GENETIC ANALYSIS OF SHADE TOLERANCE IN CHILLI (*Capsicum* spp.)

By

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DECLARATION

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

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CERTIFICATE

Certified that the thesis entitled **'Genetic analysis of shade tolerance in chilli (*Capsicum* spp.)'** is a record of research work done independently by Smt. I. Sreelathakumary, 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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INTRODUCTION

1. INTRODUCTION

Chilli is one of the most important vegetable-cum-spice crops valued for its pungency, taste, aroma and the appealing colour that it imparts to food. The fruit is a rich source of vitamins A and C. It is a strategic raw material for several of our speciality products of both traditional and modern menu. Green chilli, chilli powder, cayenne pepper, tabasco, paprika, sweet (bell) pepper, pimentos and serrano pepper are all derived from the berries of *Capsicum* species. Chilli is known by different names in different countries and even within the same country.

India is the largest producer, consumer and exporter of chillies in the world, with an annual production of 8.21 lakh tonnes from an area of 9.57 lakh hectares. During 1998 -'99, India exported 55,750 tonnes of chilli valued Rs. 210.13 crores (Peter, 2000). It is grown throughout India and Andhra Pradesh leads both in area, and production. Andhra Pradesh together with Maharashtra, Tamil Nadu, Karnataka, West Bengal, Bihar and Assam accounts for 96 per cent of the total area under chilli in India. In Kerala, cultivation of chilli is limited to an area of 417 ha with an annual production of 406 tonnes (FIB, 2000). However, chilli is one of the important vegetable crops of the state and a wide variety of chilli genotypes are grown here in garden lands in summer as well as in rainy season.

Homestead farming is a unique system of agriculture traditionally followed in Kerala. As the availability of open land is meagre in the state, farmers utilize the interspaces of perennial crops in homesteads for growing vegetables. In the homesteads shade acts as one of the abiotic stresses that reduces yield. Estimates made at the Central Plantation Crops Research Institute, Kasargod show that light infiltration in coconut gardens ranged from 10 to 70 per cent. Shade tolerant genotypes, if identified, could be economically cultivated in the interspaces of coconut palms and other perennials in a homestead-farming situation.

The three important cultivated species of the genus *Capsicum* are *C. annuum*, *C. frutescens* and *C. chinense*. The cultivars of *C. annuum* are annual, early maturing, less pungent and cultivated on an extensive scale throughout India. *C. frutescens* and *C. chinense* are the two species of *Capsicum* traditionally grown in the homesteads of Kerala. They are perennial and characterized by highly pungent fruits with distinct flavour. They are adapted to a wide range of ecological situations that exist in the humid tropics. The ability of *C. frutescens* and *C. chinense* to tolerate shade makes them suitable for intercropping with tall plantation crops, effectively harnessing the solar radiation in-filtering through the canopy of trees.

Solar radiation is considered as an essential component in biosphere activity *via* the photosynthetic performance of plants. Productivity of a plant depends on its capacity to harvest solar energy efficiently for the metabolic production and it's partitioning. This is controlled by the genetic make up of the plants to a certain extent. At present, only limited information is available on the genetic mechanism of shade tolerance. The inherent potential of a genotype to impart resistance is determined by the resistance mechanism operating within it. The shade tolerant genotypes possess various physiological, anatomical and biochemical mechanisms to increase production under shade.

Chillies have been usually studied in monoculture. Their capacity to perform well in homesteads is crucially dependent on the ability to tolerate shade beneath the canopy of tree crops. Though chilli is a common crop in the homesteads of Kerala, most of the varieties grown are those evolved specifically for cultivating in the open. Therefore, varieties that can yield substantially even under shaded conditions will be ideal for the homesteads of Kerala. Availability of such varieties would open up new vistas in chilli cultivation in the state. Since shade tolerance in vegetable crops has been considered as a high priority objective, concerted efforts are needed to elucidate the mechanism and basis of shade tolerance. Such strategic research efforts are obviously imperative in the effective utilization of the available germplasm in breeding programmes. A comprehensive study in this direction has thus become pertinent.

