GENETIC VARIABILITY IN CHILLI (*Capsicum annuum L.*) WITH EMPHASIS TO REACTION TO LEAF CURL VIRUS

BY

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THESIS

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2001

DEDICATED

TO MY BELOVED

PARENTS

DECLARATION

I hereby declare that this thesis entitled "**Genetic variability in chilli (*Capsicum annuum* L.) with emphasis to reaction to leaf curl virus**" is a *bonafide* record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis entitled "**Genetic variability in chilli (*Capsicum annuum* L.) with emphasis to reaction to leaf curl virus**" is a record of research work done independently by **Ms. Leaya Jose** 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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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) is an important vegetable as well as spice crop, widely grown throughout India. It is used in the manufacture of capsaicin, oleoresin, natural colour and vitamin C. Chilli is a crop of significance in beverages, cosmetics and pharmaceuticals also.

The green fruit contains 86 ml of water, 2.0 g of proteins, 0.8 g of fat, 10 g of carbohydrates, 2.6 g of fibre, 29 mg of calcium, 61 mg of phosphorus, 2.6 mg of iron, 180 μg of β-carotene, 0.12 mg of thiamine, 0.15 mg of riboflavin, 2.2 mg of niacin and 140 mg of ascorbic acid. The chilli seeds yield an oil rich in linoleic acid which is used in medicine as a counter-irritant.

As India is the secondary centre of origin, a lot of natural variability exists in this crop. Chilli is a facultative cross pollinated crop with high natural cross pollination and this also contributes to its variability.

Though several high yielding varieties have been released, the average yield of chilli in the country is low (0.88 t ha^{-1}). One of the main reasons for this is that most of these varieties are susceptible to pests and diseases, especially viral diseases.

Leaf curl is one of the most important and destructive diseases of chilli in India and causes severe loss in yield. It is spread by the vector, *Bemisia tabaci*. As a rule, the only way to check viral diseases is by controlling the vector population using

insecticides. But, only partial control of the disease can be achieved through the use of chemicals. More over, the use of insecticides makes chilli cultivation costly and hazardous to human beings and environment. Hence, the cost effective and stable way of combating leaf curl would be the development of resistant/tolerant varieties.

The primary objective of any crop improvement programme is to evolve a superior genotype with high yield, quality and resistance to pests and diseases. The preliminary step in this direction is to evaluate variability in the germplasm. Identifying the genotypes with high heritability and genetic advance for desirable characters contributing to yield is a prerequisite in developing high yielding varieties.

Estimation of inter relationship of yield with other traits and correlation studies would facilitate effective selection for simultaneous improvement of one or many yield contributing characters. Assessing the direct and indirect effects of each component towards yield would help in selecting the characters for crop improvement.

Grouping of genotypes based on the genetic distance between them with respect to important characters would provide a way to identify the most suitable genotypes that could be taken as parents in future breeding programmes.

Keeping all these in view the present investigation was undertaken with the objective of estimating the variability with respect to 15 economic characters (including yield and resistance to leaf curl virus) and genetic divergence among 37 genotypes of chilli and to group them into clusters based on their genetic distance using Mahalanobis D^2 statistic.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Before starting any crop improvement programme, it is important to understand the progress made so far. An effort has been made to collect and to review the available literature on genetic variability, correlation, heritability, genetic advance, path coefficient and genetic diversity in chilli. Available literature on leaf curl virus disease in the crop is also reviewed in this chapter. It is presented in two parts: yield analysis and leaf curl.

2.1 Yield analysis

2.1.1 Variability

The basic requirement for selection of superior genotypes from a population is the presence of variability with respect to different characters.

2.1.1.1 Mean performance

A high phenotypic variability and range of variation in different characters indicate the extent of genetic variability in them.

Singh and Singh (1976 b) observed high variability among 45 genetic stocks for plant height, number of branches, days to flower, days to maturity, fruit length, fruit thickness, number of fruits per plant and yield per plant. Arya and Saini (1977) also observed similar results while studying variability in 30 cultivars.

In their study using 32 varieties including two hybrids, Singh and Brar (1979) obtained significant differences for all the eight characters studied.

While comparing the mean performance of 12 varieties, Ramakumar *et al.* (1981) observed high variability for plant height, spread, fruit girth, number of seeds per fruit, number of fruits per plant and yield.

Nair *et al.* (1984 b) in their study using 30 genotypes observed wide range of variability for number of primary and secondary branches, life span and number of seeds. Similar result was obtained by Gopalakrishnan *et al.* (1987) while studying 38 chilli lines.

Fruits per plant, branches per plant and fruit weight were found to be the most variable traits in a study involving 16 cultivars (Ado *et al.*, 1987).

Teotia and Raina (1987) obtained a range of 0.67 to 1.47 g for average fruit weight, 5.79 to 10.13 for fruit length, 1.26 to 2.11 cm for fruit girth and 76 to 103 for number of seeds per fruit in six chilli lines.

Bai *et al.* (1987) reported significant variation among varieties for duration of flowering, plant height and fruit length in 12 red pepper varieties. But, Ahmed *et al.* (1990) obtained a low range of variability for days to first fruiting, plant height and plant spread in their study using 64 lines of chilli.

Adamu and Ado (1988) observed high levels of variation for fruits per plant, individual fruit weight and fresh fruit yield per plant in *Capsicum annuum* and *C. frutescens* cultivars plus 100-seed weight and dry fruit yield per plant in *C. frutescens*.

Seeds per fruit, dry yield per plant, fruits per plant and plant spread showed a wide range of variation in F_2 progenies of 45 inter-varietal crosses (Sahoo *et al.*, 1990).

Rajput *et al.* (1991) obtained wide variation in 12 cultivars for dry chilli yield and fruiting period.

Acharya *et al.* (1992) reported high variability in 19 cultivars of chilli for fruits per plant, yield per plant, fruit length and circumference and seeds per fruit. This was similar to earlier works reported by Choudhary *et al.* (1985) and Gopalakrishnan *et al.* (1985).

In their study using 20 genotypes, Singh *et al.* (1994) found that variability was greatest for weight of fresh red ripe fruits per plant.

Rani (1996 a, b) observed significant differences among 73 genotypes for fruit length, fruit diameter, fruit weight, seed weight and number of seeds per fruit.

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

While evaluating 119 accessions of chilli, Verma *et al.* (1998) observed wide range of variability in plant height, density of branches, days to 50 per cent flowering, number of fruits per plant, fruit length, fruit width, fruit green weight per ten fruits and fruit dry weight per ten fruits. Dwivedi and Bhandari (1999) reported high variability for number of seeds per fruit, 1000-seed weight and days to maturity in addition to several other characters in a collection of 160 sweet pepper germplasm.

The study involving 30 germplasm of chilli revealed the existence of considerable amount of genetic variability for all the characters studied except fruit girth (Munshi and Behera, 2000).

2.1.1.2 Variance

The components of variance give a more appropriate idea of the extent of variability in a population.

In their study using 30 cultivars of chilli, Arya and Saini (1977) reported high phenotypic and genotypic variances for fruit yield per plant, number of seeds per fruit, number of fruits per plant, fruit size per plant and plant height. Ramalingam and Murugarajendran (1977) obtained similar results for plant height, weight of dry fruits, number of fruits and number of branches. But, Hiremath and Mathapati (1977) found high phenotypic variances only for yield and number of fruits per plant in 36 cultivars of chilli.

In their study using 30 types of chilli, Elangovan *et al.* (1981) obtained high phenotypic and genotypic variances for plant height, plant spread, number of seeds per fruit and number of fruits per plant.

Bai *et al.* (1987) reported that the genotypic, environmental and phenotypic variances were maximum for fresh fruit yield per plant and minimum for branches per plant and percentage of fruit setting.

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

Sahoo *et al.* (1990) reported that seeds per fruit showed the maximum genotypic variance and 100-seed weight the minimum.

In a study using 25 genotypes, Das and Choudhary (1999 b) reported high phenotypic and genotypic variance for fruit length.

2.1.2 Coefficient of variation

This is a unit free measurement of variation and hence allows the comparison of variability of different characters.

In a study using seven bell pepper cultivars, Arya and Saini (1976) reported high genotypic and phenotypic coefficients of variation for fruit number per plant, fruit size and fruit yield per plant while number of seeds per fruit and number of branches gave medium values. But, Hiremath and Mathapati (1977) found high coefficient of variation for number of branches and number of seeds per fruit in 36 cultures of chilli.

Arya and Saini (1977) found that genotypic coefficient of variation (GCV) ranged from 12.04 for days to flower to 223.33 for rind thickness.

Variability studies in 31 varieties of sweet pepper revealed that both phenotypic and genotypic coefficients of variation were high for fruit number and fruit yield, medium for fruit weight and low for all the other characters (Singh and Brar, 1979). Rajput *et al.* (1981) also observed similar results for fruits per plant (GCV - 19.2) and yield (GCV-18.28) in seven cultivars of chilli.

Rao and Chhonkar (1981) observed low to medium phenotypic and genotypic coefficients of variation for several characters in a 10 x 10 diallel cross involving 45 F_1 and F_2 hybrids.

In a study involving 12 parents and their 66 F_1 and F_2 progenies, Gupta and Yadav (1984) found that the genotypic coefficient of variation ranged from 11.1 for plant height to 62.6 for fruit girth.

Nair *et al.* (1984 b) found high genotypic coefficient of variation among 25 cultivars for number of fruits (121.28), weight of fruit (100.65) and total yield (108.93).

Ghai and Thakur (1987) observed that the GCV varied from 8.24 for number of fruits to 41.27 for fruit weight per plant in F_2 generation of an inter-varietal cross.

Gopalakrishnan *et al.* (1987) obtained high GCV for fruit length (42.17), main stem length (44.61), fruit weight (29.70), fruit per plant (35.28) and fruit yield per plant (32.31) in 38 lines of chilli.

Dry yield per plant, plant spread, number of fruits per plant, weight of ten dry fruits and seed number per fruit showed high values for genotypic coefficient of variation in 45 crosses of a 10 x 10 diallel (Sahoo *et al.*, 1989).

Vijayalakshmi *et al.* (1989) observed greater difference between phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for plant height, plant spread, number of flowers, number of pods, total yield and total dry pod yield indicating greater influence of environment on these characters. Gopalakrishnan *et al.* (1985) also held a similar view with regard to number of branches per plant. But, Pichaimuthu and Pappiah (1992) reported a close association between the estimates of phenotypic and genotypic coefficients of variation for several characters in F_6 generation indicating low environmental influence.

Nandi (1993) in his study using nine cultivars observed that length and weight of fruit and yield per plant had the highest GCV.

In a study using 71 hot pepper lines, Jabeen *et al.* (1999) noticed that both PCV and GCV were high for fruit yield per plant, fruit number per plant, seed number per fruit and average fruit weight. Rani *et al.* (1996) and Varalakshmi and Haribabu (1991) also obtained similar results in their studies with 79 genotypes and 32 genotypes respectively.

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

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

2.1.3 Heritability

Singh and Singh (1977 a) reported high estimates of hertability in broad sense for all the characters in a variability study comprising of six genetic populations *viz.*, P_1, P_2, F_1, F_2, B_1 and B_2.

Milkova (1981) reported high heritability coefficients for plant height, fruit shape and pericarp thickness in a study involving a 5 x 5 diallel cross. Rao and Chhonkar (1981) obtained high heritability estimates for number of branches, fruit length, fruit girth, seed content, fruits per plant, ripe fruit yield per plant and fruit weight in a 10 x10 diallel.

In their study using 35 chilli genotypes, Singh *et al.* (1981) noticed high heritability estimates for mean weight per fruit, fruits per plant and fresh fruit weight per plant. High heritability was observed for fruit length and fruit diameter in addition to above mentioned traits by Singh *et al.* (1994) in 20 chilli genotypes.

Warade *et al.* (1996) noticed high heritability values for all the 13 yield related characters studied in 60 cultivars. Singh and Singh (1998) also observed similar results in 30 genotypes for all the seven traits studied except days to 50 per cent flowering.

Very high heritability (> 80 %) was estimated for fruit length, fruit diameter, fruits per plant, average fruit weight and yield per plant (Das and Choudhary, 1999 b).

2.1.4 Heritability and Genetic Advance

Heritability estimates along with genetic advance is more useful in selecting superior genotypes than using heritability values alone.

In a study using 19 strains, Singh and Singh (1970) found low estimates of heritability and expected genetic advance. The heritability estimates ranged from 11.13 per cent for 1000-seed weight to 30.68 per cent for primary forks while the expected genetic advance ranged from 1.04 per cent for fruit width to 32.07 per cent for fruit number. But Rao *et al.* (1974) obtained high heritability values ranging from 53 per cent for plant height to 81 per cent for pod length and high expected genetic advance for fruits per plant, final green fruit and dry fruit yields, fruit shape and fruit setting ability in summer in 40 F_4 progenies.

Based on their study in 30 genotypes, Ramalingam and Murugarajendran (1977) reported high heritability associated with high genetic advance for plant height, number of branches, weight of fruits per plant and length of fruit while low heritability and

genetic advance were reported for duration and number of fruits per plant. Arya and Saini (1976) also reported similar results for fruit number per plant, fruit size and number of branches. In a study comprising of six genetic populations, *viz.*, P_1, P_2, F_1, F_2, B_1 and B_2. Singh and Singh (1977 a) observed 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.

Bavaji and Murty (1982) observed high heritability coupled with high genetic advance for branches per plant, fruit length, 50-fruit weight and fruits per plant in a study involving 25 varieties of chilli.

Nair *et al.* (1984 b) noticed high heritability along with low genetic advance for days to flower, plant height, spread, number of primary branches and life span.

A wide range of heritability from 27.81 (fruit girth) to 99.86 (number of seeds per fruit) and genetic advance from 0.33 (fruit girth) to 98.99 (yield per plant) were noticed by Choudhary *et al.* (1985) in their study using 30 genotypes.

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

Meshram (1987) obtained high heritability and high expected genetic advance for fruit length and days to first flower.

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

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

Fruits per plant and number of seeds per fruit recorded high heritability and genetic advance (Varalakshmi and Haribabu, 1991 and Kumar *et al.*, 1993).

Bhatt and Shah (1996) obtained high heritability and genetic advance for average fruit weight and fruit diameter in a study involving 50 *Capsicum annuum* and *C. frutescens* cultivars.

Ghildiyal *et al.* (1996) reported high heritability and genetic advance for fruits per plant, fruit weight and length and circumference of fruit in 24 cultivars. Similar results were obtained by Ahmed *et al.* (1990) and Nandi (1993).

Rani *et al.* (1996) found high heritability coupled with high genetic advance for yield per plant, number of fruits per plant, mean fruit weight and dry matter production.

Rani and Singh (1996) reported high heritability and genetic advance for fruit length.

High heritability and genetic advance were observed for fruit yield per plant, fruit number per plant, seed number per fruit and pericarp thickness. (Jabeen *et al.*, 1999 and Devi and Arumugam, 1999).

2.1.5 Correlation

A knowledge of the correlation between yield and its component characters is essential for choosing the characters for selection.

Singh and Singh (1970) found that fruit yield showed significant positive correlation with fruit number, fruit length, fruit width and 1000-seed weight while Arya and Saini (1976) observed a negative correlation of yield with plant height and fruit number per plant.

Pandian and Sivasubramanian (1978) found that the total number of fruits harvested per plant had significant positive association with flowers produced during 66-86 days.

Yield was found to be negatively correlated with days to flowering (Rao *et al.*, 1981). But, Sundaram and Ranganathan (1978) and Veerappa (1982) reported significant positive correlation of yield with days to flowering.

Significant positive association of number of fruits and number of branches with yield was observed by Bavaji and Murty (1982).

Choudhary *et al.* (1985) observed positive correlation of yield per plant with fruit girth and weight of ten fruits, which in turn had a significant positive association with number of seeds per fruit. But Gopalakrishnan *et al.* (1985) observed negative correlation of fruit girth with fruit yield per plant while fruit length showed maximum positive correlation with yield. Ghai and Thakur (1987) found that yield was significantly associated both phenotypically and genotypically with fruit length, number of branches, number of fruits and plant spread. Similar results were obtained by Rajput *et al.* (1981) and Ramakumar *et al.* (1981).

Jayasankar *et al.* (1987) reported that fruit length, number of seeds per fruit, fruit girth and number of primary branches could be considered as secondary yield determinants owing to their loose association with yield.

Miranda *et al.* (1988) observed positive genotypic correlation of total yield per plant with early yield, average weight per sampled fruit and fruit length.

Yield per plant was found to be significantly and positively correlated with number of primary and secondary branches per plant and number of seeds per fruit in a variability study involving 30 chilli lines (Das *et al.*, 1989).

Kaul and Sharma (1989) reported the positive association of fruit yield with plant height, number of branches per plant, number of seeds per fruit and dry matter of fruit in 14 parents and 24 F_1s.

Significant negative correlation of yield with days to 50 per cent flowering and days taken for fruit set with maturity was reported by Bhagyalakshmi *et al.* (1990).

Ali (1994) reported positive association of fruit yield with number of seeds per fruit and number of fruits per plant.

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

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

Yield had a positive association with fruit length, diameter, and weight while weight of fruit had a strong positive correlation with that of pericarp (Todorova and Todorov, 1998).

Subashri and Natarajan (1999) obtained positive association of yield with branches per plant, fruits per plant, fruit weight and fruit length in F_2 population.

Correlation study in 25 genotypes showed that yield exhibited positive correlation with fruit weight, fruits per plant and primary branches per plant (Das and Choudhary, 1999 a).

Significant positive correlation of fruit yield per plant with plant height, fruit number per plant and canopy width was noted (Legesse *et al.*, 1999 and Aliyu *et al.*, 2000).

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

2.1.6 Path coefficient analysis

Rao *et al.* (1974) while studying 40 F_4 progenies observed that the principal traits influencing yield directly or indirectly were days to flower, days to maturity and number of fruits per plant.

Number of fruits per plant had a positive direct effect on yield while days to flower had a very strong negative direct effect on early yield (Gill *et al.*, 1977).

In their study using 20 varieties of chilli, Korla and Rastogi (1977) reported that fruits per plant had the highest direct effect on fruit yield followed by weight per fruit and plant height.

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

Rao *et al.*, (1981) reported that days to maturity and flowering, fruit setting ability in summer and fruits per plant were the most important factors, accounting for 55.34 per cent of the variability showed by character correlations.

Rao and Chhonkar (1981) in their study of a 10 x 10 diallel found that number of fruits, fruit weight and dry yield had a direct effect on ripe fruit yield.

Path analysis in 30 cultivars revealed that number of fruits, secondary branches, fruit weight, fruit circumference and duration had positive direct effects on yield. (Nair *et al.*, 1984 a).

Solanki *et al.* (1986) reported that number of fruits, plant height, number of primary branches per plant and fruit length had direct positive effect on yield.

In a study using 30 genotypes, Chouvey *et al.* (1986) observed positive direct effect for number of fruits per plant, 10-fruit weight, number of seeds per fruit, and fruit circumference on yield.

Path coefficient analysis of 21 varieties showed that mean fruit weight, fruits per plant and fruit width had the greatest direct effect on yield (Depestre *et al.*, 1989 b).

Path analysis in 14 parents and 24 F_1s revealed that number of fruits per plant, fruit diameter, and number of branches per plant were the main contributors to yield (Kaul and Sharma, 1989).

Sarma and Roy (1995) reported the importance of fruit diameter, fruit length and days to 50 per cent flowering as selection criteria for improving chilli genotypes based on the path analysis study in 20 chilli genotypes.

Das and Choudhary (1999 a) observed that fruits per plant and weight of fruits exhibited the highest positive effect on yield.

