 per cent and for the pungent grade, a maximum of 0.5 per cent. But the pungency level of chillies varies from 0.1 to 1.4 per cent.

Flesh thickness is directly related to industrial yield and a variety with thick flesh and a low water content in the flesh is the most suitable for processing (Casali and Stringheta, 1984).

Regional station Katrain has collected 116 foreign and indigenous accessions of chilli of which 74 accessions showed great variability and were assigned to three groups: vegetable paprika, salad paprika and spice paprika (Joshi *et al.*, 1987).

Joshi *et al.* (1993) developed spice pepper (*C. annuum*) genotypes from local and foreign sources selected for pungency and non pungency followed by crossing in a diallel design and identified kt-pl-18 and kt-pl-19 (233.70 ASTA units) as most promising lines.

Biacs *et al.* (1993) evaluated carotenoid and carotenoid esters from new cross cultivars of paprika. The F_1 hybrids had a colour composition similar to that of parents while the F_5 generation showed improved characteristics such as high colour intensity and high capsanthin / capsorubin ratio.

Capsanthin and capsaicin content of ground chilli powder decreased during storage (Rani, 1996). Having the appropriate cultivar, the right

maturity stage and the best growing condition do not insure good quality paprika powder and red colour retention mainly depends on preventions of oxidative attack of the powder (Indira and Rajan, 1997).

Pardo *et al.* (1997) evaluated paprika quality derived from selected 10 *C. annuum* cultivars and found maximum extractable colour in paprika from fruits of cultivars Larguillo and Datica (370 and 335 ASTA units respectively).

Hwang and Chung (1998) investigated the quality of dried red pepper (*C. annuum*) and found that traits of high quality were large, heavy and contained high contents of sugar and capsanthin but low contents of capsaicin.

Todorova *et al.* (1999) studied the content and quality of total pigment in *C. annuum* fruits and ground paprika in five cultivars from Bulgaria, Spain and Hungary and the colour value in ASTA units ranged between 177 and 262. Nawagatti *et al.* (1999) evaluated chilli genotypes for quality parameters like capsaicin, colouring matter, oleoresin and ascorbic acid but they could not observe a definite relationship between quality parameters and yield.

Korikanthimath *et al.* (2000) reported the work undertaken by Indian Institute of Spices Research (IISR) and University of Agricultural Sciences, Dharward on the evaluation and improvement of Byadagi paprika types. The performance of improved line kt-pl-19 was considered along with suggestion for Byadagi paprika improvement. A few selections were made from Byadagi chillies at Indian Institute of Horticultural Research (IIHR) and the selection was released as Arka Abir (John, 2000). Hosamani (2000) emphasized the importance of varietal purity in paprika chillies to fetch more price in the national and international market.

Plant breeding programmes were conducted at Sarpan Agri-Horticultural Research Centre. Dharwad district using genetically diverse

C. annuum cultivars to produce high yielding F_1 hybrids that meet the selection criteria for superior oleoresin content and organic colour (Gaddagimath, 2000).

Red fruit colour in capsicum is dominant to yellow fruit colour on the locus Y. Popovsky and Paran (2000) studied the relation of Y locus with the gene coding for capsanthin-capsorubin synthase (CCS) that synthesizes the red carotenoid pigments in the mature fruit.

At phenotypic and genotypic levels, ascorbic acid content had a positive correlation with capsanthin content (Gadal *et al.*, 2003). Long fruits contained more ascorbic acid content than short fruits (Kumar *et al.*, 2003a).

Rajinder *et al.* (2003) conducted an experiment to evaluate quality aspects of parents and F_1's of chilli. The highest colouring matter in powder (185.18 ASTA units) and in oleoresin (883.86 ASTA units) was for S 2529.

Materials and Methods

3. MATERIALS AND METHODS

The present study was carried out at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2002-2004 as four experiments with a view to evolve improved chilli (*Capsicum annuum* L.) types with paprika quality and their molecular characterization. The details of materials used and methods adopted for the study are presented below.

3.1 EXPERIMENT I – GERMPLASM EVALUATION

3.1.1 Materials

The materials for the study consisted of 44 genotypes including germplasm from different parts of the country as well as local collections. The entries are designated by accession numbers CA_1 to CA_{44}. The details of the accessions are presented in Table 1.

3.1.2 Methods

The experiment was conducted in Randomised Block Design (RBD) with three replications. Seeds were sown in pots. Thirty days old seedlings were transplanted in the main field at a spacing of 45 × 45 cm. For every genotype 15 plants were maintained in rows in each replication with a plot size of 3.04 m^2. Cultural operations and plant protection measures were carried out according to the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002). Evaluation was done based on 12 biometrical and four quality parameters. Data were subjected to statistical analysis and seven parents were selected for hybridization.

Table 1 List of genotypes

Accession No.	Genotype
CA_1	Kalliyoor local
CA_2	Thirumala local
CA_3	Pallichal local
CA_4	Palappur local
CA_5	Amaravila local
CA_6	Neyattinkara local
CA_7	Nagarkoil local 1
CA_8	Bangalore local 1
CA_9	Bangalore local 2
CA_{10}	Kattakkada local
CA_{11}	EG-85*
CA_{12}	Arka Abhir*
CA_{13}	EG-101*
CA_{14}	Sha-ema*
CA_{15}	EG-172*
CA_{16}	Kaliyikkavila local
CA_{17}	Vellayani local
CA_{18}	Nagarkoil local 2
CA_{19}	Kottikulam local
CA_{20}	Kottayam local
CA_{21}	Poonkulam local
CA_{22}	Mangalathukonam local
CA_{23}	Nemam local
CA_{24}	Jwalamukhi
CA_{25}	Jwalasakhi
CA_{26}	Karamana local
CA_{27}	Venganoor local
CA_{28}	Koliyoor local
CA_{29}	Malayam local
CA_{30}	Pravachambalam local
CA_{31}	Piriyan mulak
CA_{32}	Kt-Pl-19*
CA_{33}	Villupuram local
CA_{34}	Kattappana local
CA_{35}	Balaramapuram local
CA_{36}	Coimbatore local 1
CA_{37}	Pollachi local
CA_{38}	Coimbatore local 2
CA_{39}	Madurai local
CA_{40}	Kakkamoola local
CA_{41}	IHR*
CA_{42}	PSB-1*
CA_{43}	Dharwad local
CA_{44}	Kt-Pl-18*

*Paprika varieties

3.1.3 Biometric Observation on Yield Traits

Five plants were selected randomly from every replications of each genotype for recording the following biometric observations. The data for statistical analysis were obtained as mean values worked out thereafter.

3.1.3.1 Days to 50 per cent Flowering

Number of days taken for 50 per cent of the plants to flower was recorded.

3.1.3.2 Plant Height

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

3.1.3.3 Primary Branches per Plant

Branches arising from the main stem were counted and recorded at the full maturity of the plant.

3.1.3.4 Secondary Branches per Plant

The branches borne on the primary branches were counted and recorded as the secondary branches.

3.1.3.5 Fruits per Plant

The number of fruits at each harvest was recorded for each observational plant to obtain the total number of fruits per plant.

3.1.3.6 Fruit Length

Length of five fruits taken at random from the observational plants was recorded, the average worked out and expressed in centimetre. Length was measured from the base of the peduncle to the tip of the fruit.

3.1.3.7 Fruit Girth

The circumference at the broadest part of the fruits selected for recording length was taken. Average was worked out and expressed in centimetre.

3.1.3.8 Fruit Weight

The weight of five fruits taken at random from the observational plants over different harvests was recorded, the average worked out and expressed in gram.

3.1.3.9 Seeds per Fruit

The seeds were extracted from each fruit and the total number was counted and recorded.

3.1.3.10 Hundred Seed Weight

Seeds were extracted from a random sample of five fruits and dried uniformly. The weight of the 100 fully developed seeds were recorded and expressed in gram.

3.1.3.11 Crop Duration

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

3.1.3.12 Yield per Plant

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

3.1.4 Biochemical Analysis for Quality Parameters

3.1.4.1 Estimation of Ascorbic Acid Content (mg 100 g^{-1} fresh fruit weight)

Ascorbic acid content of fruits at red ripe stage was estimated by 2,6-dichlorophenol indophenol dye method (Sadasivam and Manickam, 1992).

Reagents

i) Oxalic acid (4 per cent)

ii) Ascorbic acid standard

Prepared a stock solution by dissolving 100 mg of ascorbic acid in 100 ml of four per cent oxalic acid. Diluted 10 ml of the stock solution to 100 ml with four per cent oxalic acid to get working standard solution.

iii) 2,6-dichlorophenol indophenol dye

Weighed 42 mg sodium bicarbonate into a small volume of distilled water. Dissolved 52 mg 2,6-dichlorophenol indophenol in it and made upto 200 ml with distilled water.

Procedure

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

Five grams of fresh fruit was extracted in four per cent oxalic acid medium, filtered the extract and volume was made upto 100 ml using oxalic acid. From this 5 ml of aliquat was taken, added 10 ml of four per cent oxalic acid and titrated as above against the dye and determined the end point (V_2 ml).

Ascorbic acid content of the sample was calculated using the formula.

Amount of ascorbic acid in mg/100 g sample

$$= \frac{0.5 \times V_2 \times 100}{V_1 \times 5 \times \text{weight of sample}} \times 100$$

3.1.4.2 Estimation of Oleoresin (per cent)

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

Procedure

Chilli fruits harvested at red ripe stage were dried in a hot air oven at 50°C, powdered finely in a mixer grinder. Weighed two grams of chilli powder and packed in filter paper and placed in Soxhlet's apparatus. Taken 200 ml of acetone in the round bottom flask of the apparatus and

heated in a water bath. The temperature is maintained at the boiling point of the solvent (around 60°C). After complete extraction (4-5 hrs), the solvent was evaporated to dryness.

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

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

3.1.4.3 Estimation of Extractable Colour (Capsanthin)

Red ripe chillies were dried and the stalk and seeds were removed before powdering. 0.1 g of ground chilli powder was transferred into a 250 ml Erlenmeyer flask with 100 ml isopropanol and kept overnight at room temperature. The contents were filtered through a Whatman No. 42 filter paper. The first 10 ml was discarded and 25 ml of the filtrate was pipetted into a volumetric flask and diluted to the mark with isopropanol. The absorbance was read at 450 nm against isopropanol as blank.

Standard colour solution was prepared by dissolving 0.5 mg/ml of reagent grade potassium dichromate in 1.8 M sulphuric acid.

Ascorbitivity of standard colour solution (a)

$$= \frac{\text{Absorbance of standard colour solution at 450 nm}}{\text{Cell length (cm)} \times \text{Concentration (mg/ml)}}$$

Extractable colour in ASTA units

$$= \frac{\text{Absorbance of extract at 450 nm} \times 200}{\text{Cell length (cm)} \times a \times \text{concentration of the solution (mg/ml)}}$$

3.1.4.4 Estimation of Capsaicin (per cent)

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

Reagent

i) Folin-Dennis reagent

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

ii) 25 per cent sodium carbonate solution

iii) Acetone

Procedure

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

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

3.1.5 Statistical Analysis

3.1.5.1 Analysis of Variance (ANOVA)

The biometric and biochemical observation recorded were subjected to ANOVA (Panse and Sukhatme, 1985) for comparison among various treatments and to estimate variance components. The mean values for all the accessions for each of the characters were worked out and compared using critical difference.

ANOVA for each character

Source of variation	Degree 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.

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

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

3.1.5.2 Estimation of Genetic Parameters

3.1.5.2.1 Components of Variance

The mean squares between treatments consisted of variances attributable to genotype, environment and phenotype (Singh and Chaudhary, 1985).

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, $\sigma^2 g = \frac{MST - MSE}{r}$

ii) Environmental variance, $\sigma^2 e = MSE$

iii) Phenotypic variance, $\sigma^2 p = \sigma^2 g + \sigma^2 e$

3.1.5.2.2 Coefficients of Variation

It is a unit free measurement used for comparison of variation of different characters measured in different units. Genotypic and phenotypic coefficients of variation were worked out using the estimate of $\sigma^2 g$ and $\sigma^2 p$ and expressed in percentage (Burton, 1952) for each trait.

i) Phenotypic coefficient of variation (PCV)

$$= \frac{\sigma p}{\text{Mean}} \times 100$$

ii) Genotypic coefficient of variation (GCV)

$$= \frac{\sigma g}{\text{Mean}} \times 100$$

3.1.5.2.3 Heritability

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

$$\text{Heritability } (H^2) = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Heritability per cent was categorized as suggested by Johnson *et al.* (1955) *viz.*, low (0 – 30), moderate (30 – 60) and high (above 60).

3.1.5.2.4 Genetic Advance

Genetic advance which measures the change in mean genotypic level of the population brought about by selection depends upon standardised selection differential, heritability and phenotypic standard deviation (Allard, 1960).

Genetic advance as percentage of mean was estimated as per the method suggested by Lush (1940) and Johnson *et al.* (1955) for each trait as

$$\text{Genetic advance, GA} = \frac{k\, H^2 \sigma p}{\overline{X}} \times 100$$

where, k is the standardised selection differential (k = 2.06) at five per cent selection intensity and $\overline{X}$ is the mean of the character over all accessions. Genetic advance was categorized into low (below 10 per cent), moderate (10-20 per cent) and high (above 20 per cent) as suggested by Johnson *et al.* (1955).

3.1.5.3 Association Analysis

3.1.5.3.1 Correlation

Phenotypic, genotypic and environmental correlation coefficients were worked out for two characters X_i and X_j as

$$\text{Genotypic correlation } (r_{g_{ij}}) = \frac{\sigma g_{ij}}{\sigma g_i \times \sigma g_j}$$

$$\text{Phenotypic correlation } (r_{p_{ij}}) = \frac{\sigma p_{ij}}{\sigma p_i \times \sigma p_j}$$

$$\text{Environmental correlation } (r_{e_{ij}}) = \frac{\sigma e_{ij}}{\sigma e_i \times \sigma e_j}$$

where, σg_{ij} , σp_{ij} and σe_{ij} denote the genotypic, phenotypic and error covariances between two traits X_i and X_j respectively.

3.1.5.4 Selection Index

The selection index developed by Smith (1937) using discriminant function of Fischer (1936) was used to discriminate the genotypes based on the characters under study.

The selection index is described by the function $I = b_1 x_1 + b_2 x_2 \ldots + b_k x_k$ and the merit of a plant is described by the function $H = a_1G_1+a_2G_2 + \ldots + a_k G_k$ where G_1, G_2, ... G_k are the genotypic values of the plants with respect to the characters x_1, x_2, ... x_n and H is the genetic worth of the plant. It is assumed that the economic weight assigned to each character is equal to unity *i.e.*, a_1, a_2, ... $a_k = 1$.

The regression coefficients (b) are determined such that the correlation between H and I is maximum. This procedure will reduce to an equation of the form $b = P^{-1}Ga$ where P is the phenotypic variance – covariance matrix and G is the genotypic variance – covariance matrix.

3.1.5.5 Mahalanobis D^2 Analysis

Genetic divergence was estimated using Mahalanobis D^2 statistic as described by Rao (1952).

For i^{th} and j^{th} accessions D^2 value is computed as

$$D^2 = \sum_{i=1}^{k} (X_{ij} - X_{ji})^2$$

where k is the number of characters, X_{ij} and X_{ji} are the uncorrelated means for the characters X_i and X_j in the i^{th} genotype. The significance of D^2 values was tested by chi-square test with k degrees of freedom.

The genotypes were grouped into several clusters based on their D^2 values following Tocher's method of clustering.

Plate 1. Field view - evaluation of parents and hybrids

3.2 EXPERIMENT II – CROSSING AND DEVELOPMENT OF F_1's

The selfed seeds of parents for hybrid seed production were raised in the field. Staggered sowing was done to facilitate synchronous flowering and to ensure successful production of hybrids. Seven selected parents were crossed in a diallel fashion without reciprocals to get 21 hybrid combinations. The technique followed for the production of selfed and crossed seeds were as follows.

Selfing

For getting selfed seeds, mature flower buds on previous day of its opening were covered with paper bags and labeled. The paper bags were retained for three to four days.

Crossing

In female parents, the mature flower buds which would open on the next day were selected in the evening and emasculation was done by standard manual method using forceps. The emasculated flower buds were covered with paper bags. Next morning, anthers were collected from the male parent and pollen was transferred to the stigma of the emasculated flower by scooping out the pollen from mature undehisced anthers through the lateral sutures with a needle. After pollination, the flowers were protected with paper bags and labeled properly. Paper bags were removed three to four days after while tags were retained till the harvest of fruits. Fully ripened fruits were harvested, seeds extracted, dried and kept for evaluation.

3.3 EXPERIMENT III – EVALUATION OF F_1's AND PARENTS

The seeds of 21 cross combinations and seven parents were raised in pots. One month old seedlings were transplanted as single seedling per pit in the main field, at a spacing of 45 x 60 cm in randomised block design (RBD) replicated thrice. Ten plants were maintained in each replication. Agronomic practices and plant protection measures were

carried out as per the Package of Practices Recommendations of the Kerala Agricultural University (KAU, 2002). Jwalamukhi and Arka Abir were taken as the check varieties.

3.3.1 Biometric Observation

From every replication, five plants each were selected at random for recording observations and the method of measuring the different characters are same as described earlier. Additionally three more observations were recorded.

3.3.1.1 Ripe Fruit Yield per Plant (g)

The weight of ripe fruit harvested from each observational plant was recorded at each harvest. Total ripe fruit yield per plant was obtained by adding the weight of the fruits at each harvest and taking the mean.

3.3.1.2 Dry Fruit Weight Recovery (per cent)

Ripe fruits were oven dried at 50°C and the dry fruit weight recovery was calculated as

$$\text{Dry fruit weight recovery (per cent)} = \frac{\text{Dry fruit weight}}{\text{Fresh fruit weight}} \times 100$$

3.3.1.3 Pericarp Thickness (mm)

Pericarp thickness of five ripe fruits taken at random was recorded using Vernier Calipers and the average was expressed in millimetre.

3.3.2 Biochemical Analysis

The same methodology as described in Experiment I was followed.

3.3.3 Statistical Analysis

Analysis of variance (ANOVA) was performed as described earlier.

3.3.3.1 Combining Ability Analysis

Combining ability analysis was performed when the genotypic difference were found to be significant. Since the experimental material comprised of parents and F_1's only (no reciprocals) Griffing's approach model I, method II (Griffing, 1956) was used.

ANOVA for combining ability

Source of variation	dt	Mean square	Expected ms	F
Replication	(r – 1)			
Genotype	$\frac{n(n+1)}{2} - 1$	M	$\sigma^2e + r\sigma^2g$	M/Me
GCA	(n – 1)	Mg	$\sigma^2e + \sigma^2sca + (n+2)\,\sigma^2gca$	Mg/Me
SCA	$\frac{n(n-1)}{2} - 1$	Ms	$\sigma^2e + \sigma^2sca$	Ms/Me
Error	$\left[\frac{n(n+1)}{2} - 1\right](r-1)$	Me	σ^2e	

Where, $Me = \frac{MSE}{r}$

MSE = Error mean square obtained from 1st ANOVA

n = number of parents

r = number of replications

If the F values for GCA and SCA were found to be significant, then their effects were estimated using the following formula.

$$gca \text{ effects } (g_i) = \frac{1}{n+2}\left[\Sigma(X_{i.} + X_{ii}) - \frac{2X..}{n}\right]$$

$$sca \text{ effects } (s_{ij}) = \left[X_{ij} - \frac{X_{i.} + X_{ii} + X_{j.} + X_{jj}}{n+2} \right] + \frac{2X..}{(n+1)(n+2)}$$

where, X_{ij} = mean of character with respect to $(ixj)^{th}$ cross over three replications.

$X_{i.}$ = total of mean values (over replications) corresponding to i^{th} parent over the other crosses involving i^{th} parent

$X_{j.}$ = total of the mean values corresponding to j^{th} parent over the other crosses involving j^{th} parent.

X.. = total of all mean values

The comparison of *gca* and *sca* effects were made by computing the respective critical difference based on the following estimate of variance.

$$\text{Var } (g_i) = \frac{(n-1)Me}{n(n+2)} \qquad \text{Var } (g_i - g_j) = \frac{2Me}{n+2}$$

$$\text{Var } (s_{ij}) = \frac{n(n-1)Me}{(n+1)(n+2)} \qquad \text{Var } (s_{ii} - s_{jj}) = \frac{2(n-2)Me}{n+2}$$

$$\text{Var } (s_{ii}) = \frac{(n^2+n+2)Me}{(n+1)(n+2)} \qquad \text{Var } (s_{ij} - S_{ik}) = \frac{2(n+1)Me}{(n+2)}$$

$$\text{Var } (s_{ij} - s_{ki}) = \frac{2nMe}{(n+2)}$$

The significance of g_i and s_{ij} values were tested using 't' test. For making pair wise comparison critical differences were worked out using corresponding estimates of variances.

$$CD = t_\alpha \times \sqrt{Variance}$$

Where, t_α = 't' value for error degrees of freedom.

Significant *gca* effect implied that additive genetic variance was operating while significant *sca* effect revealed the importance of non-additive variance for the inheritance of the character.

Components of variance for *gca* and *sca* effects can be estimated as

$$\sigma^2 gca = \frac{Mg - Ms}{n+2} \qquad \sigma^2 sca = Ms - Me$$

Additive variance $\sigma^2 A = 2\ \sigma^2 gca$

Dominance variance $\sigma^2 D = \sigma^2\ sca$

Additive to dominance ratio was worked out and if it was more than unity then there was predominance of additive gene action. Less than unity value for the ratio revealed the predominance of non-additive gene action for the character.

3.3.3.2 Heterosis

Heterosis can be estimated in three different ways.

i) As the percentage deviation of the mean performance of F_1's from its mid parent which is referred as relative / average heterosis (RH)

ii) As the percentage deviation of the mean performance of F_1's from better parent which is referred as heterobeltiosis (HB)

iii) As the percentage deviation of mean performance of F_1's from a standard parent which is referred as standard heterosis (SH).

$$RH = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100 \qquad HB = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$SH = \frac{\overline{F_1} - \overline{SP}}{\overline{SP}} \times 100$$

To test the significance of $\overline{F_1} - \overline{MP}$ observed in RH. CD is calculated as

$$CD\ (0.05) = t_\alpha \sqrt{\frac{3MSE}{2r}}$$

To test the significance of $\overline{F_1} - \overline{BP}$ and $\overline{F_1} - \overline{SP}$ observed in heterobeltiosis and SH respectively. CD is worked out as

$$CD\ (0.05) = t_\alpha \sqrt{\frac{2MSE}{r}}$$

Where, t_α = t value for error degrees of freedom at 5 per cent level of significance

MSE = error mean square

r = number of replications.

3.4 EXPERIMENT IV – MOLECULAR CHARACTERIZATION OF F_1's AND PARENTS

Molecular characterization of 21 hybrids and seven parents was carried out using RAPD markers. Young leaf samples from each genotype was collected and used for DNA extraction.

3.4.1 DNA Extraction

The extraction protocol were slightly modified from that of Mondal *et al.* (2000). Young leaf tissue samples were used immediately after collection for DNA extraction. Briefly 0.5 g of leaf material after thorough washing with distilled water was pulverized to a fine powder in liquid nitrogen with a pre-cooled mortar and pestle. The powder was transferred to a 2 ml eppendorf tube and added 1 ml of hot (65°C) extraction buffer (100 mM Tris. HCl, pH 8, 20 mM EDTA, 1.4 M NaCl, 2 % CTAB), 20 µl β-mercapto ethanol, 40 µl of 1 per cent PVP and 100 µl of 2 per cent SDS. The contents in the tube was mixed well and incubated in water bath at 65°C for 1 h with occasional gentle shaking. The sample was centrifuged at 4°C for 10 min at 10,000 rpm. The supernatant was transferred to another sterile eppendorf tube using a sterile pipetted tip. To this added equal volume of phenol : chloroform : iso amyl alcohol (25:24:1) and centrifuged as in previous step after gentle mixing. To the supernatant added equal volume of chloroform : iso amyl alcohol (24:1)

and centrifuged as said above. This step was repeated. Then, to the supernatant $1/10^{th}$ volume of 3 M sodium acetate followed by double volume of isopropyl alcohol was added. It was mixed gently and kept in freezer for 30 min for better precipitation of DNA. Then centrifuged at 10,000 rpm for 10 min at 4°C to pellet the DNA. The supernatant was discarded and the pellet was washed in 70 per cent ethanol. The pellet was air dried and then dissolved in 0.1 ml of 1 x Tris EDTA buffer (10 mM Tris HCl, 1 mM EDTA, pH 8) and stored at –20°C.

3.4.2 Quantification of DNA

The quantification of DNA is necessary before it is subjected to amplification. The quantification of DNA was carried out with the help of UV spectrophotometer (Spectronic Genys 5).

The buffer in which the DNA was already dissolved was taken in a cuvette to calibrate the spectrophotometer at 260 and 280 nm wavelengths. The optical density (OD) of the DNA samples dissolved in the buffer was recorded both at 260 and 280 nm. The concentration of the DNA was found out using the formula

$$\text{Amount of DNA } (\mu g/\mu l) = \frac{A_{260} \times 50 \times dilution\ factor}{1000}$$

Where A_{260} is the absorbance at 260 nm.

The quality of the DNA could be judged from the ratio of the OD values recorded at 260 nm and 280 nm. The A_{260}/A_{280} ratio between 1.8 and 2.0 indicates best quality of DNA, where A_{280} is the absorbance at 280 nm.

3.4.3 Agarose Gel Electrophoresis

Agarose gel electroporesis was carried out in a horizontal gel electrophoresis unit. Required amount of agarose was weighed out (0.8 per cent for visualizing the genomic DNA and 1.2 per cent for visualizing the amplified product) and melted in 1 x TAE buffer (6.04 M Tris acetate.

0.001 M EDTA, pH 8) by boiling. After cooling to about 50°C, ethidium bromide was added to a final concentration of 0.5 μg ml^{-1}. The mix was then poured to a pre set template with appropriate comb. After solidification of the agar, the comb and the sealing tapes were removed and the gel was mounted in an electrophoresis tank. The tank was loaded with 1 x TAE buffer, so that it just covered the entire gel. Required volume of DNA sample and gel loading buffer (6.0 x loading dye *viz.*, 40 per cent sucrose, 0.25 per cent bromophenol blue) were mixed. Each well was loaded with 20 μl of sample. One of the well was loaded with 5.0 μl of PCR molecular weight marker along with required volume of the gel loading buffer. Electrophoresis was performed at 60 volts until the leading dye reached ¾th of the length of the gel. The gel was visualized using an ultra-violet visible transilluminator.

3.4.4 Amplification of DNA

DNA amplification was done using arbitrarily designed decamer primer (Operon Inc.) adopting the procedure of Lim *et al.* (1999) with required modification.

The reaction was carried out in 25 μl reaction mixture containing 20 ng template DNA, 2.5 μl 1x PCR buffer (10 mM Tris HCl, pH 9.0, 1.5 mM $MgCl_2$, 50 mM KCl and 0.01 per cent gelatin), 2.5 mM $MgCl_2$, 0.2 mM each of dATP, dCTP, dGTP and dTTP, 4 pM primer and 0.6 units of Taq DNA polymerase (Bangalore Genei Pvt. Ltd., Bangalore). Amplification was performed in a programmable thermocycler (MJ Research Inc.) which was programmed as followed.

An initial denaturation at 94°C for five minutes followed by 43 cycles of denaturation at 94°C for one minute annealing at 35°C for one minute 30 seconds and extension at 72°C for two minutes. The synthesis step of the final cycle was extended further by five minutes. Finally the products of amplification were cooled at 4°C. Amplified products were

separated by agarose gel electrophoresis as described earlier and photographed using gel documentation system.

3.4.5 Data Analysis

The reproducible bands were scored for their presence (+) or absence (-) for all the genotypes studied. A genetic similarity matrix was constructed using the Jaccard's coefficient method (Jaccard, 1908).

$$Sj = a / (a + b + c)$$

Where,

a = Number of bands present in both the genotypes in a pair

b = Number of bands present in the first genotype but not in the second one.

c = Number of bands present in the second genotype but not in the first.

Based on the similarity coefficient a dendrogram was constructed with the help of the software package 'NTSYS' (version 2.02). Association between the genotypes was found out from the dendrogram.

Results

4. RESULTS

The results of the study entitled "Genetic improvement and molecular characterization of paprika (*Capsicum annuum* L.) genotypes" are presented below.

4.1 EVALUATION OF GERMPLASM

The 44 genotypes were evaluated for 16 biometrical and quality characters namely days to 50 per cent flowering, plant height (cm), primary branches per plant, secondary branches per plant, fruits per plant, fruit length (cm), fruit girth (cm), fruit weight (g), seeds per fruit, 100 seed weight (g), crop duration, yield per plant (g), ascorbic acid (mg 100 g^{-1}), oleoresin (%), capsanthin (ASTA) and capsaicin (%).

4.1.1 Variability

All the genotypes differed among themselves with significant difference for all the characters studied.

4.1.1.1 Mean Performance

The mean performance of genotypes for 16 characters studied are given in Table 2.

Days to 50 per cent flowering was maximum for CA_{39} (90.40) and was on par with CA_{34} (88.30). CA_{13} had the minimum number of days for 50 per cent flowering (65.17) and was on par with CA_{44} (65.30).

Plant height was maximum for CA_6 (96.27 cm) and it significantly differed from all other genotypes. CA_{42} recorded the minimum plant height (26.03 cm) and it was on par with CA_{36} (30.20 cm).

The genotype CA_{24} (7.17) had the maximum number of primary branches and was on par with CA_{15} (6.5). The minimum number of primary branches was for the genotypes CA_{11}, CA_{28}, CA_{41} and CA_{42} (2 each).