Against this background, the present investigation was carried out with the following objectives :

1. To identify superior genotype(s) of chilli suitable for the shaded situations
2. To study the physiological basis of shade tolerance
3. To study the anatomical basis of shade tolerance
4. To study the biochemical basis of shade tolerance and
5. To study the genetic basis of shade tolerance

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Chilli is one of the most important spice-cum-vegetable crops valued for its aroma, flavour and pungency. Despite being a common crop in the homesteads of Kerala where shade is a limiting factor, the cultivars grown are evolved specifically for the open situations. In spite of the wide spectrum of variability available in this species, not much work has been done for developing shade tolerant varieties to suit the homestead systems.

The available information on the effect of shade relevant to the present study is reviewed here under in the following heads:

2.1. Characterization of genotypes for shade tolerance

2.2. Physiological basis of shade tolerance

2.3. Anatomical basis of shade tolerance

2.4. Biochemical basis of shade tolerance and

2.5. Genetic basis of shade tolerance

2.1 Characterization of genotypes for shade tolerance

2.1.1 Growth

Shade is one of the yield limiting factors in annual vegetable crops in general and chilli in particular. The experiment conducted by Deli and Tiessen (1969) to study the effect of light on young chilli plants maintained under low light intensity resulted an increased growth and yield. Under high solar radiation, shading at an early stage of plant development increased cell division and leaf surface and whole plant dry matter in pepper (Schoch, 1972). Short day conditions (9 - 10 h light) stimulated plant growth of *Capsicum* (Ergova, 1975).

In a glass house experiment with tomato higher light intensities increased the number of leaves, total leaf area and plant dry weight. Plants grown in lower light intensities were taller, with thinner stems, particularly at higher night temperature (Nagaota *et al.*, 1979). Minami *et al.* (1981) reported that in a green house trial of tomato, unshaded plants were the strongest, with well developed root systems. Plant height was greater in shaded ones than in control. Syed Kamaruddin (1983) reported that tomato plants shaded with muslin were taller than unshaded plants mainly due to longer internodes. Similarly shaded plants of tomato grew taller with more leaves in a given time with slightly greater internodal length (Smith *et al.*, 1984 and Thangam, 1998).

Thomas and Leong (1984) reported that shade up to 40 per cent promoted foliage growth and fruiting of chilli. In another experiment the effect of different levels of shading (0, 12, 26 and 47 %) on pepper grown under high solar radiation was investigated during summer and winter. In both the seasons, when solar radiation was reduced, the plant height, number of nodes and leaf size increased (Rylski, 1986).

A field trial was conducted by El-Gizawy *et al.* (1993a) in tomato to study their performance under shading (0, 35, 51 or 63 %) provided by nets. They found that shading increased plant height and leaf area but reduced leaf number and dry weight.

Jung *et al.* (1994) reported that main stem and branch lengths of pepper increased significantly under shaded conditions.

El-Abd *et al.* (1994) observed that in tomato, percentage survival, plant height and leaf area increased with increasing shading intensity, but leaf number and transpiration rate decreased. Increase in plant height was also reported in tomato due to increase in the period of shading (Nasiruddin *et al.*, 1995). Assimilate supply for vegetative growth was varied by changing light intensity or plant density, fruit truss and leaf pruning. Area of individual leaves was increased with increasing light intensity, decreasing plant density or the removal of every other truss (Heuvelink and Marcelis, 1996).

Correia *et al.* (1996) found that in *Capsicum* cv. Ikeda, shading with black cloth from two true leaf stage had a beneficial effect on plant growth and development whereas, Leonardi (1996) observed reduced vegetative growth with increased plant height under shade. Increased plant height due to increased shade was also reported by Yinhua and Jianzhen (1998) in *Capsicum*.

2.1.2 Flowering and fruiting

Saito *et al.* (1963) reported that long day treatment at any temperature combinations produced earlier flower bud differentiation and more flowers in tomato than short day treatment. A combination of low night temperature resulted in more flowers and high fruit yields.

Tomato required longer time for flower bud differentiation at low light intensities Watanabe (1963). The number of flower buds and the degree of flower development were affected by light intensity, day length and irrigation. Higher night temperatures and / or lower light intensities retarded the morphological development of the flowers and induced heavy flower drop in tomato (Saito and Ito, 1967), whereas lower night temperatures combined with high light intensity increased fruit set (Nagota *et al.*, 1979).