Legesse *et al.* (1999) found positive direct effects of canopy width, fruit number per plant and pericarp thickness in 18 hot pepper genotypes.

Path analysis in a 6 x 6 diallel excluding reciprocals revealed the strong positive direct effect of total fruit number on total fruit weight (Tavares *et al.*, 1999).

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

Direct positive effect of number of fruits per plant, fruit weight and fruit girth on yield per plant was observed in a study involving 30 chilli germplasm (Munshi *et al.*, 2000).

2.1.7 Discriminant function

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

Singh and Singh (1976 a) obtained the maximum advance for yield in F_2 when selection indices were based on the seven characters *viz.*, plant height, number of branches, days to flower, days to maturity, fruit length, fruit thickness and number of fruits per plant. The comparison of different discriminant functions revealed that days to flower, fruit length and number of fruits per plant were major yield components.

Gill *et al.* (1977) reported that multiple regression equation constructed on the basis of number of fruits per plant and fruit size had an efficiency of 47. 74 per cent.

In their study using 45 strains of chilli, Singh and Singh (1977 b) reported that discriminant function using seven characters at a time, plant height, number of branches, days to maturity, fruit length, fruit size and fruit number per plant was more efficient than straight selection for yield. These characters can be the bases for selection to evolve high yielding lines in chillies.

The study on 50 varieties of chilli by Sundaram *et al.* (1979) revealed that number of fruits per plant and number of branches per plant were the important characters that should be taken care of for selection in hybridisation programme.

Ramakumar *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.

2.1.8 Genetic divergence

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

Singh and Singh (1976 b) grouped 45 genotypes of chilli into ten clusters based on the similarities of their D^2 values. The clustering pattern of the strains did not follow the geographical distribution. Considerable diversity within and between clusters was noted. The characters contributing maximum towards total divergence were number of branches, fruit thickness, number of fruits per plant and yield per plant.

A study of the diversity in six parents and their 15 F_1 hybrids of sweet-pepper showed that the 21 genotypes formed seven clusters. Of the six parents, three were grouped in cluster-I and the other three formed independent clusters while the remaining clusters were occupied by the F_1s. Early yield was mainly responsible for genetic divergence among the genotypes. Cluster-II containing all the high yielding crosses

should be crossed with cluster-V, which contained the derivatives of four parents (Gill *et al.*, 1982).

Varalakshmi and Haribabu (1991) classified 32 genotypes of chilli into 11 gene constellations. Grouping of genotypes in different clusters was not related to their geographical origin. The intra cluster D^2 values ranged from 0.0 (cluster-VI to XI) to 36.7 (cluster-III). The inter cluster D^2 value was maximum (159.1) between clusters-X and XI while the minimum distance was between clusters-II and V (36.9) indicating close relationship among the genotypes included. Considerable differences existed between clusters for all the characters. Fruits per plant, leaf area index, fruit weight and total yield were reported to be the chief contributors towards genetic divergence.

2.2 Leaf curl

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

Fugro (2000) reported that leaf curl incited by virus is an important disease of chilli. Inspite of its severity, little work has been done in identifying resistant sources for

developing resistant/tolerant varieties. An attempt has been made to review the available literature on leaf curl.

2.2.1 Symptomatology

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

Dhanraj and Seth (1968) reported downward curling, dark green colour and oval to rounded shape of leaves, pronounced vein-thickening and leafy outgrowths or enations on the under surface of leaves. The diseased plants produced fewer flowers and fruits.

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

2.2.2 Etiology

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

Ayyar *et al.* (1935) observed that *Scirtothrips dorsalis* was involved in the disease while Khodawe and Taley (1978) reported the involvement of *Hemitarsonemus latus* in the disease. The causal agents of leaf curl were reported to be *Scirtothrips dorsalis*

(thrips) and *Polyphagotarsonemus latus* (mite) by Amin (1979), Mallapur (2000) and Reddy *et al.* (2000).

2.2.2.1 The virus

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

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

Dhanraj and Seth (1968) reported the presence of two distinct strains of the leaf curl virus, one that does not produce enations in chilli and other solanaceous hosts, while the other has a severe effect, with the development of enations.

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

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

Infection by tomato yellow leaf curl virus in *C. annuum* plants resulted in interveinal and marginal chlorosis and upward curling of the leaflet margin (Reina *et al.*, 1999).

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

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

2.2.3 Breeding for resistance

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

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

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

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

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

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

Among 64 *C. annuum* cultivars screened under natural conditions, Karanja, Pant C-1, S46-1, IC. 18253, IC. 18885, JCA – 196, Cross – 218 and EC. 121490 showed less than 30 per cent leaf curl (Bhalla *et al.*, 1983).

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

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

Memane *et al.* (1987) while screening 69 varieties against leaf curl complex (caused by thrips and leaf curl virus) obtained lowest disease incidence in Pant C-1 (40.22 %). Pant C-1, LIC 45 and NI 46 were regarded as moderately resistant to leaf curl.

While screening 33 genotypes against leaf curl and mosaic viruses, Brar *et al.* (1989) obtained six lines tolerant to both disease.

The selection PSP 11, named 'Pusa Sadabahar' developed from Pusa Jwala x IC. 31339 was found to have high degree of tolerance to leaf curl virus (Tewari, 1991).

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

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

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

Munshi and Sharma (1996) screened 66 cultivars for resistance to leaf curl complex and reported that six lines *viz.*, Pusa Sadabahar, RHRC Clustering Erect, RHRC

Clustering Pendula, LGP-8-1, LGP-18-2-4-3 and LGP-18-10-12 were resistant to the disease.

Singh *et al.* (1998) screened seven varieties of chilli against sucking pests and leaf curl virus and observed that no variety was free from infection. But, Pusa Sadabahar, JM-218 and Pant C-2 showed only traces of infection.

Among 37 chilli genotypes evaluated for incidence of pepper leaf curl virus, three (Pusa Jwala, Suryamukhi and Japani Loungi) were rated resistant, two moderately resistant, 19 susceptible and 13 highly susceptible (Kumar *et al.*, 1999).

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

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

Jadhav *et al.* (2000) reported that 'Phule Sai' (GCH-8) selected from advanced generations of Pant C-1 x Kamandalow is moderately resistant to leaf curl virus under field conditions.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study was undertaken to estimate the genetic variability in a collection of chilli (*Capsicum annuum* L.) genotypes and to understand the reaction of these genotypes to chilli leaf curl virus. Based on their divergence and resistance to leaf curl virus, appropriate types can be chosen and used in a hybridisation programme to combine both high yield and resistance in one genotype. The data for the investigation were collected from two field experiments conducted simultaneously. The study was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during summer, 2000-2001. Of the two experiments, experiment-I was for the study of genetic divergence based on yield and related characters and experiment-II for evaluation of the genotypes for leaf curl resistance.

3.1 Experiment-I: Estimation of genetic divergence

3.1.1 Materials

The materials for the study consisted of 37 genotypes of chilli collected from different agro-climatic regions of the country. It also included four released varieties, three from Kerala Agricultural University and one from Gobind Ballabh Pant University of Science and Technology. The details of the genotypes are given in table 1.

Table 1. List of genotypes

Accession Number	Accession/Variety
T_1	Jwalasakhi
T_2	Vlathankara local-2
T_3	Kottikulam local
T_4	Vlathankara local-1
T_5	Palode local-1
T_6	Hubly local
T_7	Gadag local
T_8	Nekraje local
T_9	Kottukal local
T_{10}	Thalassery local
T_{11}	Alampady local-1
T_{12}	Neyyattinkara local
T_{13}	Mangalapuram local
T_{14}	Anadu local
T_{15}	Thenali local
T_{16}	Kuttipuram local
T_{17}	Marthandam local-1
T_{18}	Kannoor local
T_{19}	Ujjwala
T_{20}	Chandera local
T_{21}	Kanhangad charadan
T_{22}	Honnavar local
T_{23}	Nileswaram triangular
T_{24}	Pollachy local-1
T_{25}	Marthandam local-2
T_{26}	Jwalamukhi
T_{27}	Alampady local-2
T_{28}	Pollakkada local
T_{29}	Koothali local
T_{30}	Uduma local
T_{31}	Kottiyam local
T_{32}	Nagercoil local
T_{33}	Nedumangad local
T_{34}	Thrikkarippur piriyan
T_{35}	Pollachy local-2
T_{36}	Haripuram local
T_{37}	Pant C-1

3.1.2 Methods

3.1.2.1 Design and layout

The experiment was conducted in Randomised Block Design (RBD) with three replications. Plot size was 2.25 x 0.90 m with a spacing of 45 x 45 cm. Ten plants were maintained in each plot.

3.1.2.2 Sowing and cultural operations

Seeds were sown on raised nursery beds during October 2000. The seedlings were transplanted during November 2000 when they were one month old; with one seedling per pit.

Cultural operations were carried out as per the package of practices recommendations of the Kerala Agricultural University (Kerala Agricultural University, 1996).

3.1.2.3 Biometric observations

In each genotype, five plants were selected at random excluding the border plants for recording the following biometric observations. The data for statistical analysis were obtained as mean values worked out thereafter.

a. Plant height

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

b. Number of primary branches

The branches originating from the main stem were counted and recorded at the full maturity of the plant.

c. Number of secondary branches

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

d. Number of days to first flowering

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

e. Number of flowers per plant

The number of flowers were counted each day and after each counting flowers were marked to avoid repetition. At the end of the flowering phase, observation was taken once in three days.

f. Duration of flowering (fruiting span)

Number of days from the appearance of first flower to the harvest of the last fruit was recorded.

g. Number of fruits per plant

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

h. Fruit length

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

i. Fruit girth

The circumference at the broadest part of the fruits selected for recording length was taken, averaged and expressed in cm.

j. Green fruit yield per plant

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

k. Average fruit weight

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

l. Number of seeds per fruit

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

m. 100-seed weight

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

n. Duration of crop

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

o. Scoring of leaf curl symptom at 60 days after planting.

3.1.2.4 Statistical analysis

3.1.2.4.1 Analysis of variance (ANOVA) and covariance (ANCOVA) for RBD (Panse and Sukhatme, 1967) in respect of the various characters was done.

The mean values for all the accessions for each of the characters were worked out and compared using critical differences.

3.1.2.4.2 Grouping of genotypes

The genotypes were grouped into poor, average and better categories with respect to each character as follows

Definition	: Category
Less than mean –2 SE	: Poor
Between mean $\pm$ 2 SE	: Average
More than mean +2 SE	: Better

where mean is the overall mean of 37 accessions for each character and SE is the standard error of mean for each character. The above classification is reversed for days to

first flower and vulnerability index, as genotypes with low values are better for these traits.

3.1.2.4.3 Variance and covariance

The variance and covariance components were calculated as

For the character X_i,

$$\text{Environmental variance, } \sigma^2_{ei} = \text{MSE}$$

$$\text{Genotypic variance, } \sigma^2_{gi} = \frac{\text{MST-MSE}}{r}$$

$$\text{Phenotypic variance, } \sigma^2_{pi} = \sigma^2_{gi} + \sigma^2_{ei}$$

where MST and MSE are the mean sum of squares for treatment and error respectively from ANOVA, r is the number of replications and $\bar{x}_i$ is the overall mean of the i^{th} trait calculated from all accessions.

For two characters X_i and X_j, the covariances were worked out from the ANCOVA as

$$\text{Environmental covariance, } \sigma_{eij} = \text{MSPE}$$

$$\text{Genotypic covariance, } \sigma_{gij} = \frac{\text{MSPT-MSPE}}{r}$$

$$\text{Phenotypic covariance, } \sigma_{pij} = \sigma_{gij} + \sigma_{eij}$$

where MSPT and MSPE are the mean sum of products for treatment and error respectively between i^{th} and j^{th} characters.

3.1.2.4.4 Coefficient of variation

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

$$\text{Phenotypic coefficient of variation, PCV} = \frac{\sigma_{pi}}{\bar{x}_i} \times 100$$

$$\text{Genotypic coefficient of variation, GCV} = \frac{\sigma_{gi}}{\bar{x}_i} \times 100$$

$$\text{Environmental coefficient of variation, ECV} = \frac{\sigma_{ei}}{\bar{x}_i} \times 100$$

3.1.2.4.5 Heritability (H^2)

Heritability in broad sense was calculated as a percentage based on the formula given by Jain (1982).

$$H^2 = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

where σ^2_g and σ^2_p are the genotypic and phenotypic variance of the trait.

Heritability per cent was categorised as suggested by Robinson et al. (1949) viz., low (0-30), moderate (30-60) and high (above 60).

3.1.2.4.6 Genetic advance under selection

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

$$\text{Genetic advance, GA} = \frac{kH^2\sigma_p}{\bar{x}} \times 100$$

where k is the standardised selection differential (k=2.06) at five per cent selection intensity (Miller *et al.*, 1958) and $\bar{x}$ is the mean of the character over all accessions.

Genetic advance was categorised into low (less than 10 %), moderate (10-20 %) and high (more than 20 %) as suggested by Johnson *et al.* (1955 a).

3.1.2.4.7 Correlation analysis

The correlation coefficients (phenotypic, genotypic and environmental) were worked out as

$$\text{Genotypic correlation } (r_{gij}) = \frac{\sigma_{gij}}{\sigma_{gi} \times \sigma_{gj}}$$

$$\text{Phenotypic correlation } (r_{pij}) = \frac{\sigma_{pij}}{\sigma_{pi} \times \sigma_{pj}}$$

$$\text{Environmental correlation } (r_{eij}) = \frac{\sigma_{eij}}{\sigma_{ei} \times \sigma_{ej}}$$

3.1.2.4.8 Path coefficient analysis

The direct and indirect effects of component characters on yield were estimated through path analysis technique (Wright, 1954).

3.1.2.4.9 Selection index

The selection index developed by Smith (1937) using discriminant function of Fisher (1936), was used to discriminate the genotypes based on 15 characters under study.

The selection index is described by the function, $I = b_1x_1 + b_2 x_2 +.....+ b_kx_k$ and the merit of a plant is described by the function, $H = a_1G_1 + a_2G_2 +.....+ a_kG_k$ where $x_1, x_2,.....,x_k$ are the phenotypic values and $G_1, G_2,.....,G_k$ are the genotypic values of the plants with respect to the characters $x_1, x_2,.....,x_k$ and H is the genetic worth of the plant. It is assumed that the economic weight assigned to each character is equal to unity ie. $a_1, a_2,.....,a_k = 1$.

The b (regression) coefficients are determined such that the correlation between H and I is maximum. The 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.

3.1.2.4.10 Mahalanobis D^2 analysis

Genetic divergence was estimated using Mahalanobis D^2 statistic as described by Rao (1952). The genotypes were clustered by Tocher's method.

3.2 Experiment II: Reaction of leaf curl virus

3.2.2 Materials

Same as in experiment I.

3.2.3 Methods

3.2.3.4 Design and layout

Same as in experiment I.

3.2.3.5 Sowing and cultural operations

Same as in experiment I.

Spraying of insecticides in the field was avoided inorder to permit the growth and spread of *Bemisia tabaci*, the vector of leaf curl virus.

3.2.3.6 Methodology

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

Mass culture of *Bemisia tabaci*

Brinjal being a good breeding host for *B. tabaci*, the pure culture of *B. tabaci* was raised and maintained on brinjal plants. Insect proof wooden cages (65 x 65 x 70 cm) were used for this purpose. The potted brinjal plants were placed inside the cages and *B. tabaci* were released into the cages for its multiplication. The old plants inside the cages were replaced from time to time with healthy and fresh ones. Care was taken to keep the cages free of the predators of whiteflies.

Handling of whiteflies

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

Acquisition and inoculation access feeding

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

Acquisition feeding of white flies for release into the field

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

Inoculation of main field

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

3.2.2.4 Biometric observations

Observations were taken for disease scoring and yield per plant.

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

Score	Symptoms
0	No symptoms
1	Slight curling of terminal leaves
2	Curling of terminal and adjacent lower leaves
3	Curling and appearance of blisters on leaves
4	Severe curling and puckering of leaves. Stunted appearance of plants

The individual plant score was utilized to work out the 'severity index' or 'vulnerability index' so as to measure the degree of resistance. The index was calculated

using an equation adopted by Silbernagel and Jafri (1974) for measuring the degree of resistance in snap bean (*Phaseolus vulgaris*) to beet curly top virus and modified later by Bos (1982).

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

Where V. I. = Vulnerability index

$n_0, n_1, \ldots n_4$ = Number of plants in the category 0, 1,...4

n_t= Total number of plants

n_c-Total number of categories.

The genotypes were classified according to vulnerability index as

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

b. Green fruit yield per plant (g)

The yield of the observational plants over different harvests was noted and the average yield per plant was worked out.

3.2.2.5 Statistical analysis

3.2.2.5.1 Analysis of variance (ANOVA) for yield per plant and vulnerability index.

3.2.2.5.1 Pooled ANOVA

Yield and vulnerability index from experiments I and II were compared using weighted analysis as per the method of Panse and Sukhatme (1967).

RESULTS

4. RESULTS

The 37 genotypes of chilli were evaluated for various characters, *viz.*, morphological, yield and reaction to leaf curl virus and the results are presented in this chapter. First section deals with the analysis of yield and morphological characters and second section deals with the reaction to leaf curl virus.

4.1 Analysis for yield and morphological characters (Experiment No.1)

The performance of 37 genotypes was evaluated for various characters.

4.1.1 Variability

The genotypes showed significant differences for all the traits under study.

4.1.1.1 Mean performance

Table 2 gives the mean values of the genotypes for yield and other traits.

Average fruit weight was highest for T_7 (6.17 g), but was on par with T_4, T_{28} and T_2. It was lowest for T_{37} (1.17 g), on par with T_{19} and T_{23} (Fig. 2).

The genotype T_{32} produced the largest number of fruits per plant (96.67) and was statistically superior to all other genotypes, whereas T_{22} produced the least number (6.33) and was on par with T_{21}, T_{15}, T_{16} and T_{34} (Fig. 1).

Number of seeds per fruit ranged from 47.80 (T_{26}) to 148.47 (T_{13}). The genotype T_2 was on par with T_{13}.