Table 2 Mean performance of genotypes

Accession No	Days to 50 per cent flowering	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Fruits/ plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Seeds/ fruit	100 seed weight (g)	Crop duration (days)	Yield/plant (g)	Ascorbic acid (mg/ 100g)	Oleoresin (%)	Capsanthin (ASTA)	Capsaicin (%)
CA_1	77.73	52.43	3.77	7.27	24.37	7.10	7.97	7.67	95.20	0.4497	178.83	175.30	119.33	9.57	46.79	0.3060
CA_2	78.97	52.23	5.77	10.17	21.73	6.57	7.27	6.60	97.00	0.5653	169.70	141.31	102.67	8.00	62.56	0.4207
CA_3	81.97	38.27	3.10	7.67	20.20	4.87	8.93	8.87	91.27	0.5103	180.33	165.06	66.27	8.53	79.70	0.3740
CA_4	80.27	32.10	3.67	7.83	18.87	4.97	8.00	6.67	76.10	0.5330	171.20	121.90	85.53	11.53	53.87	0.3940
CA_5	76.03	46.00	4.40	11.10	21.87	5.40	8.83	6.77	92.77	0.5157	163.47	132.63	83.63	10.10	48.63	0.2760
CA_6	79.13	96.27	4.50	11.43	25.13	6.83	7.83	10.07	122.53	0.4923	183.83	216.73	89.37	8.23	76.31	0.4233
CA_7	80.63	42.53	2.80	6.17	16.90	4.67	8.80	5.73	70.03	0.3890	166.30	97.67	84.27	9.10	66.60	0.2840
CA_8	80.57	48.43	2.33	5.17	18.37	12.40	7.53	13.20	93.67	0.5727	161.70	223.70	156.27	10.53	83.04	0.2867
CA_9	75.37	52.27	2.83	5.87	21.67	8.43	7.23	8.77	85.23	0.7220	169.33	180.50	137.4	12.50	70.36	0.2833
CA_{10}	71.60	60.93	3.00	9.10	30.27	6.50	7.40	9.63	104.93	0.4187	168.27	279.63	165.43	11.63	105.30	0.2067
CA_{11}	68.30	60.57	2.00	4.00	36.37	14.50	4.67	8.63	110.37	0.6727	152.97	309.80	153.43	10.80	143.39	0.2840
CA_{12}	75.37	54.67	3.90	10.43	17.40	6.13	8.97	9.17	77.87	0.3957	179.40	153.87	126.40	11.57	186.20	0.1420
CA_{13}	65.17	40.20	4.50	9.03	36.97	10.83	6.33	12.00	98.97	0.7163	147.90	420.57	146.40	12.03	123.15	0.2100
CA_{14}	77.67	38.63	4.23	7.90	20.83	5.10	4.17	3.83	83.57	0.4667	158.37	80.03	150.57	10.07	65.83	0.3733
CA_{15}	74.27	63.70	6.50	9.23	47.77	6.27	4.73	4.00	65.43	0.6533	158.90	185.37	104.17	12.07	140.53	0.3167
CA_{16}	72.47	64.87	4.83	11.23	32.00	6.80	9.67	8.87	84.33	0.4963	170.13	260.87	172.37	12.53	87.02	0.2980
CA_{17}	78.83	72.03	3.50	7.17	48.53	7.83	9.77	12.47	83.00	0.7853	175.80	535.67	163.83	12.20	92.98	0.3220
CA_{18}	77.40	40.63	2.83	5.60	19.17	6.23	7.43	5.13	94.43	0.4153	165.97	99.37	86.17	9.47	74.52	0.1907
CA_{19}	73.63	43.53	4.50	11.60	16.53	5.77	3.87	3.93	107.00	0.4717	166.60	63.63	94.47	9.83	71.90	0.1967
CA_{20}	79.63	56.73	4.43	8.47	34.73	8.27	7.13	8.73	78.20	0.4900	178.57	292.67	88.40	11.07	44.94	0.3027
CA_{21}	76.27	57.97	3.83	10.17	16.73	7.83	8.60	12.77	62.03	0.7233	159.30	193.07	75.10	9.27	82.68	0.1633
CA_{22}	82.60	51.07	3.43	6.67	11.90	5.07	9.13	9.53	91.83	0.3277	161.37	94.50	71.53	9.10	44.29	0.2993
CA_{23}	81.17	59.10	4.20	9.07	32.27	7.57	5.57	5.00	64.87	0.6133	184.97	139.13	88.03	12.27	49.21	0.4300
CA_{24}	77.90	60.93	7.17	15.60	52.47	10.00	5.47	6.20	62.53	0.6390	182.93	316.13	114.57	13.07	64.64	0.2860

Table 2 Continued

Sl. No.	Days to flowering	Plant height (cm)	Primary branches/plant	Secondary branches/plant	Fruits/plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Seeds/fruit	100 seed weight (g)	Crop duration (days)	Yield/plant (g)	Ascorbic acid (mg/100g)	Oleoresin (%)	Capsanthin (ASTA)	Capsaicin (%)
CA_{25}	79.03	56.97	3.90	8.43	37.87	5.80	4.57	4.37	67.00	0.6220	180.37	162.00	109.33	13.50	49.03	0.2757
CA_{26}	74.13	57.23	3.67	8.50	70.37	8.83	5.70	4.73	54.33	0.4533	193.60	327.27	85.53	12.57	60.60	0.4293
CA_{27}	72.17	60.33	3.00	7.17	53.37	9.20	6.00	5.87	61.97	0.5103	184.87	308.13	134.40	10.67	68.15	0.3347
CA_{28}	87.60	64.00	2.00	4.00	36.87	8.07	5.10	3.87	49.60	0.5313	190.80	140.30	125.47	10.23	61.90	0.2957
CA_{29}	78.93	81.93	4.23	10.73	47.37	8.43	6.50	6.23	65.67	0.5273	184.10	283.47	88.40	11.07	44.94	0.3233
CA_{30}	81.30	51.63	3.57	7.17	12.77	5.97	6.57	8.47	79.53	0.5737	159.47	97.93	97.17	10.47	56.13	0.4333
CA_{31}	77.10	50.90	3.00	6.00	21.50	4.93	7.97	4.40	76.30	0.3567	172.80	90.93	126.40	11.93	84.76	0.2220
CA_{32}	75.77	45.73	2.67	4.83	9.57	8.97	6.70	7.77	88.33	0.6457	162.60	64.63	163.50	11.13	156.73	0.1900
CA_{33}	84.67	54.73	4.17	11.00	27.63	2.67	6.10	1.67	79.40	0.6707	171.20	43.93	77.00	8.57	62.20	0.3233
CA_{34}	88.30	85.43	4.37	8.57	16.07	5.80	9.17	8.00	72.77	0.4167	187.00	121.67	54.27	9.07	50.59	0.4047
CA_{35}	78.07	52.30	2.83	6.17	15.07	7.97	11.03	10.33	106.40	0.3703	156.10	139.07	79.83	9.47	76.37	0.2687
CA_{36}	81.63	30.20	4.00	8.00	35.57	3.50	4.67	1.70	86.43	0.4260	161.40	58.10	136.37	10.93	75.18	0.4960
CA_{37}	82.00	46.30	3.50	6.23	20.53	6.07	8.57	6.00	69.07	0.6127	165.13	104.77	150.57	10.07	74.51	0.3900
CA_{38}	83.90	61.40	2.90	8.17	39.63	6.73	3.50	2.33	75.70	0.5440	184.37	90.27	94.70	11.70	69.52	0.3513
CA_{39}	90.40	45.67	2.50	7.33	12.53	5.27	9.10	7.77	34.30	0.5433	194.17	88.17	96.97	10.73	50.71	0.3967
CA_{40}	73.13	51.07	5.33	9.66	21.57	6.10	11.70	10.67	53.73	0.6367	164.90	223.23	141.63	12.10	57.74	0.3153
CA_{41}	79.37	38.00	2.00	3.33	3.93	7.93	6.00	7.50	90.67	0.4180	118.10	26.90	88.77	10.57	129.58	0.1217
CA_{42}	70.67	26.03	2.00	3.83	3.17	4.43	4.27	4.00	31.83	0.3633	122.63	12.93	105.27	10.86	101.01	0.1940
CA_{43}	70.10	76.73	3.93	11.33	24.43	5.93	6.50	6.77	99.60	0.3867	180.70	169.23	119.77	12.30	165.29	0.1813
CA_{44}	65.30	35.00	2.17	4.93	3.00	9.43	6.23	8.23	65.33	0.4027	97.83	23.27	140.30	10.03	123.09	0.1633
Mean	77.65	53.58	3.68	8.017	26.27	7.00	7.07	7.16	79.57	0.5238	167.92	169.43	112.30	10.75	81.42	0.2995
SE	0.9123	1.6090	0.2809	0.6573	1.6557	0.2435	0.2307	0.2582	2.4371	0.0026	1.13	9.7314	1.3690	0.0639	0.4438	0.0018
CD	2.5676	4.5278	0.7904	1.8497	4.6597	0.6852	0.6494	0.7267	6.8587	0.0074	3.18	27.384	3.8526	0.18	1.2489	0.0051

It was on par with other four genotypes. Likewise, CA_{24} recorded maximum number of secondary branches (15.6). The number of secondary branches was least for CA_{41} (3.33) and it showed on par performance with six other genotypes.

Fruits per plant showed wide variation ranged between 3.00 (CA_{44}) to 70.37 (CA_{26}). The genotype CA_{26} differed significantly from all other genotypes, while CA_{44} was on par with CA_{42} and CA_{41}.

Fruit length varied from 14.5 cm (CA_{11}) to 2.67 cm (CA_{33}). The genotype CA_{40} (11.7 cm) had the maximum fruit girth and was on par with CA_{35}. It was minimum for CA_{38} (3.5) and was on par with CA_{19}.

Fruit weight ranged between 13.2 g (CA_8) and 1.67 g (CA_{33}). CA_{36} and CA_{38} were on par with CA_{33}.

Seeds per fruit was maximum for CA_6 (122.53) and minimum for CA_{42} (31.83), followed by CA_{39} (34.3), while CA_{17} had the highest 100 seed weight (0.7853) and was minimum for CA_{22} (0.3277).

Minimum crop duration was for the genotype CA_{44} (97.83 days) and was maximum for CA_{39} (194.17 days).

Yield per plant was highest for the genotype CA_{17} (535.67 g) followed by CA_{13} (420.57 g). CA_{42} (12.93 g) recorded the lowest yield and was on par with CA_{41} and CA_{44}.

Among quality characters, ascorbic acid was maximum for CA_{16} (172.37 mg $100g^{-1}$) and minimum for CA_{34} (54.2 mg $100g^{-1}$). Oleoresin ranged between 13.5 per cent (CA_{25}) and 8.0 per cent (CA_2). Colour value (capsanthin content) was maximum for CA_{12} (186.20 ASTA) followed by CA_{43} (165.29 ASTA), CA_{32} (156.73 ASTA) and CA_{11} (143. 39 ASTA), while it was least for CA_{22} (44.29 ASTA) followed by CA_{29}. The pungent principle, capsaicin content varied between 0.122 per cent (CA_{41}) and 0.496 per cent (CA_{36}).

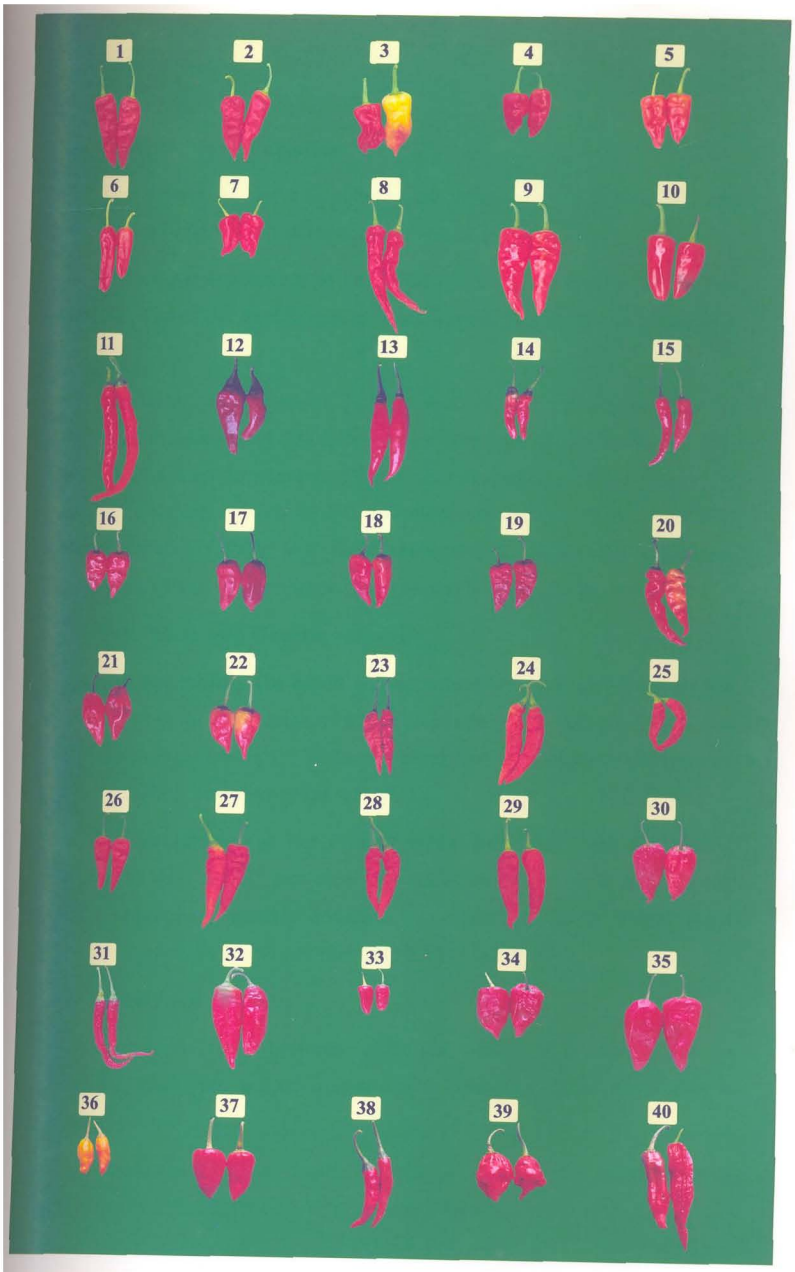

Plate 2. Variability in fruit characters

4.1.2 Coefficients of Variation

The details of the components of variance *viz*., phenotypic and genotypic coefficients of variation are given in Table 3.

Phenotypic coefficient of variation (PCV) was found to be slightly higher than genotypic coefficient of variation (GCV) for all the characters studied.

The maximum values of PCV as well as GCV were observed for yield per plant (65.31, 64.55) followed by fruits per plant (55.93, 54.86), while it was lowest for days to 50 per cent flowering (7.22, 6.93). The traits crop duration (11.35, 11.29) and oleoresin (12.81, 12.76) exhibited moderate levels of PCV and GCV respectively. All other characters showed high values of phenotypic and genotypic coefficients of variation.

4.1.3 Heritability and Genetic Advance

High heritability (in broad sense) values were observed for all the 16 characters within the range of 82.44 (secondary branches per plant) and 99.95 (capsanthin content). Yield per plant had a heritability per cent of 97.68 and that of fruits per plant was 96.19.

Genetic advance as per cent of mean was found high for all the traits except days to 50 per cent flowering for which it was moderate (13.70). Maximum genetic advance was observed for yield per plant (131.43) followed by fruits per plant (110.83) (Table 3).

4.1.4 Correlation Analysis

The correlation between different traits was computed as phenotypic, genotypic and environmental correlation coefficients (Table 4, 5 and 6).

In general the genotypic correlation coefficients were slightly higher than the phenotypic correlation coefficients.

Table 3 Genetic parameters

Sl. No.	Characters	PCV	GCV	Heritability (%)	Genetic advance as % of mean
1	Days to 50 per cent flowering	7.22	6.93	92.06	13.70
2	Plant height	27.15	26.65	96.33	53.89
3	Primary branches per plant	33.06	30.29	83.98	57.13
4	Secondary branches per plant	33.89	30.77	82.44	57.18
5	Fruits per plant	55.93	54.86	96.19	110.83
6	Fruit length	32.48	31.92	96.56	64.60
7	Fruit girth	27.99	27.41	95.92	55.33
8	Fruit weight	40.59	40.11	97.63	81.60
9	Seeds per fruit	24.73	24.16	95.40	48.61
10	Hundred seed weight	22.14	22.12	99.85	45.54
11	Crop duration	11.35	11.29	98.94	23.13
12	Yield per plant	65.31	64.55	97.68	131.43
13	Ascorbic acid	27.92	27.84	99.43	57.20
14	Oleoresin	12.81	12.76	99.35	26.21
15	Capsanthin	43.21	43.20	99.95	88.97
16	Capsaicin	30.30	30.29	99.88	62.36

Table 4 Phenotypic correlation coefficients

Character	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	0.1266	1.0000														
X3	-0.0419	0.2929*	1.0000													
X4	-0.0304	0.3951*	0.8227**	1.0000												
X5	-0.0771	0.4308**	0.3549*	0.3403*	1.0000											
X6	-0.3836**	0.1905	-0.1345	-0.1698	0.2827	1.0000										
X7	0.1407	0.1133	0.0253	0.0398	-0.2841	-0.1292	1.0000									
X8	-0.2195	0.1763	-0.0599	-0.0270	-0.2057	0.4644**	0.6334**	1.0000								
X9	-0.2123	0.1462	0.0363	0.1081	-0.1326	0.1659	0.0884	0.2954*	1.0000							
X10	-0.0210	0.1598	0.2495	0.1492	0.3366*	0.3579*	-0.1621	0.2274	-0.0812	1.0000						
X11	0.4852**	0.5442**	0.2770	0.4133**	0.5279**	-0.1207	0.1211	-0.1294	-0.0759	0.1399	1.0000					
X12	-0.2962*	0.4560**	0.2609	0.2616	0.6984**	0.5389**	0.1687	0.4890**	0.1154	0.4619**	0.3276*	1.0000				
X13	-0.4527**	-0.0713	-0.0962	-0.1633	0.1277	0.3794**	-0.0608	0.2037	0.0966	0.2669	-0.1801	0.3298*	1.0000			
X14	-0.3137*	0.0686	0.1579	0.1319	0.4711**	0.2362	-0.2101	-0.0489	-0.2885	0.2705	0.1341	0.3974**	0.4409**	1.0000		
X15	-0.5385**	-0.0353	-0.1531	-0.1315	-0.1451	0.2707	-0.1187	0.1806	0.2250	-0.0098	-0.3881**	0.0339	0.4217**	0.2105	1.0000	
X16	0.5097**	0.1736	0.2601	0.1473	0.3383*	-0.2103	-0.0010	-0.2310	-0.1088	0.1472	0.4801**	0.0693	-0.1782	-0.1219	-0.5913**	1.0000

X1: Days to 50 per cent flowering
X2: Plant height (cm)
X3: Primary branches per plant
X4: Secondary branches per plant
X5: Fruits per plant
X6: Fruit length (cm)
X7: Fruit girth (cm)
X8: Fruit weight (g)
X9: Number of seeds/fruit
X10: 100 seed weight (g)
X11: Crop duration
X12: yield/plant
X13: Ascorbic acid (mg/100g)
X14: Oleoresin (%)
X15: Capsanthin (ASTA)
X16: Capsaicin (%)

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

Table 5 Genotypic correlation coefficients

Character	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	0.1362	1.0000														
X3	-0.0476	0.3156	1.0000													
X4	-0.0432	0.4417**	0.8345**	1.0000												
X5	-0.0829	0.4424**	0.4032**	0.3895**	1.0000											
X6	-0.4148**	0.2011	-0.1582	-0.1954	0.2972*	1.0000										
X7	0.1521	0.1222	0.0291	0.0358	-0.2918*	-0.1319	1.0000									
X8	-0.2250	0.1854	-0.0728	-0.0445	-0.2022	0.4694**	0.6466**	1.0000								
X9	-0.2184	0.1511	0.0356	0.1134	-0.1281	0.1661	0.0836	0.2856	1.0000							
X10	-0.0214	0.1612	0.2768	0.1683	0.3426*	0.3654*	-0.0632	0.2318	-0.0822	1.0000						
X11	0.5059**	0.5569**	0.3028*	0.4528**	0.5388**	-0.1253	0.1247	-0.1304	-0.0760	0.1415	1.0000					
X12	-0.3077*	0.4651**	0.2877	0.2927*	0.6995**	0.5516**	0.1710	0.5003**	0.1178	0.4668**	0.3323*	1.0000				
X13	-0.4703**	-0.0749	-0.1101	-0.1839	0.1298	0.3885**	-0.0608	0.2050	0.0989	0.2684	-0.1824	0.3346*	1.0000			
X14	-0.3290*	0.0720	0.1677	0.1373	0.4812**	0.2407	-0.2153	-0.0504	-0.2974*	0.2715	0.1358	0.4011**	0.4442**	1.0000		
X15	-0.5610**	-0.0345	-0.1674	-0.1456	-0.1473	0.2754	-0.1210	0.1825	0.2297	-0.0097	-0.3904**	0.0345	0.4232**	0.2108	1.0000	
X16	0.5307**	0.1772	0.2826	0.1622	0.3456*	-0.2141	-0.0015	-0.2337	-0.1108	0.1476	0.4828**	0.0706	-0.1789	-0.1223	-0.5919**	1.0000

X1: Days to 50 per cent flowering
X2: Plant height (cm)
X3: Primary branches per plant
X4: Secondary branches per plant
X5: Fruits per plant
X6: Fruit length (cm)
X7: Fruit girth (cm)
X8: Fruit weight (g)
X9: Number of seeds/fruit
X10: 100 seed weight (g)
X11: Crop duration
X12: yield/plant
X13: Ascorbic acid (mg/100g)
X14: Oleoresin (%)
X15: Capsanthin (ASTA)
X16: Capsaicin (%)

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

Table 6 Environmental correlation coefficients

Character	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1.0000															
X2	-0.0302	1.0000														
X3	-0.0006	0.1174	1.0000													
X4	0.0610	0.0179	0.7652**	1.0000												
X5	0.0165	0.1325	-0.0955	-0.0804	1.0000											
X6	0.1433	-0.0962	0.1067	0.0577	-0.1010	1.0000										
X7	-0.0391	-0.1073	-0.0104	0.0942	-0.0975	-0.0610	1.0000									
X8	-0.1436	-0.1185	0.0973	0.2008	-0.3257*	0.3015*	0.2481	1.0000								
X9	-0.1269	0.0306	0.0512	0.0837	-0.2378	0.1630	0.1927	0.5979**	1.0000							
X10	-0.0394	0.2301	-0.2521	-0.2094	0.1072	0.1140	-0.0321	-0.2435	-0.1127	1.0000						
X11	0.0827	0.0232	0.0234	0.1020	0.1134	0.0938	-0.0151	-0.0747	-0.0955	-0.1692	1.0000					
X12	-0.1035	0.1670	0.0041	-0.0169	0.6843**	0.1134	0.1006	0.0219	0.0488	0.1544	0.0545	1.0000				
X13	-0.1315	0.1407	0.1465	0.1004	0.0495	-0.0956	-0.0916	0.1481	0.0167	-0.1795	0.1040	0.0043	1.0000			
X14	0.0436	-0.1229	0.1458	0.2265	0.0446	0.0287	0.0062	0.0582	0.0588	0.0070	-0.0720	0.1860	-0.0857	1.0000		
X15	-0.0610	-0.3501*	0.0299	0.0799	-0.1482	0.0376	-0.0594	0.0922	0.1472	-0.1182	0.1357	-0.0616	-0.0710	0.2761	1.0000	
X16	0.0831	-0.0314	0.0956	0.0722	-0.0684	-0.0030	0.0579	-0.0316	-0.0849	-0.1515	0.0466	-0.0874	0.0661	-0.0031	0.1388	1.0000

X1: Days to 50 per cent flowering
X2: Plant height (cm)
X3: Primary branches per plant
X4: Secondary branches per plant
X5: Fruits per plant
X6: Fruit length (cm)
X7: Fruit girth (cm)
X8: Fruit weight (g)
X9: Number of seeds/fruit
X10: 100 seed weight (g)
X11: Crop duration
X12: yield/plant
X13: Ascorbic acid (mg/100g)
X14: Oleoresin (%)
X15: Capsanthin (ASTA)
X16: Capsaicin (%)

*Significant at 5 per cent level

**Significant at 1 per cent level

Days to 50 per cent flowering showed positive and high phenotypic and genotypic correlation with crop duration (0.4852, 0.5059) and capsaicin content (0.5097, 0.5307). But the correlations were negative and high with fruit length (-0.3836, -0.4148), ascorbic acid (-0.4527, -0.4703), oleoresin (-0.3137, -0.3290) and capsanthin (-0.5385, -0.5610). The correlation between days to 50 per cent flowering and yield was significantly high in negative direction at genotypic level (-0.3077) while it was moderate at phenotypic level (-0.2962).

Plant height had positive and high correlation with fruits per plant, yield per plant, crop duration, primary branches per plant and secondary branches per plant both at phenotypic and genotypic levels. It showed negative but negligible correlation with ascorbic acid and capsanthin content.

Highly significant positive correlation at phenotypic and genotypic levels was observed between primary branches per plant and secondary branches per plant (0.8227, 0.8345). These two traits were also had significant and positive association with fruits per plant and crop duration.

The trait fruits per plant exhibited maximum positive correlation with yield per plant (0.6984, 0.6995) followed by crop duration (0.5279, 0.5388) and oleoresin (0.4711, 0.4812).

There was strong positive association of fruit length both at phenotypic and genotypic levels with yield per plant (0.5389, 0.5516), fruit weight (0.4644, 0.4694) and ascorbic acid (0.3794, 0.3885). Low negative correlation was observed for fruit length with fruit girth, crop duration, primary branches per plant, secondary branches per plant and capsaicin content.

Fruit girth showed high and significant correlation with fruit weight. Fruit weight had high and significant positive correlation with yield per plant (0.4890, 0.5003).

Correlation between seeds per fruit and other characters was not significant, while 100 seed weight showed positive and significant phenotypic and genotypic correlation with yield per plant (0.4619, 0.4668).

Significant positive association was observed for crop duration and capsaicin content while the correlation was significantly negative with capsanthin content.

Yield per plant was significantly correlated with plant height, fruits per plant, fruit length, fruit weight, 100 seed weight, crop duration, ascorbic acid and oleoresin.

Ascorbic acid content had positive and significant correlation with oleoresin (0.4409, 0.4442) and capsanthin (0.4217, 0.4232) but the correlation was low and negative with capsaicin content. Ascorbic acid, oleoresin and capsanthin content had negatively significant correlation with days to 50 per cent flowering.

Correlation between capsanthin content and capsaicin content (-0.5913, -0.5919) was highly significant in negative direction. But capsaicin content was positively and significantly correlated with days to 50 per cent flowering and crop duration.

Most of the characters showed a low value for environmental correlation. However, high positive correlation was observed for fruit weight and seeds per fruit (0.5979), fruits per plant and yield per plant (0.6843), primary branches per plant and secondary branches per plant (0.7652).

4.1.5 Selection Index

Selection index was computed based on all the 16 traits and is given in Table 7.

The selection index was highest for the genotype CA_{17} (3828.912) followed by CA_{13} (3349.00), CA_{11}(3201.077), CA_{10} (3048.286). CA_{16}

Table 7 Selection index and ranking of genotypes

Genotype	Selection index	Rank
CA_{17}	3828.912	1
CA_{13}	3349.007	2
CA_{11}	3201.077	3
CA_{10}	3048.286	4
CA_{16}	2950.037	5
CA_{24}	2917.042	6
CA_{27}	2912.771	7
CA_{26}	2852.82	8
CA_{43}	2828.181	9
CA_{6}	2778.436	10
CA_{12}	2731.63	11
CA_{8}	2723.027	12
CA_{29}	2714.287	13
CA_{20}	2655.908	14
CA_{15}	2606.994	15
CA_{40}	2503.866	16
CA_{9}	2500.329	17
CA_{32}	2419.85	18
CA_{1}	2405.874	19
CA_{28}	2333.941	20
CA_{25}	2319.204	21
CA_{21}	2303.793	22
CA_{2}	2279.234	23
CA_{3}	2258.133	24
CA_{37}	2230.136	25
CA_{23}	2212.774	26
CA_{35}	2207.628	27
CA_{31}	2181.978	28
CA_{38}	2173.746	29
CA_{34}	2131.508	30
CA_{14}	2102.504	31
CA_{5}	2094.116	32
CA_{36}	2049.336	33
CA_{18}	2040.555	34
CA_{4}	2022.15	35
CA_{30}	2018.673	36
CA_{19}	2003.407	37
CA_{39}	1954.539	38
CA_{7}	1943.836	39
CA_{22}	1916.425	40
CA_{33}	1859.818	41
CA_{41}	1789.661	42
CA_{44}	1757.616	43
CA_{42}	1486.346	44

(2950.037) and CA_{24} (2917.042). It was lowest for the genotype CA_{42} (1486.346) followed by CA_{44} (1757.616) and CA_{41} (1789.661).

4.1.6 Genetic Divergence Analysis

The 44 genotypes were subjected to Mahalanobis D^2 analysis based on 16 characters. The genotypes were grouped into nine clusters based on Tocher's method (Table 8).

Cluster II was the largest with 17 genotypes followed by cluster I with six genotypes. Cluster IV and cluster V contained three genotypes each, VI with two genotypes and VII, VIII and IX contained only one genotype each.

The cluster means for different characters are furnished in Table 9. Cluster VII (CA_{39}) had maximum cluster means for days to 50 per cent flowering (90.40 days) and crop duration (194.17 days). It was minimum for cluster V (71.01 days). Cluster mean for plant height was maximum for cluster VI (90.85 cm) and minimum value was shown by cluster IV (33.01 cm). The highest cluster means for primary branches per plant (4.56) and secondary branches per plant (10.28) was for cluster I followed by cluster VI and cluster VIII. Cluster IX (CA_{17}) showed maximum mean values for fruits per plant (48.53), fruit girth (9.77), fruit weight (12.47 g), 100 seed weight (0.7853 g), yield per plant (535.67 g), ascorbic acid content (163.83 mg 100 g^{-1}) and oleoresin content (12.20 %).