Sagi *et al.* (1979) observed flower drop and reduced fruit set under low solar radiation intensity (SRI). High SRI increased fruit set and stimulated fruit development. The highest fruit set occurred at 78 per cent SRI. High SRI induced early cropping and improved fruit quality. Number of days from sowing to flowering and percentage of flower drop increased as the shade increased (Jeon and Chung, 1982).

Shading was investigated as a factor to delay fruit development of sweet pepper by Rylski and Spigelman (1986a). They observed delay in fruit picking by about one month when plants were grown throughout the winter in screen houses and by eleven days when they were covered only at a later stage of their development. In all experiments, as a result of shading, fruit ripening and shrinking were slowed down, leading to a larger yield of top quality fruits. Shading during summer eliminated sunscald damage also.

El-Gizawy *et al.* (1993a) observed delay in flowering in tomato as the shading level increased, whereas the number of flowers per plant decreased under all shading rates (0, 35, 51 or 63 % shade) compared with full sunlight.

In pepper, early screening resulted in taller, more open plants, delayed harvest and prolonged harvesting period compared with later screening.

Harvest was delayed under screens giving high percentage of shade (Zuieli *et al.*, 1993).

Fruit set, days to harvest, number and weight of fruits per plant, weight and diameter of fruit of tomato were significantly influenced by shading (Sharma and Tiwari, 1993a). Nasiruddin *et al.* (1995) evaluated two varieties of tomato namely Roma and Marglobe under different periods of shading. They reported that shading delayed flowering in all the cases but insignificantly only in partial shading in comparison with full exposure.

2.1.3 Yield

According to Curme (1962), fruit set and yield of tomato was positively influenced by increased levels of incident sunlight.

Bigotti (1974) reported that reduction of solar radiation by 50 per cent increased the fresh weight of peduncle, whole fruit, pericarp, placenta and seeds in chilli but had no effect on dry weight and dry matter content of placenta, pericarp and seeds. Quaglitto (1976) opined that 30 per cent reduction in solar radiation almost doubled the yield of sweet pepper due to an increase in both number and size of fruits.

Achhireddy *et al.* (1982) studied the effect of light on the growth rate of fruit wall plus placenta and seeds in chilli. They found that after 65 days of development, fruits held in the dark weighed 15 per cent less than those receiving light whereas the seed weight remained unaltered.

Arora *et al.* (1983) reported that plant survival in the field and yield per plant in tomato were higher on non-shaded plots which was attributed to higher temperature on the shaded plots and to the smothering effect of the shade plants. Smith *et al.* (1984) found that tomato yields were best under 15 per cent shade than 40 per cent shade and open.

Rylski and Spigelman (1986b) investigated the effect of different levels of shading (0, 12, 26, and 47 %) on yield of capsicums under higher solar radiation during summer and winter. Shading inhibited the development of lateral shoots on the main stem of plant below the first flower. The changes in plant development due to shading affected fruit set, number of fruits per plant, fruit location on the plant, fruit development and yield. The lateral shoots, which developed under high light intensity, provided 25 per cent of the total yield whereas only a few fruits were picked from the lateral shoots of plants under low light intensity. The lowest number of fruits per plant was obtained under 47 per cent shading. Under shading, individual fruits were larger and had a thicker pericarp. The highest yield of high quality fruits was obtained with 12 and 26 per cent shade.

El-Aidy (1986) found higher yield in tomato plants grown under shade than those in the open field, but this trend could be reduced by increasing shade with 40 per cent shade being the best.

The micro-climatic and eco-physiological effects of shading and pinching on *Capsicum* were reported by Hou *et al.* (1987). Fruit yields were highest when the plants were pinched and shaded with plastic film. Basuki and Asandhi (1987) reported the advantage of shade and mulch on pepper yield. From 0.04 ha, a yield of 201 kg was obtained from shaded plants provided with black plastic mulch whereas in control from the same area only 50 kg yield was obtained.

In tomato and sweet pepper grown in a green house with natural sunlight, 35 and 55 per cent shading, the light intensity decreased dry weight and fruit yield with greatest effect on tomatoes and least effect in sweet pepper (Zhong and Kato, 1988).