Table 2. Varietal difference with respect to various characters

Geno-type	Average fruit weight (g)	No.of fruits per plant	No.of seeds per fruit	100-seed weight (g)	Fruit length (cm)	Fruit girth (cm)	Yield per plant (g)
T_1	4.73	41.60	59.20	.3465	11.41	7.42	177.93
T_2	5.67	24.07	146.13	.5710	6.59	8.60	130.00
T_3	4.03	60.13	79.73	.5114	6.43	7.76	233.27
T_4	6.07	28.60	116.07	.4896	8.02	8.17	163.40
T_5	2.11	47.40	80.00	.4604	7.24	3.69	96.33
T_6	2.45	18.40	132.00	.4182	3.76	5.86	39.00
T_7	6.17	17.80	118.20	.4902	7.97	8.18	109.53
T_8	2.57	17.07	91.73	.5860	7.74	3.61	42.70
T_9	1.85	38.00	86.53	.5510	6.92	3.43	63.47
T_{10}	2.79	66.40	90.93	.3312	8.21	4.29	177.20
T_{11}	2.47	53.73	102.13	.3034	8.09	4.87	124.67
T_{12}	1.69	53.60	96.00	.5136	7.33	3.63	90.07
T_{13}	4.01	56.60	148.47	.4190	6.93	7.48	219.53
T_{14}	2.29	33.13	69.13	.4328	3.97	5.57	73.60
T_{15}	2.37	14.53	113.13	.2952	4.20	7.61	36.20
T_{16}	2.72	14.73	120.40	.4436	6.45	5.63	41.00
T_{17}	2.25	28.33	100.53	.4480	7.60	3.86	59.10
T_{18}	1.71	31.73	88.07	.4112	5.68	4.45	52.47
T_{19}	1.49	44.80	78.33	.1804	5.19	3.40	61.80
T_{20}	2.01	30.33	61.67	.2974	5.03	2.52	61.00
T_{21}	3.65	14.13	126.47	.4240	8.19	5.00	49.47
T_{22}	4.00	6.33	128.13	.5060	3.48	6.21	25.20
T_{23}	1.56	17.87	124.00	.3262	2.90	6.20	25.67
T_{24}	2.63	44.13	57.80	.3496	8.27	4.17	112.60
T_{25}	2.78	42.47	83.73	.6358	8.08	3.91	111.53
T_{26}	5.33	56.07	47.80	.6528	8.15	7.14	274.53
T_{27}	2.61	33.77	101.33	.4924	6.77	4.63	78.67
T_{28}	5.99	32.13	90.33	.5784	10.72	6.75	189.07
T_{29}	3.07	72.00	68.73	.5070	7.71	4.98	204.27
T_{30}	3.48	39.33	76.40	.4650	6.59	7.32	134.13
T_{31}	3.66	33.73	129.47	.5268	5.84	7.23	119.20
T_{32}	1.75	96.67	79.07	.6324	7.66	3.55	156.60
T_{33}	1.92	55.13	77.40	.5186	6.78	3.90	99.07
T_{34}	3.31	16.20	93.53	.3630	9.20	3.96	52.27
T_{35}	2.98	24.93	95.67	.5296	10.30	4.89	71.47
T_{36}	2.23	31.73	54.60	.5734	7.28	3.35	64.73
T_{37}	1.17	40.13	74.27	.3106	5.79	3.58	44.27
Mean	3.07	37.24	94.25	.4565	6.99	5.32	104.46
F	64.15**	27.33**	172.05**	46.64**	44.48**	55.99**	33.81**
SE	0.17	3.65	1.98	.0162	0.29	0.23	11.04
CD	0.49	10.30	5.60	.0458	0.81	0.65	31.19

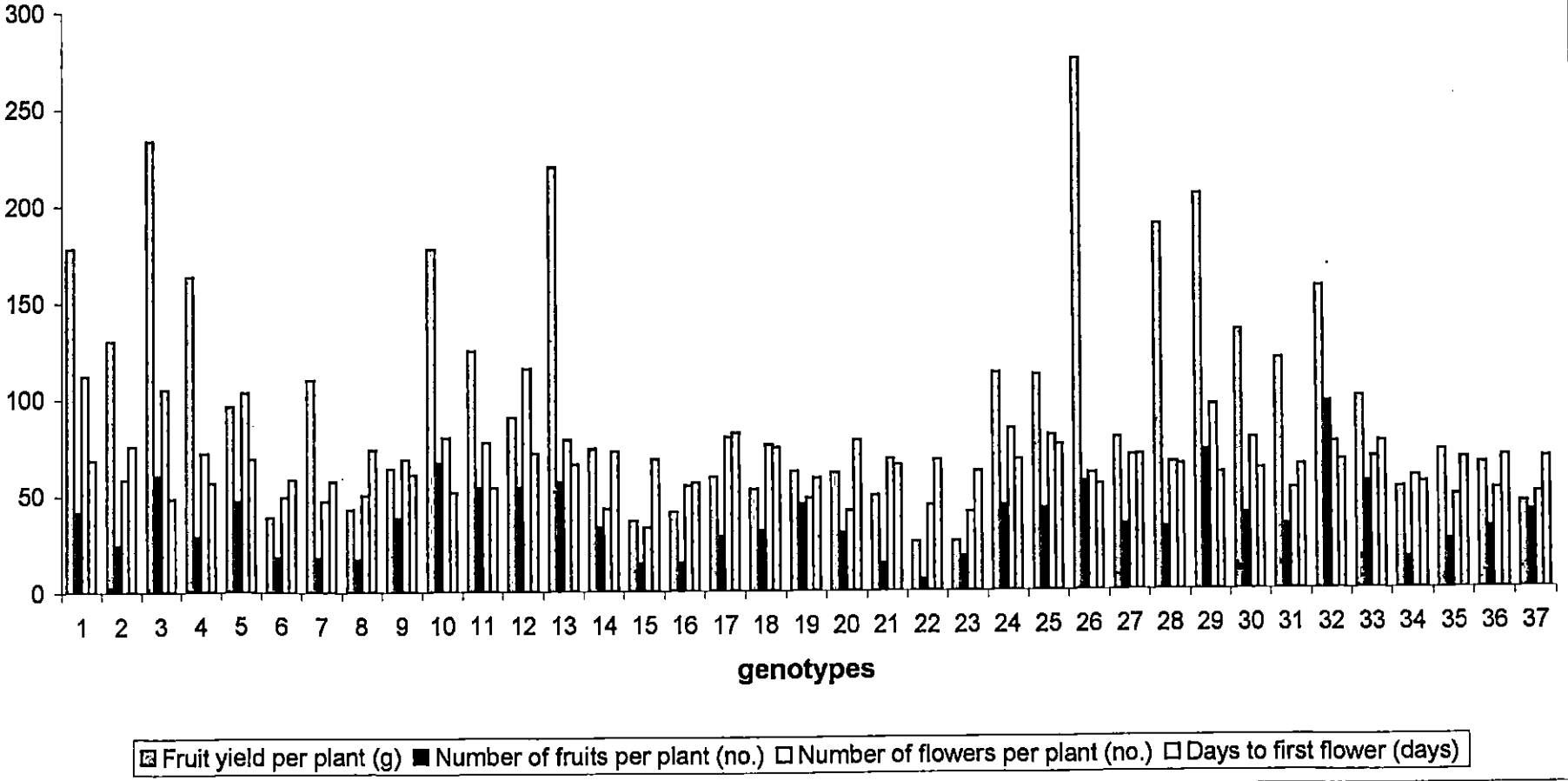
*Significant at 5 % level
** Significant at 1 % level

Table 2 (Continued)

Geno-type	Plant height (cm)	No. of primary branches	No .of secondary branches	Days to first flower (days)	No. of flowers per plant	Fruiting span (days)	Crop duration (days)	Vulner-ability index
T_1	43.33	3.40	21.53	68.47	112.20	109.00	176.00	13.84
T_2	46.63	4.00	16.67	75.47	58.27	98.33	173.33	16.67
T_3	44.77	3.13	21.93	48.33	105.20	133.67	181.67	12.37
T_4	45.17	3.33	19.93	56.53	72.00	117.00	173.00	20.00
T_5	63.05	3.20	21.27	69.33	103.80	98.00	165.33	17.50
T_6	36.38	2.53	12.40	58.47	49.47	98.33	156.33	24.90
T_7	42.87	3.13	13.60	56.93	47.07	133.33	189.67	15.37
T_8	53.39	3.20	17.73	73.47	50.13	90.00	163.00	21.93
T_9	36.46	3.93	20.33	60.47	68.47	111.67	171.00	17.10
T_{10}	46.04	3.80	22.67	51.47	79.73	122.00	173.00	16.97
T_{11}	38.23	3.53	27.00	53.80	77.07	119.00	172.33	5.75
T_{12}	45.65	3.27	23.60	71.60	115.27	92.33	163.33	6.33
T_{13}	38.96	3.53	21.47	65.53	78.27	107.67	172.67	9.10
T_{14}	29.33	3.33	16.53	72.33	42.60	90.33	162.33	15.00
T_{15}	36.26	2.47	14.93	68.47	32.80	95.00	163.67	16.77
T_{16}	35.70	3.33	17.33	56.07	54.53	99.00	156.33	17.67
T_{17}	50.83	3.67	19.67	81.53	79.67	89.33	170.33	18.83
T_{18}	38.07	3.53	19.60	74.13	75.53	90.67	164.67	15.95
T_{19}	40.87	3.20	19.47	58.40	48.13	109.00	166.67	12.37
T_{20}	33.96	3.87	18.13	77.73	41.40	81.67	159.00	8.58
T_{21}	45.57	3.00	15.33	65.07	68.33	99.00	164.00	18.50
T_{22}	34.72	3.07	11.00	67.47	43.93	101.00	168.00	25.20
T_{23}	29.62	3.20	17.73	61.60	40.80	99.00	161.00	15.00
T_{24}	50.42	3.67	21.93	67.40	83.67	105.00	172.00	13.33
T_{25}	52.50	3.80	21.93	75.20	80.97	95.33	170.33	19.17
T_{26}	40.79	4.13	22.80	54.53	60.40	122.00	176.00	14.73
T_{27}	45.76	4.40	28.93	70.07	69.73	98.00	168.00	8.77
T_{28}	45.40	2.87	18.47	64.60	65.80	107.67	171.67	15.23
T_{29}	42.90	3.40	23.00	60.53	95.60	111.67	172.00	13.33
T_{30}	35.92	4.27	22.20	62.40	77.87	109.67	171.67	14.17
T_{31}	37.64	3.13	18.20	64.07	52.07	103.00	166.67	7.42
T_{32}	55.47	3.33	23.33	66.33	75.67	102.33	170.33	14.23
T_{33}	58.21	2.20	15.80	76.07	67.67	89.00	164.67	15.00
T_{34}	46.45	2.93	16.80	54.67	58.20	107.00	162.00	22.50
T_{35}	42.89	2.80	16.20	67.27	48.40	93.33	159.67	21.27
T_{36}	45.97	2.47	13.73	68.53	51.47	102.67	170.67	7.18
T_{37}	33.10	3.47	17.07	67.53	49.47	89.67	157.67	7.63
Mean	42.95	3.34	19.06	65.19	67.07	103.26	168.11	15.02
F	10.34**	3.38*	5.68**	57.06**	90.35**	179.22**	26.63**	14.14**
SE	2.39	0.27	1.55	1.06	2.20	0.91	1.35	1.34
CD	6.76	0.79	4.37	2.98	6.22	2.57	3.82	3.78

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

Fig. 1. Variability of mean values of selected characters



The genotypes T_{26} (0.6528 g), T_{25} (0.6358 g) and T_{32} (0.6324 g) had the maximum 100-seed weight and were on par with each other while it was least for T_{19} (0.1804 g).

The longest fruit was produced by T_1 (11.41 cm) and shortest by T_{23} (2.90 cm). T_{28} was on par with T_1 while T_{22} was on par with T_{23} (Fig 2).

The genotype T_{20} showed the lowest fruit girth (2.52 cm). It was highest for T_2 (8.60 cm), on par with T_7 and T_4 (Fig 2).

Green fruit yield per plant was highest for T_{26} (274.53 g) and lowest for T_{22} (25.20 g). However, the genotypes T_{23}, T_{15}, T_6, T_{16}, T_8, T_{37}, T_{21}, T_{34} and T_{18} were statistically as low yielding as T_{22} (Fig 1).

Plant height was highest for T_5 (63.05 cm) and T_{33} (58.21 cm) and lowest for T_{14} (29.33 cm). However, T_{23}, T_{37}, T_{20}, T_{22}, T_{16} and T_{30} were on par with T_{14}.

Number of primary branches varied from 4.40 (T_{27}) to 2.20 (T_{33}). The genotype T_{27} was on par with ten other genotypes and T_{33} was on par with six genotypes.

The genotype T_{27} had the highest number of secondary branches per plant (28.93) and was significantly superior to all others. T_{22} had the lowest number (11.00) and was on par with T_6, T_7, T_{36}, T_{15} and T_{21}.

The genotype T_3 took only 48.33 days to produce the first flower whereas T_{17} took 81.53 days (Fig.1).

The largest number of flowers was produced by T_{12} (115.27) and T_1 (112.20) while T_{15} produced the lowest number (32.80) (Fig 1).

Fig.2. Variability of mean values of fruit characters

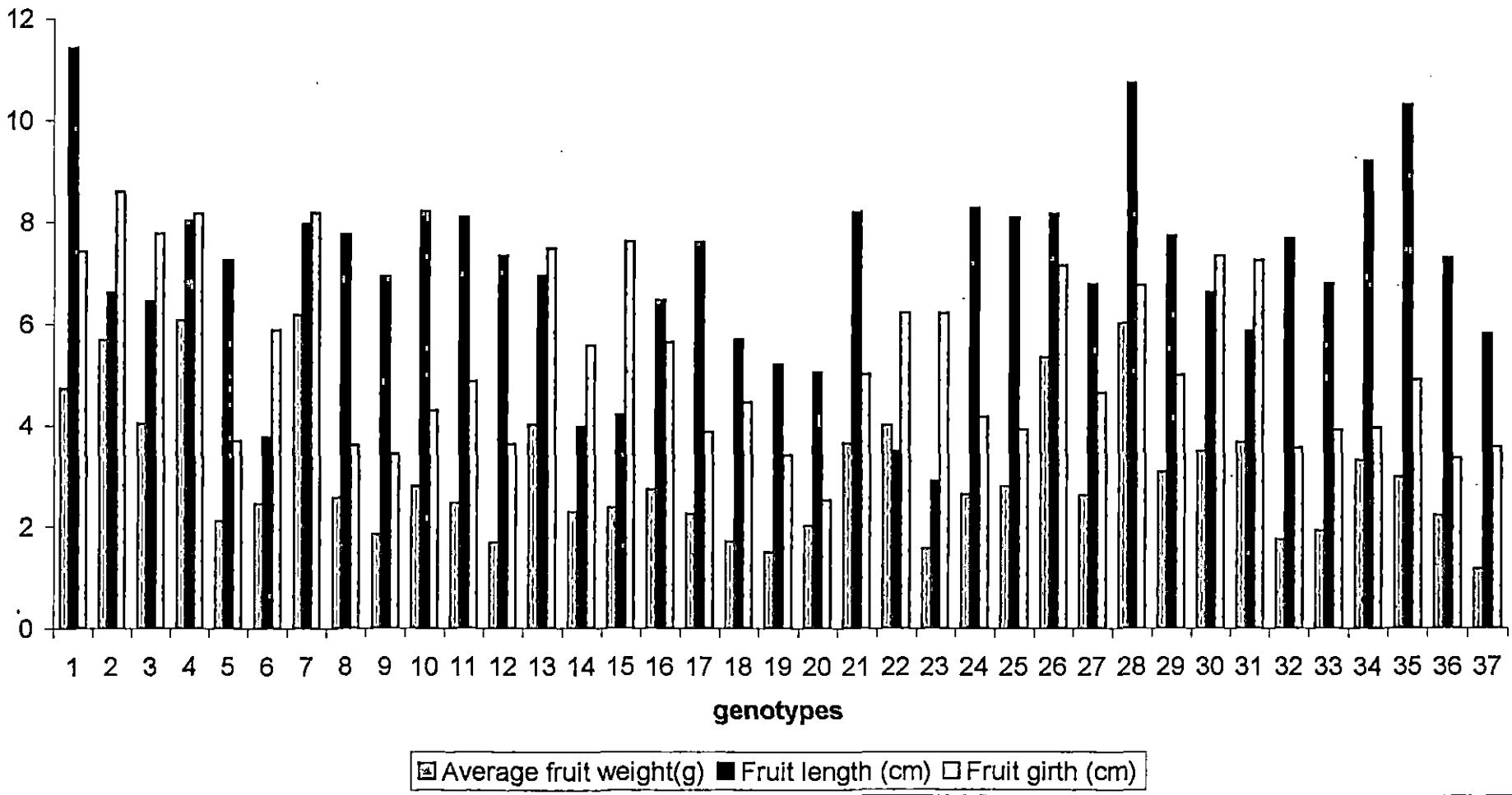


Plate 1
High yielding genotypes

Plate 2
Variability in fruit characters

Fruiting span was highest for T_3 (133.67) and T_7 (133.33) while it was lowest for T_{20} (81.67).

Crop duration ranged from 156.33 (T_{16}) to 189.67 (T_7). The genotypes T_6, T_{37}, T_{20} and T_{35} were on par with T_{16}.

The vulnerability index, calculated on the basis of virus scoring showed a range of 5.75 (T_{11}) to 25.20 (T_{22}). Seven other genotypes were on par with T_{11} while T_6, T_8 and T_{34} were on par with T_{22}.

4.1.1.2 Classification of genotypes

The 37 genotypes were classified into poor, average and better with respect to each trait.

The average fruit weight was less than 2.73 g for 19 genotypes (poor) while it was more than 3.41 g for 12 genotypes (better). Six genotypes had an average fruit weight ranging from 2.73 to 3.41 g (average).

Eleven genotypes produced more than 44.53 fruits per plant and were classified as better. The average (29.94-44.53) and poor (< 29.94) classes comprised of 13 genotypes each for this trait.

As for number of seeds per fruit, 17 genotypes were classified as poor (< 90.28), six genotypes as average (90.28-98.22) and 14 genotypes as better (> 98.22).

Table 3. Classification of genotypes

Character	Poor	Average	Better
	< Mean-2 SE	Mean ± 2 SE	> Mean + 2 SE
	< 2.73	2.73-3.41	>3.41
Average fruit weight (g)	T_5, T_6, T_8, T_9, T_{11}, T_{12}, T_{14}, T_{15}, T_{17}, T_{18}, T_{19}, T_{20}, T_{23}, T_{24}, T_{27}, T_{32}, T_{33}, T_{36}, T_{37}	T_{10}, T_{16}, T_{25}, T_{29}, T_{34}, T_{35}	T_1, T_2, T_3, T_4, T_7, T_{13}, T_{21}, T_{22}, T_{26}, T_{28}, T_{30}, T_{31}
	< 29.94	29.94 - 44.53	> 44.53
Number of fruits per plant	T_2, T_4, T_6, T_7, T_8, T_{15}, T_{16}, T_{17}, T_{21}, T_{22}, T_{23}, T_{34}, T_{35}	T_1, T_9, T_{14}, T_{18}, T_{20}, T_{24}, T_{25}, T_{27}, T_{28}, T_{30}, T_{31}, T_{36}, T_{37}	T_3, T_5, T_{10}, T_{11}, T_{12}, T_{19}, T_{26}, T_{13}, T_{29}, T_{32}, T_{33}
	< 90.28	90.28- 98.22	> 98.22
Number of seeds per fruit	T_1, T_3, T_5, T_9, T_{14}, T_{18}, T_{19}, T_{20}, T_{24}, T_{25}, T_{26}, T_{29}, T_{30}, T_{32}, T_{33}, T_{36}, T_{37}	T_8, T_{10}, T_{12}, T_{28}, T_{34}, T_{35}	T_2, T_4, T_6, T_7, T_{11}, T_{13}, T_{15}, T_{16}, T_{17}, T_{21}, T_{22}, T_{23}, T_{27}, T_{31}
	< .4241	.4241-.4890	> .4890
100-seed weight (g)	T_1, T_6, T_{10}, T_{11}, T_{13}, T_{15}, T_{18}, T_{19}, T_{20}, T_{23}, T_{24}, T_{34},T_{37}	T_4, T_5, T_{16}, T_{17}, T_{21}, T_{30}	T_2, T_3, T_4, T_7, T_8, T_9, T_{12}, T_{22}, T_{25}, T_{26}, T_{27}, T_{28}, T_{29}, T_{31}, T_{32}, T_{33}, T_{35}, T_{36}
	< 6.41	6.41-7.56	>7.56
Fruit length (cm)	T_6, T_{14}, T_{15}, T_{18}, T_{19}, T_{20}, T_{22}, T_{23}, T_{31}, T_{37}	T_2, T_3, T_5, T_9, T_{12}, T_{13}, T_{16}, T_{27}, T_{30}, T_{33}, T_{36}	T_1, T_4, T_7, T_8, T_{10}, T_{11}, T_{17}, T_{21}, T_{24}, T_{25}, T_{26}, T_{28}, T_{29}, T_{32}, T_{34}, T_{35}
	< 4.85	4.85-5.78	> 5.78
Fruit girth (cm)	T_5, T_8, T_9, T_{10}, T_{12}, T_{17}, T_{18}, T_{19}, T_{20}, T_{24}, T_{25}, T_{27}, T_{32}, T_{33}, T_{34}, T_{36}, T_{37}	T_{11}, T_{14}, T_{16}, T_{21}, T_{29}, T_{35}	T_1, T_2, T_3, T_4, T_6, T_7, T_{13}, T_{15}, T_{22}, T_{23}, T_{26}, T_{28}, T_{30}, T_{31}
	< 82.37	82.37-126.55	> 126.55
Fruit yield per plant (g)	T_6, T_8, T_9, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}, T_{21}, T_{22},T_{23}, T_{27}, T_{34}, T_{35}, T_{36}, T_{37}	T_5, T_7, T_{11}, T_{12}, T_{24}, T_{25}, T_{31}, T_{33}	T_1, T_2, T_3, T_4, T_{10}, T_{13}, T_{26}, T_{28}, T_{29}, T_{30}, T_{32}
	< 38.17	38.17 - 47.74	> 47.74
Plant height (cm)	T_6, T_9, T_{14}, T_{15}, T_{16}, T_{18}, T_{20}, T_{22}, T_{23}, T_{30}, T_{31}, T_{37}	T_1, T_2, T_3, T_4, T_7, T_{10}, T_{11}, T_{12}, T_{13}, T_{19}, T_{21}, T_{26}, T_{27}, T_{28}, T_{29}, T_{34}, T_{35}, T_{36}	T_5, T_8, T_{17}, T_{24}, T_{25}, T_{32}, T_{33}