With respect to fruit length (10.83 cm), seeds per fruit (98.97) and capsanthin content (123.15 ASTA) cluster VIII excelled other clusters. The minimum mean value for capsaicin content was for cluster IV (0.1597 %) followed by cluster VIII (0.21 %).

Average inter and intra cluster D^2 values and D values were calculated based on the total D^2 and are presented in Table 10. The intra cluster distances (D values) ranged from 204.98 (Cluster III) to 299.94 (Cluster VI) in clusters with more than one genotype. Clusters VII, VIII

Table 8 Clustering pattern of genotypes

Cluster	Number of genotypes	Genotypes
I	6	CA_{16}, CA_{20}, CA_{24}, CA_{26}, CA_{27}, CA_{29}
II	17	CA_1, CA_2, CA_3, CA_4, CA_7, CA_8, CA_9, CA_{12}, CA_{15}, CA_{21}, CA_{23}, CA_{25}, CA_{28}, CA_{31}, CA_{37}, CA_{38}, CA_{43}
III	10	CA_5, CA_{14}, CA_{18}, CA_{19}, CA_{22}, CA_{30}, CA_{32}, CA_{33}, CA_{35}, CA_{36}
IV	3	CA_{41}, CA_{42}, CA_{44}
V	3	CA_{10}, CA_{11}, CA_{40}
VI	2	CA_6, CA_{34}
VII	1	CA_{39}
VIII	1	CA_{13}
IX	1	CA_{17}

Table 9 Cluster means

Cluster	Characters															
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
I	75.87	63.67	4.56	10.28	48.39	8.59	6.75	6.77	67.84	0.5194	182.37	298.09	113.95	11.83	61.72	0.3290
II	78.96	53.53	3.64	7.84	25.71	6.73	7.05	6.83	77.41	0.5401	173.77	149.08	110.10	10.86	83.91	0.3010
III	78.88	45.45	3.66	8.00	19.09	5.67	6.85	5.91	90.97	0.4884	162.66	87.38	104.02	9.91	73.18	0.3047
IV	71.78	33.01	2.06	4.03	3.37	7.26	5.5	6.58	62.61	0.3947	112.85	21.03	111.45	10.49	117.89	0.1597
V	71.01	57.52	3.44	7.39	29.40	9.03	7.92	9.64	89.68	0.5760	162.05	270.89	153.50	11.51	102.14	0.2687
VI	83.72	90.85	4.44	10.00	20.60	6.32	8.5	9.04	97.65	0.4313	185.42	169.20	71.82	8.65	63.45	0.4140
VII	90.40	45.67	2.50	7.33	12.53	5.27	9.10	7.77	34.30	0.5433	194.17	88.17	96.97	10.73	50.71	0.3967
VIII	65.17	40.20	4.50	9.03	36.97	10.83	6.33	12.00	98.97	0.7163	147.90	420.57	146.40	12.03	123.15	0.2100
IX	78.83	72.03	3.50	7.17	48.53	7.83	9.77	12.47	83.00	0.7853	175.80	535.67	163.83	12.20	92.98	0.3220
Mean	77.18	55.77	3.59	7.89	27.17	7.50	7.53	8.56	78.05	0.5549	166.33	226.68	119.12	10.91	85.46	0.3006

X1: Days to 50 per cent flowering
X2: Plant height (cm)
X3: Primary branches per plant
X4: Secondary branches per plant
X5: Fruits per plant
X6: Fruit length (cm)
X7: Fruit girth (cm)
X8: Fruit weight (g)
X9: Number of seeds/fruit
X10: 100 seed weight (g)
X11: Crop duration
X12: yield/plant
X13: Ascorbic acid (mg/100g)
X14: Oleoresin (%)
X15: Capsanthin (ASTA)
X16: Capsaicin (%)

Table 10 Average intra cluster and inter cluster D^2 values

Cluster	I	II	III	IV	V	VI	VII	VIII	IX
I	52351.41 (228.80)	270427.56 (520.03)	598293.96 (773.49)	1047214.74 (1023.34)	83763.87 (289.42)	371907.46 (609.84)	304668.47 (551.97)	121392.53 (348.40)	462339.08 (679.96)
II		52567.01 (229.27)	123969.72 (352.09)	416060.27 (645.03)	137364.90 (370.63)	166874.76 (408.50)	113259.34 (336.54)	492790.13 (701.99)	1288956.44 (1135.32)
III			42015.80 (204.98)	116936.80 (341.96)	358575.68 (598.81)	239345.13 (489.23)	256645.19 (506.60)	856583.27 (925.52)	1904968.11 (1380.21)
IV				62972.76 (250.94)	756897.8 (869.99)	5161110.87 (718.41)	453483.40 (673.41)	1382464.00 (1175.78)	2736432.33 (1654.22)
V					55468.65 (235.52)	229944.82 (479.53)	240544.67 (490.45)	167161.57 (408.85)	695105.8 (833.73)
VI						89965.18 (299.94)	310339.1 (557.08)	639449.05 (799.66)	670587.5 (818.89)
VII							0 (0)	629544.30 (793.44)	1333197.00 (1154.64)
VIII								0 (0)	298414.20 (546.27)
IX									0 (0)

'D' values given in parenthesis

and IX had only one genotype each. The distance between cluster IV and cluster IX was the highest (1654.22) while it was least between cluster I and cluster V (289.42). The character yield per plant followed by fruits per plant showed maximum variability for clustering.

4.2 HALF DIALLEL ANALYSIS

Based on selection indices and quality parameters seven genotypes were selected from different clusters and used as parents for hybridization. The selected parents *viz.*, CA_{11}-EG-85 (P_1), CA_{17}-Vellayani local (P_2), CA_{24}- Jwalamukhi (P_3), CA_{10}-Kattakkada local (P_4), CA_{16} - Kaliyikkavila local (P_5), CA_{13} - EG-101 (P_6) and CA_{12} - Arka Abir (P_7) were crossed in half diallel fashion to produce 21 hybrids.

Results of half diallel analysis was presented in Table 11. Significant variation was observed among treatments for all the characters studied.

4.2.1 Mean Performance of Parents and Hybrids

Mean performance of seven parents and 21 hybrids with respect to 16 characters are presented in Table 12.

1. Days to 50 per cent flowering (days)

Among parents, days to 50 per cent flowering was lowest for P_7 (61.67) while P_2 was taken maximum number of days (75.67) for 50 per cent flowering. Among hybrids earliness was observed for P_1 x P_7 (51.67) and P_4 x P_6 (52.67). The maximum number of days for 50 per cent flowering was taken by P_3 x P_5 (66.67) followed by P_5 x P_7 (65.00). Generally all hybrids exhibited earliness in flowering with respect to their parents.

2. Plant height (cm)

Plant height varied between 58.33 (P_6) and 85.50 (P_3) for parents. The minimum plant height was recorded for P_1 x P_5 (59.19). The tallest hybrid was P_2 x P_4 (90.31) and was on par with P_3 x P_7 (88.77).

Table 11 Analysis of variance for various characters

Sl No.	Character	Mean squares		
		Treatment	Replication	Error
1	Days to 50 per cent flowering	95.02**	11.76*	2.31
2	Plant height	229.63**	23.07	9.03
3	Primary branches per plant	9.14**	0.31	0.34
4	Secondary branches per plant	34.81**	0.18	1.36
5	Fruits per plant	1014.01**	112.47	39.15
6	Fruit length	19.10**	0.19	0.17
7	Fruit girth	5.87**	0.01	0.05
8	Fruit weight	34.82**	0.13	0.85
9	Seeds per fruit	1716.03**	79.84	94.09
10	Hundred seed weight	0.02**	0.29×10^{-4}	0.83×10^{-4}
11	Crop duration	172.91**	1.71	2.11
12	Yield per plant	113669.96**	2643.07	3071.31
13	Ascorbic acid content	2257.23**	39.56	28.13
14	Oleoresin content	8.69**	0.26	0.12
15	Capsanthin content	5782.42**	5.52	8.35
16	Capsaicin content	0.59×10^{-2}	0.36×10^{-4}	0.66×10^{-4}

**Significant at 1 per cent level

Table 12 Mean performance of parents and hybrids

	Days to 50 per cent flowering	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Fruits per plant	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)
P_1	66.00	60.90	2.17	4.47	44.50	14.74	4.74	10.33
P_2	75.67	75.15	3.30	6.50	41.33	8.89	10.46	14.78
P_3	73.67	85.50	5.73	12.67	57.47	10.56	5.71	7.37
P_4	67.00	68.16	2.57	6.53	47.33	7.15	8.86	10.17
P_5	65.33	65.83	5.43	8.43	46.27	6.65	8.82	8.88
P_6	62.00	58.33	3.33	7.17	40.40	11.69	6.51	12.78
P_7	61.67	60.32	3.50	7.77	26.17	7.75	8.58	11.27
$P_1 \times P_2$	59.67	74.92	5.83	12.80	54.73	14.99	7.90	17.53
$P_1 \times P_3$	61.33	78.50	3.82	9.83	93.77	14.41	5.39	10.96
$P_1 \times P_4$	61.00	70.69	5.82	13.00	81.73	13.36	6.98	15.91
$P_1 \times P_5$	56.33	59.19	4.77	12.25	64.00	12.80	7.02	10.85
$P_1 \times P_6$	52.00	69.31	3.17	6.31	69.50	15.67	5.38	15.10
$P_1 \times P_7$	51.67	67.91	3.12	7.47	52.13	15.98	6.67	14.41
$P_2 \times P_3$	60.67	82.67	5.67	13.50	84.80	12.12	7.08	15.22
$P_2 \times P_4$	63.67	90.31	5.28	12.97	84.17	9.44	9.45	20.61
$P_2 \times P_5$	63.67	77.43	7.97	15.18	66.17	9.13	10.13	17.97
$P_2 \times P_6$	60.67	84.33	9.08	19.03	93.37	11.70	8.19	21.28
$P_2 \times P_7$	54.67	82.60	5.39	11.82	75.60	11.41	8.34	17.45
$P_3 \times P_4$	61.00	79.03	2.17	6.37	59.00	11.58	7.86	14.68
$P_3 \times P_5$	66.67	74.14	5.69	13.42	86.90	10.97	8.12	12.02
$P_3 \times P_6$	63.00	75.40	4.38	10.33	89.10	13.04	6.34	14.04
$P_3 \times P_7$	64.00	88.77	2.83	10.61	80.67	12.93	6.58	12.32
$P_4 \times P_5$	56.33	66.67	3.47	8.73	58.67	7.59	8.82	12.55
$P_4 \times P_6$	52.67	71.95	2.56	6.40	50.93	11.40	7.43	16.82
$P_4 \times P_7$	58.67	78.41	2.83	7.47	45.60	10.29	7.42	14.45
$P_5 \times P_6$	63.67	72.70	3.73	10.83	52.20	11.42	7.15	14.94
$P_5 \times P_7$	65.00	80.27	2.33	6.77	56.47	10.04	8.35	12.37
$P_6 \times P_7$	60.00	78.58	2.87	8.00	50.93	12.03	7.47	18.74
Grand mean	61.70	74.21	4.24	9.88	62.64	11.42	7.56	14.14
SE	1.240	2.454	0.478	0.953	5.110	0.332	0.180	0.753
CD (5%)	2.430	4.810	0.937	1.868	10.016	0.651	0.353	1.476

Table 12 Continued

	Seeds per fruit	Hundred seed weight (g)	Crop duration (days)	yield per plant (g)	Ascorbic acid content (mg/ 100 g)	Oleoresin content (%)	Capsanthin content (ASTA)	Capsaicin content (%)
P_1	107.37	0.6579	157.07	389.74	161.24	12.57	140.81	0.2853
P_2	83.37	0.8062	176.90	566.60	127.89	14.23	82.76	0.3147
P_3	68.83	0.6402	182.40	394.37	142.16	16.10	60.64	0.2873
P_4	110.57	0.6681	169.23	418.55	164.50	13.50	171.97	0.2007
P_5	86.63	0.4075	171.07	349.65	171.52	13.27	96.95	0.2547
P_6	98.67	0.6024	151.63	463.63	153.92	12.50	136.36	0.2060
P_7	76.53	0.6068	164.73	264.74	190.19	13.75	182.13	0.1540
$P_1 \times P_2$	104.07	0.7077	171.80	677.84	150.61	18.08	92.25	0.2473
$P_1 \times P_3$	105.87	0.6145	176.23	738.71	169.16	17.08	132.41	0.2940
$P_1 \times P_4$	144.93	0.5622	171.30	745.92	242.02	15.50	136.78	0.2053
$P_1 \times P_5$	155.87	0.5853	164.77	595.87	207.71	15.10	172.38	0.1773
$P_1 \times P_6$	109.80	0.6337	169.17	629.48	157.29	14.57	198.31	0.1980
$P_1 \times P_7$	90.53	0.6580	164.07	586.05	176.35	16.92	235.35	0.1487
$P_2 \times P_3$	80.27	0.7003	178.10	794.19	159.16	19.17	103.44	0.2400
$P_2 \times P_4$	149.57	0.6938	170.33	870.01	230.32	17.57	86.94	0.2500
$P_2 \times P_5$	157.40	0.6025	171.13	680.04	185.57	15.70	85.86	0.2883
$P_2 \times P_6$	131.07	0.6718	174.23	1134.39	171.02	14.92	122.66	0.1820
$P_2 \times P_7$	124.47	0.6881	181.37	858.56	191.53	15.75	205.19	0.1817
$P_3 \times P_4$	100.27	0.7652	161.33	610.60	178.57	17.06	198.69	0.2030
$P_3 \times P_5$	143.53	0.6902	175.83	789.44	143.04	15.13	91.83	0.1933
$P_3 \times P_6$	108.40	0.6933	166.93	867.51	166.93	14.50	132.49	0.1780
$P_3 \times P_7$	108.80	0.7186	173.07	743.61	196.21	14.90	153.97	0.1980
$P_4 \times P_5$	123.40	0.6118	164.90	460.00	195.35	13.93	150.34	0.2433
$P_4 \times P_6$	108.97	0.7038	154.73	665.43	167.44	12.93	107.59	0.1913
$P_4 \times P_7$	122.47	0.6072	158.37	504.08	219.29	13.67	170.84	0.2000
$P_5 \times P_6$	115.73	0.6662	169.07	472.02	207.92	15.17	172.54	0.2207
$P_5 \times P_7$	106.20	0.5960	166.20	450.06	194.09	14.13	126.81	0.1850
$P_6 \times P_7$	125.40	0.7113	171.00	576.92	205.94	13.50	170.39	0.1907
GM	112.29	0.6525	168.82	617.80	179.53	15.04	139.95	0.2190
SE	7.920	0.0074	1.185	45.250	4.330	0.286	2.360	0.0067
CD (5%)	15.523	0.015	2.323	88.690	8.487	0.561	4.626	0.013

3. Primary branches per plant

The maximum and minimum number of primary branches were observed for P_3 (5.73) and P_1 (2.17) respectively. The maximum number of primary branches among hybrids was for P_2 x P_6 (9.08). It was minimum for P_3 x P_4 (2.17) and was on par in performance with P_5 x P_7 (2.33), P_4 x P_6 (2.56), P_3 x P_7 (2.83) and P_6 x P_7 (2.87).

4. Secondary branches per plant

The parent P_1 (4.47) had the minimum number of secondary branches whereas P_3 (12.67) had the maximum. The hybrid with maximum number of secondary branches was P_2 x P_6 (19.03) whereas the hybrid P_1 x P_6 (6.31) had the minimum number of secondary branches. The hybrids P_3 x P_4 (6.37), P_4 x P_6 (6.40), P_5 x P_7 (6.77), P_1 x P_7 (7.47) and P_6 x P_7 (8.00) were on par with P_1 x P_6.

5. Fruits per plant

Among parents, number of fruits per plant ranged between 26.17 (P_7) and 57.47 (P_3). Among hybrids, the maximum number of fruits per plant was for P_1 x P_3 (93.77) which was on par with P_2 x P_6 (93.37), P_3 x P_6 (89.10), P_3 x P_5 (86.90), P_2 x P_3 (84.80) and P_2 x P_4 (84.17). It was minimum for the hybrid P_4 x P_7 (45.60) and showed on par performance with P_6 x P_7 (50.93), P_4 x P_6 (50.93), P_1 x P_7 (52.13), P_5 x P_6 (52.20) and P_1 x P_2 (54.73).

6. Fruit length (cm)

The parents with longest and shortest fruits were P_1 (14.74) and P_5 (6.65) respectively. Fruit length of hybrids varied between 15.98 (P_1 x P_7) and 7.59 (P_4 x P_5). The hybrid P_1 x P_6 (15.67) was on par with P_1 x P_7 for fruit length.

7. Fruit girth (cm)

Fruit girth was maximum for the parent P_2 (10.46) and minimum for P3 (5.71). The hybrids with maximum and minimum fruit girth were P_2 x P_5 (10.13) and P_1 x P_6 (5.38) respectively.

8. Fruit weight (g)

The parent P_2 produced fruits with maximum mean weight (14.78) while P_3 produced fruits with minimum weight (7.37). Among hybrids, P_2 x P_6 produced fruits with maximum mean weight (21.28) while P_1 x P_5 produced fruits with minimum weight (10.85). The hybrid P_2 x P_4 (20.61) was on par with P_2 x P_6, while the hybrids P_1 x P_3 (10.96), P_3 x P_5 (12.02) and P_3 x P_7 (12.32) showed on par performance with P_1 x P_5.

9. Seeds per fruit

P_4 (110.57) and P_3 (68.83) were the parents with maximum and minimum number of seeds respectively. Maximum number of seeds per fruit among hybrids was observed for P_2 x P_5 (157.40) which was on par with P_1 x P_5 (155.87), P_2 x P_4 (149.57), P_1 x P_4 (144.93) and P_3 x P_5 (143.53) whereas the minimum number was for the hybrid P_2 x P_3 (80.27) followed by P_1 x P_7 (90.53).

10. Hundred seed weight (g)

Hundred seed weight for parent ranged from 0.8062 (P_2) to 0.4075 (P_5). For hybrids it was maximum for P_3 x P_4 (0.7652) and minimum for P_1 x P_4 (0.5622).

11. Crop duration (days)

Maximum crop duration was observed for the parent P_3 (182.40) and minimum for P_6 (151.63). It was longest for the hybrid P_2 x P_7 (181.37) and shortest for P_4 x P_6 (154.73).

12. Yield per plant (g)

The parent P_2 recorded the maximum fruit yield of 566.60 g per plant and it was minimum for the parent P_7 (264.74). Maximum yield was observed for the hybrid P_2 x P_6 (1134.39) followed by P_2 x P_4 (870.01) and P_2 x P_7 (858.56) while yield was lowest for P_5 x P_7 (450.06) and it was on par with P_4 x P_5 (460.00), P_5 x P_6 (472.02) and P_4 x P_7 (504.08).

13. Ascorbic acid content (mg/100 g)

Among the parents ascorbic acid content was maximum for P_7 (190.19) and minimum for P_2 (127.89). The hybrid with maximum ascorbic acid content was P_1 x P_4 (242.02) and it was least for P_3 x P_5 (143.04).

14. Oleoresin (%)

Oleoresin content varied between 16.10 (P_3) and 12.50 (P_5). High oleoresin content was observed for the hybrid P_2 x P_3 (19.17) followed by P_1 x P_2 (18.08) whereas it was least for P_4 x P_6 (12.93) followed by P_6 x P_7 (13.50).

15. Capsanthin content (ASTA)

The parent P_7 had the highest capsanthin content (182.13) while P_3 (60.64) recorded the minimum value. For hybrids, capsanthin content varied from 235.35 (P_1 x P_7) to 85.86 (P_2 x P_5). P_2 x P_4 (86.94) was on par with P_2 x P_5.

16. Capsaicin content (%)

The maximum and minimum capsaicin content among parents were for P_2 (0.3147) and P_7 (0.1540) respectively. The hybrid P_1 x P_7 showed minimum capsaicin content (0.1487) while it was maximum for P_1 x P_3 (0.2940) followed by P_2 x P_5 (0.2883).

4.2.2 Comparative Study on Green Fruit Yield per Plant, Ripe Fruit Yield per Plant, Dry Fruit Weight Recovery and Pericarp Thickness

Mean performance of parents and hybrids for green fruit yield, ripe fruit yield, dry weight recovery and pericarp thickness as well as their simple correlations are given in Table 13.

The maximum green fruit yield as well as ripe fruit yield was for P_2 (566.60g, 502.80g) among parents and for P_2 x P_6 (1134.39g, 832.65g) among hybrids respectively. The correlation between these two characters was high and positively significant (0.9549).

The maximum and minimum dry fruit weight recovery among parents was for P_1 (18.49%) and P_4 (13.06%) respectively. Among hybrids P_1 x P_7 (18.97%) had the maximum dry fruit weight recovery while it was least for P_2 x P_6 (13.55%).

Maximum pericarp thickness was for the parents P_4 (2.48mm) and minimum for P_1 (1.26mm). Among hybrids P_2 x P_4 (2.41mm) had the maximum pericarp thickness and P_1 x P_7 (1.27) recorded the minimum value. The correlation between dry fruit weight recovery and pericarp thickness was high and negatively significant (-0.7120).

4.2.3 Combining Ability Analysis

Analysis of variance of combining ability revealed significance of general combining ability and specific combining ability for all the characters (Table 14).

4.2.3.1 Combining Ability Variances

Additive variance (σ^2A), dominance variance (σ^2D) and the ratio of additive to dominance variance for all the 16 characters are presented in Table 15. The ratio of additive to dominance variance was less than unity for 14 characters while it was more than unity for fruit length (2.67) and fruit girth (8.48). Additive and dominance variances were found to be

Table 13 Comparative study on green fruit yield, ripe fruit yield, dry fruit weight recovery and pericarp thickness

Variety	(X_1) Average green fruit yield per plant (g)	(X_2) Average ripe fruit yield per plant (g)	(X_3) Dry weight recovery (per cent)	(X_4) Pericarp thickness (mm)
P_1	389.74	312.65	18.49	1.26
P_2	566.60	502.80	13.75	1.98
P_3	394.37	295.00	17.97	1.59
P_4	418.55	323.50	13.06	2.48
P_5	349.61	285.50	16.51	1.85
P_6	463.63	360.72	14.89	1.79
P_7	264.74	210.35	14.47	1.56
$P_1 \times P_2$	677.84	505.50	15.60	1.73
$P_1 \times P_3$	738.71	514.30	6.83	1.59
$P_1 \times P_4$	745.71	489.49	14.48	1.61
$P_1 \times P_5$	595.87	528.50	18.48	1.41
$P_1 \times P_6$	629.48	457.00	15.73	1.39
$P_1 \times P_7$	586.05	518.57	18.97	1.27
$P_2 \times P_3$	794.19	625.00	14.54	1.62
$P_2 \times P_4$	870.01	589.33	14.47	2.41
$P_2 \times P_5$	680.04	555.67	14.30	2.15
$P_2 \times P_6$	1134.39	832.65	13.35	1.89
$P_2 \times P_7$	858.56	694.00	14.86	1.85
$P_3 \times P_4$	610.60	436.00	13.91	1.79
$P_3 \times P_5$	789.44	539.00	16.08	1.44
$P_3 \times P_6$	867.51	632.50	14.73	1.45
$P_3 \times P_7$	743.61	485.00	16.98	1.39
$P_4 \times P_5$	460.00	394.00	15.67	1.72
$P_4 \times P_6$	665.43	491.67	13.93	1.90
$P_4 \times P_7$	504.08	378.33	13.69	1.79
$P_5 \times P_6$	472.02	377.32	16.19	1.41
$P_5 \times P_7$	450.46	340.00	16.92	1.36
$P_6 \times P_7$	576.92	383.33	16.24	1.53

r_{12} : 0.9549
r_{13} : -0.2962
r_{23} : -0.2603
r_{14} : 0.1388
r_{24} : 0.1468
r_{34} : -0.7120

Table 14 Mean squares of GCA and SCA for individual characters

Sl No.	Character	Mean squares		
		GCA (df = 6)	SCA (df = 20)	Error (df = 54)
1	Days to 50 per cent flowering	44.97**	27.87**	0.77
2	Plant height	180.92**	46.72**	3.01
3	Primary branches per plant	5.24**	2.42**	0.11
4	Secondary branches per plant	15.56**	10.47**	0.45
5	Fruits per plant	415.67**	315.82**	13.05
6	Fruit length	22.03**	1.89**	0.06
7	Fruit girth	8.02**	0.23**	0.02
8	Fruit weight	28.29**	6.84**	0.28
9	Seeds per fruit	592.12**	566.29**	31.37
10	Hundred seed weight	0.013**	0.003**	0.27×10^{-4}
11	Crop duration	144.12**	32.92**	0.70
12	Yield per plant	54201.41**	33229.78**	1023.77
13	Ascorbic acid content	1191.04**	627.09**	9.38
14	Oleoresin content	5.99**	2.01**	0.04
15	Capsanthin content	4385.41**	1225.19**	2.78
16	Capsaicin content	0.46×10^{-2}**	0.12×10^{-2}	0.22×10^{-4}

**Significant at 1 per cent level

df – Degrees of freedom

Table 15 Genetic components of variance for different characters

Sl. No.	Character	σ^2A	σ^2D	σ^2A / σ^2D
1	Days to 50 per cent flowering	9.82	27.1	0.36
2	Plant height	39.54	43.71	0.90
3	Primary branches per plant	1.14	2.31	0.49
4	Secondary branches per plant	3.36	10.02	0.34
5	Fruits per plant	89.47	302.77	0.30
6	Fruit length	4.88	1.83	2.67
7	Fruit girth	1.78	0.21	8.48
8	Fruit weight	6.22	6.62	0.94
9	Seeds per fruit	124.61	534.92	0.23
10	Hundred seed weight	2.26×10^{-3}	3.18×10^{-3}	0.71
11	Crop duration	31.87	32.20	0.99
12	Yield per plant	11817.25	32206.01	0.37
13	Ascorbic acid content	262.59	617.71	0.43
14	Oleoresin content	1.32	1.97	0.67
15	Capsanthin content	973.92	1222.41	0.80
16	Capsaicin content	1.02×10^{-3}	1.18×10^{-3}	0.87

equally important for crop duration where, the ratio σ^2A/σ^2D was approximately unity (0.99).

4.3.2.2 Combining Ability Effects

General combining ability (*gca*) effects of parents and specific combing ability (*sca*) effects of hybrids are presented in Table 16 and Table 17 respectively.

1. Days to 50 per cent flowering

All the parents exhibited significant *gca* effects of which *gca* effects of P_2, P_3 and P_5 in positive direction and that of P_1, P_4, P_6 and P_7 in negative direction. P_1, P_6 and P_7 showed on par performance.

Significant *sca* effects in positive direction were shown by $P_1 \times P_4$ (2.18), $P_5 \times P_6$ (2.95), $P_5 \times P_7$ (4.14) and $P_6 \times P_7$ (2.06), while it was negative and significant for $P_1 \times P_2$ (-2.16), $P_1 \times P_3$ (-1.56), $P_1 \times P_5$ (-4.16), $P_1 \times P_6$ (-5.56), $P_1 \times P_7$ (-6.05), $P_2 \times P_3$ (-6. 71), $P_2 \times P_7$ (-7.53), $P_3 \times P_4$ (-3.38), $P_4 \times P_5$ (-5.64) and $P_4 \times P_6$ (-6.38).

2. Plant height

The *gca* effects for plant height ranged from –5.71 (P_1) to 6.20 (P_3). Negatively significant *gca* effects were showed by P_1 (-5.71), P_5 (-3.52) and P_6 (-2.75) and it was positively significant for P_2 (5.43) and P_3 (6.20).

Negatively significant *sca* effects were observed for $P_1 \times P_5$ (-5.80). $P_4 \times P_5$ (-3.99) and $P_2 \times P_3$ (-3.17) while the hybrids $P_2 \times P_4$ (10.70), $P_5 \times P_7$ (9.19), $P_3 \times P_7$ (7.97), $P_2 \times P_6$ (7.44), $P_6 \times P_7$ (6.74), $P_5 \times P_6$ (4.75), $P_4 \times P_7$ (3.85) and $P_1 \times P_6$ (3.56) exhibited positive significance. Of these $P_2 \times P_4$, $P_5 \times P_7$, $P_3 \times P_7$, $P_2 \times P_6$ and $P_6 \times P_7$ exhibited on par performance.