Shade studies on tropical crops *viz.* colocasia, coleus, cowpea, brinjal, amaranthus, cluster bean, bhindi and sweet potato were conducted in Kerala Agricultural University under 0, 25, 50 and 75 per cent shade levels (Nair, 1991). In all these crops, the yield was highest under open (0 % shade) and declined with increasing shade levels.

Hedge *et al.* (1993) reported that among the different vegetable crops tried in coconut garden, snake gourd, amaranthus and brinjal in khariff, bottle gourd, ridge gourd and coccinia in rabi and amaranthus, brinjal and coccinia in summer, were found highly productive and economical.

El-Gizawy *et al.* (1993b) found increased number of fruits per plant and total yield in tomato. Highest yields were obtained under 35 per cent shading (2.46 and 4.12 kg m^{-2} in 1988 and 1989 respectively). Shading significantly improved the physical characteristics of the fruits. The greatest weight, length, diameter and volume of fruits were obtained from plants grown under 35 per cent shading.

To study the effect of shade in tomato, four shade treatments ranging from 1:1 (1 row of tomato : 1 row of maize) to 4:1 (4 rows of tomato : 1 row of maize) were tried. The treatment 1:1 proved significantly effective for fruit set, number of fruits per plant (Sharma and Tiwari, 1993b).

Jung *et al.* (1994) reported that pepper plant set fewer, smaller fruits in proportion to the degree of shading.

Tomato plants grown at full (100 %) or reduced (50 %) natural light intensities were sampled at flower bud formation, flowering and after cropping and found that light reduction markedly decreased biomass and fruit production (Borowski, 1994). Francescangeli *et al.* (1994 b) observed reduced incidence of blossom end rot and decreased yield under shade in tomato. Yamashiti and Hayashi (1994) reported that dense shading (69 %) had little effect on fruit cracking but reduced fruit yield and quality in tomato.

Warren Roberts and Anderson (1994) observed that marketable yield of bell pepper from plots shaded with spun bonded polypropylene row covers were equal to or greater than those from other treatments. Leonardi (1996) found reduced fruit growth, fruit precocity and yield due to shading in pepper.

Shukla *et al.* (1997) reported the effect of subabul canopy on yield of vegetables like chilli, brinjal, cauliflower and okra. Yields of all vegetables were significantly lower when grown under shaded conditions than in open.

Yinghua and Jianzhen (1998) reported highest yield in pepper under 30 per cent shade. Kitano *et al.* (1998) analysed the effect of light and day or night air temperature on the dynamics of fruit growth and photoassimilate translocation in tomato plants in relation to respiration, photosynthesis and transpiration of the fruit and the leaf. They found that irradiation clearly enhanced the fruit growth and photoassimilate translocation. Approximately

70 per cent of fruit growth and 80 per cent of photoassimilate translocation occurred during the light period, with highly activated leaf photosynthesis and fruit respiration under a day or night air temperature of 25^0 C and 15^0 C respectively.

2.1.4 Genetic variability, heritability and correlation

Variability either naturally existing or created artificially forms the basis for any crop improvement programme. Many workers have reported considerable variability for a number of characters in chilli. In *C. annuum* genetic variability was reported by Singh and Singh (1979), Arya and Saini (1976), Rajput *et al.* (1982) Ahmed *et al.* (1990) and Nandi (1992).

Amarchandra *et al.* (1983) reported high genotypic coefficient of variation (GCV) in chilli for fruit length, fruit circumference, fresh and dry weight of fruits. Gupta and Yadav (1984) observed higher phenotypic and genotypic coefficients of variation for fruit girth. High values of GCV for fruit size were reported in chilli by Arya and Saini (1976), Rajput *et al.* (1982), Nandi (1992) and Sarma and Roy (1995). Higher phenotypic and genotypic coefficients of variation were reported for fruit size, fruit weight, yield per plant and fruit length in *C. frutescens* (Sheela, 1998).