Table 3 (continued)

Character	Poor	Average	Better
	< 2.79	2.79-3.88	> 3.88
Number of primary branches per plant	T_6, T_{15}, T_{33}, T_{36}	T_1, T_3, T_4, T_5, T_7, T_8, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}, T_{21}, T_{22}, T_{23}, T_{24}, T_{25}, T_{28}, T_{29}, T_{31}, T_{32}, T_{34}, T_{35}, T_{37}	T_2, T_9, T_{26}, T_{27}, T_{30}
	< 15.97	15.97-22.16	> 22.16
Number of secondary branches per plant	T_6, T_7, T_{15}, T_{21}, T_{22}, T_{33}, T_{36}	T_1, T_2, T_3, T_4, T_5, T_8, T_9, T_{11}, T_{13}, T_{14}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}, T_{23}, T_{24}, T_{25}, T_{28}, T_{31}, T_{34}, T_{35}, T_{37}	T_{10}, T_{12}, T_{26}, T_{27}, T_{29}, T_{30}, T_{32}
	> 67.30	63.07-67.30	< 63.07
Days to first flower (days)	T_1, T_2, T_5, T_8, T_{12}, T_{14}, T_{15}, T_{17}, T_{18}, T_{20}, T_{22}, T_{24}, T_{25}, T_{27}, T_{33}, T_{36}, T_{37}	T_{13}, T_{21}, T_{28}, T_{31}, T_{32}, T_{35}	T_3, T_4, T_6, T_7, T_9, T_{10}, T_{11}, T_{16}, T_{19}, T_{23}, T_{26}, T_{29}, T_{30}, T_{34}
	< 62.67	62.67-71.48	> 71.48
Number of flowers per plant	T_2, T_6, T_7, T_8, T_{14}, T_{15}, T_{16}, T_{19}, T_{20}, T_{22}, T_{23}, T_{26}, T_{31}, T_{34}, T_{35}, T_{36}, T_{37}	T_9, T_{21}, T_{27}, T_{28}, T_{33}	T_1, T_3, T_4, T_5, T_{10}, T_{11}, T_{12}, T_{13}, T_{17}, T_{18}, T_{24}, T_{25}, T_{29}, T_{30}, T_{32}
	<101.44	101.44-105.08	> 105.08
Fruiting span (days)	T_2, T_5, T_6, T_8, T_{12}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}, T_{20}, T_{21}, T_{23}, T_{25}, T_{27}, T_{33}, T_{35}, T_{37}	T_{22}, T_{24}, T_{31}, T_{32}, T_{36}	T_1, T_3, T_4, T_7, T_9, T_{10}, T_{11}, T_{13}, T_{19}, T_{26}, T_{28}, T_{29}, T_{30}, T_{34}
	< 165.40	165.40-170.81	> 170.81
Crop duration (days)	T_5, T_6, T_8, T_{12}, T_{14}, T_{15}, T_{16}, T_{18}, T_{20}, T_{21}, T_{23}, T_{33}, T_{34}, T_{35}, T_{37}	T_{17}, T_{19}, T_{22}, T_{25}, T_{27}, T_{31}, T_{32}, T_{36}	T_1, T_2, T_3, T_4, T_7, T_9, T_{10}, T_{11}, T_{13}, T_{24}, T_{26}, T_{28}, T_{29}, T_{30}
	> 17.69	12.34-17.69	<12.34
Vulnerability index	T_4, T_6, T_8, T_{17}, T_{21}, T_{22}, T_{25}, T_{34}, T_{35}	T_1, T_2, T_3, T_5, T_7, T_9, T_{10}, T_{14}, T_{15}, T_{16}, T_{18}, T_{19}, T_{23}, T_{24}, T_{26}, T_{28}, T_{29}, T_{30}, T_{32}, T_{33}	T_{11}, T_{12}, T_{13}, T_{20}, T_{27}, T_{31}, T_{36}, T_{37}

Hundred seed weight was less than 0.4241 g for 13 genotypes (poor) whereas it was more than 0.4890 g for 18 genotypes (better). Only six genotypes (0.4241-0.4890 g) fell in the average class.

Length of fruit of 11 genotypes varied from 6.41 cm to 7.56 cm (average) whereas ten genotypes had fruits shorter than 6.41 cm and 16 genotypes had fruits longer than 7.56 cm.

Seventeen genotypes had fruit girth less than 4.85 cm (poor) while 14 genotypes had more than 5.78 cm (better). The average class comprised of six genotypes lying within the range of 4.85 cm to 5.78 cm.

Eighteen genotypes were low yielders (poor) producing less than 82.37 g per plant while 11 genotypes producing more than 126.55 g per plant were included under the better class. The average class was made up of eight genotypes (82.37 g to 126.55 g).

For plant height, 12 genotypes were grouped under poor (< 38.17 cm), 18 under average (38.17 - 47.74 cm) and seven under the better category (> 47.74 cm).

The average category had the largest number (28) of genotypes lying in the range 2.79 to 3.88 for the trait number of primary branches. Five genotypes were classified as better (> 3.88) and four as poor (< 2.79).

Seven genotypes each were included in the poor (< 15.97) and better (> 22.16) categories for the trait number of secondary branches whereas the remaining 23 genotypes were included in the average class (15.97 - 22.16).

Fourteen genotypes took less than 63.07 days to produce the first flower and were grouped under the better class while 17 genotypes took more than 67.30 days (poor). The remaining six genotypes were grouped in the average category (63.07 - 67.30 days).

The number of flowers produced was less than 62.67 for 17 genotypes (poor) while it was more than 71.48 for 15 genotypes (better). The average class consisted of five genotypes with a range of 62.67 to 71.48.

The fruiting span was less than 101.44 days for 18 genotypes (poor). Five genotypes having the range of 101.44 to 105.08 days were classified as average and 14 genotypes with more than 105.08 days were grouped in the better class.

The crop duration was less than 165.40 days for 15 genotypes (poor) whereas it was more than 170.81 days for 14 genotypes (better). Eight genotypes fell under the average class (165.40 - 170.81 days).

Vulnerability index was less than 12.34 (better) for eight genotypes while it was more than 17.69 for nine genotypes (poor). Twenty genotypes lying within the range of 12.34 to 17.69 were included in the average class.

4.1.1.3 Components of variability

The details of the components of variance *viz.*, phenotypic, genotypic and environmental variances are given in Table 4.

Table 4. Genetic parameters

Character	Variance			Coefficient of variation			Heritability (%)	Genetic advance (as % of mean)
	σ^2p	σ^2g	σ^2e	PCV	GCV	ECV		
Average fruit weight (g)	1.95	1.87	0.09	45.54	44.50	1.04	95.47	89.56
Number of fruits per plant	390.36	350.43	39.93	53.06	50.27	2.79	89.77	98.12
Number o seeds per fruit	685.26	673.45	11.81	27.78	27.54	0.24	98.28	56.23
100-seed weight (g)	0.01	0.01	0.00	24.79	24.01	0.78	93.83	47.91
Fruit length (cm)	3.80	3.55	0.25	27.90	26.98	0.92	93.55	53.76
Fruit girth (cm)	3.11	2.95	0.16	33.17	32.30	0.87	94.83	64.78
Fruit yield per plant (g)	4367.37	4001.51	365.86	63.27	60.56	2.71	91.62	119.41
Plant height (cm)	70.70	53.52	17.18	19.58	17.03	2.54	75.69	30.53
Number of primary branches	0.39	0.18	0.22	18.91	12.57	6.34	44.21	17.22
Number of secondary branches	18.37	11.19	7.18	22.49	17.55	4.94	60.92	28.22
Days to first flower (days)	65.97	62.62	3.35	12.46	12.14	0.32	94.92	24.36
Number of flowers per plant	448.22	433.66	14.56	31.57	31.05	0.52	96.75	62.91
Fruiting span (days)	149.87	147.39	2.48	11.86	11.76	0.1	98.34	24.02
Crop duration (days)	52.42	46.93	5.49	4.31	4.08	0.23	89.53	7.94
Vulnerability index	28.98	23.60	5.39	35.85	32.35	3.50	81.42	60.12

4.1.2 Coefficient of variation

The phenotypic, genotypic and environmental coefficients of variation were worked out and are furnished in Table 4.

4.1.2.1 Phenotypic coefficient of variation

The phenotypic coefficient of variation (PCV) was highest for fruit yield per plant (63.27) while it was lowest for crop duration (4.31). Other traits showing high PCV were number of fruits per plant (53.06), average fruit weight (45.54), vulnerability index (35.85), fruit girth (33.17) and number of flowers per plant (31.57) (Fig. 3).

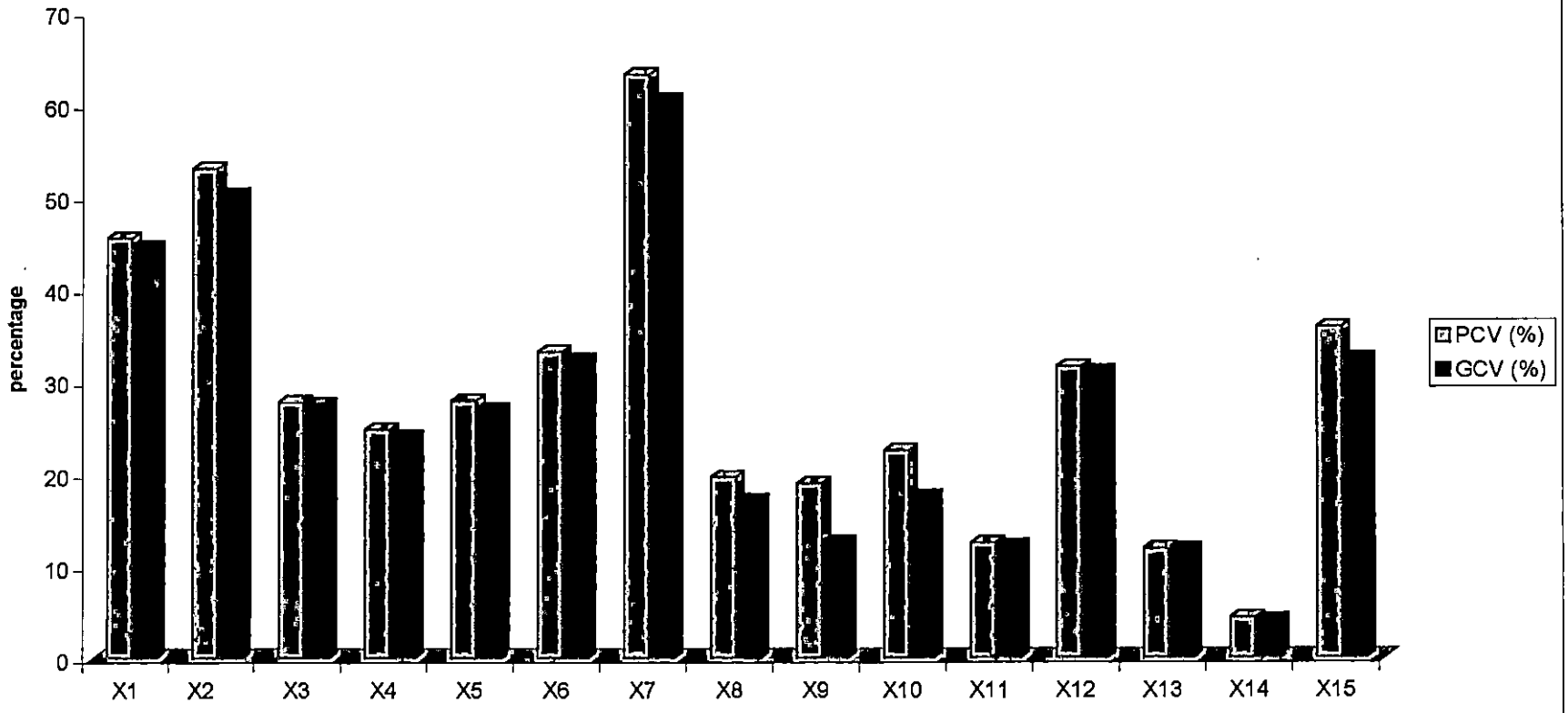
4.1.2.2 Genotypic coefficient of variation

Genotypic coefficient of variation (GCV) ranged from 4.08 for crop duration to 60.56 for fruit yield per plant (Fig. 3). High values of GCV were also obtained for number of fruits per plant (50.27), average fruit weight (44.50), vulnerability index (32.35), fruit girth (32.30) and number of flowers per plant (31.05).

4.1.2.3 Environmental coefficient of variation

The environmental coefficient of variation was low for most of the traits except number of primary branches (6.34), number of secondary branches (4.94) and vulnerability index (3.50) indicating greater influence of environment on these characters.

Fig. 3. Phenotypic and genotypic coefficients of variation for fifteen characters



X1- Average fruit weight
X2- Number of fruits per plant
X3- Number of seeds per fruit
X4- 100 seed weight
X5- Fruit length
X6- Fruit girth
X7- Fruit yield per plant
X8-Plant height
X9- Number of primary branches
X10- Number of secondary branches
X11- Days to first flower
X12- Number of flowers per plant
X13- Fruiting span
X14- Crop duration
X15-Vulnerability index

4.1.3 Heritability (In broad sense)

Moderate to high heritability estimates were recorded for the different traits under study (Table 4). Heritability was highest for fruiting span (98.34 %) followed by number of seeds per fruit (98.28 %), number of flowers per plant (96.75 %) and average fruit weight (95.47 %). Fruit yield per plant also showed high heritability (91.62 %). The lowest value of heritability was recorded for number of primary branches (44.21 %) followed by number of secondary branches (60.92 %) (Fig. 4).

4.1.4 Genetic advance (as percentage of mean)

The highest estimate of genetic advance (Table 4) obtained was 119.41 per cent for fruit yield per plant (Fig. 4). Other traits with high genetic advance included number of fruits per plant (98.12 %), average fruit weight (89.56 %), fruit girth (64.78 %) and number of flowers per plant (62.91 %). However, crop duration showed low genetic advance (7.94 %) and number of primary branches recorded moderate genetic advance (17.22 %).

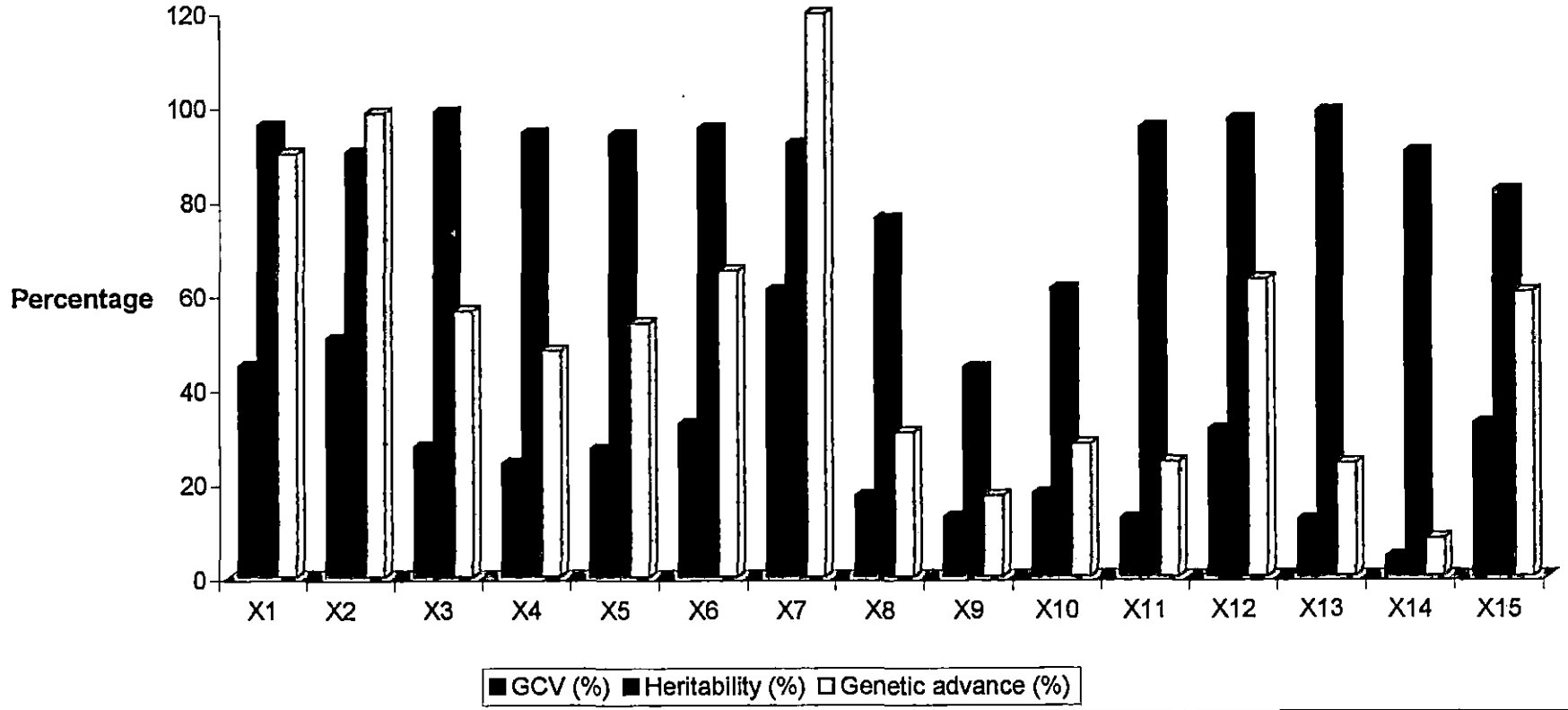
4.1.5 Correlation analysis

The correlation between different traits was computed as phenotypic, genotypic and environmental correlation coefficients.

4.1.5.1 Phenotypic correlation coefficient

The phenotypic correlation coefficients are presented in Table 5.

Fig.4. Genotypic coefficient of variation, heritability and genetic advance for fifteen characters



X1- Average fruit weight
X2- Number of fruits per plant
X3- Number of seeds per fruit
X4- 100 seed weight
X5- Fruit length
X6- Fruit girth
X7- Fruit yield per plant
X8-Plant height
X9- Number of primary branches
X10- Number of secondary branches
X11- Days to first flower
X12- Number of flowers per plant
X13- Fruiting span
X14- Crop duration
X15-Vulnerability index

Average fruit weight showed high positive phenotypic correlation with fruit girth (0.7619), crop duration (0.5945), fruit yield per plant (0.5572), fruiting span (0.5489) and fruit length (0.4172).