3. Primary branches per plant

P_2 significantly differed from all other genotypes with maximum positive and significant *gca* effect (1.32) followed by P_5 (0.54) and

Table 16 General combining ability effects of parents

Characters	P_1	P_2	P_3	P_4	P_5	P_6	P_7	SE (gi)	SE (gi-gj)	CD (5%)
Days to 50 per cent flowering	-2.18**	2.30**	3.38**	-0.70**	0.97**	-1.96**	-1.81**	0.271	0.413	0.809
Plant height	-5.71**	5.43**	6.20**	-0.04	-3.52**	-2.95**	0.39	0.536	0.818	1.603
Primary branches per plant	-0.34**	1.32**	0.23*	-0.74**	0.54**	-0.17	-0.84**	0.104	0.159	0.311
Secondary branches per plant	-0.94**	2.14**	1.15**	-1.23**	0.56**	-0.42*	-1.26**	0.208	0.318	0.623
Fruits per plant	0.42	4.49**	12.01**	-2.93**	-2.69*	-1.58	-9.71**	1.115	1.703	0.338
Fruit length	2.82**	-0.53**	0.53**	-1.49**	-1.79**	0.81**	-0.35**	0.072	0.111	0.218
Fruit girth	-1.30**	1.28**	-0.86**	0.58**	0.75**	-0.61**	0.17**	0.039	0.060	0.117
Fruit weight	-0.85**	2.95**	-2.12**	0.25	-1.63**	1.49**	-0.09	0.164	0.251	0.492
Seeds per fruit	3.06	1.70	-13.72**	8.05**	8.57**	-0.18	-7.48**	1.728	2.640	5.170
Hundred seed weight	-0.02**	0.05**	0.03**	0.01**	-0.07**	0.01**	0.00	0.002	0.008	0.016
Crop duration	-2.12**	5.58**	5.08**	-3.46**	0.39	-4.68**	-0.78**	0.259	0.395	0.774
Yield per plant	-21.00*	133.98**	43.38**	-27.69**	-88.37**	36.74**	-77.03**	9.874	15.083	29.560
Ascorbic acid content	-1.18	-10.25**	-15.43**	13.97**	4.50**	-5.77**	14.17**	0.945	1.443	2.828
Oleoresin content	0.23**	1.04**	-1.07**	-0.30**	-0.51**	-1.08**	-0.44**	0.062	0.095	0.186
Capsanthin content	14.39**	-28.64**	-20.61**	8.39**	-14.00**	6.34**	34.13**	0.515	0.787	1.543
Capsaicin content	0.01**	0.03**	0.01**	-0.01**	0.01**	-0.02**	-0.04**	0.002	0.002	0.004

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

Table 17 Specific combining ability effects of hybrids

Crosses	Days to 50 per cent flowering	Plant height	Primary branches per plant	Secondary branches per plant	Fruits per plant	Fruit length	Fruit girth	Fruit weight
$P_1 \times P_2$	-2.16**	0.99	0.61*	1.72**	-12.81**	1.29**	0.36**	1.29**
$P_1 \times P_3$	-1.56*	3.80*	-0.31	-0.26	18.70**	-0.36	-0.02	-0.20
$P_1 \times P_4$	2.18**	2.23	2.66**	5.28**	21.61**	0.61**	0.14	2.37**
$P_1 \times P_5$	-4.16**	-5.80**	0.32	2.75**	3.64	0.35	0.00	-0.81
$P_1 \times P_6$	-5.56**	3.56*	-0.57	-2.21**	8.03*	0.62**	-0.27**	0.32
$P_1 \times P_7$	-6.05**	-0.98	0.06	-0.21	-1.22	2.10**	0.24**	1.22**
$P_2 \times P_3$	-6.71**	-3.17*	-0.13	0.33	5.67	0.70**	-0.91**	0.26
$P_2 \times P_4$	0.36	10.70**	0.46	2.17**	19.97**	0.04	0.03	3.28**
$P_2 \times P_5$	-1.31	1.31	1.86**	2.61**	1.73	0.03	0.54**	2.51**
$P_2 \times P_6$	-1.38	7.44**	3.69**	7.43**	27.82**	0.01	-0.04	2.71**
$P_2 \times P_7$	-7.53**	2.57	0.67*	1.06	18.18**	0.87**	-0.66**	0.46
$P_3 \times P_4$	-3.38**	-1.34	-1.56**	-3.44**	-12.71**	1.11**	0.58**	2.41**
$P_3 \times P_5$	0.62	-2.76	0.68*	1.83**	14.95**	0.80**	0.67**	1.63**
$P_3 \times P_6$	-0.12	-2.26	0.07	-0.28	16.04**	0.28	0.25*	0.54
$P_3 \times P_7$	0.73	7.97**	-0.80**	0.84	15.73**	1.33**	-0.29*	0.40
$P_4 \times P_5$	-5.64**	-3.99*	-0.58	-0.48	1.59	-0.55**	-0.07	-0.21
$P_4 \times P_6$	-6.38**	0.52	-0.78*	-1.83**	-7.19*	0.66**	-0.10	0.94*
$P_4 \times P_7$	-0.53	3.85*	0.17	0.08	-4.40	0.71**	-0.88**	0.15
$P_5 \times P_6$	2.95**	4.75**	-0.89**	0.82	-6.16	0.98**	-0.54**	0.94*
$P_5 \times P_7$	4.14**	9.19**	-1.61**	-2.41**	6.23	0.76**	-0.13	-0.05
$P_6 \times P_7$	2.06**	6.74**	-0.37	-0.19	-0.41	0.15	0.35**	3.20**
SE (sij)	0.7877	1.5574	0.3035	0.6051	3.2423	0.2106	0.1143	0.4779
CD (S_{ij} - S_{ik}) (5%)	2.2906	4.5350	0.8837	1.7618	9.4405	0.6133	0.3328	1.3914
CD (S_{ij} – S_{kl}) (5%)	2.1429	4.2418	0.8267	1.6479	8.8308	0.5737	0.3112	1.3014

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

Table 17 Continued

Crosses	Seeds per fruit	Hundred seed weight	Crop duration	Yield per plant	Ascorbic acid content	Oleoresin content	Capsanthin content	Capsaicin content
$P_1 \times P_2$	-12.97**	0.02**	-0.48**	-52.94	-17.49**	1.78**	-33.45**	-0.01*
$P_1 \times P_3$	4.24	-0.05**	4.45**	98.54**	6.24*	0.74**	-1.32	0.05**
$P_1 \times P_4$	21.54**	-0.08**	8.06**	176.82**	49.70**	0.53**	-25.95**	-0.02**
$P_1 \times P_5$	31.95**	0.02**	-2.32**	87.44**	24.87**	0.34	32.03**	-0.06**
$P_1 \times P_6$	-5.37	-0.01*	7.15**	-4.05	-15.30**	0.38*	37.63**	-0.01*
$P_1 \times P_7$	-17.33**	0.02**	-1.85*	66.29**	-16.17**	2.09**	46.88**	-0.04**
$P_2 \times P_3$	-20.00**	-0.03**	-1.38	-0.97	5.31	2.02**	12.74**	-0.02**
$P_2 \times P_4$	27.53**	-0.02**	-0.61	145.92**	47.07**	1.79**	-32.76**	0.01*
$P_2 \times P_5$	34.85**	-0.03**	-3.65**	16.63	11.79**	0.14	-11.45**	0.03**
$P_2 \times P_6$	17.26**	-0.04**	4.52**	345.88**	7.50**	-0.08	5.01**	-0.05**
$P_2 \times P_7$	17.97**	-0.01*	7.75**	183.81**	8.08**	0.11	59.75**	-0.03**
$P_3 \times P_4$	-6.35	0.08**	-9.11**	-22.88	0.50	1.19**	70.96**	-0.02**
$P_3 \times P_5$	36.40**	0.08**	1.55*	216.63**	-25.56**	-0.47**	-13.51**	-0.05**
$P_3 \times P_6$	10.01*	0.01*	-2.28**	169.59**	8.59**	-0.53**	6.80**	-0.04**
$P_3 \times P_7$	17.72**	0.04**	-0.05	159.46**	17.94**	-0.77**	0.50	0.00
$P_4 \times P_5$	-5.50	0.03**	-0.85	-41.73	-2.65	-0.29	16.00**	0.02**
$P_4 \times P_6$	-11.19*	0.04**	-5.94**	38.59	-20.29**	-0.72**	-47.00**	0.00**
$P_4 \times P_7$	9.61	-0.05**	-6.21**	-8.99	11.62**	-0.63**	-11.63**	0.02**
$P_5 \times P_6$	-4.95	0.08**	4.55**	-94.15**	29.66**	1.72**	40.24**	0.01*
$P_5 \times P_7$	-7.17	0.02**	-2.22**	-1.94	-4.11	0.05	-33.28**	0.00
$P_6 \times P_7$	20.77**	0.05**	7.65**	-0.59	18.01**	-0.02	-10.04**	0.03**
SE (sij)	5.0265	0.004	0.7523	28.718	2.7481	0.1816	1.4976	0.0042
CD (S_{ij} - S_{ik}) (5%)	14.6357	0.0137	2.1905	83.6175	8.0027	0.5288	4.3604	0.0123
CD (S_{ij} - S_{kl}) (5%)	13.6904	0.0129	2.0489	78.2177	7.4850	0.4947	4.0788	0.0116

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

P_3 (0.23). It was negative and significant for P_7 (-0.84), P_4 (-0.74) and P_1 (-0.34).

Specific combining ability effects ranged between –1.61 (P_5 x P_7) and 3.69 (P_2 x P_6). Six hybrids showed significantly positive *sca* effects and it was significantly negative for five hybrids. P_2 x P_6 significantly differed from all other hybrids.

4. Secondary branches per plant

All the parents showed significant *gca* effects for this trait and it varied between –1.26 (P_7) to 2.14 (P_2). P_2 significantly differed from other parents. Positive and significant specific combining ability effects were showed by the hybrids P_2 x P_6 (7.43) and P_1 x P_4 (5.28).

5. Fruits per plant

P_3 (12.01) and P_2 (4.49) displayed significant positive *gca* effects while P_7 (-9.71), P_4 (-2.93) and P_5 (-2.69) showed significant negative *gca* effects. P_3 was significantly differed from P_2.

Among the hybrids *sca* effects ranged between –12.81 (P_1 x P_2) and 27.82 (P_2 x P_6). Nine hybrids showed significant positive *sca* effects while three hybrids had significant but negative *sca* effects. The hybrids P_1 x P_4, P_2 x P_4 and P_1 x P_3 showed on par performance with P_2 x P_6.

6. Fruit length

All parents had significant *gca* effects for fruit length and it ranged between –1.49 (P_4) to 2.82 (P_1).

Maximum significant positive *sca* effect for fruit length was observed for P_1 x P_7 (2.10) followed by P_3 x P_7 (1.33). None of the hybrids were found to be on par with P_1 x P_7 for fruit length. Thirteen hybrids showed positive and significant *sca* effects. It was negative and significant for P_4 x P_5 (-0.55).

7. Fruit girth

Significant *gca* effects were observed for all parents and its value ranged from –1.30 (P_1) to 1.28 (P_2).

Twelve hybrids showed significant *sca* effects ranged from –0.91 (P_2 x P_3) to 0.67 (P_3 x P_5) with positive and negative values for six hybrids each.

8. Fruit weight

Significant *gca* effects were observed for all parents except P_4 and P_7. It was positive for P_2 (2.95) and P_6 (1.49) and negative for P_3 (-2.12), P_5 (-1.63) and P_1 (-0.85). P_2 significantly differed from all other parents.

sca effects were positive and significant for 11 hybrids with maximum value of 3.28 (P_2 x P_4) followed by 3.20 (P_6 x P_7). No hybrids had significantly negative *sca* effect for fruit weight.

9. Seeds per fruit

Positively significant *gca* effect was showed by P_5 (8.57) and P_7 (8.05) whereas P_3 (-13.72) and P_7 (-7.48) had negative and significant *gca* effect for this trait.

Maximum *sca* effect was for the hybrid P_3 x P_5 (36.40) and was maximum in negative direction for the hybrid P_2 x P_3 (-20.00). Ten hybrids had positive and significant *sca* effects and four hybrids showed negative and significant *sca* effects.

10. Hundred seed weight

All the hybrids except P_7 exhibited significant *gca* effects of which P_2 (0.05) had maximum *gca* effect in positive direction and P_5 (-0.07) in the negative direction.

All the hybrids had significant *sca* effects, twelve in positive direction and ten in negative direction within the range of –0.08 (P_1 x P_4) to 0.08 (P_3 x P_4, P_3 x P_5 and P_5 x P_6).

11. Crop duration

Significant *gca* effects in the positive direction were shown by P_2 (5.58) and P_3 (5.08). The parents P_6 (-4.68), P_4 (-3.46), P_1 (-2.12) and P_7 (-0.78) had significant negative *gca* effects.

Significant *sca* effects for crop duration were showed by 16 hybrids with maximum positive and negative values for $P_1 \times P_4$ (8.06) and $P_3 \times P_4$ (-9.11) respectively.

12. Yield per plant

Significant *gca* effects were observed for all the parents and it was positive for P_2 (133.98), P_3 (43.38) and P_6 (36.74) while negative for P_5 (-88.37), P_7 (-77.03), P_4 (-27.69) and P_1 (-21.00). P_2 significantly differed from other parents.

Specific combining ability effects for yield per plant ranged between -94.15 ($P_5 \times P_6$) and 345.88 ($P_2 \times P_6$). It was positive and significant for eleven hybrids and negative and significant for only one hybrid $P_5 \times P_6$. None of the hybrids showed on par performance with $P_2 \times P_6$.

13. Ascorbic acid content

General combining ability effects of parents for ascorbic acid content varied between –15.43 (P_3) and 14.17 (P_7). The parent P_7 (14.17) followed by P_4 (13.97) exhibited maximum significant positive *gca* effects while P_3 (-15.43) had maximum significant negative *gca* effect.

Thirteen hybrids had positively significant *sca* effects with maximum value for $P_1 \times P_4$ (49.70), whereas five hybrids showed negative and significant *sca* effects. $P_2 \times P_4$ (47.07) was on par with $P_1 \times P_4$.

14. Oleoresin

All the hybrids showed significant *gca* effects and was positive for P_1 (0.23), P_2 (1.04), P_3 (1.07) and negative for P_4 (-0.30), P_5 (-0.51).

P_6 (-1.08) and P_7 (-0.44). P_2 differed significantly from other parents for this trait.

The range of *sca* effects was between –0.77 (P_3 x P_7) and 2.09 (P_1 x P_7). Fourteen hybrids showed significant *sca* effects for this trait, nine in positive direction and one in negative direction.

15. Capsanthin content

General combining ability effects for this trait was highly significant for all the parents. P_1 (14.39), P_4 (8.39), P_6 (6.34) and P_7 (34.13) showed positive significance and P_2 (-28.64), P_3 (-20.61) and P_5 (-14.00) had negative significance. P_7 significantly differed from other parents.

All the hybrids except P_1 x P_3 and P_3 x P_7 had significant *sca* effects, ten in positive direction and nine in negative direction. The values ranged between –47.00 (P_4 x P_6) and 70.96 (P_3 x P_4). P_3 x P_4 had significantly differed *sca* effect for this trait.

16. Capsaicin content

The parents P_1 (0.01), P_2 (0.03), P_3 (0.01) and P_5 (0.01) exhibited positively significant and P_4 (-0.01), P_6 (-0.02) and P_7 (-0.04) showed negatively significant *gca* effects, where P_7 significantly differed from other parents.

The range of *sca* effects was from –0.06 (P_1 x P_5) to 0.05 (P_1 x P_3). Seven hybrids had positive significance and eleven hybrids had negative significance for *sca* effects.

4.2.4 Heterosis

Relative heterosis (RH), heterobeltiosis (HB) and standard heterosis (SH) were estimated for 21 hybrids with respect to 16 characters under study and the results are furnished in Table 18 to 25. The variety Jwalamukhi was taken as check variety for estimating standard heterosis

for 12 characters namely, days to 50 per cent flowering, plant height, primary branches per plant, secondary branches per plant, fruits per plant, fruit length, fruit girth, fruit weight, seeds per fruit, hundred seed weight, crop duration and yield per plant, while for four quality characters *viz.*, ascorbic acid content, oleoresin content, capsanthin content and capsaicin content, Arka Abir was used as the check variety.

1. Days to 50 per cent flowering

Significant negative heterosis was observed in 18 hybrids over mid parent, 13 hybrids over better parent and all the hybrids over standard parent. The maximum negative relative heterosis was for the hybrid P_2 x P_7 (-20.39) followed by P_1 x P_7 (-19.06), heterobeltiosis for P_2 x P_3 (-17.65) and standard heterosis for P_1 x P_7 (-29.86) (Fig. 1).

2. Plant height

Fourteen hybrids possessed positively significant relative heterosis for the character while two hybrids P_1 x P_4 (-9.56) and P_1 x P_5 (-6.59) displayed negatively significant heterosis. The maximum positive value was for P_6 x P_7 (32.46) followed by P_5 x P_7 (27.27). Ten hybrids exhibited positively significant heterobeltiosis, the maximum being shown by P_6 x P_7 (30.27) and for five hybrids it was negatively significant. Only two hybrids exhibited positive standard heterosis, while all others showed negatively significant values, the maximum being possessed by P_1 x P_5 (-30.77).

3. Primary branches per plant

The hybrid P_2 x P_6 was superior over mid parent (173.87), better parent (172.67) and standard parent (58.46) for this trait. Eight hybrids showed significantly positive relative heterosis, while it was significantly negative for three hybrids. Heterobeltiosis was significant and positive for eight hybrids, but negative and significant for seven hybrids. Only two hybrids had positively significant standard heterosis. For 13 hybrids

Table 18 Heterosis (%) for days to 50 per cent flowering and plant height

Treatments	Days to 50 per cent flowering			Plant height		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	-15.76**	-9.59**	-19.00**	10.14**	-0.31	-12.37**
$P_1 \times P_3$	-12.17**	-7.08**	-16.75**	7.24*	-8.19**	-8.19**
$P_1 \times P_4$	-8.27**	-7.58**	-17.20**	-9.56**	3.71	-17.32**
$P_1 \times P_5$	-14.21**	-13.78**	-23.54**	-6.59*	-10.09**	-30.77**
$P_1 \times P_6$	-18.75**	-16.13**	-29.41**	16.26**	13.81**	-18.94**
$P_1 \times P_7$	-19.06**	-16.22**	-29.86**	12.05**	11.51**	-20.57**
$P_2 \times P_3$	-18.75**	-17.65**	-17.65**	2.93	-3.31	-3.31
$P_2 \times P_4$	-10.75**	-4.97**	-13.57**	26.04**	20.17**	5.62*
$P_2 \times P_5$	-9.69**	-2.54	-13.57**	9.85**	3.03	-9.44**
$P_2 \times P_6$	-11.86**	-2.15	-17.65**	26.36**	12.22**	-1.37
$P_2 \times P_7$	-20.39**	-11.35**	-25.79**	21.95**	9.91**	-3.39
$P_3 \times P_4$	-13.27**	-8.96**	-17.20**	2.87	-7.57**	-7.57**
$P_3 \times P_5$	-4.08**	2.05	-9.50**	-2.02	-13.29**	-13.29**
$P_3 \times P_6$	-7.13**	1.61	-14.48**	4.84	-11.81**	-11.81**
$P_3 \times P_7$	-5.42**	3.78	-13.13**	21.76**	3.82**	3.82
$P_4 \times P_5$	-14.86**	-13.78**	-23.54**	-0.49	-2.19	-22.02**
$P_4 \times P_6$	-18.35**	-15.05**	-28.50**	13.76**	5.56	-15.85**
$P_4 \times P_7$	-8.81**	-4.86*	-20.36**	22.06**	15.04**	-8.29**
$P_5 \times P_6$	0.00	2.69	-13.57**	17.10**	11.28**	-14.97**
$P_5 \times P_7$	2.36	5.40**	-11.77**	27.27**	21.94**	-6.11*
$P_6 \times P_7$	-2.96	-2.70	-18.56**	32.46**	30.27**	-8.09**

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

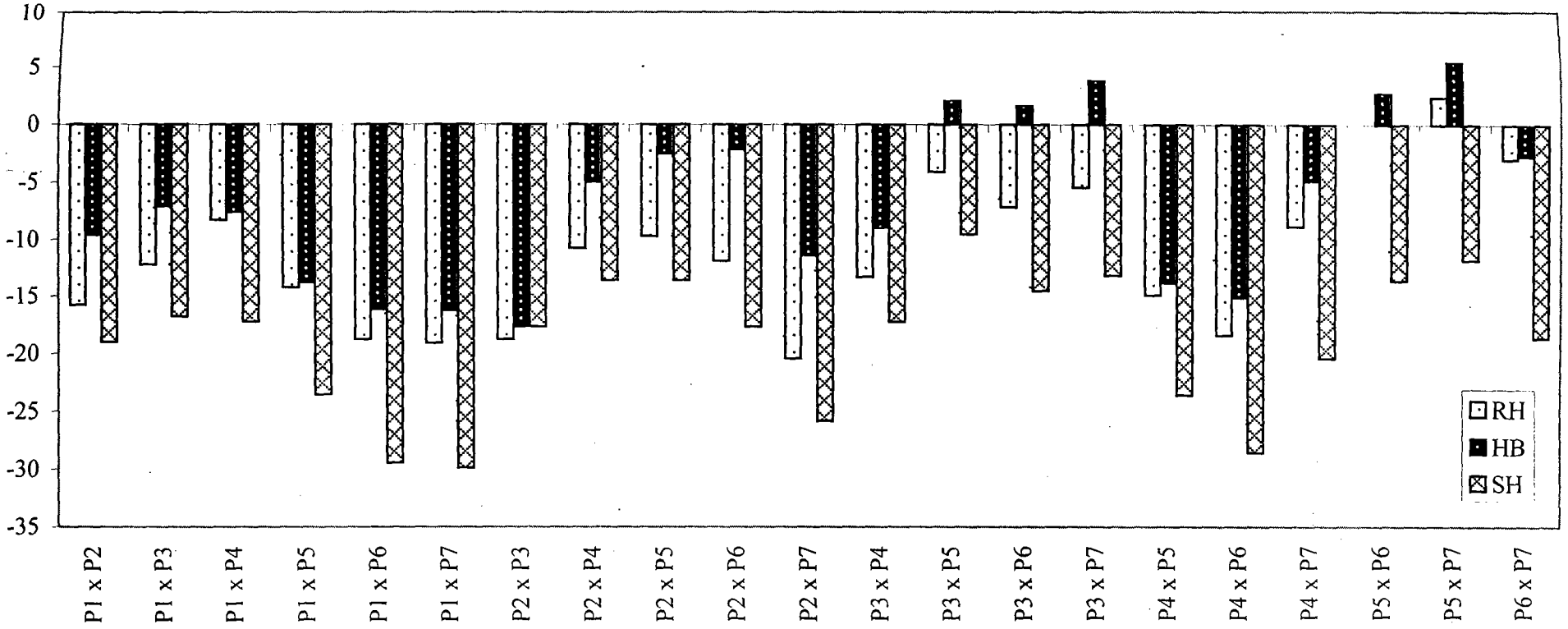

Fig. 1 Heterosis (%) for days to 50 per cent floweirng

negatively significant standard heterosis was observed. But for P_2 x P_5 (39.09) and P_2 x P_6 (58.46) it was positively significant.

4. Secondary branches per plant

Relative heterosis for this trait ranged from –33.68 (P_3 x P_4) to 178.54 (P_2 x P_6). Ten hybrids showed significant and positive heterosis.

Eight hybrids possessed positive and significant heterobeltiosis while five hybrids had negatively significant heterobeltiosis and its value ranged from –49.72 (P_3 x P_4) to 165.41 (P_2 x P_6). Only two hybrids, P_2 x P_5 (19.81) and P_2 x P_6 (50.20) showed positive and significant standard heterosis, whereas for eleven hybrids it was negative and significant.

5. Fruits per plant

All the hybrids showed positive relative heterosis, nineteen were significant, with maximum heterotic value for P_2 x P_6 (128.47). Heterosis over better parent ranged from –3.66 (P_4 x P_7) to 125.91 (P_2 x P_6). Sixteen hybrids had positively significant heterobeltiosis. Only one hybrid P_4 x P_7 (-20.65) registered negatively significant standard heterosis, whereas ten hybrids found to be significantly superior to check variety for number of fruits per plant (Fig. 2).

6. Fruit length

All the 21 hybrids were found to be significantly superior to their mid parent for the trait fruit length. The value ranged between 10.02 (P_4 x P_5) and 42.07 (P_1 x P_7). Positive and significant heterobeltiosis was observed for nine hybrids with maximum heterotic value of 28.35 (P_2 x P_7), whereas two hybrids had negatively significant heterobeltiosis. Fifteen hybrids had positive and significant standard heterosis value and three hybrids showed significantly negative standard heterosis. Maximum heterotic value was for P_1 x P_7 (51.33) (Fig. 3).

Table 19 Heterosis (%) for primary branches per plant and secondary branches per plant

Treatments	Primary branches per plant			Secondary branches per plant		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	113.41**	76.67**	1.75	133.43**	96.92**	1.03
$P_1 \times P_3$	-3.38	-33.33**	-33.33**	14.79	-22.42**	-22.42**
$P_1 \times P_4$	145.77**	126.46**	1.57	136.36**	99.08**	2.60
$P_1 \times P_5$	25.44*	-12.15	-16.75**	89.92**	45.31**	-3.31
$P_1 \times P_6$	15.15	-4.80	-44.68**	8.48	-11.99	-50.20**
$P_1 \times P_7$	10.00	-10.86	-45.55**	22.07	-3.86	-41.04**
$P_2 \times P_3$	25.46*	-1.05	-1.05	40.87**	6.55	6.55
$P_2 \times P_4$	80.11**	60.00**	-7.85	98.98**	98.62**	2.37
$P_2 \times P_5$	82.44**	46.78**	39.09**	103.35**	80.07**	19.81**
$P_2 \times P_6$	173.87**	172.67**	58.46**	178.54**	165.41**	50.20**
$P_2 \times P_7$	58.53**	54.00**	-5.93	65.65**	52.21**	-6.71
$P_3 \times P_4$	-47.79**	-62.13**	-62.13**	-33.68**	-49.72**	-49.72**
$P_3 \times P_5$	1.97	-0.70	-0.70	27.17**	5.92	5.92
$P_3 \times P_6$	-3.38	-23.56**	-23.56**	4.20	-18.47*	-18.47*
$P_3 \times P_7$	-38.63**	-50.61**	-50.61**	3.85	-16.26*	-16.26*
$P_4 \times P_5$	-13.33	-36.10**	-39.44**	16.70	3.56	-31.10**
$P_4 \times P_6$	-13.33	-23.12	-55.32**	-6.57	-10.74	-49.49**
$P_4 \times P_7$	-6.59	-19.14	-50.61**	4.43	-3.86	-41.04**
$P_5 \times P_6$	-14.83	-31.31**	-34.90**	38.89**	28.47*	-14.52
$P_5 \times P_7$	-47.76**	-57.09**	-59.34**	-16.46	-19.69	-46.57**
$P_6 \times P_7$	-16.10	-18.00	-49.91**	7.14	2.96	-36.86**

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

Table 20 Heterosis (%) for fruits per plant and fruit length

Treatments	Fruits per plant			Fruit length		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	27.53**	22.99*	-4.77	26.87**	1.70	41.95**
$P_1 \times P_3$	83.92**	63.16**	63.16**	13.87**	-2.24	36.46**
$P_1 \times P_4$	78.00**	72.68**	42.21**	22.00**	-9.36**	26.52**
$P_1 \times P_5$	41.02**	38.32**	11.36	19.66**	-13.16**	21.21**
$P_1 \times P_6$	63.72**	56.18**	20.93*	18.55**	6.31**	48.39**
$P_1 \times P_7$	47.55**	17.15	-9.29	42.07**	8.41**	51.33**
$P_2 \times P_3$	71.66**	47.56**	47.56**	24.64**	14.77**	14.77**
$P_2 \times P_4$	89.85**	77.84**	46.46**	17.62**	6.19	-10.60**
$P_2 \times P_5$	51.07**	43.01**	15.14	17.44**	2.70	-13.54**
$P_2 \times P_6$	128.47**	125.91**	62.47**	13.74**	0.09	10.80**
$P_2 \times P_7$	124.00**	82.92**	31.55**	37.08**	28.35**	8.05**
$P_3 \times P_4$	12.60	2.66	2.66	30.71**	9.66**	9.66**
$P_3 \times P_5$	67.54**	51.21**	51.21**	27.45**	3.88	3.88
$P_3 \times P_6$	82.02**	55.04**	55.04**	17.20**	11.55**	23.48**
$P_3 \times P_7$	92.91**	40.37**	40.37**	41.17**	22.44**	22.44**
$P_4 \times P_5$	25.21**	23.81*	1.97	10.02*	6.15	-28.13**
$P_4 \times P_6$	16.11	7.61	-11.38	21.02**	-2.48	7.95**
$P_4 \times P_7$	24.08*	-3.66	-20.65*	38.01**	32.77**	-2.56**
$P_5 \times P_6$	20.46*	12.82	-9.17	24.52**	-2.31	8.14**
$P_5 \times P_7$	55.91**	22.04*	-1.74	39.41**	29.33**	-4.92
$P_6 \times P_7$	53.03**	26.06*	-11.38	23.73**	2.91	13.92**