Several workers reported high heritability coupled with high genetic advance for fruit yield in chilli (Nandapuri *et al.*, 1970; Arya and Saini, 1986 and Ahmed *et al.*, 1990). Nair *et al.* (1984) reported higher magnitude of heritability for fruit weight, fruit girth, fruit length, yield per plant and dry chilli recovery in *C. annuum.*

Vallego and Costu (1987) reported a narrow sense heritability estimate of 10.6 per cent for days to first flowering, 47 per cent for days to maturity and 2.9 per cent for plant height in *C. chinense.*

High heritability and high genetic advance for fruit size and high heritability and medium genetic advance for yield per plant, fruit length and fruit girth were reported in *C. frutescens* by Sheela (1998).

Characters such as yield are quantitative in nature and are strongly related to other characters. Padda *et al.* (1970) reported significant positive correlation in chilli between yield and fruit size. Factor analysis of chilli by Rao *et al.* (1981) indicated that fruit yield per plant had high significant positive correlation with fruits per plant, plant spread and height.

In a study of ten genotypes of chilli Khurana *et al.* (1993) observed a significant positive correlation of fruit yield with fruit weight, fruit number and fruit length. Sheela (1998) reported that economic traits like number of harvests, fruit girth, fruit length, fruit weight and fruit size were significantly correlated with yield in *C. frutescens.* A significant negative correlation was observed between yield and days to first harvest.

2.2 Physiological basis of shade tolerance

2.2.1 Leaf area index (LAI)

Positive influences of shade on various growth attributes had been reported by many workers. Bhat and Ramanujam (1975) observed low leaf area index (LAI) in cotton at high light intensity. Rice crops shaded during the vegetative phase were smaller with a lower leaf area index and hence had better light penetration than the control during the reproductive phase (Yoshida and Parao, 1976). . Thangaraj and Sivasubramanian (1990) reported that irrespective of varieties, low light intensity significantly increased the leaf area index in rice.

In ginger, turmeric and coleus Bai (1981) did not find any influence of shade on their leaf area indices. However a high leaf area index was reported by Ravisankar and Muthuswamy (1988) when ginger was grown as an intercrop in six year old arecanut plantations. Ancy (1992) observed that the leaf area index in ginger was significantly lower under open condition compared to other shade levels in all growth stages. The highest leaf area index was recorded at 25 per cent shade.

Smith *et al.* (1984) observed that shaded plants of tomato produced a greater leaf area with more dry matter in leaves and stem. Heuvelink and Marcelis (1996) reported that area of individual leaves of tomato increased with increasing light intensity.

Yinhua and Jianzhen (1998) reported increased leaf area in Capsicum with increasing shade.

2.2.2 Specific leaf weight (SLW)

Murty *et al.* (1973) reported that low light stress reduced the specific leaf weight (SLW) by 25 per cent in rice especially at early stages of growth. Reduction in specific leaf weight was also reported in cassava plants grown under shade compared to plants exposed to full sunlight (Ramanujam and Jose, 1984).

Duncan grapefruit, pineapple and sweet orange seedlings were grown in full sunlight or 50 or 90 per cent shade. In fully expanded mature leaves, specific leaf weight was highest in full sun and lowest in 90 per cent shade (Syvertsen and Smith, 1984).

Ward and Woolhouse (1986) reported that specific leaf weight was reduced more by shading in maize, whereas it was 15 per cent higher in coffee plants grown in full sunlight than in shaded plants (Fahl *et al.*, 1994).

Yinghua and Jianzhen (1998) found that specific leaf weight decreased with increasing shade in *C. annuum.*

Kitaya *et al.* (1998) reported that as photosynthetic photon flux increased, dry mass percentage and leaf number increased while the ratio of shoot : root dry mass (S / R), the ratio of leaf length : leaf width (LL/LW), specific leaf area and hypocotyl length decreased.

2.2.3 Crop growth rate (CGR)

Ramadasan and Satheesan (1980) reported highest crop growth rate in turmeric cultivars grown in open condition compared to shaded condition. Ramanujam and Jose (1984) found that the CGR of cassava grown under shade were reduced significantly when compared to those plants grown under normal light.

2.2.4 Relative growth rate (RGR)

Murata (1961) reported that the relative growth rate (RGR) of leaf area was practically free from the influence of solar radiation as long as the level of radiation was higher than the one third of the full incident radiation. However Janardhan and Murty (1980) reported that leaf area ratio and relative growth rate of rice increased under low light situations.