A strong positive association was observed for number of fruits per plant with fruit yield per plant (0.6640), number of secondary branches (0.5965) and number of flowers per plant (0.5706). There was high negative correlation of number of fruits per plant with number of seeds per fruit (–0.4313) and vulnerability index (–0.4109).

Number of seeds per fruit had positive correlation with fruit girth (0.4514) and negative correlation with number of fruits per plant (–0.4313). All the other traits except vulnerability index were negatively correlated with it.

Hundred seed weight showed positive correlation with plant height (0.3761), average fruit weight (0.3300) and yield per plant (0.3076).

The inter relationship of fruit length with plant height (0.4890), number of flowers per plant (0.4802) yield per plant (0.4630), average fruit weight (0.4172) and crop duration (0.3703) was positive.

Fruit girth had high positive correlation with average fruit weight (0.7619), fruiting span (0.4819), number of seeds per fruit (0.4514), crop duration (0.4439) and yield per plant (0.4280). But it had strong negative association with days to first flower (–0.3239).

Yield per plant showed high positive association with number of fruits per plant (0.6640), crop duration (0.6214), fruiting span (0.6174), average fruit weight (0.5572),

Table 5. Phenotypic correlation coefficients

Characters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
Average fruit weight (X_1)	1.0000														
No.of fruits per plant (X_2)	-0.1644	1.0000													
No.of seeds per fruit (X_3)	0.2582*	-0.4313**	1.0000												
100-seed weight (X_4)	0.3300**	0.1538	-0.0254	1.0000											
Fruit length (X_5)	0.4172**	0.2409*	-0.2742*	0.2718*	1.0000										
Fruit girth (X_6)	0.7619**	-0.1870	0.4514**	0.1257	0.0002	1.0000									
Yield/plant (X_7)	0.5572**	0.6640**	-0.2193	0.3076**	0.4630**	0.4280**	1.0000								
Plant height (X_8)	0.0461	0.3193**	-0.1745	0.3761**	0.4890**	-0.2436*	0.1985	1.0000							
No.of primary branches (X_9)	0.0725	0.2094	-0.1130	0.0364	0.0322	0.0115	0.2546*	-0.0784	1.0000						
No.of Secondary branches (X_{10})	-0.0686	0.5965**	-0.2818*	0.0718	0.2913*	-0.1100	0.4813**	0.2503*	0.5322**	1.0000					
Days to first flower (X_{11})	-0.2813*	-0.1557	-0.0783	0.1427	-0.0931	-0.3239**	-0.3669**	0.2170	0.0344	-0.0898	1.0000				
No. of flowers per plant(X_{12})	0.0604	0.5706**	-0.2590*	0.1421	0.4802**	-0.0430	0.5159**	0.4506**	0.2097	0.5865**	-0.0418	1.0000			
Fruiting span (X_{13})	0.5489**	0.2741*	-0.0126	0.0674	0.2919*	0.4819**	0.6174**	-0.0075	0.1026	0.1830	-0.8080	0.2578*	1.0000		
Crop duration (X_{14})	0.5945**	0.2982*	-0.0932	0.2672*	0.3703**	0.4439**	0.6214**	0.2043	0.2280	0.2037	-0.2521*	0.3648**	0.7663**	1.0000	
Vulnerability index (X_{15})	0.1948	-0.4109**	0.2449*	0.1472	-0.0071	0.0948	-0.2307	0.1213	-0.1873	-0.3801**	-0.0266	-0.1993	-0.0650	-0.1467	1.0000

* significant at 5 % level **significant at 1 % level

number of flowers per plant (0.5159), number of secondary branches (0.4813) and fruit length (0.4630) whereas its correlation with days to first flower was strongly negative (–0.3669).

Plant height was strongly correlated with fruit length (0.4890), number of flowers per plant (0.4506), 100-seed weight (0.3761) and number of fruits per plant (0.3193) but had a negative association with fruit girth (–0.2436).

Number of primary branches had positive correlation with number of secondary branches (0.5322) and yield per plant (0.2546).

There was strong positive association of number of secondary branches with number of fruits per plant (0.5965), number of flowers per plant (0.5865), number of primary branches (0.5322), and yield per plant (0.4813) while the correlation was negative with vulnerability index (–0.3801).

Days to first flower had a strong negative association with fruiting span (–0.8080), yield per plant (–0.3669), fruit girth (–0.3239) and average fruit weight (–0.2813).

High positive correlation was recorded for number of flowers per plant with number of secondary branches (0.5865), number of fruits per plant (0.5706), yield per plant (0.5159), fruit length (0.4802) and plant height (0.4506).

The association of fruiting span with crop duration (0.7663), yield per plant (0.6174), average fruit weight (0.5489) and fruit girth (0.4819) was strong and positive while it was highly negative with days to first flower (–0.8080).

Crop duration recorded positive correlation with fruiting span (0.7663), yield per plant (0.6214), average fruit weight (0.5945) and fruit girth (0.4439) whereas its association with days to first flower was negative (–0.2521).

Vulnerability index was negatively correlated with number of fruits per plant (–0.4109) and number of secondary branches (–0.3801). Its association with most of the other traits also was negative.

4.1.5.2 Genotypic correlation coefficient

The genotypic correlation coefficients are furnished in Table 6.

Average fruit weight showed positive genotypic association with all the characters except number of fruits per plant, number of secondary branches and days to first flower. However, its correlation with fruit girth (0.7896), crop duration (0.6436), fruiting span (0.5677) and yield per plant (0.5665) was substantial.

The inter relationship of number of fruits per plant was negative with average fruit weight, number of seeds per fruit, fruit girth, vulnerability index and days to first flower while it was positive for the rest of the traits. It showed high positive correlation with number of secondary branches (0.7173), yield per plant (0.6593) and number of flowers per plant (0.5969). Its negative correlation with vulnerability index (–0.4770) and number of seeds per fruit (–0.4566) was substantial.

Most of the traits were negatively correlated with number of seeds per fruit except fruit girth, average fruit weight and vulnerability index. It had high positive correlation

Table 6. Genotypic correlation coefficients

Characters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
Average fruit weight (X_1)	1.0000														
No.of fruits per plant(X_2)	-0.1694	1.0000													
No.of seeds per fruit (X_3)	0.2628	-0.4566	1.0000												
100-seed weight (X_4)	0.3615	0.1589	-0.0240	1.0000											
Fruit length (X_5)	0.4216	0.2576	-0.2883	0.2920	1.0000										
Fruit girth (X_6)	0.7896	-0.2108	0.4610	0.1281	-0.0138	1.0000									
Yield/plant (X_7)	0.5665	0.6593	-0.2292	0.3411	0.4767	0.4458	1.0000								
Plant height (X_8)	0.0440	0.3644	-0.2118	0.4117	0.5520	-0.3120	0.2179	1.0000							
No.of primary branches (X_9)	0.1003	0.2587	-0.1663	0.0680	0.1175	0.0099	0.3302	-0.1501	1.0000						
No.of Secondary branches (X_{10})	-0.0962	0.7173	-0.3730	0.0881	0.3695	-0.1484	0.5666	0.2806	0.8037	1.0000					
Days to first flower (X_{11})	-0.2945	-0.1528	-0.0757	0.1489	-0.0930	-0.3345	-0.3764	0.2517	0.0199	-0.0821	1.0000				
No. of flowers per plant(X_{12})	0.0542	0.5969	-0.2657	0.1535	0.4985	-0.0444	0.5314	0.5103	0.2950	0.7212	-0.0452	1.0000			
Fruiting span (X_{13})	0.5667	0.2950	-0.0108	0.0628	0.3021	0.4921	0.6516	-0.0129	0.1653	0.2413	-0.8331	0.2670	1.0000		
Crop duration (X_{14})	0.6436	0.3498	-0.0941	0.2869	0.4024	0.4800	0.7017	0.2556	0.2987	0.3319	-0.3320	0.3905	0.7993	1.0000	
Vulnerability index (X_{15})	0.1984	-0.4770	0.2765	0.1940	0.0069	0.1065	-0.2766	0.1703	-0.2628	-0.4791	-0.0336	-0.2252	-0.0700	-0.1629	1.0000

only with fruit girth (0.4610). High negative correlation coefficients were recorded for number of fruits per plant (–0.4566) and number of secondary branches (–0.3730).

The correlation of 100-seed weight was positive and high with plant height (0.4117) and average fruit weight (0.3615).

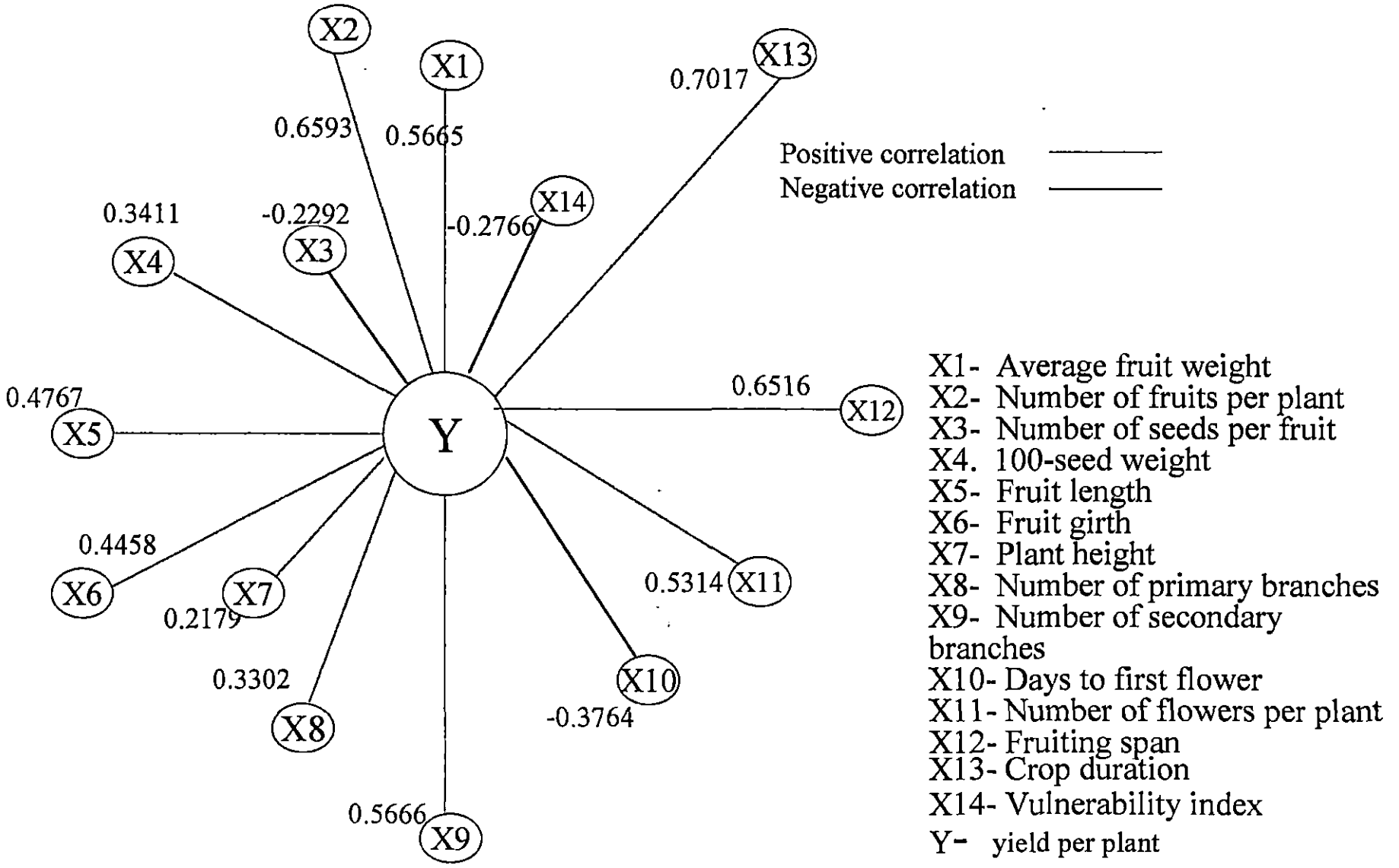
Except number of seeds per fruit, fruit girth and days to first flower, all the other traits showed positive association with fruit length. Highest correlation was with plant height (0.5520) followed by number of flowers per plant (0.4985), yield per plant (0.4767) and average fruit weight (0.4216).

The association of fruit girth was positive with eight traits and negative with six traits. Its correlation with average fruit weight (0.7896), fruiting span (0.4921), crop duration (0.4800) and number of seeds per fruit (0.4610) was high and positive.

Yield per plant was positively associated with most of the traits other than number of seeds per fruit, vulnerability index and days to first flower (Fig. 5). Correlation was high with crop duration (0.7017), number of fruits per plant (0.6593), fruiting span (0.6516), number of secondary branches (0.5666), average fruit weight (0.5665), number of flowers per plant (0.5314) and fruit length (0.4767).

Plant height showed negative association with number of seeds per fruit, number of primary branches, fruit girth and fruiting span while with the remaining ten traits, it was positive. Correlation with fruit length (0.5520) and number of flowers per plant (0.5103) was high.

Fig. 5. Genotypic correlation of yield with other characters



Number of primary branches was positively associated with all the traits except number of seeds per fruit, plant height and vulnerability index. High value of correlation was noticed only with number of secondary branches (0.8037).

The correlation of number of secondary branches with average fruit weight, number of seeds per fruit, fruit girth, vulnerability index and days to first flower was negative while it was positive for the remaining traits. The correlation with number of primary branches (0.8037), number of fruits per plant (0.7173), number of flowers per plant (0.7212) and yield per plant (0.5666) was high and positive.

Most of the traits showed negative correlation with days to first flower except number of primary branches, plant height and 100-seed weight. Only fruiting span (-0.8331) had a high correlation with it.

There was positive association of number of flowers per plant with most of the characters other than number of seeds per fruit, fruit girth, vulnerability index and days to first flower. Number of secondary branches (0.7212), number of fruits per plant (0.5969), yield per plant (0.5314), plant height (0.5103) and fruit length (0.4985) showed high positive correlation with number of flowers.

Fruiting span recorded a positive association with ten traits whereas negative correlation was observed with number of seeds per fruit, plant height, vulnerability index and days to first flower. High negative correlation with days to first flower (–0.8331) and positive correlation with yield per plant (0.6516), average fruit weight (0.5677) and fruit girth (0.4921) was noticed.

A positive correlation of crop duration with all the traits other than number of seeds per fruit, vulnerability index and days to first flower was noticed. Its correlation with fruiting span (0.7993), yield per plant (0.7017), average fruit weight (0.6436) and fruit girth (0.4800) was high.

Six traits were positively correlated with vulnerability index while eight traits showed negative correlation with it. Its negative association with number of secondary branches (–0.4791) and number of fruits per plant (–0.4770) was high. Positive correlation with any trait was not substantial.

4.1.5.3 Environmental correlation coefficient

The environmental correlation coefficients are presented in Table 7. Most of the characters showed a low value for environmental correlation.

However, high positive correlation was observed for yield per plant with number of fruits per plant (0.7141) and average fruit weight (0.4456). Crop duration also exhibited a strong positive association with days to first flower (0.7399).

4.1.6 Path coefficient analysis

The direct and indirect effects of the component characters on yield was estimated using path coefficient analysis (Table 8). The characters with high genotypic correlation to yield were selected and they included average fruit weight, number of fruits per plant, number of flowers per plant, number of secondary branches, 100-seed weight, fruit length, fruit girth, days to first flower, fruiting span and crop duration (Fig. 6).

Table 8. Path coefficient analysis

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Genotypic correlation coefficient
Average fruit weight (X_1)	**0.6581**	-0.1119	-0.0142	0.0023	0.0818	-0.0118	0.5712	0.0041	-1.6773	1.0642	0.5665
Number of fruits (X_2)	-0.1115	**0.6608**	-0.0062	0.0014	-0.0218	0.0880	0.2964	0.0455	-0.8716	0.5784	0.6593
100-seed weight (X_3)	0.2379	0.1050	**-0.0392**	0.0016	0.0133	0.0108	-0.2888	0.0117	-0.1855	0.4744	0.3411
Fruit length (X_4)	0.2775	0.1702	-0.0114	**0.0054**	-0.0014	0.0453	0.1804	0.0380	-0.8925	0.6653	0.4767
Fruit girth (X_5)	0.5196	-0.1393	-0.0050	-0.0001	**0.1036**	-0.0182	0.6488	-0.0034	-1.4539	0.7937	0.4458
Number of secondary branches (X_6)	-0.0633	0.4740	-0.0035	0.0020	-0.0154	**0.1226**	0.1592	0.0550	-0.7129	0.5488	0.5666
Days to first flower (X_7)	-0.1938	-0.1010	-0.0058	-0.0005	-0.0347	-0.0101	**-1.9396**	-0.0034	2.4614	-0.5489	-0.3764
Number of flowers (X_8)	0.0357	0.3944	-0.0060	0.0027	-0.0046	0.0884	0.0877	**0.0763**	-0.7888	0.6457	0.5314
Fruiting span (X_9)	0.3736	0.1949	-0.0025	0.0016	0.0510	0.0296	1.6158	0.0204	**-2.9545**	1.3216	0.6516
Crop duration (X_{10})	0.4236	0.2311	-0.0112	0.0022	0.0497	0.0407	0.6439	0.0298	-2.3615	**1.6534**	0.7017

Residual, R = 0.0810

Figures in bold are the direct effects

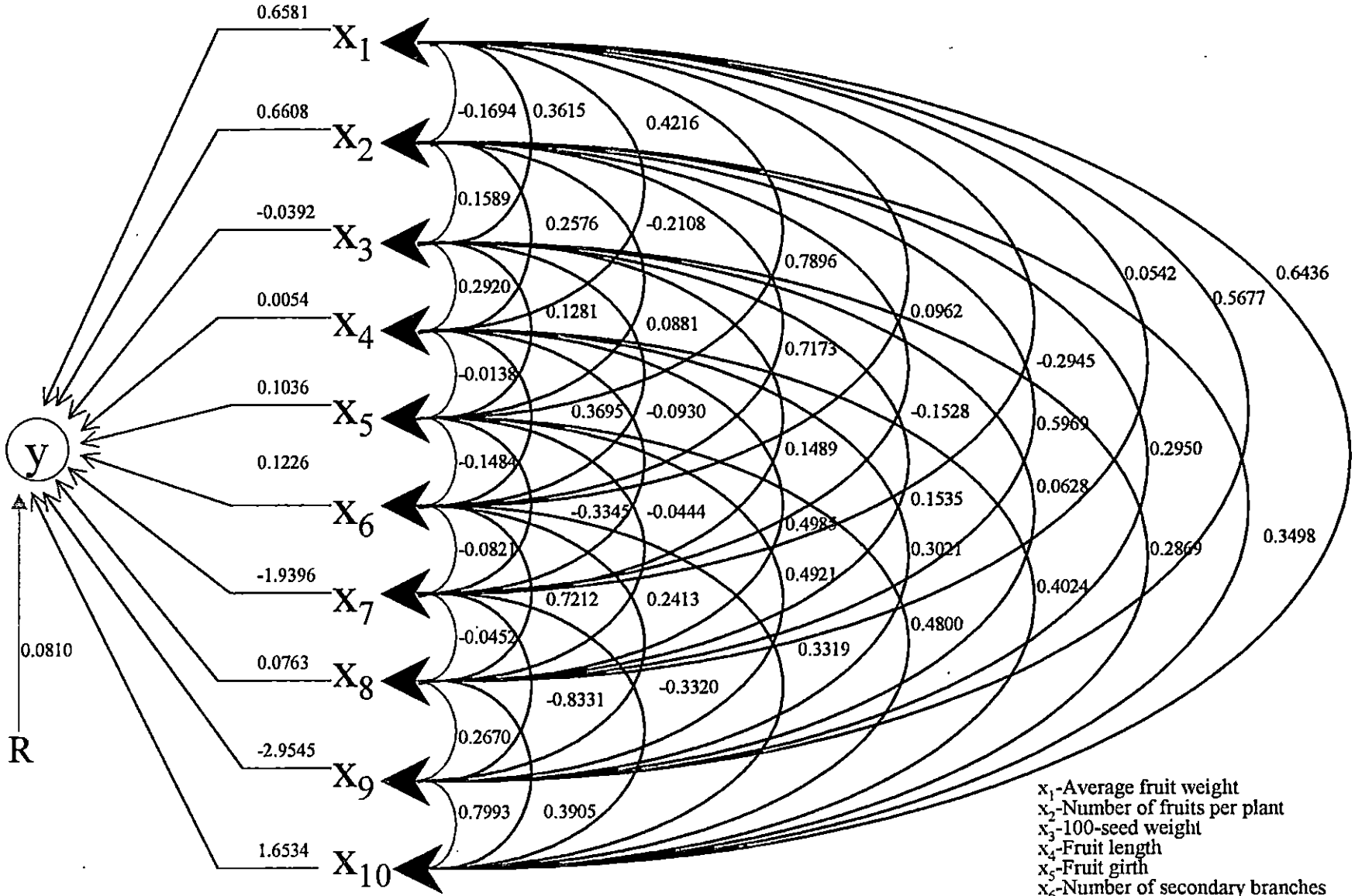
Except 100-seed weight, fruiting span and days to first flower, all the traits had a positive direct effect on yield. The direct effects of average fruit weight, number of fruits per plant, days to first flower, fruiting span and crop duration on yield were high.