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

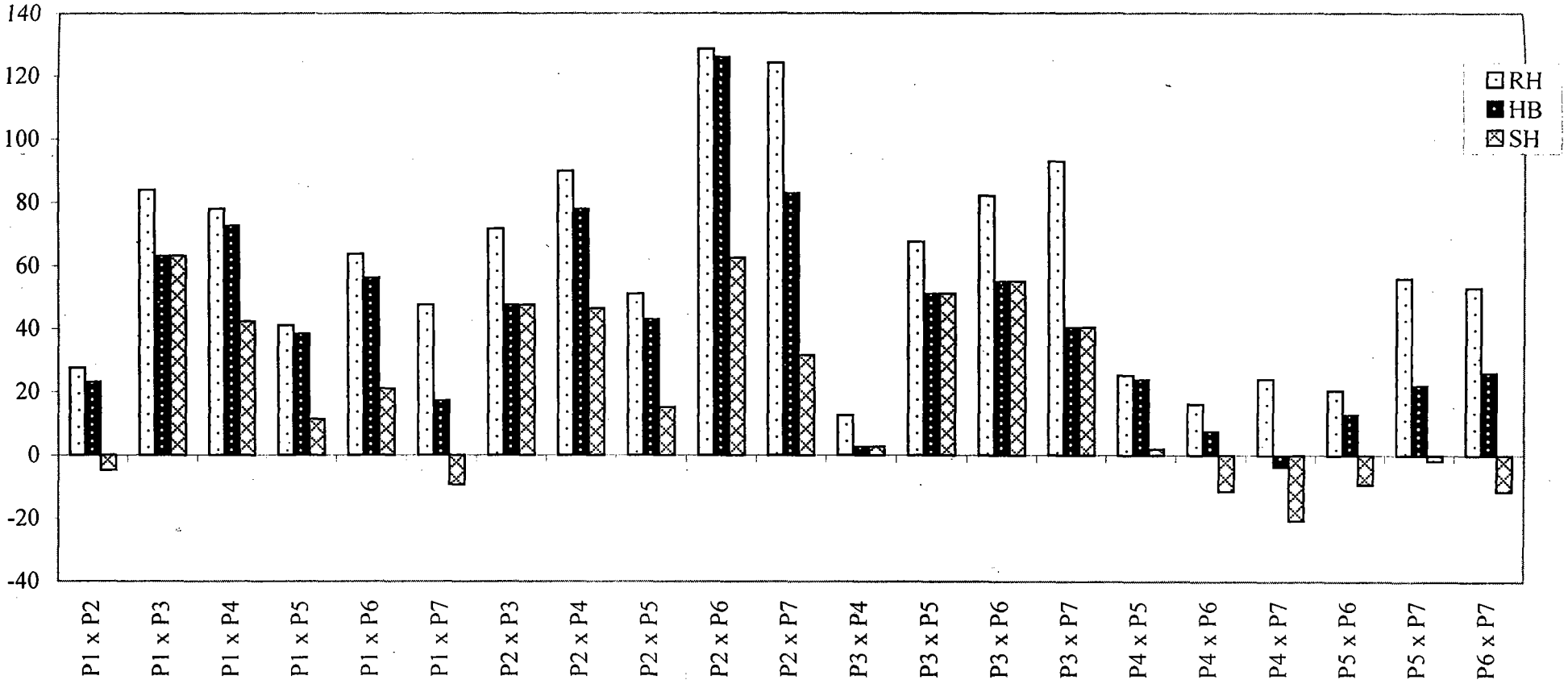

Fig. 2 Heterosis (%) for fruits per plant

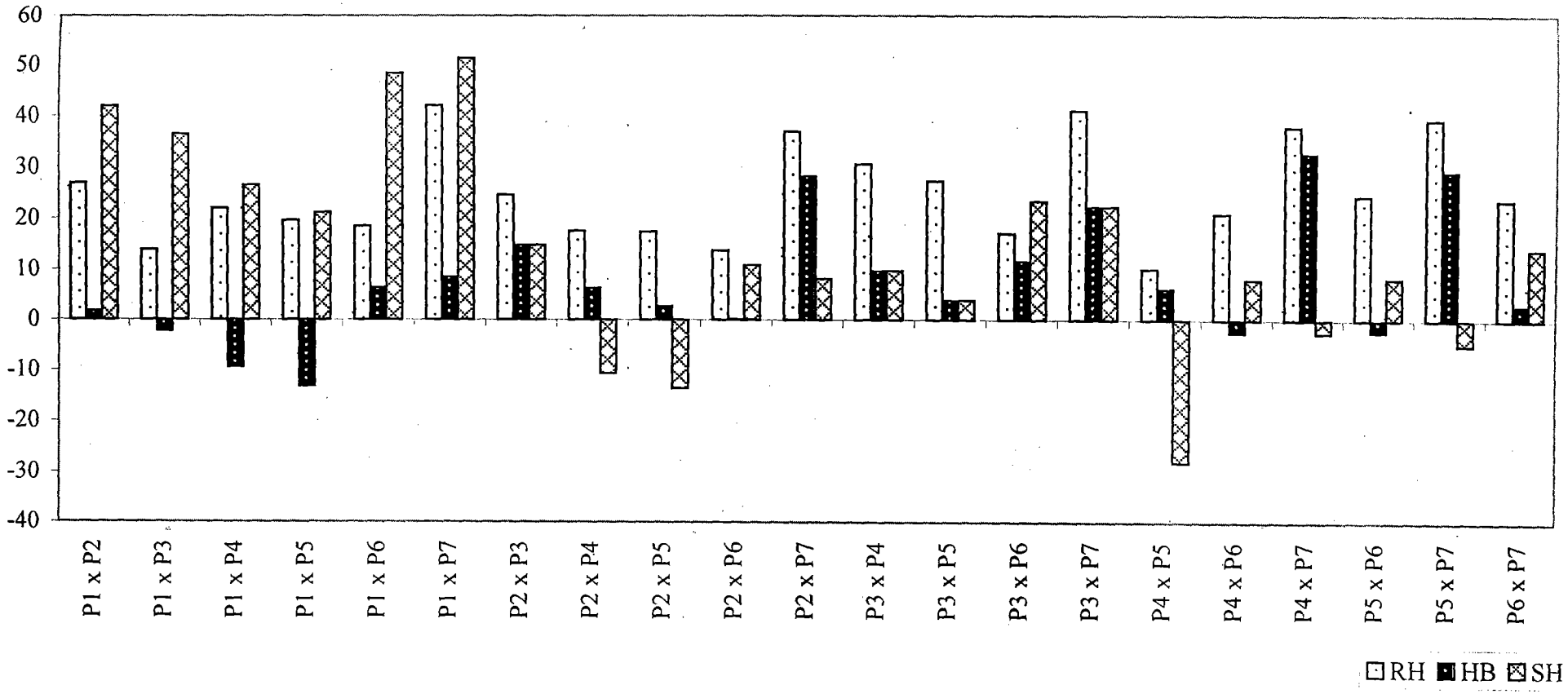

Fig. 3 Heterosis (%) for fruit length

7. Fruit girth

The extent of heterosis over mid parent ranged between –14.89 (P_4 x P_7) and 11.82 (P_3 x P_5). Four hybrids showed positive and significant heterosis, while for seven hybrids it was significant but negative. All the hybrids showed negative heterobeltiosis ranging from –32.31 (P_2 x P_3) to –0.45 (P_4 x P_5) of which sixteen were significant. Most of the hybrids had significant and positive standard heterosis except for P_1 x P_3 (-5.60) and P_1 x P_6 (-5.78).

8. Fruit weight

Relative heterosis for this trait was positively significant for 20 hybrids and the value varied from 12.93 (P_1 x P_5) to 65.24 (P_2 x P_4). Heterobeltiosis was found positive for all hybrids and was significant for 16 hybrids. All hybrids were significantly superior to check variety for fruit weight (Fig. 4).

9. Seeds per fruit

Sixteen hybrids exhibited positively significant relative heterosis, the maximum being shown by P_2 x P_5 (85.18). P_1 x P_7 displayed negative heterosis (-1.54) but was not significant. Positively significant heterobeltiosis was shown by eleven hybrids, while it was negative and significant for P_1 x P_7 (-15.68). Standard heterosis ranged between 41.83 (P_1 x P_7) and 146.59 (P_2 x P_5), all were positive and significant.

10. Hundred seed weight

Eleven hybrids possessed positively significant relative heterosis while seven hybrids displayed negatively significant heterosis. The maximum positive value was for P_5 x P_6 (31.93) closely followed by P_3 x P_5 (31.76). The value of heterobeltiosis varied from –25.27 (P_2 x P_5) to 17.22 (P_6 x P_7), of which twelve were negatively significant and seven hybrids showed positive significance. Twelve hybrids possessed positively

Table 21 Heterosis (%) for fruit girth and fruit weight

Treatments	Fruit girth			Fruit weight		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	3.92*	-24.47**	38.35**	39.58**	18.61**	137.86**
$P_1 \times P_3$	3.09	-5.60	-5.60	23.86**	6.10	48.71**
$P_1 \times P_4$	2.67	-21.22**	22.24**	55.23**	54.02**	115.88**
$P_1 \times P_5$	3.49	-20.41**	22.94**	12.93	54.03**	47.22**
$P_1 \times P_6$	-4.35	-17.36**	-5.78**	30.61**	18.15**	104.88**
$P_1 \times P_7$	0.15	-22.26**	16.81**	33.43**	27.86**	95.52**
$P_2 \times P_3$	-12.45**	-32.31**	23.99**	37.43**	2.98	106.51**
$P_2 \times P_4$	-2.21	-9.66**	65.50**	65.24**	39.45**	179.65**
$P_2 \times P_5$	5.14**	-3.15	77.41**	51.90**	21.58**	143.83**
$P_2 \times P_6$	-3.46*	-21.70**	43.43**	54.43**	43.98**	188.74**
$P_2 \times P_7$	-12.34**	-20.27**	46.06**	33.99**	18.06**	136.77**
$P_3 \times P_4$	7.96**	-11.29**	37.65**	67.35**	44.35**	99.19**
$P_3 \times P_5$	11.82**	-7.94**	42.21**	47.93**	35.36**	63.09**
$P_3 \times P_6$	3.82	-2.61	11.03**	39.36**	9.86	90.50**
$P_3 \times P_7$	-7.82**	-23.31**	15.24**	32.21**	9.32	66.16**
$P_4 \times P_5$	-0.21	-0.45	54.47**	31.82**	23.40**	70.28**
$P_4 \times P_6$	-3.38	-16.14**	30.12**	46.59**	31.61**	128.22**
$P_4 \times P_7$	-14.89**	-13.52**	29.95**	34.85**	28.22**	96.07**
$P_5 \times P_6$	-6.68**	-18.93**	25.22**	37.95**	16.90**	102.71**
$P_5 \times P_7$	-3.99*	-2.68	46.23**	22.85**	9.76	67.84**
$P_6 \times P_7$	-0.99	-12.94**	30.82**	55.81**	46.64**	154.27**

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

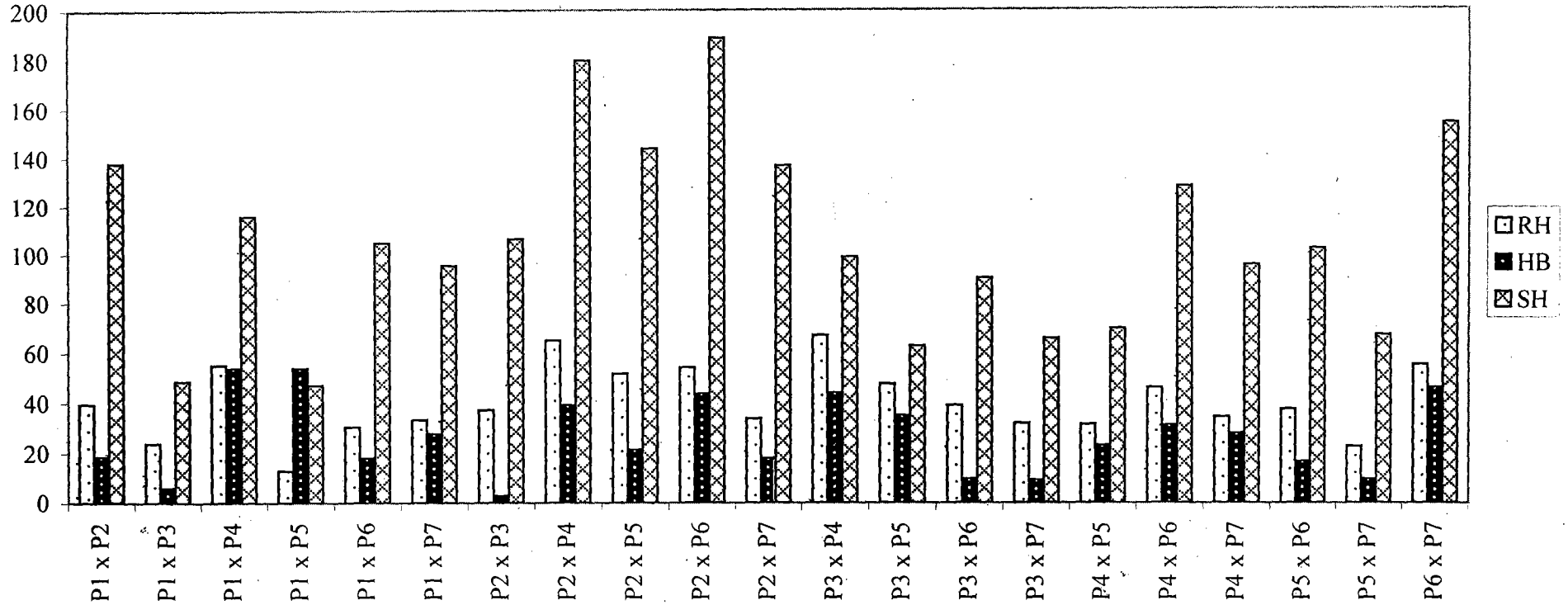

Fig. 4 Heterosis (%) for fruit weight

Table 22 Heterosis (%) for Seeds per fruit and hundred seed weight

Treatments	Seeds per fruit			Hundred seed weight		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	9.12	-3.07	63.04**	-3.47*	-12.34**	10.38**
$P_1 \times P_3$	23.68**	-1.39	65.86**	-5.32**	-6.60**	-4.01*
$P_1 \times P_4$	33.01**	31.08**	127.06**	-15.19**	-15.85**	-12.18**
$P_1 \times P_5$	60.69**	45.17**	144.20**	9.89**	-11.04**	-8.58**
$P_1 \times P_6$	6.58	2.26	72.02**	0.56	-3.68*	-1.02
$P_1 \times P_7$	-1.54	-15.68*	41.83**	4.06*	0.02	2.78
$P_2 \times P_3$	9.06	-3.72	25.76*	-3.17*	-13.14**	9.39**
$P_2 \times P_4$	54.25**	35.27**	134.33**	-5.88**	-13.94**	8.37**
$P_2 \times P_5$	85.18**	81.69**	146.59**	-0.72	-25.27**	-5.89**
$P_2 \times P_6$	44.00**	32.84**	105.34**	-4.61**	-16.67**	4.94**
$P_2 \times P_7$	55.68**	49.30**	95.00**	-2.60	-14.65**	7.48**
$P_3 \times P_4$	14.98*	-9.32	57.09**	16.98**	14.53**	19.53**
$P_3 \times P_5$	90.78**	65.68**	124.86**	31.76**	7.81**	7.81**
$P_3 \times P_6$	33.42**	9.86	69.83**	11.59**	8.29**	8.29**
$P_3 \times P_7$	55.02**	92.17**	70.45**	15.26**	12.25**	12.25**
$P_4 \times P_5$	25.15**	11.60	93.33**	13.77**	-8.43**	-4.44**
$P_4 \times P_6$	4.16	-1.45	70.72**	10.80**	5.34**	9.93**
$P_4 \times P_7$	30.91**	10.76	91.87**	-4.75**	-9.12**	-5.15**
$P_5 \times P_6$	24.91**	17.29*	81.31**	31.93**	10.59**	4.06**
$P_5 \times P_7$	30.17**	22.59**	66.38**	17.52**	-1.78	-6.90**
$P_6 \times P_7$	43.15**	27.09**	96.46**	17.65**	17.22**	11.11**

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

significant standard heterosis, while seven hybrids had negative significance.

11. Crop duration

Relative heterosis was positive and significant for nine hybrids and negatively significant for six hybrids. Heterobeltiosis was negative and significant for almost all the hybrids except for P_1 x P_6 (7.70), P_2 x P_7 (2.53) and P_6 x P_7 (3.81). Standard heterosis was negatively significant for all the hybrids and it ranged from –15.17 (P_4 x P_6) to –0.56 (P_2 x P_7).

12. Yield per plant

The heterosis per cent ranged from 16.08 (P_5 x P_6) to 125.68 (P_3 x P_7) for relative heterosis, from 1.81 (P_5x P_6) to 100.21 (P_2 x P_6) for heterobeltiosis and 14.22 (P_5 x P_7) to 187.65 (P_2 x P_6) for standard heterosis. Positive and significant relative heterosis and heterobeltiosis were found for all hybrids except P_4 x P_5 and P_5 x P_6. Standard heterosis was significant for 19 hybrids (Fig. 5).

13. Ascorbic acid content

Positively significant relative heterosis was observed for 17 hybrids, maximum value being possessed by P_2 x P_4 (57.54). Only one hybrid P_3 x P_5 (-8.80) recorded negatively significant relative heterosis. Thirteen hybrids exhibited positive and significant heterobeltiosis, while four had negative significance. Standard heterosis ranged between –24.79 (P_3 x P_5) and 27.25 (P_1 x P_4), with negative significance for ten hybrids and positive significance for six hybrids.

14. Oleoresin content

The hybrid P_1 x P_2 showed maximum positive relative heterosis (34.95) and minimum was recorded by P_4 x P_6 (-0.51). Fifteen hybrids exhibited positive and significant heterosis over mid parent. Heterobeltiosis was positively significant for 13 hybrids with maximum value for P_1 x P_2 (27.06), while four hybrids had negatively significant heterobeltiosis.

Table 23 Heterosis (%) for crop duration and yield per plant

Treatments	Crop duration			Fruit yield per plant		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	2.88**	-2.88**	-5.81**	41.76**	19.60**	71.88**
$P_1 \times P_3$	3.83**	-3.38**	-3.38**	88.42**	87.31**	87.37**
$P_1 \times P_4$	5.00**	1.22	-6.09**	84.57**	78.22**	89.14**
$P_1 \times P_5$	0.43	-3.68**	-9.67**	61.19**	52.89**	51.09**
$P_1 \times P_6$	9.60**	7.70**	-7.25**	47.53**	35.77**	59.62**
$P_1 \times P_7$	1.97**	-0.40	-10.05**	79.10**	50.37**	48.60**
$P_2 \times P_3$	-0.86	-2.36**	-2.36**	65.29**	40.17**	101.38**
$P_2 \times P_4$	-1.58**	-3.71**	-6.62**	76.62**	53.55**	120.91**
$P_2 \times P_5$	-1.64**	-3.26**	-6.18**	48.45**	20.02*	72.44**
$P_2 \times P_6$	6.07**	-1.51*	-4.48**	120.22**	100.21**	187.65**
$P_2 \times P_7$	6.18**	2.53**	-0.56	106.58**	51.53**	117.70**
$P_3 \times P_4$	-8.24**	-11.55**	-11.55**	50.22**	45.88**	54.83**
$P_3 \times P_5$	-0.51	-3.60**	-3.60**	112.22**	100.18**	100.18**
$P_3 \times P_6$	-0.05	-8.48**	-8.48**	102.22**	87.11**	119.97**
$P_3 \times P_7$	-0.29	-5.12**	-5.12**	125.68**	88.56**	88.56**
$P_4 \times P_5$	-3.09**	0.56	-9.59**	19.77	9.90	16.64
$P_4 \times P_6$	-3.55**	-8.57**	-15.17**	50.86**	43.53**	68.73**
$P_4 \times P_7$	-1.56**	-6.42**	-13.17**	47.55**	20.43	27.82*
$P_5 \times P_6$	4.78**	-1.17	-7.37**	16.08	1.81	19.69
$P_5 \times P_7$	-1.01	-2.85**	-8.88**	46.65**	28.85*	14.22
$P_6 \times P_7$	8.10**	3.81**	-6.25**	58.42**	24.44*	46.29**

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

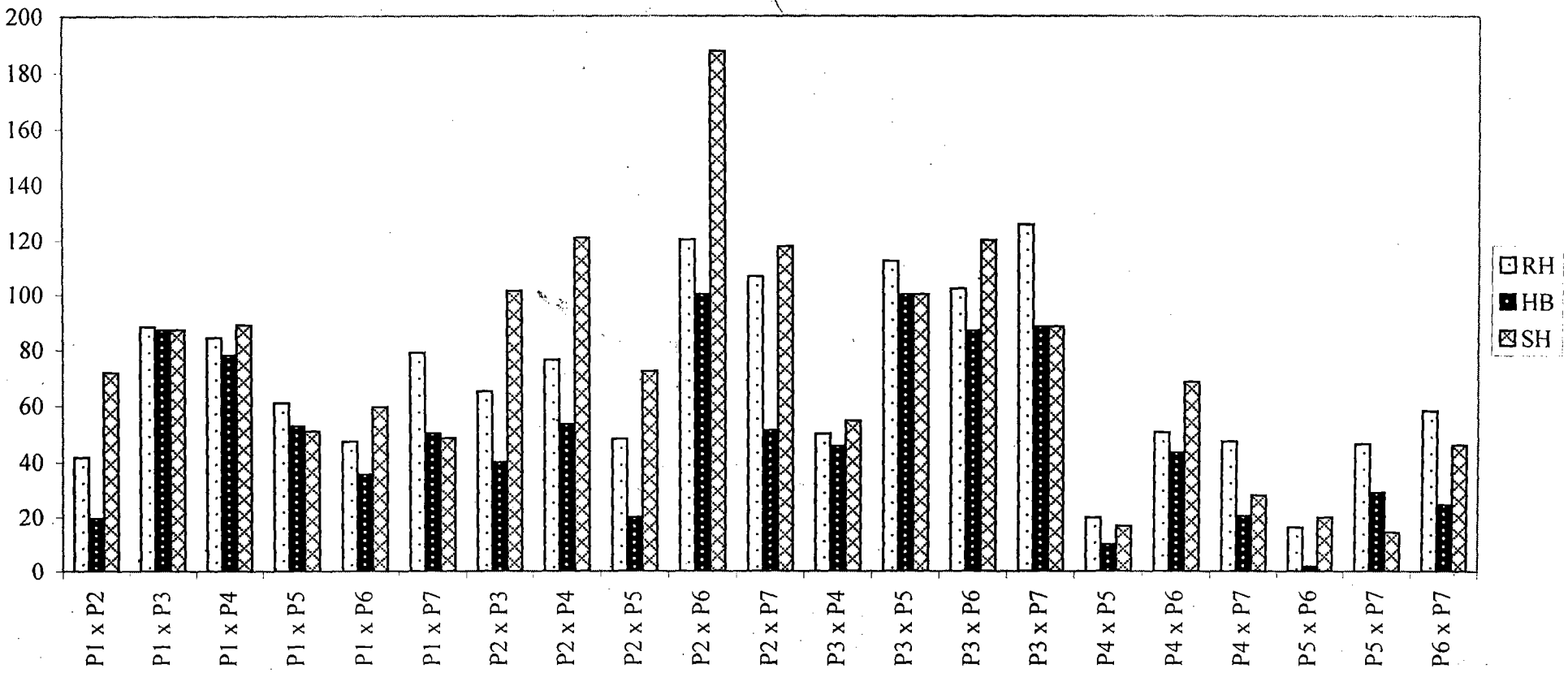

Fig. 5 Heterosis (%) for yield per plant

Table 24 Heterosis (%) for ascorbic acid content and oleoresin content

Treatments	Ascorbic acid content			Oleoresin content		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	4.18	-6.59**	-20.81**	34.95**	27.06**	31.49**
$P_1 \times P_3$	11.51**	4.91*	-11.06**	19.19**	6.09*	24.22**
$P_1 \times P_4$	48.60**	47.12**	27.25**	18.93**	14.81**	12.73**
$P_1 \times P_5$	24.84**	2110**	9.21**	16.90**	13.79**	9.82**
$P_1 \times P_6$	-0.19	-2.45	-17.30**	16.22**	15.91**	5.96*
$P_1 \times P_7$	0.36	-7.28**	-7.28**	28.56**	23.05**	23.05**
$P_2 \times P_3$	17.88**	11.96**	-16.32**	26.37**	19.07**	31.42**
$P_2 \times P_4$	57.54**	40.01**	21.10**	26.68**	23.47**	27.78**
$P_2 \times P_5$	23.96**	8.19**	-2.43	14.18**	10.33**	14.18**
$P_2 \times P_6$	21.37**	11.11**	-10.08**	11.60**	4.85*	8.51**
$P_2 \times P_7$	20.43**	0.70	0.70	12.57**	10.68**	14.55**
$P_3 \times P_4$	16.46**	8.55**	-6.10**	14.86**	5.59**	23.64**
$P_3 \times P_5$	-8.80**	-16.60**	-24.79**	3.06	-6.02**	10.04**
$P_3 \times P_6$	12.76**	8.45**	-12.23**	1.40	-9.94**	5.45**
$P_3 \times P_7$	18.08**	3.17	3.17	-0.47	-7.45**	8.36**
$P_4 \times P_5$	16.27**	13.89**	2.72	4.11*	3.18	1.30
$P_4 \times P_6$	5.17*	1.79	-11.96**	-0.51	-4.22-*	-5.96**
$P_4 \times P_7$	23.65**	15.30**	15.30**	0.31	-0.58	-0.58
$P_5 \times P_6$	27.78**	21.2**	9.32**	17.82**	14.32**	10.33**
$P_5 \times P_7$	7.32**	2.05	2.48	4.63**	2.76	2.76
$P_6 \times P_7$	19.70**	8.28**	8.28**	2.86	-1.82	-1.82

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

Table 25 Heterosis (%) for capsanthin content and capsaicin content

Treatments	Capsanthin content			Capsaicin content		
	RH	HB	SH	RH	HB	SH
$P_1 \times P_2$	-17.48**	-34.49**	-47.35**	-17.56**	-13.32**	60.58**
$P_1 \times P_3$	31.45**	-5.97**	-27.30**	2.68	3.05	90.90**
$P_1 \times P_4$	-12.54**	-24.46**	-24.90**	-15.50**	2.29	33.31**
$P_1 \times P_5$	45.00**	22.42**	-5.35**	-34.32**	-30.39**	15.13*
$P_1 \times P_6$	43.09**	40.84**	8.88**	-19.40**	-3.88	28.57**
$P_1 \times P_7$	45.76**	29.22**	29.22**	-32.32**	-3.44	-3.44
$P_2 \times P_3$	44.26**	24.99**	-43.20**	-20.27**	-16.46**	55.84**
$P_2 \times P_4$	-31.74**	49.44**	-52.26**	-2.98	24.56**	62.33**
$P_2 \times P_5$	-4.44	-11.44**	-52.86**	1.29	13.19**	87.21**
$P_2 \times P_6$	11.96**	-10.05**	-32.65**	-30.09**	-11.65*	18.18**
$P_2 \times P_7$	54.93**	12.66**	12.66**	-22.48**	17.99**	17.99**
$P_3 \times P_4$	70.84**	15.53**	9.09**	-16.80**	1.15	31.82**
$P_3 \times P_5$	16.54**	-5.28*	-49.58**	-28.66**	-24.11**	25.52**
$P_3 \times P_6$	34.50**	-2.84	-27.26**	-27.84**	-13.59**	15.58*
$P_3 \times P_7$	26.85**	-15.46**	-15.46**	-10.27*	28.57**	28.57**
$P_4 \times P_5$	11.81**	-12.58**	-17.45**	6.88	21.23**	57.99**
$P_4 \times P_6$	-30.21**	-37.44**	-40.96**	-5.90	-4.68	24.22**
$P_4 \times P_7$	-3.51*	-6.20**	-6.20**	12.78*	29.87**	29.87**
$P_5 \times P_6$	47.90**	26.53**	-5.27**	-4.20	7.14	43.31**
$P_5 \times P_7$	-9.13**	-30.37**	-30.37**	-9.46	20.13**	20.13**
$P_6 \times P_7$	7.00**	-6.45**	-6.45**	5.93	23.83**	23.83**

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

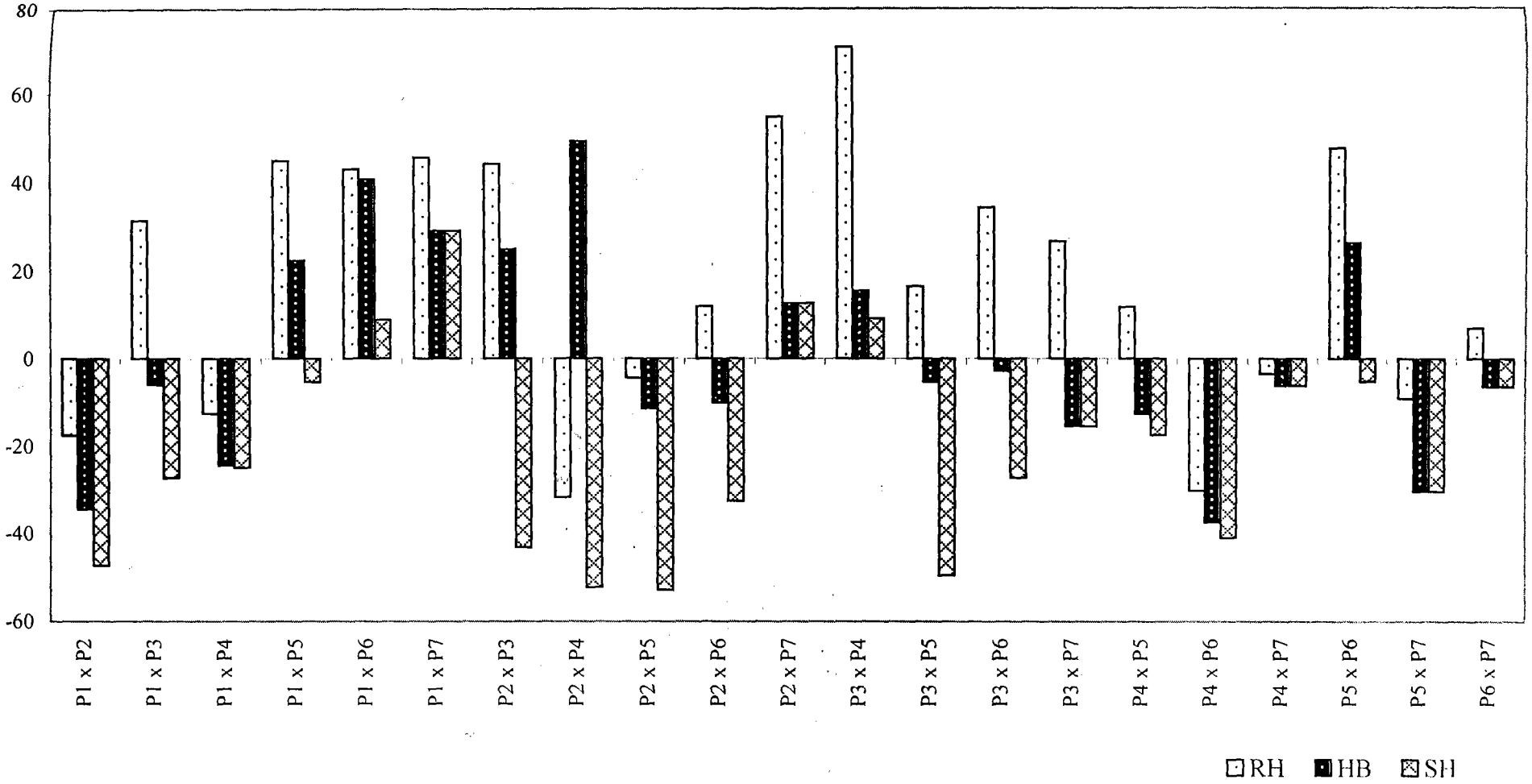

Fig. 6 Heterosis (%) for capsanthin content

Standard heterosis for oleoresin content ranged between –5.96 (P_4 x P_6) and 39.42 (P_2 x P_3) with positively significant heterosis for 16 hybrids.