Shaded plants of pepper had considerably lower relative growth rate during flowering and early fruit development stages compared to exposed plants (Jung *et al.*, 1994). The stress susceptible cultivar of pepper Shamrock recorded a larger reduction in relative growth rate under low light stress and partitioned less dry matter to reproductive structures and more to leaves than the more tolerant cultivar Ace (Turner and Wien, 1994).

2.2.5 Net assimilation rate (NAR)

The NAR of chickpea decreased with decrease in light intensities (Pandey *et al.*, 1980). Similarly, Ramadasan and Satheesan (1980) observed highest NAR with turmeric cultivars grown in open condition compared to shade.

Ramanujam and Jose (1984) found that NAR of cassava grown under shade was reduced significantly when compared to those plants grown under normal light. Similar observations of reduced NAR were also noticed in shade plants of cucumber (Smith *et al.*, 1984) and sweet potato (Laura *et al.*, 1986) compared to those plants exposed to full sunlight.

Ancy (1992) found that the net assimilation rate under 25 and 50 per cent shade levels were significantly high in ginger with a drastic decrease under heavy shade.

Jung *et al.* (1994) reported that shaded plants of pepper had considerably lower net assimilation rate during flowering and early fruit development stages compared to exposed plants. Turner and Wien (1994) observed that the stress susceptible cultivar of pepper Shamrock recorded a larger reduction in net assimilation rate under low light stress than the more tolerant cultivar Ace. Yinghua and Jianzhen (1998) reported that net photosynthetic rate of pepper was highest under 30 per cent shade.

2.3 Anatomical basis of shade tolerance

Schoch (1972) reported that shading increased leaf surface, cell division and cell expansion in sweet pepper *C. annuum.* Shade decreased the number of stomata per mm^2 and the percentage of stomata in relation to other cells.

In cotton, non-shaded leaves were typically thicker than shaded leaves because they formed longer palisade parenchyma (Salisbury and Ross, 1978). Syvertsen and Smith (1984) found highest leaf thickness in citrus plants grown in full sunlight and the lowest thickness in the plants under 90 per cent shade. Similarly, under shade spongy parenchyma was thinner in cassava leaves compared to those grown in normal light (Ramanujam and Jose, 1984). They also reported that the density of distribution of stomata was less in plants grown under shade than in plants exposed to full sunlight.

In a pot trial on beans grown at different light intensity revealed an increased leaf thickness with increasing light intensity (Silva and Anderson, 1985). Similarly Ward and Woolhouse (1986) reported that shading in maize reduced leaf thickness and chlorenchyma volume.

An examination of the vascular bundle of mid rib of shaded leaves in cotton revealed that it was larger and thinner than that in non-shaded leaves (Dhopte *et al.*, 1991).

Ashton and Berlyn (1992) reported that experimental plants of Shorea species grown in full sun had thicker leaves compared to shade grown plants. Cuticles of full sun leaves were significantly thicker than shade leaves. Plants had significantly higher number of stomata per unit area in leaves that were exposed to full sun.

Buisson and Lee (1993) reported that characteristics such as leaf thickness, stomatal density, palisade parenchyma cell shape and the ratio of mesophyll air surface to leaf surface in papaya were reduced by reduction in irradiance.

Fahl *et al.* (1994) reported that coffee leaves were 11 per cent thicker in unshaded plants than in shaded ones, because of the increased size of the palisade and spongy parenchyma tissues. In pepper, leaf thickness decreased with increasing shade (Yinghua and Jianzhen, 1998).

2.4 Biochemical basis of shade tolerance

2.4.1 Chlorophyll

An increase in chlorophyll content with increase in shade levels was reported in cotton (Bhat and Ramanujam, 1975), winged bean (Sorenson, 1984), tobacco (Anderson *et al.*, 1985), potato (Singh, 1988) and colocasia (Prameela, 1990).

Ramanujam and Jose (1984) reported that chlorophyll a : chlorophyll b ratio was less in cassava plants grown under shade than in plants exposed to full sunlight.

Thangaraj and Sivasubramanian (1990) reported that low light intensity significantly increased the total leaf chlorophyll content in rice irrespective of varieties.