The direct effect of average fruit weight on yield was positive and high (0.6581). Its indirect effect via crop duration (1.0642) and days to first flower (0.5712) were also high and positive whereas it was negative via fruiting span (–1.6773). Its genotypic correlation with yield was positive (0.5665).

Number of fruits per plant had high positive direct (0.6608) and indirect effect through crop duration (0.5784) and days to first flower (0.2964). But its indirect effects via fruiting span (–0.8716) and average fruit weight (–0.1115) were negative. The genotypic correlation coefficient (0.6593) was close to the direct effect indicating a strong influence of the character on yield.

The direct effect of number of flowers per plant was positive (0.0763), but it exerted greater influence on yield indirectly via crop duration (0.6457) and number of fruits per plant (0.3944). This trait had a strong negative indirect effect through fruiting span (–0.7888). Its correlation with yield was positive and high (0.5314).

Number of secondary branches had a positive direct effect on yield (0.1226). The indirect effect of the trait via crop duration (0.5488), number of fruits per plant (0.4740) and days to first flower (0.1592) was positive whereas it was negative through fruiting span (–0.7129).



Direct effect shown in blue arrows.
Intercorrelations shown in curved arrows

Fig. 6. Path diagram of direct effects and inter correlations

x_1-Average fruit weight
x_2-Number of fruits per plant
x_3-100-seed weight
x_4-Fruit length
x_5-Fruit girth
x_6-Number of secondary branches
x_7-Days to first flower
x_8-Number of flowers per plant
x_9-Fruiting span
x_{10}-Crop duration
Y-Yield per plant
R-Residual

Hundred seed weight had negative direct (–0.0392) and indirect effect through days to first flower (–0.2888) and fruiting span (–0.1855). Its positive correlation with yield (0.3411) was the result of the positive indirect effect via crop duration (0.4744) and average fruit weight (0.2379).

The direct effect of fruit length was positive, but negligible (0.0054) though its genotypic correlation with yield was high (0.4767). Its direct effect via crop duration (0.6653) and number of fruits per plant (0.2775) was positive while that via fruiting span (–0.8925) was negative.

Fruit girth showed positive direct (0.1036) and indirect effect through crop duration (0.7937), days to first flower (0.6488) and average fruit weight (0.5196). The indirect effects through all the other traits were negative. Its genotypic correlation with yield was positive (0.4458).

The direct effect (–1.9396) as well as correlation with yield (–0.3764) were negative for days to first flower. Its indirect effect through the remaining traits was negative except fruiting span which showed a high positive value (2.4614).

Fruiting span showed a high negative direct effect on yield (–2.9545) though it had a positive correlation with yield (0.6516). It exerted positive indirect effect through all the traits except 100-seed weight. Its indirect effect through days to first flower (1.6158), crop duration (1.3216), and average fruit weight (0.3736) was high and contributed to its positive correlation with yield (0.6516).

Crop duration had positive direct (1.6534) as well as indirect effect on yield through days to first flower (0.6439), average fruit weight (0.4236) and number of fruits (0.2311). The highest negative indirect effect on yield was exerted by crop duration via fruiting span (–2.3615).

The ten traits taken for path analysis explained 91.92 per cent of the variation in yield as evidenced by the residual value of 0.0810.

4.1.7 Selection index

Selection index was computed based on all the 15 traits and is provided in Table 9. The index values were closer for genotypes with traits of similar nature.

The selection index was highest for the genotype T_3 (3023.30) followed by T_{13} (2942.07), T_{26} (2811.84), T_{29} (2808.22) and T_1 (2746.29) while it was lowest for the genotypes T_{37} (1983.57) and T_{20} (1929.12).

4.1.8 Genetic divergence analysis

The 37 genotypes were subjected to Mahalanobis D^2 analysis based on 11 characters *viz*., average fruit weight, number of fruits per plant, number of flowers per plant, number of secondary branches, 100-seed weight, fruit length, fruit girth, fruit yield per plant, vulnerability index, days to first flower and crop duration.

The genotypes were grouped into four clusters based on Tocher's method. (Table10).

Table 9. Selection index

Genotype	Selection index	Rank
T_1	2746.29	5
T_2	2577.58	10
T_3	3023.30	1
T_4	2658.75	8
T_5	2503.18	14
T_6	2114.23	30
T_7	2562.18	12
T_8	2097.89	31
T_9	2322.85	21
T_{10}	2720.83	6
T_{11}	2564.66	11
T_{12}	2549.29	13
T_{13}	2942.07	2
T_{14}	2055.64	33
T_{15}	2007.11	35
T_{16}	2084.88	32
T_{17}	2330.69	20
T_{18}	2204.60	24
T_{19}	2127.16	28
T_{20}	1929.12	37
T_{21}	2261.33	23
T_{22}	2115.89	29
T_{23}	2016.47	34
T_{24}	2411.73	18
T_{25}	2487.14	15
T_{26}	2811.84	3
T_{27}	2322.02	22
T_{28}	2648.60	9
T_{29}	2808.22	4
T_{30}	2483.97	16
T_{31}	2449.47	17
T_{32}	2683.53	7
T_{33}	2365.81	19
T_{34}	2128.68	27
T_{35}	2180.08	25
T_{36}	2165.21	26
T_{37}	1983.57	36

Table 10. Clustering pattern of genotypes

Cluster	Number of genotypes	Genotypes
I	23	T_5, T_6, T_8, T_9, T_{12}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}, T_{21}, T_{22}, T_{23}, T_{24}, T_{25}, T_{27}, T_{33}, T_{34}, T_{35}, T_{36}, T_{37},
II	8	T_2, T_4, T_7, T_{10}, T_{11}, T_{30}, T_{31}, T_{32}
III	5	T_1, T_3, T_{13}, T_{28}, T_{29}
IV	1	T_{26}

Cluster I was the largest with 23 genotypes. Cluster II had eight and cluster III had five genotypes respectively while there was only one genotype in cluster IV.

The cluster means for 11 characters are furnished in Table 11.

Cluster IV had the maximum cluster means for average fruit weight (5.33 g), number of fruits per plant (56.07), number of secondary branches (22.80), 100-seed weight (0.6528), fruit girth (7.14), crop duration (176.00) and yield per plant (274.53). It showed the least mean values for number of flowers per plant (60.40) and days to first flower (54.53).

On the contrary, cluster I exhibited the minimum cluster means for all those traits that had maximum mean values in cluster IV, in addition to fruit length (6.44). It gave the largest cluster means for vulnerability index (15.93) and days to first flower (67.95).

The highest cluster means for number of flowers per plant (91.41) and fruit length (8.64 cm) were observed in cluster III. It also had the minimum value for vulnerability index (12.77).

Average inter and intra cluster D^2 values were calculated based on the total D^2 values and are presented in Table 12.

The intracluster distances (D values) ranged from 65.57 (cluster III) to 82.23 (cluster II). Cluster IV had only one genotype. The distance between clusters I and IV was the highest (436.26) while it was least between the clusters II and III (156.44).

Table 11. Cluster means

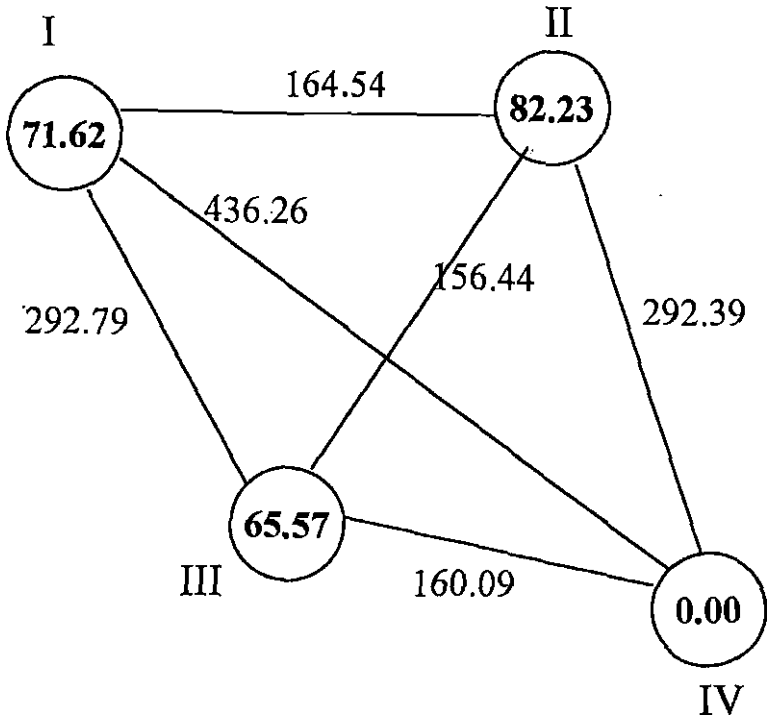
Character	Cluster				Mean
	I	II	III	IV	
Average fruit weight (g)	2.36	4.01	4.37	5.33	4.02
Number of fruits per plant	30.39	45.04	52.49	56.07	45.99
Number of flowers per plant	61.93	67.47	91.41	60.40	70.30
100-seed weight (g)	0.4377	0.4762	0.4725	0.6528	0.5098
Fruit length (cm)	6.44	7.37	8.64	8.15	7.65
Fruit girth (cm)	4.48	6.53	6.88	7.14	6.26
Fruit yield per plant (g)	63.12	139.34	204.81	274.53	170.45
Number of secondary branches	18.15	19.83	21.28	22.80	20.51
Days to first flower	67.95	60.88	61.49	54.53	61.21
Crop duration (days)	164.35	173.75	174.80	176.00	172.22
Vulnerability index	15.93	13.82	12.77	14.73	14.32

Table 12. Average inter and intra cluster D^2 values

	I	II	III	IV
I	5129.96	27073.12	85725.42	190325.57
	(71.62)	(164.54)	(292.79)	(436.26)
II		6761.96	24472.82	85489.99
		(82.23)	(156.44)	(292.39)
III			4299.08	25628.63
			(65.57)	(160.09)
IV				0
				(0)

(Average inter and intra cluster distances, (D) given in paranthesis)

Fig.7. Cluster diagram



The values in circles indicate intracluster distances and others indicate intercluster distances

The intercluster distances were much higher than the intracluster values (Fig. 7). The minimum intercluster distance (156.44) was nearly twice the maximum intracluster distance (82.23).

4.2 Reaction to leaf curl virus (Experiment II)

The 37 genotypes were screened against leaf curl virus under field conditions.

4.2.1 Vulnerability Index

Vulnerability index varied from 14.37 (T_{11}) to 55.29 (T_6). The genotypes T_{12}, T_{31}, T_{36}, T_{37} and T_{20} were on par with T_{11} whereas T_{17} and T_{33} were on par with T_6 (Table 14).

The cultivars were classified according to their reaction to leaf curl virus, estimated as vulnerability index and is furnished in Table 13. It was observed that none of the varieties showed immunity to the virus *ie*, no variety had a vulnerability index of zero and score of zero. Eight accessions, *viz.*, T_{11}, T_{12}, T_{36}, T_{37}, T_{31}, T_{20}, T_{13} and T_3 having vulnerability index between 1.00 to 25.00 and showing slight curling of terminal leaves (score 0-1) were classified under the tolerant category (Plate 3).Even Pant C-1, a resistant variety took mild infection expressing a vulnerability index of 20.00. A maximum of 27 genotypes fell under the susceptible class with the virus score ranging from one to three in most cases. This class included the genotypes with vulnerability index in the range 25.01 to 50.00. These accessions showed curling of terminal and adjacent lower leaves with some of them having blisters on leaves. Two genotypes *viz.*, T_{33} and T_6 were highly susceptible to the disease as evinced by the high vulnerability index of more than 50.00.

Table 13. Reaction to leaf curl virus

Genotype	Vulnerability index	Range of score	Reaction
T_1	31.11	1-2	S
T_2	38.02	1-3	S
T_3	25.00	1	T
T_4	40.67	1-3	S
T_5	33.99	1-2	S
T_6	55.29	2-4	HS
T_7	41.04	1-3	S
T_8	28.57	1-2	S
T_9	29.30	1-2	S
T_{10}	29.61	1-2	S
T_{11}	14.37	0-1	T
T_{12}	17.54	0-1	T
T_{13}	24.21	1-2	T
T_{14}	31.46	1-2	S
T_{15}	36.23	1-2	S
T_{16}	33.41	1-2	S
T_{17}	48.68	1-3	S
T_{18}	31.28	1-2	S
T_{19}	25.47	1	S
T_{20}	22.03	0-1	T
T_{21}	39.28	2-3	S
T_{22}	36.61	1-3	S
T_{23}	35.94	1-3	S
T_{24}	45.27	2-3	S
T_{25}	34.17	1-3	S
T_{26}	36.67	1-2	S
T_{27}	35.43	1-2	S
T_{28}	30.67	1-2	S
T_{29}	38.58	1-3	S
T_{30}	28.05	1-2	S
T_{31}	19.79	0-2	T
T_{32}	32.98	1-2	S
T_{33}	54.86	2-4	HS
T_{34}	47.60	2-3	S
T_{35}	39.19	2-3	S
T_{36}	16.12	0-1	T
T_{37}	20.00	0-1	T

Table 14. Vulnerability index and yield per plant in experiments I and II

Genotype	Experiment I with control measures		Experiment II without control measures	
	Vulnerability index	Yield per plant	Vulnerability index	Yield per plant(g)
T_1	13.84	177.93	31.11	70.33
T_2	16.67	130.00	38.02	67.40
T_3	12.37	233.27	25.00	120.30
T_4	20.00	163.40	40.67	84.03
T_5	17.50	96.33	33.99	52.13
T_6	24.90	39.00	55.29	13.67
T_7	15.37	109.53	41.04	67.80
T_8	21.93	42.70	28.57	13.60
T_9	17.10	63.47	29.30	35.10
T_{10}	16.97	177.20	29.61	83.20
T_{11}	5.75	124.67	14.37	91.87
T_{12}	6.33	90.07	17.54	65.60
T_{13}	9.10	219.53	24.21	174.70
T_{14}	15.00	73.60	31.46	35.27
T_{15}	16.77	36.20	36.23	15.33
T_{16}	17.67	41.00	33.41	20.93
T_{17}	18.83	59.10	48.68	20.93
T_{18}	15.95	52.47	31.28	30.13
T_{19}	12.37	61.80	25.47	54.23
T_{20}	8.58	61.00	22.03	40.70
T_{21}	18.50	49.47	39.28	22.50
T_{22}	25.20	25.20	36.61	11.93
T_{23}	15.00	25.67	35.94	12.47
T_{24}	13.33	112.60	45.27	45.27
T_{25}	19.17	111.53	34.17	36.53
T_{26}	14.73	274.53	36.67	150.00
T_{27}	8.77	78.67	35.43	30.07
T_{28}	15.23	189.07	30.67	74.57
T_{29}	13.33	204.27	38.58	68.47
T_{30}	14.17	134.13	28.05	54.93
T_{31}	7.42	119.20	19.79	94.90
T_{32}	14.23	156.60	32.98	74.27
T_{33}	15.00	99.07	54.86	31.80
T_{34}	22.50	52.27	47.60	23.20
T_{35}	21.27	71.47	39.19	18.53
T_{36}	7.18	64.73	16.12	54.20
T_{37}	7.63	44.27	20.00	26.87
Mean	15.02	104.46	33.20	53.72
F	14.14**	33.81**	13.95**	76.09**
CD	3.78	31.19	7.47	12.32

Plate 3
Genotypes tolerant to leaf curl virus

In addition to curling and presence of blisters on leaves, they also showed stunting of plants. The score ranged from two to four for these genotypes.

4.2.2. Yield per plant

The varieties differed significantly for yield per plant (Table 14). The highest yielding genotype was T_{13} followed by T_{26} and T_3. The genotype T_{22} showed the lowest yield which was on par with T_{23}, T_6, T_8 and T_{15}.

4.2.3 Comparison of yield and reaction to leaf curl virus in Experiment I (with control measures) and Experiment II (without control measures)

The data on yield and vulnerability index from the two experiments were subjected to weighted analysis. There was significant genotype x experiment interaction indicating the possible role of environment in the expression of the traits. The genotypes differed significantly with respect to yield per plant and vulnerability index.

4.2.3.1 Yield per plant

The genotype T_{26} was the highest yielder followed by T_{13} and T_3 while the lowest yielders were T_6, T_8, T_{15}, T_{16} and T_{21}, on par in performance (Table 15). The difference between locations was significant with the insecticide treated plot giving higher yields for all the genotypes.

Table 15. Pooled means

Genotype		Vulnerability index	Yield per plant (g)
T_1		22.47	124.13
T_2		27.34	98.70
T_3		18.68	176.79
T_4		30.33	123.72
T_5		25.75	74.23
T_6		40.10	26.33
T_7		28.21	88.67
T_8		25.25	28.15
T_9		23.20	49.28
T_{10}		23.29	130.20
T_{11}		10.06	108.27
T_{12}		11.94	77.83
T_{13}		16.65	197.12
T_{14}		23.23	54.43
T_{15}		26.50	27.77
T_{16}		25.54	30.97
T_{17}		33.76	40.02
T_{18}		23.62	41.30
T_{19}		18.92	58.02
T_{20}		15.31	50.85
T_{21}		28.89	35.99
T_{22}		30.91	18.57
T_{23}		25.47	19.07
T_{24}		29.30	78.93
T_{25}		26.67	74.03
T_{26}		25.70	212.27
T_{27}		22.10	54.37
T_{28}		22.95	131.82
T_{29}		25.96	136.37
T_{30}		21.11	94.53
T_{31}		13.61	107.05
T_{32}		23.61	115.43
T_{33}		34.93	65.43
T_{34}		35.05	37.73
T_{35}		30.23	45.00
T_{36}		11.65	59.47
T_{37}		13.85	35.57
Varieties	F	3.66**	7.83**
	CD	10.06	49.24
Location	F	231.82**	75.46**
	CD	2.34	11.45

4.2.3.2 Vulnerability Index

A low value of this index shows greater tolerance to leaf curl virus. The genotypes T_{11}, T_{36}, T_{12}, T_{31} and T_{37} showed the lowest values for vulnerability index, but they were on par with the genotypes T_{20}, T_{13}, T_3 and T_{19} (Table 15). High values of vulnerability index were observed for T_6, T_{34}, T_{33}, T_{22}, T_{35} and T_4, on par in performance. There was considerable difference between the treated and untreated plots indicating the effectiveness of insecticide treatment in reducing the disease incidence.