15. Capsanthin content

Relative heterosis for capsanthin content was positive and significant for thirteen hybrids whereas, six hybrids had negative significance. The value varied from –31.74 (P_2 x P_4) to 70.84 (P_3 x P_4). The extent of heterobeltiosis ranged between –37.49 (P_4 x P_6) and 49.44 (P_2 x P_4). Positively significant heterobeltiosis was possessed by eight hybrids while twelve others possessed negatively significant values. The hybrids possessed significant positive standard heterosis for this trait include P_1 x P_7 (29.22), P_2 x P_7 (12.66), P_3 x P_6 (9.09) and P_1 x P_6 (8.88) while other 17 hybrids had negative significance (Fig. 6).

16. Capsaicin content

The extent of heterosis ranged between –34.32 (P_1 x P_5) and 12.78 (P_4 x P_7). Negative significance was showed by 13 hybrids while P_4 x P_7 had positive significance (12.78). Heterobeltiosis ranged from –30.39 (P_1 x P_5) to 29.87 (P_4 x P_7). Six hybrids had negative significance while eight hybrids showed positive significance. Standard heterosis was positive and significant for all hybrids except P_1 x P_7 (-3.44).

4.3 MOLECULAR CHARACTERIZATION

The DNA isolation was done from the tender leaves of chilli using CTAB method. The DNA yield of 28 chilli genotypes including seven parents and 21 hybrids ranged from 75 (P_4 x P_6) to 330 (P_1) $\mu g\ ml^{-1}$. The initial purity of DNA ranged between 1.38 (P_2 x P_7) and 2.48 (P_2 x P_5) with an average purity of 1.86.

The elecrophoretic assay of DNA samples using agarose gel (0.8 %) revealed that the DNA samples isolated were intact and native without any shearing.

The 25 µl reaction mixture consisting of 2.5 µl of 1 x buffer. 2.5 mM $MgCl_2$, 200 µM dNTP mix, 4 pM primer, 0.6 units of Taq DNA polymerase and 20 ng of DNA gave good amplification. The programme consisted of an initial denaturation at 94°C for five minutes followed by 43 cycles of denaturation at 94°C for one minute, annealing at 35°C for one minute 30 seconds and extension at 72°C for two minutes. The synthesis step of the final cycle was extended further by five minutes. Amplification products were cooled to 4°C after the reaction.

Forty seven decamer primers (OPA, OPB, OPE) were screened for their efficiency using the DNA isolated from P_1 (EG-85) as the representative sample. Out of forty seven decamer primers, 36 yielded amplification products. There was no amplification with 11 primers. The total number of bands, number of faint bands and the number of intense bands produced by the primers were recorded (Table 26). These primers produced 83 bands (average 2.31 bands per primer) of which 69 bands were polymorphic and 14 bands were monomorphic.

The maximum number of bands was produced by the primer OPA-01 (7 bands). Six bands were produced by OPA-10 and the primers OPA-03, OPB-06 and OPB-20 produced five bands each.

For further amplification only four primers were selected which produced good amplification and more number of polymorphic bands. From the four primers, only one primer (OPA-10) was used for DNA amplification of 28 genotypes and three primers (OPA-01, OPB-06 and OPB-20) were used for amplification of selected hybrid P_1 x P_7 and its parents. The nucleotide sequences of primers used are given in Table 27.

The primer OPA-10 used in this analysis yielded 96 scorable bands with the 28 genotypes. The amplification products ranged in size approximately from 300 to 1300 base pairs. Number of bands per genotype varied from one to six.

Table 26 Primer associated banding patterns with the DNA of chilli variety EG-85

Primers	Intense bands	Faint bands	Total number of bands
OPA - 01	5	2	7
OPA - 02	2	1	3
OPA - 03	3	2	5
OPA - 04	0	2	2
OPA - 05	1	1	2
OPA - 06	0	1	1
OPA - 07	0	2	2
OPA - 08	0	0	0
OPA - 09	0	0	0
OPA - 10	4	2	6
OPA - 11	1	2	3
OPA - 12	0	1	1
OPA - 13	0	2	2
OPA - 15	1	0	1
OPA - 16	0	0	0
OPA - 17	0	1	1
OPA - 18	0	3	3
OPA - 19	1	0	1
OPA - 20	1	1	2
OPB - 02	0	0	0
OPB - 03	0	2	2
OPB - 04	0	3	3
OPB - 05	2	2	4
OPB - 06	2	3	5
OPB - 08	1	1	2
OPB - 09	0	0	0
OPB - 10	1	0	1
OPB - 11	1	1	2
OPB - 12	2	0	2
OPB - 13	0	0	0
OPB - 14	0	0	0
OPB - 15	1	0	1
OPB - 16	0	1	1
OPB - 17	0	0	0
OPB - 18	0	0	0
OPB - 19	0	1	1
OPB - 20	3	2	5
OPE - 1	1	0	1
OPE - 2	1	0	1
OPE - 3	1	1	2
OPE - 4	1	0	1
OPE - 5	1	1	2
OPE - 6	0	1	1
OPE - 7	2	1	3
OPE - 8	0	0	0
OPE - 9	0	0	0
OPE - 10	0	1	1

Table 27 Nucleotide sequences of primers used for RAPD analysis

Primer	Sequence
OPA-01	CAGGCCCTTC
OPA-10	GTGATCGCAG
OPB-06	TGCTCTGCCC
OPB-20	GGACCCTTAC

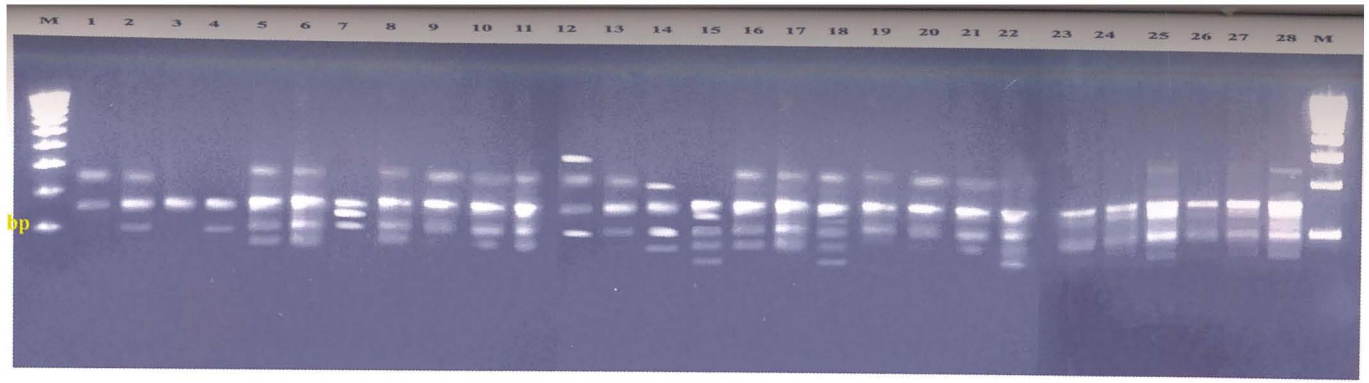

Plate 3. Amplification profiles of the DNA of 28 chilli genotypes using the primer OPA-10

1 - P1	5 - P5	9 - P1 x P3	13 - P1 x P7	17 - P2 x P6	21 - P3 x P6	25 - P4 x P7	M - DNA marker
2 - P2	6 - P6	10 - P1 x P4	14 - P2 x P3	18 - P2 x P7	22 - P3 x P7	26 - P5 x P6	
3 - P3	7 - P7	11 - P1 x P5	15 - P2 x P4	19 - P3 x P4	23 - P4 x P5	27 - P5 x P7	
4 - P4	8 - P1 x P2	12 - P1 x P6	16 - P2 x P5	20 - P3 x P5	24 - P4 x P6	28 - P6 x P7	

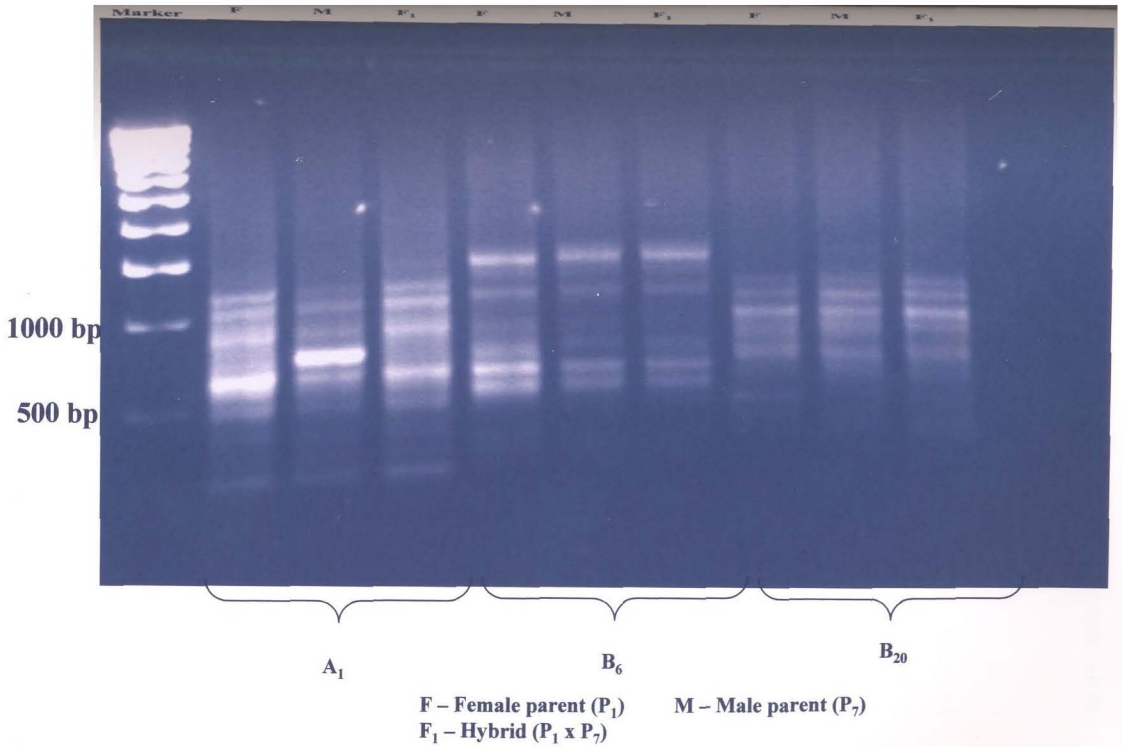

Plate 4. Amplification profiles of the DNA of selected hybrids and its parents using the primers OPA-01, OPB-06 and OPB-20

The primers OPA-01, OPB-06 and OPB-20 yielded a total of 46 scorable bands with three genotypes.

4.3.1 Data Analysis

Reproducible bands were scored for their presence (+) or absence (-) for all the genotypes studied (Fig. 7, 8, 9 and 10). A genetic similarity matrix was constructed using the Jaccard's coefficient method (Tables 28). The pair wise coefficient values varied between 0.20 and 1.00 among the 28 genotypes.

The genetic similarity coefficient between P_1 and F_1 as well as P_2 and F_1 were 0.84 and 0.94 respectively. Between P_1 and P_2, similarity coefficient was 0.80 (Table 29).

On drawing a vertical line in the dendrogram along the point corresponding to the similarity coefficient 0.712, all the 28 genotypes got divided into six clusters. The largest cluster with 16 genotypes which included three parents P_2, P_5 and P_6 and 13 hybrids. Within this, nine genotypes had similar genetic base and the other six formed another cluster. Second largest cluster consisted of five genotypes which include $P_2 \times P_4$, $P_3 \times P_7$, $P_2 \times P_7$, $P_6 \times P_7$ and $P_4 \times P_7$. Within this, $P_4 \times P_7$ and $P_6 \times P_7$ had similar genetic base. The parents P_4 and P_7 formed a separate cluster. Maximum divergence was observed for P_3 as well as P_1 and they formed independent clusters. The hybrids $P_4 \times P_5$, $P_5 \times P_6$, $P_4 \times P_6$ and $P_5 \times P_7$ were found grouped in the same cluster (Fig. 11).

Table 28 Similarity matrix for 28 genotypes of chilli generated using RAPD primer

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1.00																											
0.66	1.00																										
0.50	0.33	1.00																									
0.33	0.66	0.50	1.00																								
0.50	0.75	0.25	0.50	1.00																							
0.50	0.75	0.25	0.50	1.00	1.00																						
0.25	0.50	0.33	0.66	0.40	0.40	1.00																					
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00																				
0.66	1.00	0.33	0.66	0.75	0.75	0.50	0.75	1.00																			
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00																		
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00	1.00																	
0.66	1.00	0.33	0.66	0.75	0.75	0.50	0.75	1.00	0.75	0.75	1.00																
0.66	1.00	0.33	0.66	0.75	0.75	0.50	0.75	1.00	0.75	0.75	1.00	1.00															
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00	1.00	0.75	0.75	1.00														
0.16	0.33	0.20	0.40	0.50	0.50	0.60	0.50	0.33	0.50	0.50	0.33	0.33	0.50	1.00													
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00	1.00	0.75	0.75	1.00	0.50	1.00												
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00	1.00	0.75	0.75	1.00	0.50	1.00	1.00											
0.33	0.50	0.16	0.33	0.66	0.66	0.50	0.66	0.50	0.66	0.66	0.50	0.50	0.66	0.83	0.66	0.66	1.00										
0.66	1.00	0.33	0.66	0.75	0.75	0.50	0.75	1.00	0.75	0.75	1.00	1.00	0.75	0.33	0.75	0.75	0.50	1.00									
0.66	1.00	0.33	0.66	0.75	0.75	0.50	0.75	1.00	0.75	0.75	1.00	1.00	0.75	0.33	0.75	0.75	0.50	1.00	1.00								
0.50	0.75	0.25	0.50	1.00	1.00	0.40	1.00	0.75	1.00	1.00	0.75	0.75	1.00	0.50	1.00	1.00	0.66	0.75	0.75	1.00							
0.20	0.40	0.25	0.50	0.60	0.60	0.40	0.60	0.40	0.60	0.60	0.40	0.40	0.60	0.80	0.60	0.60	0.66	0.40	0.40	0.60	1.00						
0.33	0.25	0.50	0.33	0.50	0.50	0.25	0.50	0.25	0.50	0.50	0.25	0.25	0.50	0.40	0.50	0.50	0.33	0.25	0.25	0.50	0.50	1.00					
0.25	0.20	0.33	0.25	0.40	0.40	0.50	0.40	0.20	0.40	0.40	0.20	0.20	0.40	0.60	0.40	0.40	0.50	0.20	0.20	0.40	0.40	0.66	1.00				
0.40	0.33	0.20	0.16	0.50	0.50	0.33	0.50	0.33	0.50	0.50	0.33	0.33	0.50	0.66	0.50	0.50	0.83	0.33	0.33	0.50	0.50	0.40	0.60	1.00			
0.33	0.25	0.50	0.33	0.50	0.50	0.25	0.50	0.25	0.50	0.50	0.25	0.25	0.50	0.40	0.50	0.50	0.33	0.25	0.25	0.50	0.50	1.00	0.66	0.40	1.00		
[illegible]								0.40	0.20	0.40	0.40	0.20	0.20	0.40	0.66	0.40	0.40	0.50	0.20	0.20	0.40	0.40	1.00	0.66	0.66	1.00	
0.33	0.50	0.16	0.33	0.66	0.66	0.50	0.66	0.50	0.66	0.66	0.50	0.50	0.66	0.83	0.66	0.67	1.00	0.50	0.50	0.66	0.66	0.33	0.50	0.83	0.33	0.50	1.00

Table 29 Similarity matrix for the selected hybrid and its parents generated using RAPD primers

P1	P2	F1
1.00		
0.80	1.00	
0.84	0.94	1.00

P1 – Female parent P2 – Male parent F1 – Hybrid

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
+	+	-	-	+	+	-	+	+	+	+	+	+	+	-	+	+	+	+	+	+	-	-	-	+	-	-	+
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	+	+	-	+	+
-	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	+
-	-	-	-	+	+	-	+	-	+	+	-	-	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	+	-	-	+	-	-	+

Fig. 7 Representation of the amplification profile of 28 chilli genotypes (parents and hybrids) using the primer OPA-10

1 – 7 = Parents 8 – 28 = Hybrids + = Presence of band - = Absence of band

P1	P2	F1
+	+	+
+	+	+
+	+	+
-	+	-
+	+	+
+	-	-
+	+	+

Fig. 8 Representation of the amplification profile of the DNA of selected hybrid and its parents using the primer OPA-01

P1	P2	F1
+	+	+
+	+	+
+	+	+
+	-	-
+	+	+
+	+	+

Fig. 9 Representation of the amplification profile of the DNA of selected hybrid and its parents using the primer OPB-06

P1	P2	F1
+	+	+
+	+	+
+	+	+
+	+	+
+	+	+
+	+	+
+	-	-

Fig. 10 Representation of the amplification profile of the DNA of selected hybrid and its parents using the primer OPB-20

P1 = Female parent P2 = Male parent F1 = Hybrid

+ = Presence of band - = Absence of band

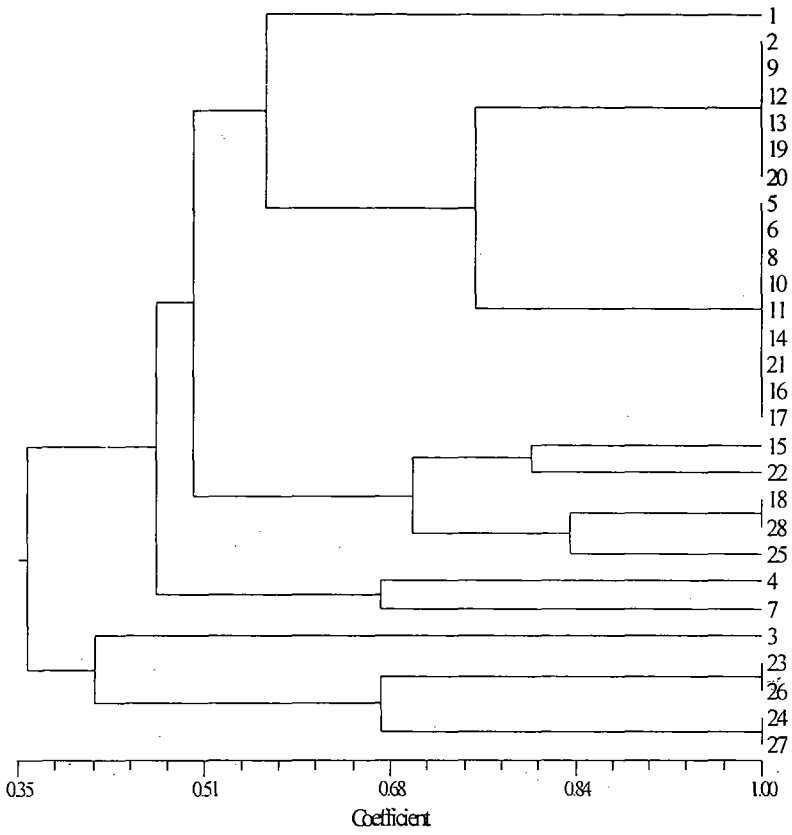

Fig. 11 Dendrogram for 28 genotypes of chilli based on data from RAPD analysis

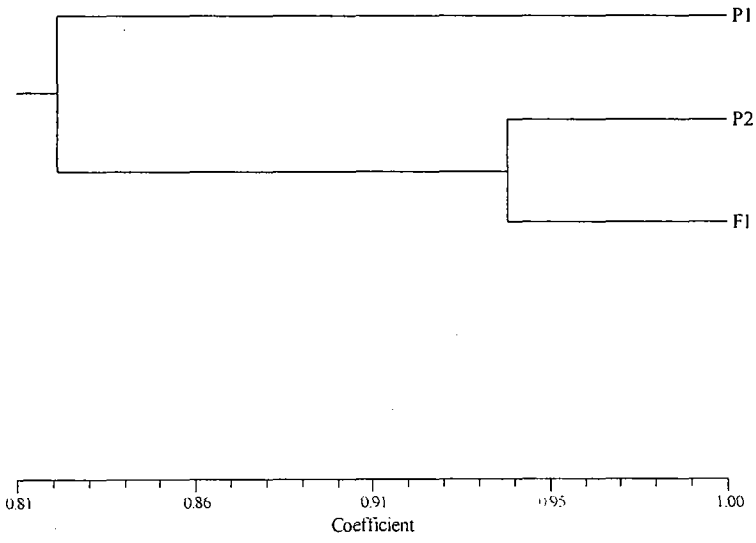

Fig. 12 Dendrogram for selected hybrid and its parents based on data from RAPD analysis

The dendrogram constructed for the parents and hybrid revealed more closeness of F_1 towards P_2, the male parent (Fig. 12). Similarity coefficient between F_1 and the parents was higher than that between the parents. This indicates the hybridity of the selected hybrid.

Discussion

5. DISCUSSION

Spices including chillies are in use to augment colour, taste and flavour of foods. They are used both at domestic and industrial levels in different forms like fresh, dried or other processed products. Paprika belongs to the family of chillies, *Capsicum annuum*. The fruits may vary from roughly spherical form to conical and elongated. Paprika was divided into two groups – vegetable (bell shaped, salad and table chillies) and spice (non-pungent and pungent) paprika. The dried ground product is available in sweet and mild pungent form and in a range of colouring powder. The production of paprika now extends commercially to a number of countries such as Spain, Hungary, Bulgaria, Yugoslavia, Romania, Russia, Turkey, Greece, Portugal, Mexico, USA, Canada, etc. (John, 2000). In India chilli contributes nearly 15 per cent of the total value of exports (Somasekharan and Shenoy, 2004). India is a major producer and exporter of chilli, but still India is lagging behind in commercial cultivation of paprika. Main traits required for paprika commercial varieties are high yield, high pigment content (visual and extractable red colour) and other qualities like thin flesh, less water content and low pungency (Verma and Joshi, 2000). The varieties or hybrids possessing the above traits is to be developed to popularize paprika cultivation. The paprika variety released elsewhere are not stable performers with respect to paprika quality in the tropics. So the varieties or hybrids specific to different agro-climatic conditions need to be developed. Importance must be given to improvement in paprika both as a vegetable (raw consumption, stuffed sweet pepper dishes, pickling) and a condiment plant for paprika powder. Hence in this study, germplasm collected from different sources are evaluated for yield attributes and

paprika quality. Attempt was also made for the development of improved chillies with paprika quality through hybridization.

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

5.1 EVALUATION OF GERMPLASM

In both evolution and in plant breeding populations are consistently being sifted for superior types. In this continual sifting, the primary force is selection in which individuals with certain characteristics are favoured in reproduction (Allard, 1960). The efficiency of selection and thereby genetic improvement is largely depends on the extent of genetic variability present in the population (Singh and Narayanan, 1993). Hence the efficiency of selection and final success depend on the germplasm chosen. So, as many genotypes as possible from different localities should be assembled and evaluated before adopting any particular breeding strategy. Keeping this in view, 44 genotypes of *Capsicum annuum* were evaluated for yield traits and quality parameters.

5.1.1 Variability and Mean Performance

Considerable variation observed for all the 16 characters studied implied that selection would be fruitful in the germplasm evaluated. Several workers like Singh *et al.* (1994), Das and Choudhary (1999a), Mishra *et al.* (2001). Rathod *et al.* (2002b) and Khurana *et al.* (2003) had reported considerable variability for different characters in chilli.

Mean performance of the genotypes is the principal criterion for understanding the extent of variability as it is the reflection of field performance of genotypes.

Among 44 genotypes evaluated, those which excelled in various characters are listed below.

Sl. No.	Characters	Genotypes
1	Early flowering	CA_{13}, CA_{44}
2	Plant height	CA_{6}
3	Primary branches per plant	CA_{24}
4	Secondary branches per plant	CA_{24}
5	Fruits per plant	CA_{26}
6	Fruit length	CA_{11}
7	Fruit girth	CA_{40} ,CA_{35}
8	Fruit weight	CA_{8} , CA_{21}, CA_{17}
9	Seeds per fruit	CA_{6}
10	100 seed weight	CA_{17}
11	Crop duration	CA_{39}
12	Yield per plant	CA_{17}
13	Ascorbic acid content	CA_{16}
14	Oleoresin content	CA_{25}
15	Capsanthin content	CA_{12}
16	Low pungency	CA_{41}

5.1.2 Coefficient of Variation

The critical assessment of the nature and magnitude of variability is important in formulating an effective breeding programme. Coefficient of variation is a unit free measurement and hence comparison can be made among various characters that are measured in different 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 present study, the closeness between PCV and GCV revealed the less environmental influence on the characters studied (Fig. 13). High genotypic and phenotypic coefficients of variations were observed for yield per plant and fruits per plant. Similar result was reported by Singh and Brar (1979). Similarly other traits like plant height, primary branches per plant, secondary branches per plant, fruit length, fruit weight, fruit girth, seeds per fruit, 100 seed weight, ascorbic acid content, capsanthin content and capsaicin content also exhibited high PCV as well as GCV. This was in accordance with the findings of Gopalakrishnan *et al.* (1987b) who reported high PCV and GCV for fruit length, fruit weight, number of fruits and fruit yield per plant. Rani (1994) reported high PCV and GCV for ascorbic acid content, capsanthin content and capsaicin content. Similarly high PCV and GCV were reported for all the above characters by Devi and Arumugam (1999) for fruits per plant, fruit weight, fruit length, fruit girth and yield per plant by Sreelathakumari and Rajamony (2002) and for number of primary branches by Nandadevi and Hosamany (2003b).

Low values of PCV and GCV observed for days to 50 per cent flowering is in line with the findings of Devi and Arumugam (1999), Munshi and Behera (2000) and Mini (2003).

5.1.3 Heritability and Genetic Advance

Selection acts on genetic differences and the benefits from selection for a particular trait depend on its heritability (Allard, 1960). Burton (1952) suggested that variability together with heritability estimates would give the extent of advance to be expected by selection. Hence it will be appropriate to combine variability and heritability components along with genetic advance to make an effective selection. Genetic advance indicates

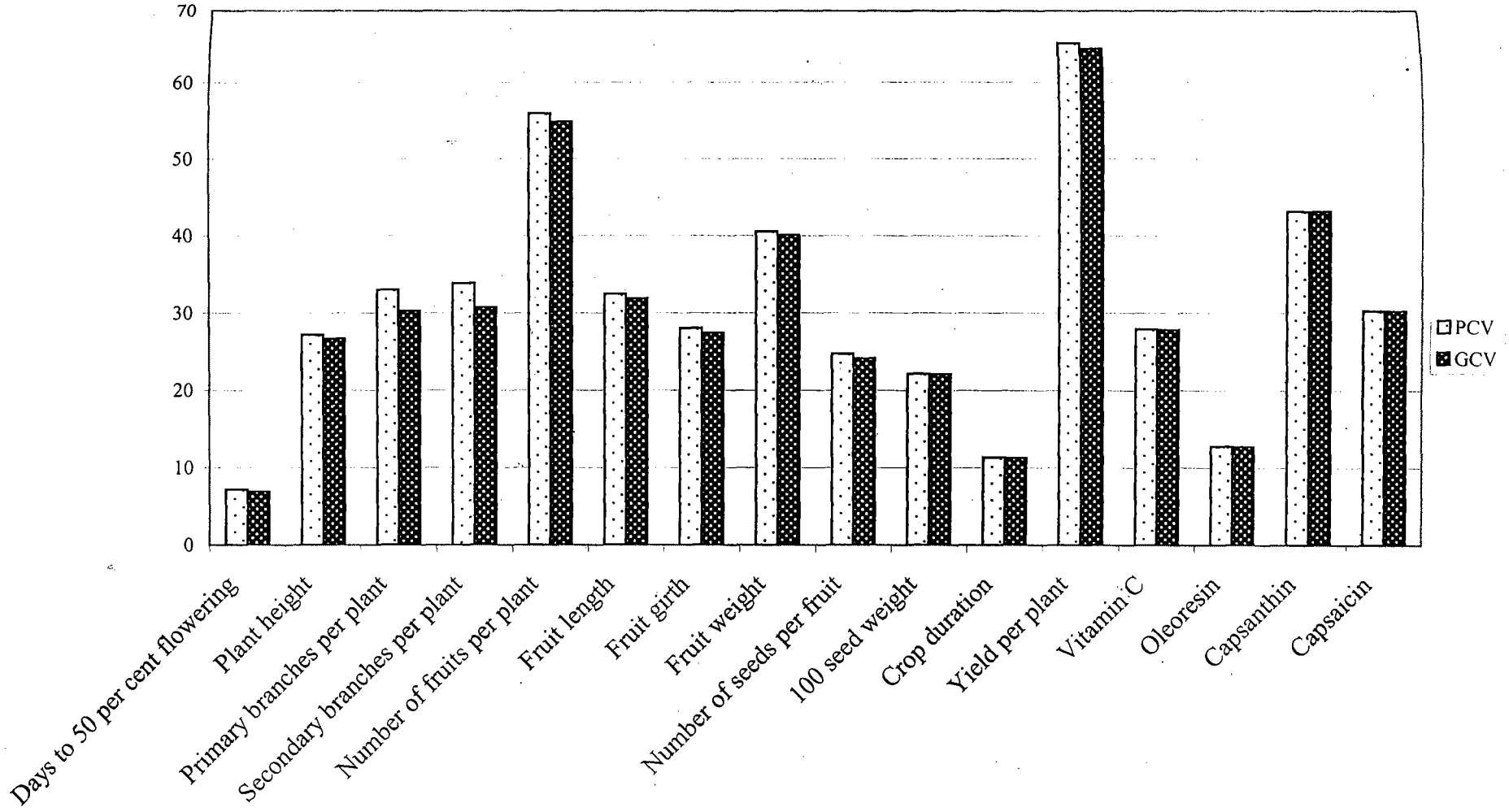

Fig. 13 Phenotypic and genotypic coefficients of variation for different characters

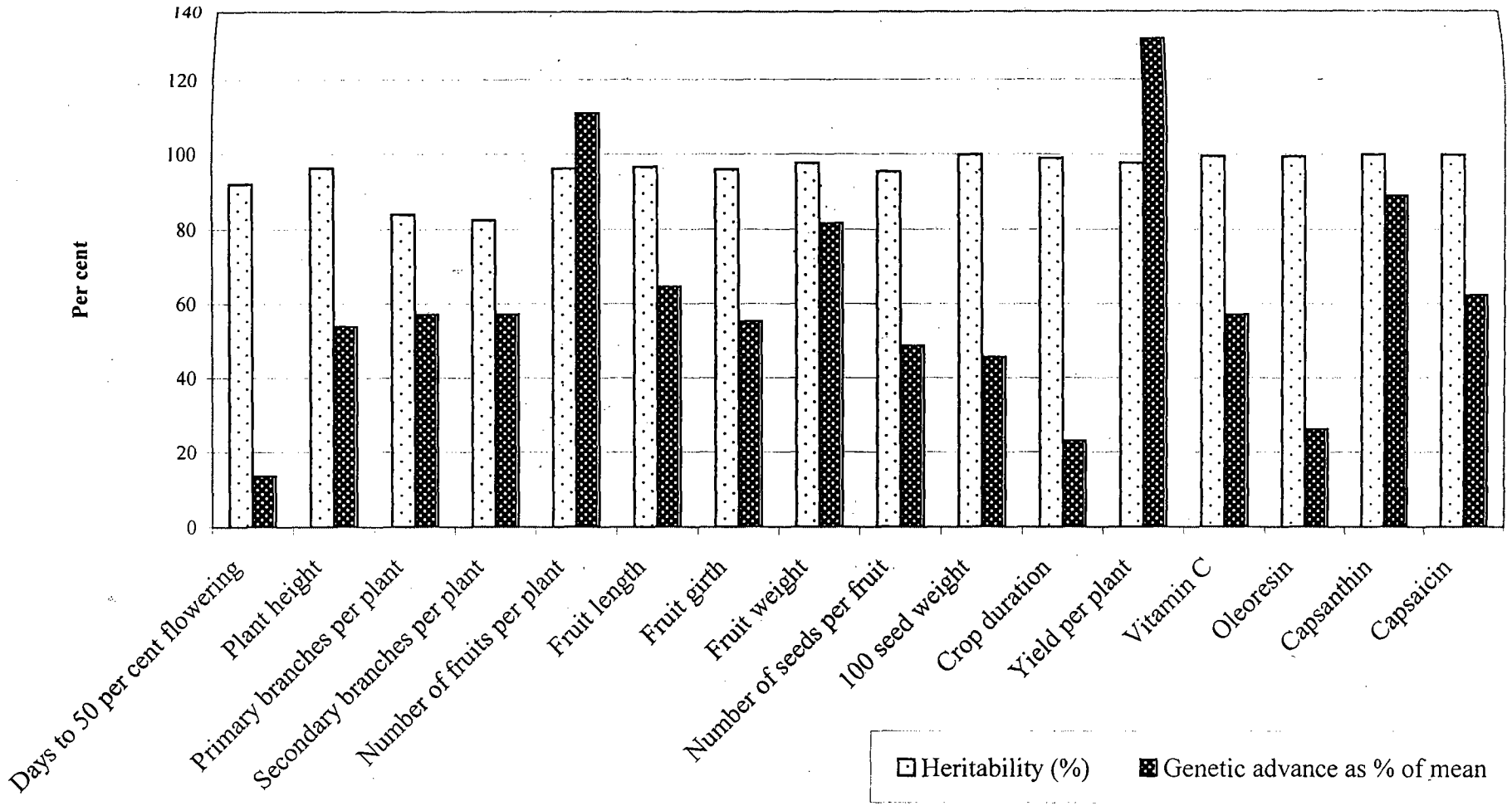

Fig. 14 Heritability and genetic advance

the progress that could be expected as a result of selection on a particular population. It is the measure of genetic gain under selection (Singh and Narayanan, 1993).