Chlorophyll a, chlorophyll b, carotenoids and total pigment contents of leaves of tomato were increased with increased shading (El-Gizawy *et al.*, 1993a). Shading caused profound increase in the content of chlorophyll b in okra, french bean, groundnut, rice, maize and hybrid napier (Singh, 1994).

Fahl *et al.* (1994) reported that chlorophyll a and b, protochlorophyll and total leaf chlorophyll contents increased in shade grown coffee plants compared to those in full sunlight. Similarly, chlorophyll and carotenoid content of leaves of pepper found increased with increasing shade (Yinghua and Jianzhen, 1998).

2.4.2 Capsaicin

Reduction of solar radiation by 50 per cent had no effect on the capsaicin content of fruits of pepper (Bigotti, 1974). Jeon and Chung (1982) also reported that capsaicin content of pepper was not affected by different shade intensities. Minami *et al.* (1998) reported that capsaicinoid concentration were highest between 20 and 40 days after flowering in *C.*

annuum, C. *frutescens* and C. *chinense*. A longer photoperiod compensated for a low photosynthetic photon flux.

Soohyun *et al.* (1998) analysed the chemical constituents of fruits of red pepper *C. annuum*. They found that the concentration of total capsaicinoid in fruit was 5.4 mg per 100 g of fresh weight.

2.4.3 Oleoresin

Ancy (1992) found that the non-volatile ether extract content of ginger grown under 25 and 50 per cent shade was on par with each other and significantly superior to that under open and 75 per cent shade. However the oleoresin content of ginger under open and 25 per cent shade was reported higher than that of 50 and 75 per cent shade level (George, 1992; Babu, 1993).

2.4.4 Carotenoids

Spectral quality of radiation influences carotenoids of *C. annuum* fruits (Lopez *et al.*, 1986). Fruits exposed to full sun had the highest carotenoid content and in shade grown fruits it was the lowest. Shade inhibited formation of capsanthin, the major red pigment in maturing fruit. The other red pigment capsorubin, developing during maturation was found most plentiful in shade grown fruits.

Soohyun *et al.* (1998) analysed the chemical constituents of fruits of red pepper *C. annuum* and identified carotenoids including capsanthin estimated to a total concentration of 65 mg per 100 g of fresh weight.

2.4.5 Ascorbic acid

Reduction of solar radiation by 50 per cent had no effect on the ascorbic acid content of the fruit of pepper (Bigotti, 1974).

El-Gizawy *et al.* (1993b) reported that in tomato with increased shading, ascorbic acid content and soluble solids decreased while fruit titrable acidity increased. Sharma and Tiwari (1993a) observed that tomato fruits harvested from shaded plants accumulated significantly higher ascorbic acid as compared to non-shaded plants. Extended shading period decreased the ascorbic acid content of fruits considerably (Nasiruddin *et al.*, 1995). Yanagi *et al.* (1995) reported that in both summer and autumn crops of tomato ascorbic acid and reducing sugar content of fruits significantly decreased with increased shading.

Yinghua and Jianzhen (1998) found that ascorbic acid content of pepper fruits decreased with the increase in shade. Soohyun *et al.* (1998) analysed the chemical constituents of fruits of red pepper (*C. annuum*) and reported that the total amount of ascorbic acid in fruits was 121 mg per 100g of fresh weight.

2.4.6 Proline

Proline accumulation in plants has been shown to be the adaptive mechanism to stress tolerance. Cellular solutes have been considered as having a protective role under heat stress. Accumulation of proline under water stress has been reported in crops *viz.*, coffee (Vasudeva *et al.*, 1981), cocoa (Balasimha, 1982), tea (Rajasekhar *et al.*, 1988) and coconut (Voleti *et al.*, 1990).

Hervieu *et al.* (1994) reported that the concentration of proline in cotyledons of radish grown in light was increased as an inverse function of the relative water content.

Three pepper (*C. frutescens*) varieties differing in heat tolerance were subjected to temperature of 35 to 40^0 C for two to eight days and evaluated for changes in the free proline content in their leaves. The result indicated that the free proline accumulation in leaves showed significant differences between varieties (Yao *et al.*, 1998).

Joonkook *et al.* (1998) reported that excised leaves of the salt sensitive tomato accumulated the highest proline content compared to salt tolerant accessions.