On comparing the performance of genotypes in both experiments, it was observed that three varieties *viz.*, T_{26}, T_3 and T_{13}, having highest yields in experiment I yielded maximum in experiment II also (Table 14). In experiment I, the highest yield was recorded by T_{26} followed by T_3 and T_{13} while in experiment II, T_{13} showed the maximum yield followed by T_{26} and T_3 (Fig. 8). Vulnerability index in experiment II was much higher than that in experiment I (Fig. 9).

4.2.4 *Correlation analysis*

Table 16. Simple correlation between yield and vulnerability index of experiments I and II

	Yield per plant in Experiment I	Yield per plant in Experiment II	Vulnerability index in Experiment I	Vulnerability index in Experiment II
	1	2	3	4
1	1.0000	0.8565**	–0.2280	–0.1014
2	0.8565**	1.0000	–0.4090*	–0.3400*
3	–0.2280	-0.4090*	1.0000	0.6543**
4	–0.1014	-0.3400*	0.6543**	1.0000

* significant at 5 % level ** significant at 1 % level

Fig. 9. Comparison of vulnerability index in experiments I and II

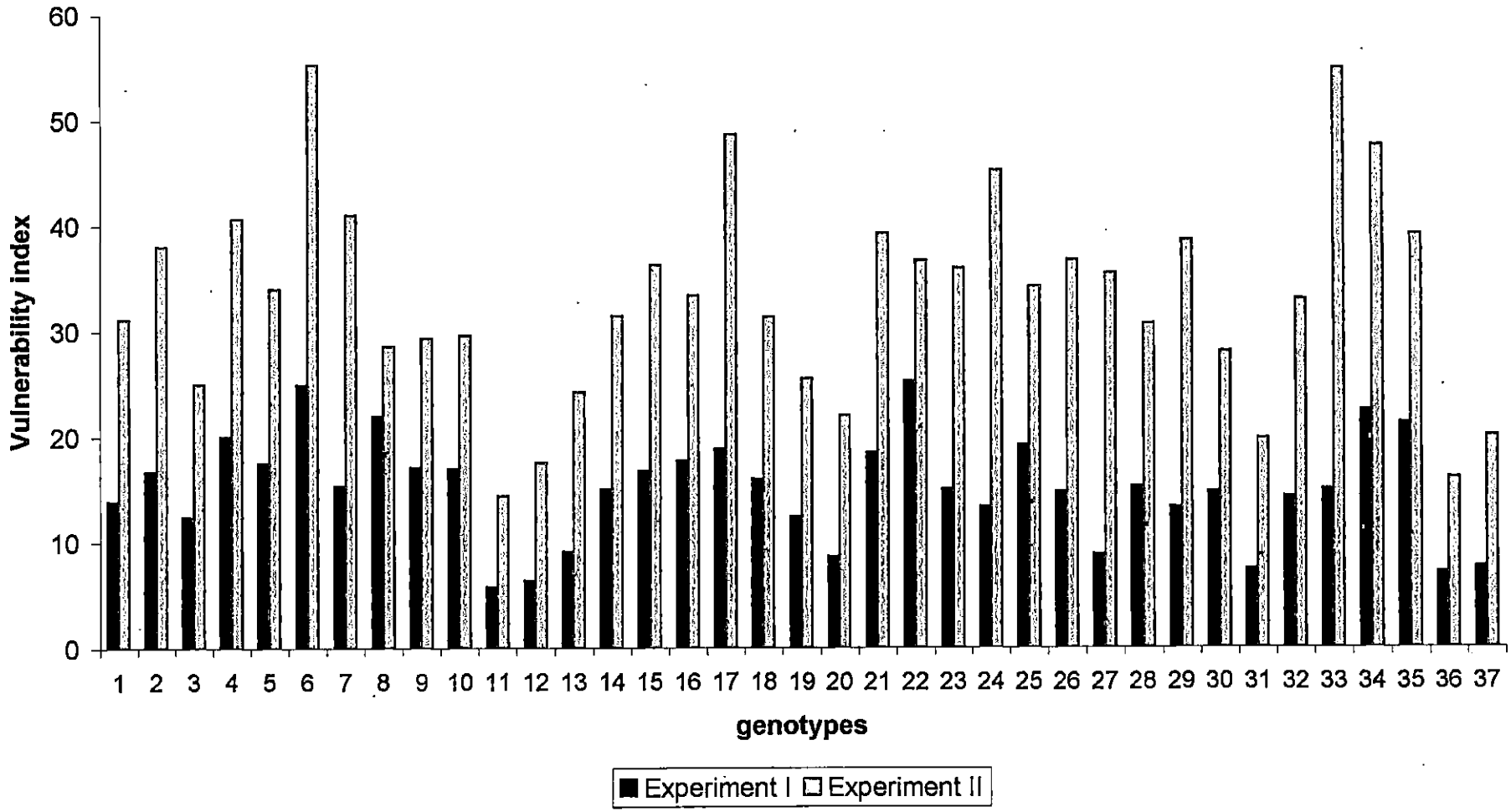
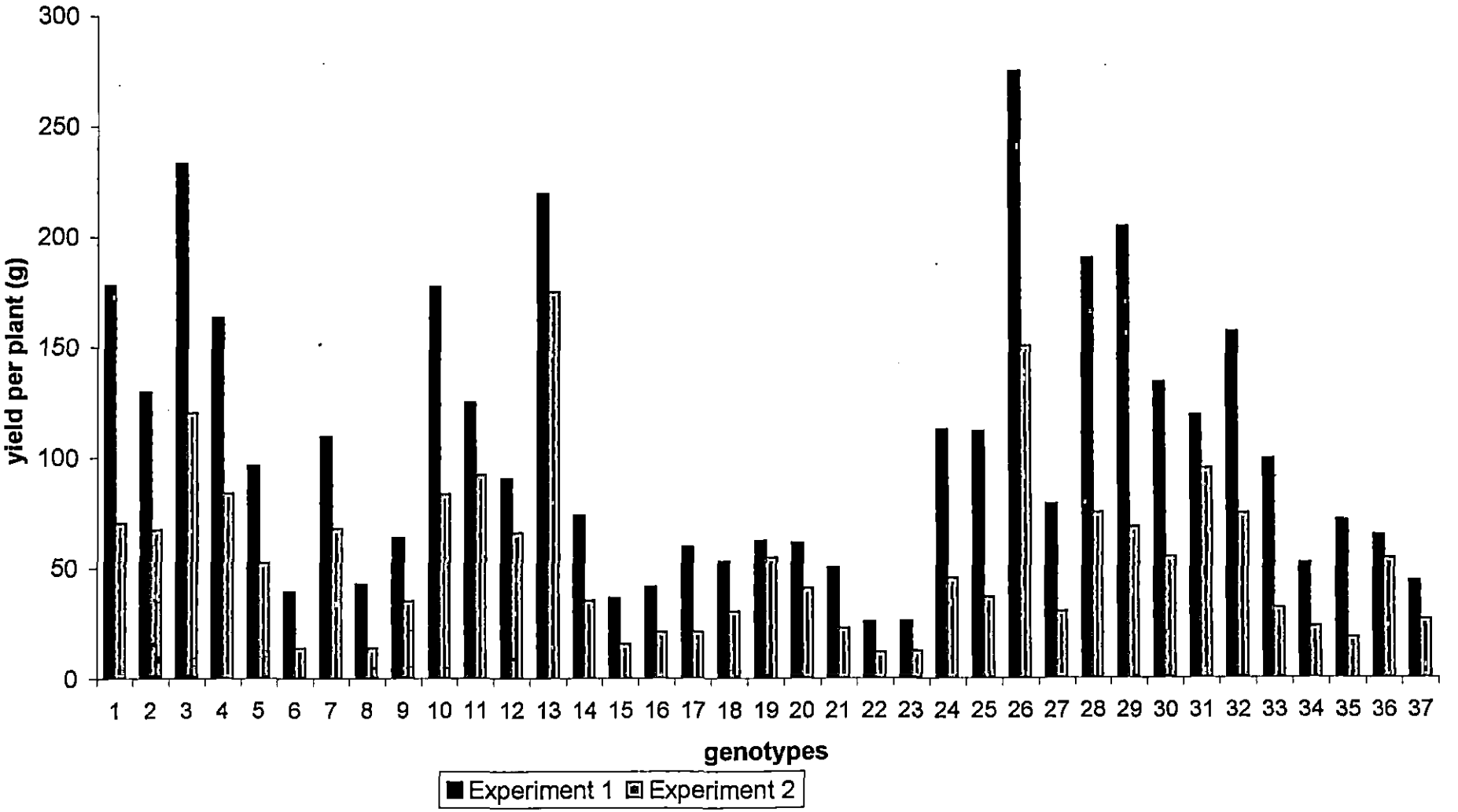


Fig. 8. Comparison of yield per plant in experiments I and II



The yield per plant in experiments I and II showed highly significant positive correlation. The vulnerability indices were also significantly and positively correlated with each other. The two traits showed the same trend in controlled and uncontrolled conditions. The yield per plant was negatively correlated with vulnerability index in both experiments. Hence, greater susceptibility leads to a reduction in yield.

DISCUSSION

5. DISCUSSION

The results of the study conducted to evaluate the genetic variability with respect to various characters including yield and reaction to leaf curl virus in chilli are discussed below.

5.1 Experiment I

5.1.1 Assessment of variability

The phenotypic variation present in a population with respect to various characters gives the basic idea of the extent of variability.

All the 15 characters studied showed a wide range of variation except number of primary branches (Table 2). This was further confirmed by analysis of variance in which significant differences were observed for all the traits.

Fruit yield per plant showed the greatest range of variation. The genotype T_{26} (Jwalamukhi) was the highest yielder followed by T_3 (Kottikulam local), T_{13} (Mangalapuram local) and T_{29} (Koothali local)(Plate 1) while T_{22} (Honnavar local), T_{18} (Kannoor local), T_{34} (Thrikkarippur piriyan), T_{21} (Kanhangad charadan), T_{37} (Pant C –1), and T_8 (Nekraje local) were the lowest yielders. High phenotypic variability was observed for number of fruits per plant, average fruit weight, number of seeds per fruit and days to first flower in addition to yield per plant. This was in accordance with the findings of Arya and Saini (1976), Hiremath and Mathapati (1977), Ramakumar *et al.*

(1981), Nair *et al.* (1984 b), Choudhary *et al.* (1985), Ahmed *et al.* (1990), Acharya *et al.* (1992) and Munshi and Behera (2000). Number of flowers per plant also showed high range of variation and was supported by the findings of Pillai (1967). Wide variation in fruit length, fruit girth and average fruit weight was observed (Fig.2 and Plate 2). Similar view was expressed by Singh and Brar (1979), Gopalakrishnan *et al.* (1985) and Verma *et al.* (1998). Hundred seed weight also showed high phenotypic variability. Dwivedi and Bhandari (1999) also expressed similar view with respect to 1000-seed weight.

5.1.2 Classification of genotypes

Grouping of genotypes into different classes based on their mean values helps to identify the phenotypically superior genotypes for each character.

Twelve genotypes with average fruit weight higher than the mean were included in the better class (Table 3). Fruit length and fruit girth were higher than mean for 16 and 14 cultivars respectively. The better class consisted of 11 genotypes each for number of fruits per plant and yield per plant. Fifteen genotypes had number of flowers per plant higher than mean. Fourteen genotypes each were included in the better class for fruiting span and crop duration.

Fourteen and eight genotypes with values less than mean were included in the better class for days to first flower and vulnerability index respectively.

The genotypes T_1 (Jwalasakhi), T_3 (Kottikulam local), T_4 (Vlathankara local-1), T_7 (Gadag local), T_{13} (Mangalapuram local), T_{26} (Jwalamukhi), T_{28} (Pollakkada local), T_{29} (Koothali local) and T_{30} (Uduma local) fell in the better class while T_6 (Hubly local),

T_8 (Nekraje local), T_{15} (Thenali local), T_{16} (Kuttipuram local), T_{20} (Chandera local), T_{22} (Honnavar local), T_{23} (Nileswaram triangular) and T_{36} (Haripuram local) were included in the poor class for most of the traits except vulnerability index.

5.1.3 Analysis of variance

The estimates of variance *viz*., phenotypic, genotypic and environmental variance will give a better idea of the extent of variation in genotypes. High genotypic and phenotypic variances indicate the scope for phenotypic selection of these traits.

High estimates of phenotypic and genotypic variances were observed for green fruit yield per plant followed by number of seeds per fruit, number of flowers per plant and number of fruits per plant (Table 4). Arya and Saini (1977), Hiremath and Mathapati (1977), Elangovan *et al.* (1981), Vijayalakshmi *et al.* (1989) and Das and Choudhary (1999 b) also observed similar results. The difference between phenotypic and genotypic variances was less in most of the traits suggesting the predominance of genetic component over environmental effect on its phenotype. Ahmed *et al.* (1990) also expressed a similar view with respect to all the characters studied in a set of 64 chilli lines. However, environmental variance was higher than genotypic variance for number of primary branches per plant suggesting the high influence of environment on this trait. This was in accordance with the report by Bai *et al.* (1987) who obtained similar results for branches per plant.

5.1.4 Coefficient of variation

The comparison of variation among the different characters studied is possible only if they are unit free. Unlike the estimates of variance, the coefficients of variation provide an excellent basis for such comparison.

The phenotypic coefficient of variation (PCV) ranged from 4.31 for crop duration to 63.26 for fruit yield per plant. High estimates of PCV were also noticed for number of fruits per plant, average fruit weight and fruit girth (Table 4). This was in accordance with the reports by Arya and Saini (1976), Hiremath and Mathapati (1977), Elangovan *et al.* (1981), Rajput *et al.* (1981), Nair *et al.* (1984 b), Rani *et al.* (1996) and Jabeen *et al.* (1999). Vulnerability index and number of flowers per plant also had high values for PCV.

The genotypic coefficient of variation (GCV) describes the inherent genetic variation. GCV also showed a similar trend as PCV. Highest estimate of GCV was observed for fruit yield per plant followed by number of fruits per plant, average fruit weight and fruit girth. These findings are in agreement with those of Arya and Saini (1977), Singh and Brar (1979), Ramakumar *et al.* (1981), Gopalakrishnan *et al.* (1987), Bai *et al.* (1987), Sahoo *et al.* (1989), Ahmed *et al.* (1990), Varalakshmi and Haribabu (1991), Nandi (1993), Jabeen *et al.* (1999) and Munshi and Behera (2000). GCV was also high for vulnerability index and number of flowers per plant indicating the inheritance of these characters.

A major portion of the PCV was contributed by GCV for most of the traits including yield and vulnerability index suggesting that the observed variation was mainly due to genetic factors (Fig. 3). Pichaimuthu and Pappiah (1992) also reported a close association of the phenotypic and genotypic coefficients of variation. However, comparatively high values for environmental coefficient of variation were observed for number of primary and secondary branches suggesting the role of environment in the expression of these traits. This was supported by the findings of Gopalakrishnan *et al.* (1985). Contrary to it, Vijayalakshmi *et al.* (1989) observed narrow difference between PCV and GCV for number of primary branches.

5.1.5 Heritability and genetic advance

The heritable portion of total variance is more important and this is defined by heritability coefficient. It indicates the effectiveness with which selection of genotype could be based on phenotypic performance.

In the present study, high values of heritability were observed for all the traits except number of primary branches, which recorded moderate heritability (Table 4). Fruiting span showed the highest value closely followed by number of seeds per fruit, number of flowers per plant, average fruit weight, days to first flower, fruit girth, fruit length, 100-seed weight and fruit yield per plant. This was in accordance with the reports of Rao and Chhonkar (1981), Singh *et al.* (1994) with respect to fruit girth, seed content and fruit yield per plant. Arya and Saini (1977) reported high heritability for days to flower and duration of availability of green fruits per plant. Choudhary *et al.* (1985) and

Sahoo *et al.* (1989) obtained high heritability for number of seeds per fruit and average fruit weight. Vulnerability index also showed high heritability. Number of primary branches recorded moderate heritability in the present study. Mean while, Singh and Singh (1970) and Singh and Brar (1979) observed low heritability for number of branches per plant.

Heritability estimates along with genetic advance are more useful than simple heritability values in predicting the resultant effect from selecting the best individuals (Johnson *et al.*, 1955 b). If heritability is mainly due to non-additive gene effect, the expected genetic advance would be low and if there is additive gene effect, a high genetic advance may be expected (Panse, 1957).

High heritability along with high genetic advance was observed for most of the traits studied (Table 4). Both these estimates were comparatively higher for fruit yield per plant, average fruit weight, number of fruits per plant, number of flowers per plant, number of seeds per fruit, fruit length and fruit girth indicating additive gene action. This was in agreement with the reports of Rao *et al.* (1974), Singh and Singh (1977 a), Bavaji and Murty (1982), Choudhary *et al.* (1985), Shah *et al.* (1986), Das *et al.* (1989), Depstre *et al.* (1989 a), Sahoo *et al.* (1989), Kumar *et al.* (1993), Bhatt and Shah (1996), Ghildiyal *et al.* (1996), Rani and Singh (1996), Jabeen *et al.* (1998) and Devi and Arumugam (1999). However, Singh and Brar (1979) reported low heritability and genetic advance for fruit length and high heritability coupled with low genetic advance for average fruit weight. High heritability and high genetic advance were noticed for

vulnerability index suggesting additive gene effect. High heritability and low genetic advance exhibited by crop duration was indicative of non-additive gene action offering less scope for selection for duration. Nair *et al.* (1984 b) also obtained similar results while Ramalingam and Murugarajendran (1977) reported low heritability coupled with low genetic advance for this trait.

Moderate heritability associated with medium genetic advance was noticed for number of primary branches suggesting that this trait was highly influenced by environment. Singh and Brar (1979) obtained low heritability and genetic advance while Nair *et al.* (1984 b) observed high heritability and low genetic advance for this trait. Mean while, Ghai and Thakur (1981) and Bavaji and Murty (1982) reported high heritability coupled with high genetic advance.

The genetic parameters give a clear insight into the extent of variability and provide a reliable measure of the efficiency of selection based on phenotype. Characters with high genotypic coefficient of variation, heritability and genetic advance offer a better scope for improvement through selection. Fruit yield per plant, number of fruits per plant, average fruit weight, fruit girth, vulnerability index and number of flowers per plant possessed high values for the above genetic parameters (Fig. 4).

5.1.6 Correlation analysis

Yield is a complex character influenced by a number of other component characters. The extent of relationship between yield and its component traits as well as

among the component traits is revealed through correlation analysis. Improvement of characters with high correlation to yield can lead to significant increase in yield.

The genotypic correlations were higher than the phenotypic correlations (Table 5 and 6) for most of the characters indicating that phenotypic expression for the correlation is reduced by the influence of environment despite inherent association between various characters. Similar observations were made by Sundaram and Ranganathan (1978), Rao and Chhonkar (1981) and Choudhary *et al.* (1985).