Present investigation revealed high heritability values for all the characters (Fig. 14). Genetic advance as per cent of mean was found high for all the traits except days to 50 per cent flowering for which it was moderate.

High heritability coupled with high genetic advance for different traits in chillies was reported by many workers. Vijayalakshmi *et al.* (1989) for fruits per plant, fruit weight, fruit length, fruit girth and seeds per fruit, and Kumar *et al.*(1993) for fruits per plant, yield per plant, seeds per fruit and ascorbic acid content. High heritability and genetic advance were reported by Das and Choudhary (1999a) and Munshi and Behera (2000) for fruit length, fruit number, fruit weight and yield, Rathod *et al.* (2002b) for plant height, primary branches, fruit number, fruit length, 100 seed weight, fresh fruit yield and Doshi (2003) for capsaicin content, fruit weight, fruits per plant and plant height. Khurana *et al.* (2003) observed high heritability coupled with moderate genetic advance for capsaicin content and colouring matter.

High heritability values for all the traits confirmed negligible influence of environment. High heritability coupled with high genetic advance indicate that the traits are controlled by additive gene action which make selection very effective. According to Johnson *et al.* (1955) high heritability coupled with high genetic advance would be a more reliable criterion for selection than selection based on heritability alone.

5.1.4 Association of Characters

Being a polygenic trait, yield is dependent on several component characters and there exist interrelationship among the component

characters. Correlation analysis provides reliable estimate on the nature, extent and direction of selection.

In general, the genotypic correlation coefficients were higher than phenotypic correlation coefficients for all the characters studied. Low phenotypic correlation might be due to the masking or modifying effect of the environment in genetic association between characters (Johnson *et al.*, 1955). But the difference between the two types of correlation coefficients was relatively low for most of the characters and indicated negligible influence of environment (Dewey and Lu, 1959) on the relationship of characters at genotypic level and hence selection could be based on phenotypic performance itself.

Yield per plant exhibited positively significant association with fruits per plant, fruit length, fruit weight, 100 seed weight, plant height, oleoresin content, ascorbic acid content and crop duration. Such a positive and significant association of yield per plant with fruits per plant (Nair *et al.*, 1984; Khurana *et al.*, 1993; Pawade *et al.*, 1995; Ahmed *et al.*, 1997b; Jose and Khader, 2002) with fruit weight (Ahmed *et al.*, 1997b; Mishra *et al.*, 1998; Das and Choudhary, 1999b) with 100 seed weight (Chatterjee *et al.*, 2001; Jose and Khader, 2002) with plant height (Ahmed *et al.*, 1997b and Khurana *et al.*, 2003) with ascorbic acid content (Kaul and Sharma, 1989) and with crop duration (Nair *et al.*, 1984 and Jose and Khader, 2002) were reported.

Yield per plant showed desirable negatively significant association with days to 50 per cent flowering. Bhagyalakshmi *et al.* (1990), Jose and Khader (2002) and Mini (2003) also reported similar results.

In contradictory to the present findings, He *et al.* (1989) observed negative correlation of fruit yield with fruit length. Positive association of yield with days to flowering was reported by Sundaram and Renganathan (1978), Meshram (1987) and Rathod *et al.* (2002a). According to Aliyu *et al.* (2000) yield was negatively correlated with plant height.

Interrelationships of component characters were also analysed. Days to fifty per cent flowering was negatively correlated with most of the characters except with crop duration and capsaicin content. Mini (2003) also found negative association of days to flowering with most of the characters. Plant height had positive and high correlation with fruits per plant, crop duration and number of secondary branches per plant. Similar view was expressed by Ibrahim *et al.* (2001).

Highly significant positive correlation was observed between number of primary branches and number of secondary branches. Similar observation was made by Mini (2003). Significant positive correlation of these two traits with fruits per plant was supported by the findings of Ahmed *et al.* (1997b) and Ibrahim *et al.* (2001).

Positive and significant correlation of fruits per plant with oleoresin content revealed in this study is in agreement with the findings of Muthuswamy (2004). The strong positive association of fruit length with fruit weight was supported by Kumar *et al.* (2003b).

Positive correlation between fruit length and ascorbic acid content reported by Kumar *et al.* (2003b) also confirmed in this study. But fruit length had negative correlation with capsaicin content which is contradictory to the findings of Muthuswamy (2004). Fruit girth showed high and significant association with fruit weight as reported by Echeverri *et al.* (1999).

The relationship of quality parameters with yield and their interrelationship were also investigated in this study. Ascorbic acid content had positive and significant correlation with oleoresin and capsanthin content. Positive correlation of ascorbic acid content with capsanthin was also reported by Gadal *et al.* (2003). However, negative association of ascorbic acid with capsaicin content was reported by Kumar *et al.* (2003b).

Correlation between capsanthin content and capsaicin content was significantly negative. No significant correlation was observed either for capsanthin content or for capsaicin content with yield per plant. Similar studies conducted by Nawagatti *et al.* (1999) also failed to establish a definite relationship between quality parameters and yield.

5.1.5 Selection Index

Selection index provides scope for greater efficiency in increasing the yield through selection for yield components rather than straight selection for yield alone.

In the present study selection index was constructed based on all the 16 traits studied. Many of the high yielding and superior genotypes such as CA_{17} (Vellayani local), CA_{13} (EG-101), CA_{11} (EG-85), CA_{10} (Kattakkada local), CA_{16} (Kaliyikkavila local) and CA_{24} (Jwalamukhi) were found to have high selection indices while low yielding types like CA_{42} (PSB-1), CA_{44} (kt-pl-18) and CA_{41} (IHR) were having low selection indices. The genotype CA_{12} (Arka Abir) which excelled in quality characters got eleventh rank based on selection index. Gill *et al.* (1977), Ramkumar *et al.* (1981), Vallejo *et al.* (1998), Jose (2001) and Mini (2003) were also used selection indices for the ranking of genotypes.

5.1.6 Genetic Divergence Analysis

Genetic diversity plays an important role in crop improvement because hybrids between lines of diverse origin generally display a greater heterosis than those between closely related strains. D^2 statistic proposed by Mahalanobis (1936) is one of the potent techniques of measuring genetic divergence. In addition to aiding in selection of divergent parents for hybridization, D^2 statistic measures the degree of diversification and determines the relative proportion of each component character to the total divergence. The genotypes grouped together are less divergent than the ones which are placed in different clusters. The clusters which are

separated by the greatest statistical distance show the maximum divergence (Singh, 1983).

Forty four genotypes were grouped into nine clusters considering 16 characters, each cluster with varying number of genotypes. Cluster II with 17 genotypes was the largest cluster and cluster VII, VIII and IX were with only one genotype.

Cluster I had six genotypes which include Jwalamukhi and five local types. This cluster showed high mean values for number of primary branches, number of secondary branches and fruits per plant. Mean value for yield per plant was moderate. Cluster II comprised of 17 genotypes recorded average performance for most of the characters. The variety Arka Abir (CA_{12}) which is superior in quality traits was included under this cluster.

Cluster III contained ten genotypes of medium performance. Cluster IV included genotypes which are very low yielders, but characterized by low pungency and early flowering habit. Three genotypes were included in cluster V *viz.*, CA_{10}, CA_{11} and CA_{40}. Cluster VI had maximum cluster mean for plant height and two genotypes were in this cluster. Cluster VII recorded maximum days to 50 per cent flowering and crop duration. With respect to fruit length, seeds per fruit and capsanthin content cluster VIII (CA_{13}) were superior to other clusters. Cluster IX also had one genotype CA_{17} which was the highest yielder and showed high cluster means for fruits per plant, fruit girth, fruit weight, 100 seed weight, ascorbic acid content and oleoresin content.

Average intracluster distance (D value) was minimum for cluster III and maximum for cluster VI. So there is considerable variation among the genotypes included in cluster VI. The intercluster distance was maximum between cluster IV and cluster IX. This may be due to the wide variation in yield and yield related traits between genotypes included in these two clusters.

In general, intercluster distances were much higher than the intracluster values suggesting that there was homogeneity among the genotypes included in a cluster while heterogeneity existed between clusters.

5.1.7 Selection of Parents for Hybridization

Based on the variability studies, mean performance, selection index and genetic divergence analysis, seven genotypes were selected as parents for hybridization. Among these, six parents are the top rankers based on the selection index. They are CA_{17} (Vellayani local), CA_{13} (EG-101), CA_{11} (EG-85), CA_{10} (Kattakkada local), CA_{16} (Kaliyikkavila local) and CA_{24} (Jwalamukhi), and the last one Arka Abir (CA_{12}) was selected because it is a released paprika variety eventhough ranked in the eleventh position in selection index ranking. Singh (1983) suggested that while selecting parents on the basis of D^2 statistic, one or two genotypes should be selected from each cluster which is genetically divergent with respect to the prime characters under consideration. Traits like quality, earliness etc. should also be given quite importance. So the selected parents are from five clusters, CA_{16} and CA_{24} from cluster I, CA_{12} from cluster II, CA_{10} and CA_{11} from cluster V, CA_{13} from cluster VIII and CA_{17} from cluster IX. The genotypes in cluster IV, though highly divergent genetically from other clusters could not be included because of their very poor field performance.

The selected genotypes were redesignated as P_1 (EG-85), P_2 (Vellayani local), P_3 (Jwalamukhi), P_4 (Kattakkada local), P_5 (Kaliyikkavila local), P_6 (EG-101) and P_7 (Arka Abir). These were crossed in all possible combinations excluding reciprocals and the 21 hybrids thus obtained were evaluated along with their parents.

EG-85 (P1)

Vellayani local (P2)

Jwalamukhi (P3)

Kattakkada local (P4)

Plate 5. Parents selected for hybridization

Kaliyikkavila local (P5)

EG-101 (P6)

Arka abir (P7)

Plate 5. Continued

5.2 HALF DIALLEL ANALYSIS

Various biometrical methods can be used to evaluate the combining ability of genotypes for developing a suitable breeding strategy. Half diallel analysis is a method of Griffing's (1956) in which the selected parents are crossed in all possible combinations excluding reciprocals. Combining ability analysis enables a plant breeder to decide the choice of parents for hybridization, construction of inbreds or composite breeding programme. It also helps to employ suitable selection procedures (Dabholkar, 1992).

Half diallel analysis was carried out to evaluate the parents and hybrids on the basis of mean performance, general combing ability of parents, specific combining ability of hybrids and heterosis of hybrids. Significant variation existed for most of the traits as revealed by ANOVA.

5.2.1 Combining Ability and Heterosis

Combining ability is the relative ability to transmit the desirable attributes of 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 the parents. Specific combining ability indicates situations where particular cross do relatively better or worse than would be expected on the basis of average performance of their respective parents and is a measure of non-additive gene action (Rojas and Sprague, 1942).

5.2.1.1 Gene Action

Nature of gene action as measured by GCA and SCA variances is particularly useful in deciding the inheritance of character and thereby selection of a suitable breeding programme. Greater GCA variance for a character indicates the predominance of additive gene action and if SCA variance is grater non-additive gene action plays an important role in controlling that trait. Simple selection is enough for a character

controlled by additive gene action as it is fixable, but if non-additive gene action is predominant for a character, which is non-fixable, heterosis breeding may be rewarding or selection has to be postponed to later generations.

In the present study, the characters like days to 50 per cent flowering, plant height, primary branches per plant, secondary branches per plant, fruits per plant, seeds per fruit, 100 seed weight, yield per plant, ascorbic acid content, oleoresin content, capsanthin content and capsaicin content were influenced by non-additive gene action as evidenced from the low additive : dominance (σ^2A / σ_2D) ratio. Similar findings were reported by Miranda and Costa (1988), Doshi (2003) and Nandadevi and Hosmani (2003a) for days to flowering, Miranda and Costa (1988) and Ahmed *et al.* (2003) for primary branches per plant and secondary branches per plant, Ahmed *et al.* (2003) and Nandadevi and Hosamani (2003a) for fruit weight, Sousa and Maluf (2003) for seeds per fruit. Pandey *et al.* (2002) for ascorbic acid content, Rajinder *et al.* (2001) for oleoresin content and capsanthin content and Patel *et al.* (1997) and Sousa and Maluf (2003) for capsaicin content.

Fruit length and fruit girth was highly influenced by additive gene action. Many workers reported additive gene action for fruit length (Singh and Singh, 1977b; Miranda and Costa, 1988; Ahmed *et al.*, 1997a; Shukla *et al.*, 1999; Lohitheswa *et al.*, 2001 and Nandadevi and Hosamani, 2003a) and fruit girth (Sundaram and Irulappan, 1998 and Shukla *et al.*, 1999).

Additive and non-additive gene action had equal importance for the control of the trait crop duration where σ^2A : σ^2D value was more or less unity.

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

5.2.1.2 *Evaluation of Parents*

According to Yadav and Murthy (1966), the choice of parents especially for heterosis breeding should be based on the combining ability test and their mean performance. Dhillon (1975) pointed out that combining ability of parents give useful information on the choice of parents in terms of expected performance of their progenies. Therefore, the parents chosen for present study were assessed based on their mean performance and general combining ability effects (Table 30).

For fruit yield and yield related characters P_2 was the best compared to other parents and it showed good *per se* performance for yield per plant, fruit weight, fruit girth, plant height, 100 seed weight and oleoresin content. For quality traits like ascorbic acid content, capsanthin content, low pungency and for earliness P_7 performed best. P_3 showed superiority for the traits plant height, primary branches per plant, secondary branches per plant, crop duration and oleoresin content. P_1 excelled in fruit length. For earliness, fruit length, fruit weight and yield per plant P_6 showed comparatively better performance, while P_5 was good for primary branches per plant, secondary branches per plant and ascorbic acid content.

P_2 was a good general combiner for nine traits *viz.*, yield per plant, fruit weight, fruit girth, plant height, 100 seed weight, oleoresin content, primary branches per plant, secondary branches per plant and crop duration. For plant height, primary branches per plant, secondary branches per plant, fruits per plant, fruit length, 100 seed weight, crop duration and yield per plant P_3 was a good general combiner. P_7 was the best general combiner for ascorbic acid content, capsanthin content, low pungency, earliness and fruit girth. P_1 showed superiority for fruit length and a good combiner for earliness, capsanthin content and oleoresin content. P_6 was a good general combiner for earliness, fruit weight, 100 seed weight, yield per plant, capsanthin content and low

Table 30 Evaluation of parents based on *gca* effects and mean performance

Characters	Mean performance	*gca* effects	Mean performance and *gca* effects
Earliness	P_7	P_1, P_4, P_6, P_7	P_7
Plant height	P_3	P_2, P_3	P_3
Primary branches per plant	P_3, P_5	P_2, P_3, P_5	P_3, P_5
Secondary branches per plant	P_3, P_5	P_2, P_3, P_5	P_3, P_5
Fruits per plant	P_3, P_4	P_2, P_3	P_3
Fruit length	P_1, P_6	P_1, P_3, P_6	P_1, P_6
Fruit girth	P_2, P_4	P_2, P_4, P_5, P_7	P_2, P_4
Fruit weight	P_2, P_6	P_2, P_6	P_2, P_6
Seeds per fruit	P_4, P_1	P_4, P_5	P_4
Hundred seed weight	P_2, P_4	P_2, P_3, P_4, P_6	P_2, P_4
Crop duration	P_3, P_2	P_2, P_3	P_3, P_2
Yield per plant	P_2, P_6	P_2, P_3, P_6	P_2, P_6
Ascorbic acid content	P_7, P_5	P_4, P_5, P_7	P_5, P_7
Oleoresin content	P_3, P_2	P_1, P_2	P_2
Capsanthin content	P_7, P_4	P_1, P_4, P_6, P_7	P_4, P_7
Low pungency	P_7, P_4	P_4, P_6, P_7	P_4, P_7

pungency, P_4 was a good general combiner for ascorbic acid content, capsanthin content and low pungency while P_5 was a good general combiner for primary and secondary branches per plant, fruit girth, seeds per fruit and ascorbic acid content.

Combined appraisal of the mean performance and *gca* effects of the parents revealed that the mean values of parents truly reflected the *gca* effects of 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, superiority can be attributed to P_2 (Vellayani local) for yield and yield related traits while P_7 (Arka Abir) performed best for quality parameters. P_3 (Jwalamukhi) and P_4 (Kattakkada local) showed best performance for five yield contributing characters each. The other parents also showed good general combining ability and mean performance for different characters. P_6 (EG-101) was good for fruit yield, earliness, fruit length and fruit weight, while P_5 was good for ascorbic acid content and branches per plant. Based on these findings it can be assumed that the selected parents would perform well in hybridization programmes and can be used effectively in a series of hybrid combinations.

5.2.1.3 Evaluation of Hybrids

The aim of any hybridization programme is the bringing together of desirable genes present in parents into a single variety. Better hybrids were generally identified based on their mean performance, *sca* effects and heterotic expression. The hybrids thus obtained either can be used as F_1 hybrid to exploit heterosis or forwarded to further generations for selecting superior recombinants with desirable gene combinations from the segregating population.

As mean performance is the reflection of field performance of hybrids, it should be given prime importance. The selection of combinations either for heterosis breeding or for recombination breeding largely depends on the *sca* effects of hybrids as well as *gca* effects of parents. This was based on the assumption that additive gene action is reflected by *gca* effects and hence immediate hybrid may perform poorly but selection for elite genotypes in subsequent generations would be fruitful. On the contrary, high *sca* effect of hybrids is a reflection of non-additive gene action, so that superiority can be expected in the F_1 hybrids (Singh and Narayanan, 1993). The expression of heterosis even to a small magnitude for individual component character is a desirable factor (Hotchcock and McDaniel, 1973).

Based on the above points, the hybrids were evaluated for all the traits and discussed hereunder (Table 31).

1. Days to 50 per cent flowering

Early flowering is a desirable character for the hybrids. With respect to mean performance P_1 x P_7 and P_4 x P_6 were superior. P_2 x P_7, P_2 x P_3, P_4 x P_6, P_1 x P_7, P_4 x P_5, P_1 x P_6, P_1 x P_5, P_1 x P_4 and P_1 x P_2 were found good with regard to *sca* effects. The parents involved *viz.*, P_1, P_4, P_6 and P_7 were good general combiners for this trait. All the hybrids had significant standard heterosis and majority of them had significant relative heterosis as well as heterobeltiosis for earliness. While considering *per se* performance, *sca* effect and heterotic value, P_1 x P_7 (good x good general combiners) projects as the best hybrid with additive effects fixable through selection. The first report on heterosis for earliness in chilli was made by Deshpande (1933). Later on Pious and Peter (1986), Gopalakrishnan *et al.* (1987a) and Prasad *et al.* (2003) also supported this findings.

Table 31 Evaluation of hybrids on the bases of mean performance, *sca* effects and standard heterosis

Characters	Mean performance	*sca* effects	Standard heterosis	Superior hybrids
Earliness	$P_1 \times P_7$, $P_1 \times P_6$, $P_4 \times P_6$	$P_2 \times P_7$, $P_2 \times P_3$, $P_4 \times P_6$, $P_1 \times P_7$, $P_1 \times P_6$, $P_4 \times P_5$, $P_1 \times P_5$, $P_1 \times P_4$	$P_1 \times P_7$, $P_1 \times P_6$, $P_4 \times P_6$, $P_2 \times P_7$	$P_1 \times P_7$, $P_1 \times P_6$, $P_4 \times P_6$
Plant height	$P_2 \times P_4$, $P_3 \times P_7$	$P_2 \times P_4$, $P_5 \times P_7$, $P_3 \times P_7$, $P_2 \times P_6$, $P_6 \times P_7$	$P_2 \times P_4$	$P_2 \times P_4$
Primary branches per plant	$P_2 \times P_6$	$P_2 \times P_6$, $P_1 \times P_4$, $P_2 \times P_5$, $P_3 \times P_5$, $P_1 \times P_2$, $P_2 \times P_7$	$P_2 \times P_6$, $P_2 \times P_5$	$P_2 \times P_6$
Secondary branches per plant	$P_2 \times P_6$	$P_2 \times P_6$, $P_1 \times P_4$, $P_1 \times P_5$, $P_2 \times P_5$, $P_2 \times P_4$	$P_2 \times P_6$, $P_2 \times P_5$	$P_2 \times P_6$
Fruits per plant	$P_1 \times P_3$, $P_2 \times P_6$, $P_3 \times P_6$, $P_3 \times P_5$, $P_2 \times P_3$, $P_2 \times P_4$	$P_2 \times P_6$, $P_1 \times P_4$, $P_2 \times P_4$, $P_1 \times P_3$, $P_2 \times P_7$	$P_1 \times P_3$, $P_2 \times P_6$, $P_3 \times P_6$, $P_3 \times P_5$, $P_2 \times P_3$, $P_2 \times P_4$	$P_1 \times P_3$, $P_2 \times P_6$, $P_2 \times P_4$
Fruit length	$P_1 \times P_7$, $P_1 \times P_6$	$P_1 \times P_7$, $P_3 \times P_7$, $P_1 \times P_2$, $P_3 \times P_4$, $P_5 \times P_6$, $P_2 \times P_3$, $P_2 \times P_7$, $P_1 \times P_6$	$P_1 \times P_7$, $P_1 \times P_6$, $P_1 \times P_2$, $P_1 \times P_3$	$P_1 \times P_7$, $P_1 \times P_6$
Fruit girth	$P_2 \times P_5$	$P_3 \times P_5$, $P_3 \times P_4$, $P_2 \times P_5$, $P_1 \times P_2$, $P_6 \times P_7$	$P_2 \times P_5$, $P_2 \times P_4$, $P_4 \times P_5$, $P_5 \times P_7$	$P_2 \times P_5$
Fruit weight	$P_2 \times P_6$, $P_2 \times P_4$, $P_6 \times P_7$	$P_2 \times P_4$, $P_6 \times P_7$, $P_2 \times P_6$, $P_2 \times P_5$, $P_3 \times P_4$	$P_2 \times P_6$, $P_2 \times P_4$, $P_6 \times P_7$, $P_2 \times P_5$, $P_1 \times P_2$, $P_4 \times P_6$	$P_2 \times P_6$, $P_2 \times P_4$, $P_6 \times P_7$
Seeds per fruit	$P_2 \times P_5$, $P_1 \times P_5$, $P_2 \times P_4$, $P_1 \times P_4$, $P_3 \times P_5$	$P_3 \times P_5$, $P_2 \times P_5$, $P_1 \times P_5$, $P_2 \times P_4$, $P_1 \times P_4$	$P_2 \times P_5$, $P_1 \times P_5$, $P_2 \times P_4$, $P_1 \times P_4$, $P_3 \times P_5$	$P_2 \times P_5$, $P_1 \times P_5$, $P_2 \times P_4$, $P_3 \times P_5$, $P_1 \times P_4$
Hundred seed weight	$P_3 \times P_4$	$P_3 \times P_4$, $P_3 \times P_5$, $P_5 \times P_6$, $P_6 \times P_7$	$P_3 \times P_4$, $P_3 \times P_7$, $P_6 \times P_7$	$P_3 \times P_4$
Crop duration	$P_2 \times P_7$	$P_1 \times P_4$, $P_2 \times P_7$, $P_6 \times P_7$, $P_1 \times P_6$	-	-
Yield per plant	$P_2 \times P_6$, $P_2 \times P_4$, $P_3 \times P_6$, $P_2 \times P_7$	$P_2 \times P_6$, $P_3 \times P_5$, $P_2 \times P_7$, $P_1 \times P_4$, $P_3 \times P_6$, $P_3 \times P_7$, $P_2 \times P_4$	$P_2 \times P_6$, $P_2 \times P_4$, $P_3 \times P_6$, $P_2 \times P_7$, $P_2 \times P_3$	$P_2 \times P_6$, $P_2 \times P_4$, $P_3 \times P_6$, $P_2 \times P_7$
Ascorbic acid content	$P_1 \times P_4$	$P_1 \times P_4$, $P_2 \times P_4$, $P_5 \times P_6$, $P_1 \times P_5$	$P_1 \times P_4$, $P_2 \times P_4$, $P_4 \times P_7$, $P_1 \times P_5$	$P_1 \times P_4$
Oleoresin content	$P_2 \times P_3$, $P_2 \times P_4$, $P_1 \times P_3$, $P_1 \times P_2$, $P_3 \times P_4$, $P_1 \times P_7$	$P_1 \times P_7$, $P_2 \times P_3$, $P_2 \times P_4$, $P_5 \times P_6$, $P_1 \times P_2$.	$P_2 \times P_3$, $P_2 \times P_4$, $P_1 \times P_3$, $P_1 \times P_2$, $P_3 \times P_4$, $P_1 \times P_7$	$P_2 \times P_3$, $P_2 \times P_4$, $P_1 \times P_7$, $P_1 \times P_2$
Capsanthin content	$P_1 \times P_7$, $P_2 \times P_7$, $P_3 \times P_4$, $P_1 \times P_6$	$P_3 \times P_4$, $P_2 \times P_7$, $P_1 \times P_7$, $P_5 \times P_6$, $P_1 \times P_6$	$P_1 \times P_7$, $P_2 \times P_7$, $P_3 \times P_4$, $P_1 \times P_6$	$P_1 \times P_7$, $P_2 \times P_7$, $P_3 \times P_4$, $P_1 \times P_6$
Low pungency	$P_1 \times P_7$	$P_1 \times P_5$, $P_2 \times P_6$, $P_3 \times P_5$, $P_1 \times P_7$, $P_3 \times P_6$	$P_1 \times P_7$	$P_1 \times P_7$

2. Plant height

On the basis of mean performance, the hybrids P_2 x P_4 and P_3 x P_7 were found to be superior. The female parents in both the hybrids were good general combiners while the male parents were poor combiners. High mean performance of crosses between poor and good general combiners can be attributed to interaction between positive alleles from good combiner and negative alleles from poor combiner as reported by Dubey (1975). High *sca* effects were noticed for the crosses P_2 x P_4, P_5 x P_7, P_3 x P_7, P_2 x P_6 and P_6 x P_7 but significant positive standard heterosis was observed for P_2 x P_4 only. These hybrids also had significant relative heterosis and heterobeltiosis. Lohithaswa *et al.* (2001) and Jadhav *et al.* (2001) reported significant *sca* effects for plant height, Pious and Peter (1986) and Nayaki and Natarajan (2000) observed heterosis for plant height in chilli.

3. Primary branches per plant

The cross P_2 x P_6 was superior on the bases of mean performance, *sca* effect and standard heterosis. Here, P_2 was a good general combiner. Other crosses with significant *sca* effects include P_1 x P_4, P_2 x P_5, P_3 x P_5 and P_1 x P_2. All the three types of heterosis was significant for P_2 x P_6 and P_2 x P_5.

4. Secondary branches per plant

The superior mean performance was shown by the hybrid P_2 x P_6 and *sca* effects were high for P_2 x P_6, P_1 x P_4, P_2 x P_5, P_3 x P_5 and P_1 x P_2. Standard heterosis was positive and significant for P_2 x P_6 (good x poor general combiners) and P_2 x P_5 (good x good general combiners). Most of the hybrids had positive relative heterosis. The pattern of heterotic expression and *sca* effects for this trait was similar to that of primary branches per plant. This was due to the strong interrelation between

primary branches per plant and secondary branches per plant as revealed from the correlation studies. Nayaki and Natarajan (2000) reported heterosis for number of branches in chilli. Gaddagimath (1992) and Pandian and Shanmugavelu (1992) found *sca* effects for number of branches, while Bhagyalakshmi *et al.* (1991) reported high relative heterosis.

5. Fruits per plant

The hybrids P_1 x P_3, P_2 x P_6, P_3 x P_6, P_3 x P_5, P_2 x P_3 and P_2 x P_4 were performed well for this trait. One of the parents in all these hybrids was a good general combiner, either P_2 or P_3. High *sca* effects were noticed in P_2 x P_6, P_2 x P_4 and P_1 x P_3. Eventhough the hybrid P_1 x P_4 possessed high *sca* effect, its mean performance was average, might be due to the poor general combining ability of both of its parents.

Almost all the hybrids possessed positive and significant relative heterosis and heterobeltiosis. Standard heterosis was high and significant for P_1 x P_3, P_2 x P_6, P_3 x P_6, P_3 x P_5, P_2 x P_3 and P_2 x P_4. Hence based on *per se* performance, *sca* effect and heterosis value, P_1 x P_3 was the best hybrid suitable for heterosis breeding followed by P_2 x P_6 and P_2 x P_4.

6. Fruit length

High mean values and standard heterosis for fruit length was observed for P_1 x P_7 and P_1 x P_6 of which P_1 x P_7 had good x poor general combiners as parents. Whereas both parents in P_1 x P_6 were good general combiners. These crosses also had significant *sca* effects. Relative heterosis for all hybrids was positive and significant. Rajinder *et al.* (2001) reported high relative heterosis for fruit length in chilli.

7. Fruit girth

Best *per se* performance for fruit girth was exhibited by the hybrid P_2 x P_5 (good x good general combiners). High *sca* effects were shown by the hybrids P_3 x P_5, P_3 x P_4, P_2 x P_5, P_1 x P_2 and P_6 x P_7 of which standard

heterosis was highest for the hybrid P_2 x P_5. Most of the hybrids possessed positive and significant standard heterosis, but no one had positive heterobeltiosis. This can be due to the predominance of additive variance in controlling this trait. Further, many hybrids having high *sca* effects were poor in *per se* performance and all had good x poor combiners as parents. It was reported that hybrids with low mean values also possess high *sca* effects (Grakh and Chaudhary, 1985) and hence, *sca* effect alone may not be the appropriate criterion for the choice of a hybrid for heterosis exploitation.

8. Fruit weight

For the character fruit weight no hybrid was inferior compared to their parents and standard variety as all the hybrids possessed positive values for all types of heterosis. The hybrids P_2 x P_6 (good x good general combiners) and P_2 x P_4 (good x poor general combiners) had high mean values and standard heterosis. High *sca* effects were found for P_2 x P_4, P_6 x P_7, P_2 x P_6, P_2 x P_5 and P_3 x P_4. Jadhav *et al.* (2001) and Nandadevi and Hosmani (2003a) observed high *sca* effects for average fruit weight. The hybrids P_2 x P_6, P_6 x P_7 and P_2 x P_4 had superior overall performance for this trait.

9. Seeds per fruit

High *per se* performance, high *sca* effects and significant standard heterosis were showed by the hybrids P_2 x P_5, P_1 x P_5, P_2 x P_4, P_1 x P_4 and P_3 x P_5. For these hybrids one parent was a good general combiner. All the hybrids had positively significant standard heterosis and most of them possessed high relative heterosis as well as heterobeltiosis.

10. Hundred seed weight

The hybrid P_3 x P_4 (good x good general combiners) was superior based on mean performance, *sca* effect and standard heterosis. Other hybrids, P_3 x P_5, P_5 x P_6 and P_6 x P_7 also had high *sca* effects but mean

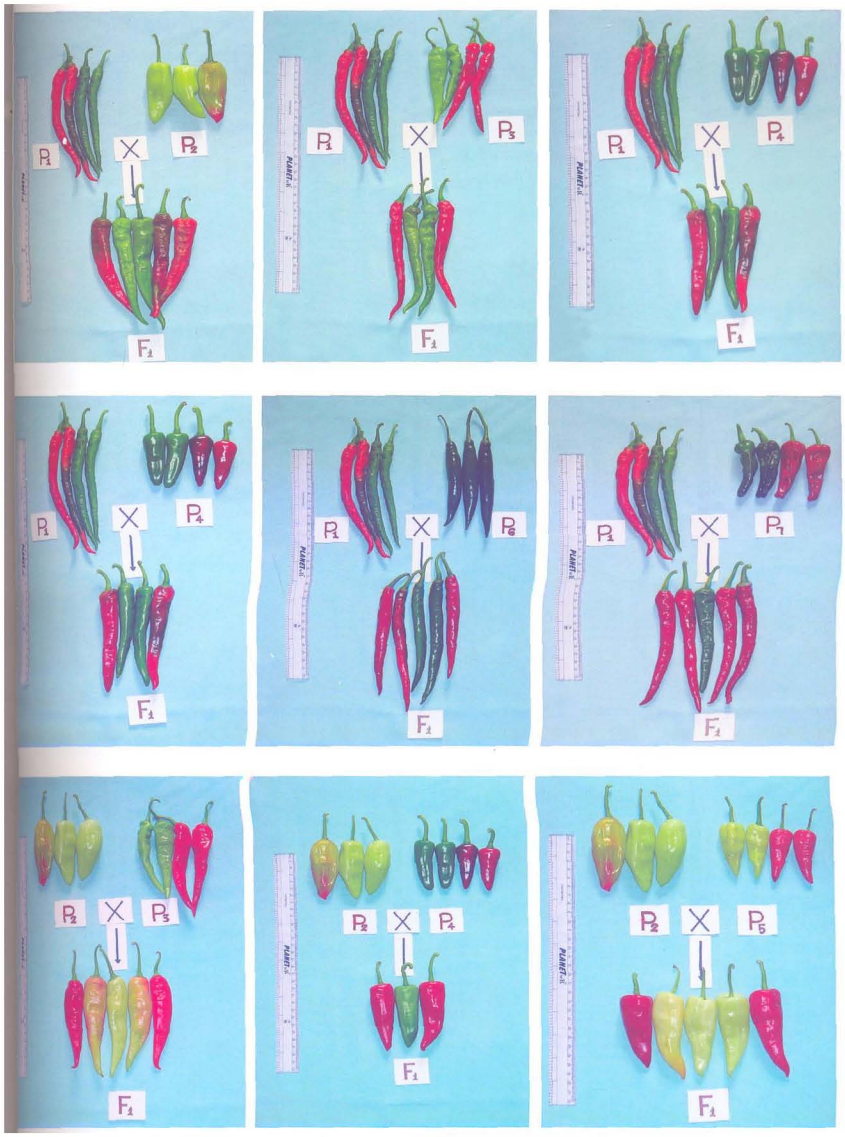

Plate 6. Heterosis for fruit characters

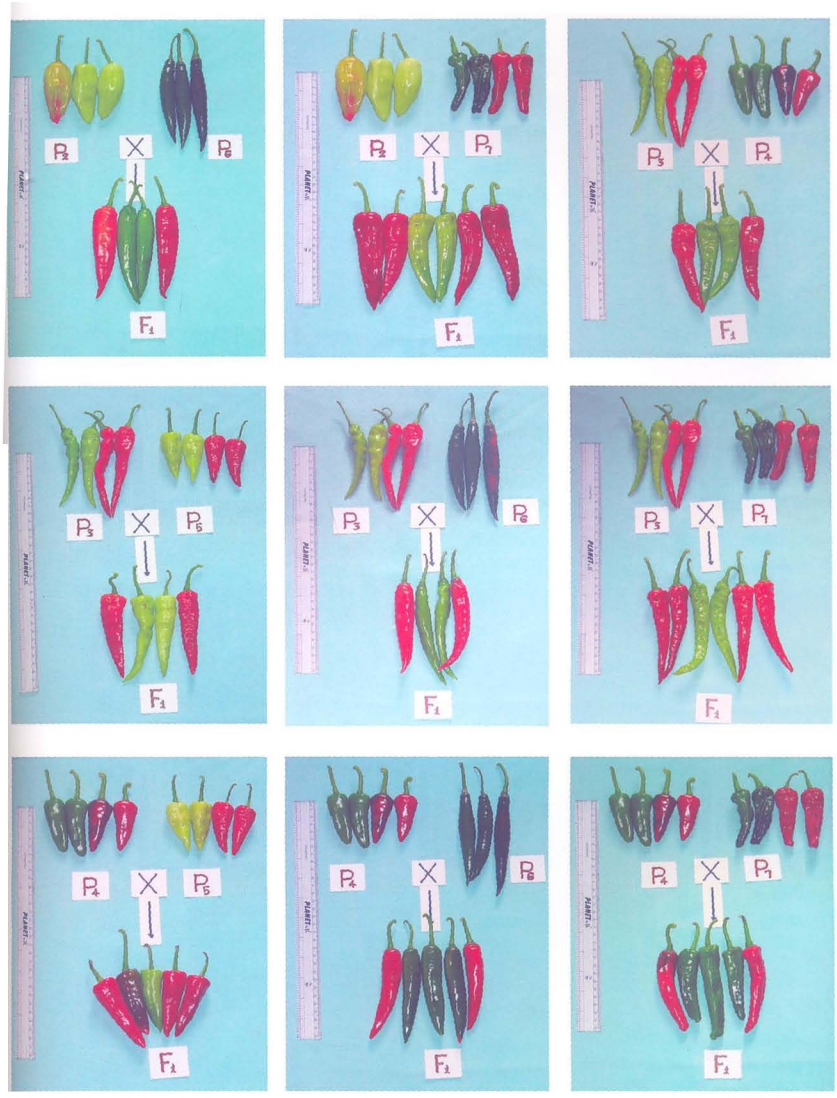

Plate 6. Continued

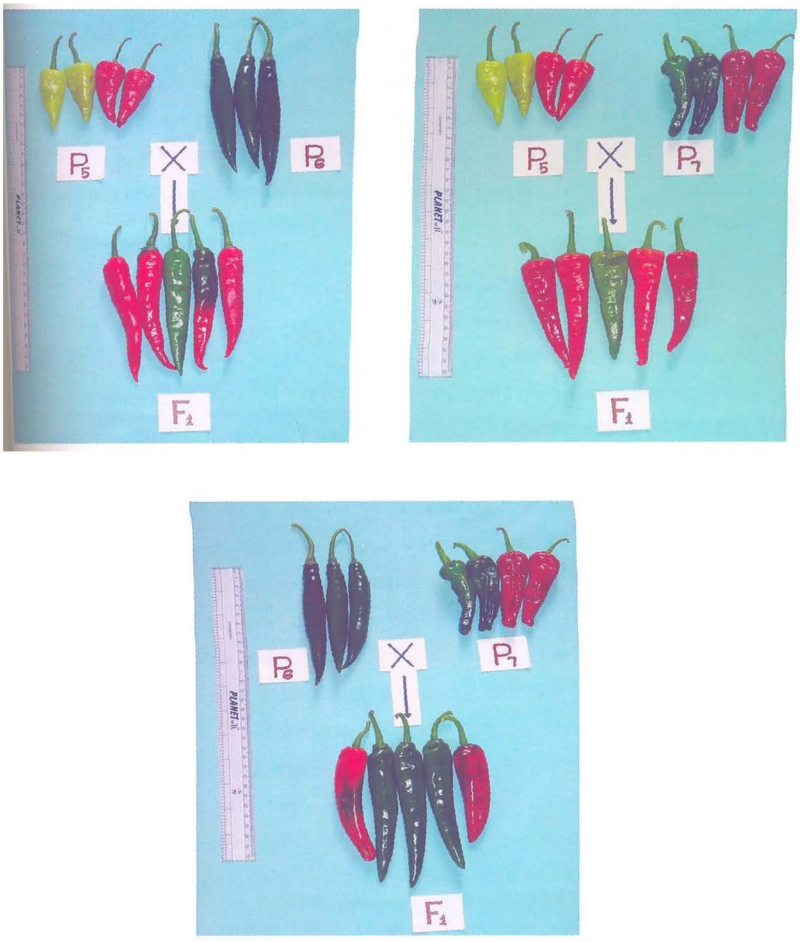

Plate 6. Continued

performance was not satisfactory. Many hybrids had positive and significant relative heterosis and heterobeltiosis for this trait.

11. Crop duration

No hybrid exhibited positive standard heterosis for crop duration but the minimum negative heterosis for crop duration was for the hybrid P_2 x P_7 which had high mean performance, *sca* effect and positively significant relative heterosis as well as heterobeltiosis.

12. Yield per Plant

The hybrids P_2 x P_6, P_2 x P_4, P_3 x P_6 and P_2 x P_7 were the best for yield with respect to mean performance, sca effects and standard heterosis. For all these combinations one parent was a good general combiner, whereas for the crosses P_2 x P_6 and P_3 x P_6 both the parents were good general combiners. High *sca* effects were observed for P_2 x P_6, P_3 x P_5, P_2 x P_7, P_1 x P_4, P_3 x P_6, P_3 x P_7 and P_2 x P_4. Among these, the crosses P_1 x P_4, P_3 x P_5 and P_3 x P_7 had low values for mean performance. Considering the heterotic performance, P_2 x P_6 excelled all other crosses. All the hybrids possessed positive values for all types of heterosis. The value exceeded 100 per cent for many crosses. This indicates the suitability of parents selected for hybridization. Poor yielding parents showed high heterosis over better parent as reported by Mishra *et al.* (1988), Deshpande (1933), Pious and Peter (1986), Doshi *et al.* (2001), Kumar and Lal (2001) and Pandey *et al.* (2002) reported significant heterosis for yield per plant. Considering mean performance, *sca* effect and heterosis, the hybrid P_2 x P_6 was the best one suitable for heterosis breeding for fruit yield followed by P_2 x P_4, P_3 x P_6 and P_2 x P_7.

13. Ascorbic acid content

The hybrid P_1 x P_4 differed from other hybrids in having high mean value, *sca* effect and heterosis for ascorbic acid content. Other hybrids with high *sca* effects and significant heterosis were P_2 x P_4, P_5 x P_6 and

P_1 x P_5. Relative heterosis was significant for 17 hybrids. Pandey *et al.* (2002) reported significant relative heterosis for this trait. From this it is obvious that P_1 x P_4 is best for heterosis breeding.

14. Oleoresin content

Mean value and standard heterosis were high for the hybrids P_2 x P_3, P_2 x P_4, P_1 x P_3, P_1 x P_2, P_3 x P_4 and P_1 x P_7. Of these P_1 x P_7 (good x poor general combiners), P_2 x P_3 (good x poor general combiners) and P_2 x P_4 (good x poor general combiners) were having high *sca* effects also. So these hybrids can be considered as superior for the trait oleoresin content. Many hybrids showed positive and significant heterosis.

15. Capsanthin content

High colour value in terms of capsanthin content is an important trait for paprika quality. High mean performance was showed by the hybrid P_1 x P_7 followed by P_2 x P_7, P_3 x P_4 and P_1 x P_6 with significant heterosis over mid parent, better parent and standard variety. These were also had significant *sca* effects confirming their superiority over other hybrids for this trait.

16. Capsaicin content

Low pungency (low capsaicin content) is a desirable character for paprika genotypes. Only one hybrid P_1 x P_7 was superior with respect to mean performance and standard heterosis. High *sca* effects were found for P_1 x P_5, P_2 x P_6, P_3 x P_5, P_1 x P_7 and P_3 x P_6. A number of hybrids exhibited desirable negative relative heterosis as well as heterobeltiosis.

From the above discussion, it was clear that heterosis was expressed for all the characters. No hybrid can be said to be inferior as each performed well for different characters. For some characters like earliness, yield and fruit length heterosis was positive for all the hybrids. But still, upon considering the overall performance some hybrids can be projected as the best ones. The hybrid P_1 x P_7 (EG-85 x Arka Abir) was

the best in terms of quality, which has given prime importance in this study as it excelled for earliness, capsanthin content, low pungency, fruit length and better oleoresin content. Here, P_7 is a good general combiner for many traits. For yield attributes two hybrids can be considered as superior ones. The hybrid P_2 x P_6 (Vellayani local x EG-101) performed best for yield per plant, fruit weight, primary branches per plant, secondary branches per plant and fruit number. The other one P_2 x P_4 (Vellayani local x Kattakkada local) showed best performance for plant height and also superior for number of fruits, yield per plant, fruit weight and oleoresin content. For both the hybrids, the common parent P_2 (Vellayani local) was a good general combiner for many yield related traits. Next to these three hybrids, P_1 x P_6 (EG-85 x EG-101) was superior for earliness, fruit length and capsanthin content. while P_2 x P_7 (Vellayani local x Arka Abir) showed superiority for yield per plant, capsanthin content and crop duration. The identified hybrids can be effectively used for heterosis breeding to exploit maximum hybrid vigour.

Comparative study on green fruit yield per plant, ripe fruit yield per plant, dry fruit weight recovery and pericarp thickness revealed high positive correlation between green fruit yield per plant and ripe fruit yield per plant. Ali (1994) observed significant positive correlation between dry fruit weight and fresh fruit weight in chilli. Correlation between pericarp thickness and dry fruit weight recovery was negative. Maximum dry fruit weight recovery was for the hybrid EG 85 x Arka Abir. According to Casali and Stringheta (1984) flesh thickness is directly related to industrial yield and a variety with thick flesh and low water content in the flesh is the most suitable for processing. On the contrary, Verma and Joshi (2000) emphasized thin flesh as an important trait for paprika commercial varieties.

Paprika fetches nearly two-fold price in the international market compared to chilli powder. Colour value especially capsanthin content is

Plate 7. Superior hybrid selected for quality (EG-85 x Arka Abir)

Vellayani local x EG-101

Vellayani local x Kattakkada local

Plate 8. Superior hybrids selected for yield attributes

the most important trait for assessing paprika quality. Present investigation resulted in identification of a hybrid EG 85 x Arka Abir having high colour value of 235.35 ASTA units. Joshi *et al.* (1993) developed *Capsicum annuum* genotypes from local and foreign sources selected for pungency and non-pungency followed by crossing in a diallel design and identified Kt-Pl-18 and Kt-Pl-19 (233.70 ASTA units) as most promising lines. According to Govindarajan (1985), the true paprika contains less than 0.1 per cent of capsaicinoids, the best grade of Spanish paprika having 0 to 0.003 per cent and for the pungent grade a maximum of 0.5 per cent. The pungency level of EG 85 x Arka Abir was 0.148 per cent and hence it can be included under pungent grade paprika. Further improvement through recombination breeding or back crossing is possible to reduce the pungency to a minimum level.

5.3 MOLECULAR CHARACTERIZATION

Detection of polymorphism at DNA level is used for estimation of genetic diversity, similarity and characterizing cultivars or for testing the purity of hybrid seeds. In the present study an attempt was made to determine the extent of relationship among the 28 genotypes of chilli including seven parents and their hybrids and also to characterize the selected hybrid along with its parents using random primers.

Four promising primers identified through screening *viz.*, OPA-01, OPA-10, OPB-06 and OPB-20 were used for further amplification. OPA-10 was used for amplification of 28 genotypes. The genotypes were grouped into six clusters based on similarity coefficients. The parents P_3 (Jwalamukhi), followed by P_1 (EG-85) being comparatively narrow fruited types showed the maximum deviation from other genotypes. The parents P_4 (Kattakkada local) and P_7 (Arka Abir) came under the same cluster were having similarity with respect to fruit size and colour. The largest cluster comprised of 16 genotypes, included three parents and 13 hybrids. Hundred per cent similarity coefficient was observed between some

genotypes and for many genotypes clustering pattern was not in accordance with the morphological characters or quality parameters. This may be due to the insufficiency of the primer used. More number of primers may help to get better results.

Three primers (OPA-01, OPB-06 and OPB-20) used for characterizing the selected hybrid were sufficient to differentiate between the parents and the hybrid. The dendrogram revealed more closeness of hybrid towards the male parent P_2. Moreover, the similarity coefficients between the hybrid and the parents were higher than that between the parents. These indicate the purity as well as hybridity of the selected hybrid. Paran *et al.* (1995), Ballester *et al.* (1998) and Wang *et al.* (2002) used DNA molecular markers to determine the hybrid seed purity of vegetable crop.

Summary

6. SUMMARY

The present investigations on "Genetic improvement and molecular characterization of paprika (*Capsicum annuum* L.) genotypes" were conducted at the College of Agriculture, Vellayani during 2002-2004 with the major objective of development of improved chilli varieties with paprika quality suitable for cultivation in tropical conditions through hybridization.

Chilli germplasm consisting of 44 genotypes including released paprika varieties and local collections from different parts of India were evaluated for 12 yield traits *viz.*, days to 50 per cent flowering, plant height, primary branches per plant, secondary branches per plant, fruits per plant, fruit length, fruit girth, fruit weight, seeds per fruit, 100 seed weight, crop duration and yield per plant. Four quality parameters like ascorbic acid content, oleoresin content, capsanthin (colouring matter) content and capsaicin content were also analysed.

The important findings of the present study are summarized below.

Significant differences among genotypes for all the sixteen characters studied indicated high variability among genotypes for the traits studied. Vellayani local and EG-101 were the highest yielders, while Arka Abir was superior for quality traits.

Phenotypic and genotypic coefficients of variation were maximum for yield per plant and fruits per plant. Other traits also exhibited high values of PCV and GCV while, it was low for days to 50 per cent flowering. All the traits exhibited high heritability especially yield per plant and fruits per plant. Genetic advance as per cent of mean was found high for all the characters except days to 50 per cent flowering for which it was moderate.

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. Yield per plant exhibited positively significant association with fruits per plant, fruit length, fruit weight, 100 seed weight, plant height, oleoresin content, ascorbic acid content and crop duration, while negative correlation with days to 50 per cent flowering. The relationship of quality parameters with yield and their inter-relationship revealed positive and significant correlation of ascorbic acid content with oleoresin content and capsanthin content. Negative correlation was observed between capsanthin content and capsaicin content.

Selection indices were constructed based on the 16 characters studied and the genotypes were ranked based on this. High yielding and superior genotypes like Vellayani local, EG-101, EG-85, Kattakkada local, Kaliyikkavila local and Jwalamukhi had high selection indices while, low yielding genotypes like PSB-1, Kt-Pl-18, IHR were having low selection indices.

Genotypes were grouped into nine clusters considering 16 characters, each cluster with varying number of genotypes. Cluster II with 17 genotypes was the largest cluster and cluster VII, VIII and IX were with only one genotype each.

Based on selection index and quality parameters, seven genotypes *viz.*, EG-85, Vellayani local, Jwalamukhi, Kattakkada local, Kaliyikkavila local, EG-101 and Arka Abir were selected from different clusters as parents for hybridization.

The selected parents were crossed in diallel fashion excluding reciprocals to obtain 21 hybrids. Half diallel analysis was carried out to evaluate the parents and hybrids on the bases of mean performance,

general combining ability of parents, specific combining ability of hybrids and heterosis of hybrids.

Study of gene action showed higher magnitude of SCA variance for most of the characters except for fruit length and fruit girth which indicated predominance of non-additive gene action in controlling those traits. Additive and non-additive gene action had equal importance for the control of the trait crop duration. As non-additive gene action is more preponderant for most of the characters heterosis breeding would yield better results in the improvement of those characters.

On the basis of *gca* effects and mean performance, Vellayani local was superior for yield and yield related traits while Arka Abir performed best for quality parameters. Jwalamukhi and Kattakkada local showed good general combining ability and mean performance for five yield contributing characters each.

Among hybrids, based on mean performance, *sca* effects and standard heterosis the hybrid EG-85 x Arka Abir was superior with respect to earliness, capsanthin content, low pungency, fruit length and oleoresin content, where Arka Abir was a good general combiner for many traits. For yield attributes two hybrids can be projected as superior ones. The hybrid Vellayani local x EG – 101 performed best for yield per plant, fruit weight, primary branches per plant, secondary branches per plant and fruits per plant. Vellayani local x Kattakkada local showed best performance for plant height, fruits per plant, yield per plant, fruit weight and oleoresin content. For both the hybrids, the common parent Vellayani local was a good general combiner for many yield related traits. These hybrids can be effectively used for heterosis breeding to exploit maximum hybrid vigour.

For most of the hybrids heterotic expression was appreciable. For yield per plant, fruit length and fruit weight, majority of the hybrids exhibited positive and significant relative heterosis, heterobeltiosis as well

as standard heterosis. Heterosis for earliness was significant for all the hybrids.

Comparative study on green fruit yield per plant, ripe fruit yield per plant, dry fruit weight recovery and pericarp thickness revealed high positive correlation between green fruit yield per plant and ripe fruit yield per plant and negative correlation between pericarp thickness and dry fruit weight recovery. Maximum dry fruit weight recovery was for the hybrid EG-85 x Arka Abir.

Forty seven decamer primers were screened for their efficiency using the DNA isolated from EG-85 as the representative sample. Out of this 36 primers yielded amplification products. RAPD analysis was performed using the random primer OPA-10 and the 28 genotypes including seven parents and 21 hybrids were characterized using Jaccard's similarity coefficient analysis and a dendrogram was constructed to cluster the genotypes.

The superior hybrid with respect to paprika quality EG-85 x Arka Abir was characterized using three random primers and its hybridity was proved.

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GENETIC IMPROVEMENT AND MOLECULAR CHARACTERIZATION OF PAPRIKA (*Capsicum annuum* L.) GENOTYPES

BINI PHILIP

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

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ABSTRACT

Chilli (*Capsicum annuum* L.) is an important spice cum vegetable crop yielding capsaicin, oleoresin and natural colour besides green and dry fruits. Paprika belonging to *Capsicum annuum* is characterised by good colour and low pungency can be used both as vegetable and spice. The increasing commercial importance world over for paprika as sources of paprika powder and oleoresin has resulted in establishing breeding programmes to develop varieties or hybrids to meet domestic as well as export demands. The present investigation entitled "Genetic improvement and molecular characterization of paprika (*Capsicum annuum* L.) genotypes" conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2002-2004 was given prime importance for the development of improved chillies with paprika quality through hybridization.

Chilli germplasm consisting of 44 genotypes were evaluated for yield traits and quality characters and considerable variations were observed among genotypes for 16 traits *viz.*, days to 50 per cent flowering, plant height, primary branches per plant, secondary branches per plant, fruits per plant, fruit length, fruit girth, fruit weight, seeds per fruit, 100 seed weight, crop duration, yield per plant, ascorbic acid content, oleoresin content, capsanthin content and capsaicin content.

The maximum values of both phenotypic and genotypic coefficients of variation were noticed for yield per plant and fruits per plant. All the traits exhibited high heritability especially yield per plant and fruits per plant. Genetic advance as per cent of mean was found high for all the characters except days to 50 per cent flowering for which it was moderate.

Correlation analysis indicated significant positive correlation of yield per plant with fruits per plant, fruit length, fruit weight, 100 seed weight, plant height, oleoresin content, ascorbic acid content and crop duration and negative correlation with days to 50 per cent flowering. Negative correlation was observed between capsanthin content and capsaicin content.

Selection indices were computed based on 16 traits and genotypes were ranked accordingly. Genotypes were grouped into nine clusters based on Mahalanobis D^2 statistic. Based on the selection index and quality parameters seven genotypes *viz.*, EG-85, Vellayani local, Jwalamukhi, Kattakkada local, Kaliyikkavila local, EG-101 and Arka Abir were selected from different clusters as parents for hybridization.

Half diallel analysis revealed predominantly non-additive gene action for most of the characters but additive gene action was found for fruit length and fruit girth. On the basis of *gca* effects and mean performance Arka Abir was the best parent for quality characters and Vellayani local for yield related characters.

Among the 21 hybrids evaluated with respect to mean performance, standard heterosis and *sca* effects P_1 x P_7 (EG-85 x Arka Abir) was superior with respect to earliness, capsanthin content, low pungency, fruit length and oleoresin content. For yield attributes two hybrids can be projected as superior ones. The hybrid Vellayani local x EG – 101 performed best for yield per plant, fruit weight, primary branches per plant, secondary branches per plant and fruits per plant. Vellayani local x Kattakkada local showed best performance for plant height, fruits per plant, yield per plant, fruit weight, oleoresin content and ascorbic acid content.

Comparative study on green fruit yield per plant, ripe fruit yield per plant, dry fruit weight recovery and pericarp thickness revealed high positive correlation between green fruit yield and ripe fruit yield per plant and negative correlation between pericarp thickness and dry fruit weight recovery. Maximum dry fruit weight recovery was for the hybrid EG-85 x Arka Abir.

RAPD analysis was performed using the random primer OPA-10 and the 28 genotypes including seven parents and 21 hybrids were characterized using Jaccard's similarity coefficient analysis and a dendrogram was constructed to cluster the genotypes. The superior hybrid with respect to paprika quality EG-85 x Arka Abir was characterized using three random primers and its hybridity was proved.