The genotypic correlation of yield per plant was positive with average fruit weight, number of fruits per plant, number of flowers per plant, number of primary branches, number of secondary branches, plant height, 100-seed weight, fruit length, fruit girth, fruiting span and crop duration while it was negative with number of seeds per fruit, vulnerability index and days to first flower (Table 6 and Fig. 5).

Average fruit weight was positively associated with yield suggesting its importance in improving yield. Veerappa (1982), Gopalakrishnan *et al.* (1985), Choudhary *et al.* (1985), Miranda *et al.* (1988) and Das and Choudhary (1999 a) were also of the same opinion. Average fruit weight was positively correlated with fruit length and girth, as observed by Munshi *et al.* (2000).

Another important economic trait showing high positive genotypic correlation with yield was number of fruits per plant. Similar view was expressed by Sundaram and Ranganathan (1978), Rao *et al.* (1981), Bavaji and Murty (1982), Bhagyalakshmi *et al.* (1990), Ali (1994), Rani (1995), Legesse *et al.* (1999) and Aliyu *et al.* (2000). The

positive association of number of fruits with number of secondary branches was high. Arya and Saini (1976) and Rajput *et al.* (1981) obtained similar results for number of branches while Hiremath and Mathapati (1977) contradicted it. Days to first flower was negatively correlated with number of fruits per plant and was supported by the findings of Rao *et al.* (1974) and Bhagyalakshmi *et al.* (1990).

Hundred seed weight was positively associated with yield, as reported earlier by Singh and Singh (1970) with respect to 1000-seed weight. It also showed positive correlation with average fruit weight.

High positive genotypic correlation was observed between fruit length and fruit yield per plant. Similar observation was made by Rajput *et al.* (1981), Gopalakrishnan *et al.* (1985), Ghai and Thakur (1987), Jayasankar *et al.* (1987), Miranda *et al.* (1988) and Todorova and Todorov (1998).

The genotypic correlation of fruit girth with yield was positive, as reported earlier by Veerappa (1982) and Choudhary *et al.* (1985).

Plant height showed positive, but low correlation with yield. Similar observation was made by Singh and Singh (1970), Rajput *et al.* (1981), Rao *et al.* (1981), Kaul and Sharma (1989), Rani (1995), Legesse *et al.* (1999) and Aliyu *et al.* (2000). However, Gopalakrishnan *et al.* (1985) and Ghai and Thakur (1987) observed significant negative association of plant height with yield.

Yield showed small positive association with number of primary branches, as reported earlier by Jayasankar *et al.* (1987) and Das and Choudhary (1999 a).

The genotypic association of number of secondary branches with yield was high and positive. This was in tune with earlier reports by Sundaram and Ranganathan (1978), Kaul and Sharma (1989), Rani (1995) and Subashri and Natarajan (1999).

Yield per plant was negatively correlated with days to first flower indicating that selection for earliness can lead to an increase in yield. Similar view was expressed by Singh and Singh (1970), Rao *et al.* (1981) and Bhagyalakshmi *et al.* (1990). However, positive correlation was reported by Sundaram and Ranganathan (1978) and Veerappa (1982). Days to first flower had high negative correlation with fruiting span and crop duration suggesting that the early flowering genotypes had longer duration of fruit production and life span.

Number of flowers per plant was also positively correlated with yield and number of secondary branches. This was in accordance with the report of Pillai (1967). There was high positive correlation of number of flowers with number of secondary branches and plant height suggesting that greater vegetative growth can enhance flower production.

The correlation of fruiting span and crop duration with yield was high and positive suggesting that increased fruiting span and life span can lead to increased yield.

Vulnerability index showed a negative correlation to yield indicating that lesser susceptibility to the disease (leaf curl) leads to increase in yield.

5.1.7 Path coefficient analysis

The genotypic correlation can at times be misleading because it may not indicate the actual effect of one character upon another. Path analysis provides information on the

real nature of association of several yield related characters contributing to yield, by separating the genotypic correlation into direct and indirect effects.

The direct effects of average fruit weight, number of fruits per plant and crop duration were high and positive while that of days to first flower and fruiting span were highly negative (Table 8 and Fig. 6).

The direct effect of average fruit weight was positive and much higher than its genotypic correlation with yield. Its indirect effect through crop duration was high and positive indicating that direct selection for average fruit weight and indirect selection for crop duration can increase yield. Rao and Chhonkar (1981) also observed direct effect of fruit weight.

Number of fruits had high and positive direct effect, very close to its genotypic correlation with yield indicating that the correlation represents a true relationship between the two traits. It exerted positive indirect effect through days to first flower and crop duration while its contribution through fruiting span and average fruit weight was negative. Rao *et al.* (1973) found negative indirect effect through days to first flower, contrary to the result in this study. Positive direct effect of number of fruits was supported by Gill *et al.* (1977), Sundaram and Ranganathan (1978), Subashri and Natarajan (1999) and Munshi *et al.* (2000). Korla and Rastogi (1977) found negative indirect effect through average fruit weight.

Days to first flower showed a very high negative direct effect on yield though its correlation with yield was much smaller and negative. This strong negative direct effect

might have been subdued by its strong positive indirect effect through fruiting span. This led to the conclusion that early flowering varieties produced higher yields. The negative direct effect of days to first flower was supported by the findings of Gill *et al.* (1977), Sundaram and Ranganathan (1978) and Rao *et al.* (1981).

Fruiting span exerted a strong negative direct effect, though its correlation with yield was positive. The high negative direct effect was nullified by the strong positive indirect effects through days to first flower and crop duration. The positive indirect effect through average fruit weight and number of fruits per plant could have contributed to its positive correlation with yield. Also, the indirect effect of most of the traits through fruiting span was negative. This led us to conclude that a greater duration of flowering need not necessarily increase yield. Although flowers were produced throughout the period, fruit production might be concentrated more towards the initial phase of fruiting span. This was supported by Pandian and Sivasubramanian (1978) who obtained negative correlation for flowers produced in later stage with total number of fruits per plant. The early yield (from first two harvests) was an important factor contributing to total yield and this might have undermined the importance of fruiting span. So the genotypes producing higher fruit yield within the shortest period appeared better than that with a long fruiting span.

Crop duration exerted high positive direct effect on yield. Its indirect effect through fruiting span was high and negative, leading to a lower genotypic correlation

with yield. The indirect effect through days to first flower and average fruit weight was positive.

The residual value was low indicating that most of the important component characters contributing to yield were included in the study. Rao and Chhonkar (1981) and Munshi *et al.* (2000) also observed low residual value in their study.

Based on correlation and path analysis studies, it could be concluded that selection for average fruit weight, number of fruits per plant, crop duration, early flowering and yielding types might lead to increase in yield.

5.1.8 Selection Index

Selection index involving several yield related characters would be more efficient in identifying a superior genotype. Use of selection index also provides scope for greater efficiency in increasing yield through selection rather than straight selection for yield alone.

In the present study, selection index was constructed based on all the 15 traits studied (Table 9). Many of the high yielding and superior genotypes such as T_3 (Kottikulam local), T_{13} (Mangalapuram local), T_{26} (Jwalamukhi), T_{29} (Koothali local), T_1 (Jwalasakhi) and T_{10} (Thalassery local) were found to have high selection indices while low yielding types like T_{37} (Pant C-1), T_{23} (Nileswaram triangular) and T_{36} (Haripuram local) were having low selection index, indicating its efficiency in identifying the superior genotypes. This may be due to the inclusion of several economically important yield related characters in computing the selection index. Sundaram *et al.* (1977) and

Singh and Singh (1977 b) also observed higher efficiency for selection for yield when all the traits studied were included in the selection index. It was also noted that many of the genotypes with high selection index fell under the 'better' class and the genotypes with low index under 'poor' class with respect to the mean values for yield per plant.

5.1.9 Genetic divergence analysis

A knowledge of genetic divergence between genotypes helps to identify suitable parents from a population. Mahalanobis D^2 statistic was found to be a powerful tool to assess the degree of relationship among the genotypes and to group them into different clusters. This would provide a dependable means for identifying genetically divergent parents to be used in breeding programmes.

Thirty seven accessions were grouped into four clusters with varying number of genotypes in each (Table 10). The genotypes with minimum divergence got clustered together. Cluster I with 23 genotypes was the largest. It contained most of the genotypes grouped under the 'poor' class for yield per plant, average fruit weight and fruit girth. It also had the lowest cluster means for average fruit weight, number of fruits per plant, number of secondary branches, 100-seed weight, fruit girth, crop duration and yield per plant and highest cluster means for vulnerability index and days to first flower indicating its inferiority (Table 11).

Cluster II had eight genotypes and showed intermediate cluster means for all the traits taken for clustering. Most of the genotypes included belonged to the high yielding class.

Third cluster consisted of five genotypes, all of them belonging to the high yielding class. It had the highest cluster means for number of flowers per plant and fruit length while it exhibited the lowest value for vulnerability index indicating the superiority of the genotypes included in this cluster for these traits.

Cluster IV with only one genotype (Jwalamukhi) had the highest cluster means for the traits average fruit weight, number of fruits per plant, number of secondary branches, 100-seed weight, fruit girth, crop duration and yield per plant and lowest cluster means for flowers per plant and days to first flower. This indicated its superiority over all the other genotypes in respect of desirable attributes. The mean for vulnerability index was high for this genotype.

It was noted that the clustering pattern was in agreement with the phenotypic classification based on mean values of genotypes for yield per plant. Selection index was also high for most of the genotypes grouped in the clusters IV, III and II which contained superior genotypes. Similarly, many of the low yielding genotypes grouped in cluster I were found to have low selection indices.

The inter cluster distance (D) was maximum between clusters I and IV suggesting that these were the most divergent clusters (Table 12 and Fig. 7). Clusters II and III were genetically close a indicated by the low value of inter cluster distance.

High intra cluster distance indicated high degree of variability within that cluster offering scope for improvement by various selection methods. In this study, cluster II containing eight genotypes had the highest intra cluster distance.

In general, the inter cluster distances were more than twice the intra cluster distances suggesting that there was homogeneity among the genotypes included in a cluster while heterogeneity existed between clusters.

5.2 Experiment II

5.2.1 Screening for leaf curl virus resistance

The 37 genotypes were screened against leaf curl virus under field conditions.

The genotype T_{11} (Alampady local-1) showed the lowest value for vulnerability index and was on par with T_{12} (Neyyattinkara local), T_{31} (Kottiyam local), T_{36} (Haripuram local), T_{37} (Pant C-1), and T_{20} (Chandera local) (Table 13). These genotypes were tolerant to leaf curl as indicated by the low value of vulnerability index (Plate 3). The genotypes T_6 (Hubly local), T_{33} (Nedumangad local) and T_{17} (Marthandam local-1) were most susceptible to leaf curl as they recorded the highest values for vulnerability index.

The genotypes were classified into tolerant, susceptible and highly susceptible based on their vulnerability index values. Eight genotypes *viz.*, T_{11} (Alampady local-1), T_{12} (Neyyattinkara local), T_{31} (Kottiyam local), T_{36} (Haripuram local), T_{37} (Pant C-1), T_{20} (Chandera local), T_{13} (Mangalapuram local) and T_3 (Kottikulam local) showed tolerance to the disease. They exhibited mild symptoms such as slight curling of a few terminal leaves for some plants. The susceptible class comprised of 27 genotypes with many of them showing curling of terminal and adjacent leaves and presence of blisters on leaves. Two genotypes *viz.*, T_6 (Hubly local) and T_{33} (Nedumangad local) were highly

susceptible to the disease with severe curling of leaves and stunting of plants. In some cases, small clusters of leaves were produced due to proliferation of axillary buds.

There was no variety showing immunity to the disease. Even Pant C-1, a known resistant variety took slight symptom. This was supported by the findings of Bhalla *et al.*(1983) and Memane *et al.* (1987). However, the genotypes included in the tolerant category could be considered as fairly resistant to the disease.

5.2.2 Comparison of yield and reaction to leaf curl in Experiment I (with control measures) and Experiment II (without control measures)

Based on pooled analysis, it was found that the genotype T_{13} (Mangalapuram local) was the highest yielding while the lowest yielders were T_{22} (Honnavar local), T_{23} (Nileswaram triangular), T_8 (Nekraje local), T_6 (Hubly local) and T_{15} (Thenali local) (Table 15). Insecticide treatment was found to be effective in reducing the disease incidence.

Comparison of yield per plant of the two experiments showed that yield reduction in tolerant genotypes was comparatively lesser than that in susceptible varieties.

The correlations between yield and vulnerability index of both experiments were worked out (Table 16). The high positive correlation between yield per plant in experiments I and II suggested that the high yielding varieties produced good yields under controlled and uncontrolled conditions while the low yielding ones produced low yields under both situations. Vulnerability index also showed a similar trend as indicated by the high positive correlation. This led to the conclusion that there was an inherent

genetic difference among genotypes in respect of yield potential and reaction to leaf curl virus.

Vulnerability index was negatively correlated with yield per plant in both experiments indicating that greater susceptibility to the disease leads to reduction in yield.

Based on variability and screening studies, it was concluded that the superior genotypes with high yield and other desirable characters *viz*., Jwalamukhi, Kottikulam local, Mangalapuram local, Pollakkada local and Koothali local (belonging to clusters III and IV) and leaf curl tolerant types such as Alampady local-1, Neyyattinkara local, Haripuram local, Pant C-1 and Kottiyam local can be used as parents in a hybridisation programme to evolve high yielding and disease resistant/ tolerant varieties.

SUMMARY

SUMMARY

The present study entitled "Genetic variability in chilli (*Capsicum annuum* L.) with emphasis to reaction to leaf curl virus' was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2000-2001 with the objective of estimating the extent of genetic diversity in a collection of chilli cultures, including yield and resistance to leaf curl virus. The data for the investigations were collected from two field experiments.

In experiment I, 37 cultivars of chilli including four improved varieties, *viz.*, Jwalamukhi, Jwalasakhi, Ujjwala and Pant C-1 were evaluated for yield and its component characters in Randomised Block Design with three replications. Observations were recorded on 15 characters, *viz.*, average fruit weight, number of fruits per plant, number of seeds per fruit, 100-seed weight, fruit length, fruit girth, fruit yield per plant, plant height, number of primary branches, number of secondary branches, days to first flower, number of flowers per plant, fruiting span, crop duration and vulnerability index calculated on the basis of virus disease scoring.

Analysis of variance revealed significant difference among varieties for all the 15 traits studied. Jwalamukhi was the highest yielder whereas the lowest yielders included Honnavar local and Nileswaram triangular. Nagercoil local produced the highest number of fruits while Honnavar local and Kanhangad charadan produced the least number.

A major portion of phenotypic variance was contributed by genotypic variance for most of the traits other than number of primary branches. Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) also showed a similar trend. High values of PCV and GCV were obtained for fruit yield per plant, number of fruits per plant, average fruit weight, vulnerability index, fruit girth and number of flowers per plant. Fruit yield per plant recorded the maximum values for PCV and GCV while crop duration recorded the minimum.

The heritability estimates were moderate to high for the 15 traits under study and ranged from 44.21 per cent (number of primary branches) to 98.28 per cent (number of seeds per fruit). High heritability coupled with high genetic advance was noticed for average fruit weight, number of fruits per plant, number of seeds per fruit, fruit length, fruit girth, yield per plant, number of flowers per plant and vulnerability index suggesting additive gene action for these traits.

At genotypic level, fruit yield per plant showed high correlation with number of fruits per plant, average fruit weight, number of secondary branches per plant, number of flowers per plant, fruiting span and crop duration. The genotypic correlation was found to be greater than phenotypic correlation for most of the traits.

Path coefficient analysis revealed that average fruit weight, number of fruits per plant and crop duration had high positive direct effect while days to first flower and fruiting span showed high negative direct effect on yield. The low residual value (0.0810)

indicated that the major portion of the variation in yield could be explained by the characters considered in path analysis.

Genetic diversity studies using Mahalanobis D^2 statistic indicated considerable diversity among the 37 genotypes of chilli. Clustering pattern showed that cluster I was the largest with 23 genotypes followed by cluster II with eight, cluster III with five and cluster IV with one genotype respectively. Intercluster distance was maximum between clusters I and IV while intracluster distance was maximum in cluster II. The intercluster distances were much higher than the intracluster values. Based on cluster mean values, cluster IV with a single genotype was found to be superior for most of the desirable traits.

In experiment II, the 37 chilli genotypes were screened for leaf curl virus resistance in a field experiment in Randomised Block Design with three replications. Observations were taken on yield per plant and virus disease scoring (based on which vulnerability index was calculated).

Significant differences were observed among cultivars for yield and vulnerability index. Eight genotypes were found to be tolerant to leaf curl while 27 were susceptible and two were highly susceptible to the disease.

Comparison of yield and vulnerability index in both experiments showed that reduction in yield was less in tolerant varieties than in susceptible ones. The performance of Jwalamukhi, Kottikulam local and Mangalapuram local were comparable under controlled and uncontrolled conditions. Mangalapuram local was identified as a desirable accession as it produced high yields inspite of the disease. Correlation analysis showed

negative association of yield with vulnerability index in both experiments indicating that susceptibility to the disease leads to a reduction in yield.

Based on the study, it was concluded that the high yielding genotypes like Jwalamukhi, Kottikulam local, Mangalapuram local, Koothali local and Pollakkada local and leaf curl tolerant types such as Alampady local-1, Neyyattinkara local, Haripuram local, Kottiyam local and Pant C-1 could be used as parents in a crop improvement programme to evolve high yielding and disease resistant/tolerant varieties.

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GENETIC VARIABILITY IN CHILLI (*Capsicum annuum L.*) WITH EMPHASIS TO REACTION TO LEAF CURL VIRUS

BY

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ABSTRACT OF THE THESIS

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ABSTRACT

The present investigation entitled "Genetic variability in chilli (*Capsicum annuum* L.) with emphasis to reaction to leaf curl virus" was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2000-2001. The data for the investigation were collected from two field experiments, each laid out in Randomised Block Design with three replications. The second experiment was conducted without taking any control measures against leaf curl virus.

The 37 genotypes included in the study showed significant difference for all the 15 traits. The maximum values for phenotypic coefficient of variation (PCV) genotypic coefficient of variation (GCV) were recorded for fruit yield per plant and the minimum values for crop duration. PCV and GCV were high for fruit yield per plant, number of fruits per plant, average fruit weight, vulnerability index, fruit girth and number of flowers per plant. These traits also showed high heritability coupled with high genetic advance.

Yield per plant was positively correlated with number of fruits per plant, average fruit weight, number of secondary branches, number of flowers per plant, fruiting span and crop duration. Path analysis revealed high positive direct effect for average fruit weight, number of fruits per plant and crop duration. Hence selection for these traits can improve yield.

The 37 genotypes were grouped into four clusters based on Mahalanobis D^2 statistic. Cluster I was largest with 23 genotypes while cluster IV had only one genotype. Cluster II had eight and cluster III had five cultivars respectively. Cluster IV containing a single variety was superior to the other clusters in respect of desirable characters.

Field screening of the 37 cultivars for leaf curl resistance (experiment II) showed that eight genotypes were tolerant to the disease while 27 were susceptible and two were highly susceptible to the disease.

Comparison of yield and vulnerability index in both experiments showed that reduction in yield was less in tolerant varieties than in susceptible ones. The performance of T_{26}, T_3 and T_{13} were comparable under controlled and uncontrolled conditions. The genotype T_{13} was identified as a desirable accession as it produced high yields inspite of the disease. Correlation analysis showed negative association of yield with vulnerability index in both experiments indicating that susceptibility to the disease leads to a reduction in yield.

The high yielding types and leaf curl tolerant types identified from the study could be used as parents in crop improvement programme to evolve high yielding leaf curl tolerant varieties.