2.4.7 Phenols

Smart *et al.* (1985) reported that the phenol concentration was negatively correlated with shading in *Vitis*. Sun leaves have greater content of phenolic compound than shade leaves.

2.5 Genetic basis of shade tolerance

The study of gene effects or inheritance pattern of quantitative characters in different vegetables suggested that majority of the characters like yield, fruits per plant, fruit weight, fruit length, fruit diameter and days to flowering are polygenicaly inherited (Swarup, 1991).

Fisher *et al.* (1932) partitioned the total variance of F2 generation into heritable and non-heritable components in allelic interaction. Several investigators have proposed genetic models to determine the additive (D), dominance (H) and environmental variance (E) and gene effects (Comstock and Robinson, 1948; Mather 1949; Jinks 1954; Hayman 1954 and Mather and Jinks, 1982) that cause heterosis. Methods were also proposed to detect the non-allelic interaction or epistasis (Cavalli, 1952; Anderson and Kempthorne, 1954; Jinks, 1955 and Hayman 1957 and 1958a). A, B, C, D scaling test to detect non-allelic interaction was proposed by Mather, (1949) and Hayman and Mather, (1955). Cockerham (1954), Henderson (1954), Kempthorne (1955) and Horner *et al.* (1955) developed methods for partitioning the epistatic variance into additive x additive, additive x dominance and dominance x dominance components which gave a new momentum to plant breeding. Later, Hayman (1958b) and Jinks and Jones (1958) analysed the generation means to estimate these components.

The six-parameter model was first proposed by Anderson and Kempthorne (1954) the parameters being K2, E, F, G, L and M to measure additive, dominant and interaction components. Hayman (1958a) and Jinks and Jones (1958) used the six parameter model with m (mean effects of F2), d (additive effects) h (dominance effects), i (additive x additive), j (additive x dominant) and l (dominant x dominant) components.

The amount of work on the genetic aspects of shade tolerance of vegetable is in general very little and on chillies in particular is practically insignificant. However the work available on shade tolerance in vegetables is reviewed below.

Shifriss *et al.* (1994) reported the variation in flower abscission in pepper under stress shading conditions. Seedlings from seventy seven accessions of (*C. annuum*) including inbreds, F1s and seven F2 populations were exposed to approximately 60 per cent shading for 35 days following transplanting in the shade. Most of the lines did not set fruits under shading due to heavy abscission of flowers. A few exceptional lines, hybrids and F2 segregants showed resistance to abscission and set normal fruits under the shading regime. They suggested that there was an association between resistance to shading and to high temperature and its genetic control.

Relationship between photosynthetic light compensation point and tolerance to low irradiance in cucumber were investigated by Yongjian *et al.* (1998). The genetic model of photosynthetic light compensation point of cucumber at 15^0 C based on parental, F1, F2 and back cross generations agreed with additive - dominance - epistatic model.

MATERIALS & METHODS

3. MATERIALS AND METHODS

The present investigations were carried out at the College of Agriculture, Vellayani during 1997 - 2000. The crops were raised at the vegetable research plot of the Department of Olericulture. The area is situated at 8.5^0 N latitude, 76.9^0 E longitude at an altitude of 29.0 m above MSL. Experimental site has a lateritic red loam soil with a pH of 5.2. The area enjoys a warm humid tropical climate.

The study consisted of the following experiments:

3.1. Characterization of chilli genotypes for shade tolerance

3.2. Physiological basis of shade tolerance

3.3. Anatomical basis of shade tolerance

3.4. Biochemical basis of shade tolerance and

3.5. Genetic basis of shade tolerance

3.1 Characterization of chilli genotypes for shade tolerance

The basic material for the study consisted of 70 diverse genotypes of chilli belonging to *Capsicum annuum* (35), *C. frutescens* (20) and *C. chinense* (15) collected from different parts of the country. The genotypes were evaluated during the season November '97 to May '98. The details of the genotypes and their sources are presented in Table 1.

Table 1. Particulars of chilli genotypes used in the experiment and their sources

Sl. No.	Accession No.	Source
I	*Capsicum annuum*	
1.	CA 1	CO-1, Tamil Nadu Agricultural University, Coimbatore
2.	CA 2	CO-2, Tamil Nadu Agricultural University, Coimbatore
3.	CA 3	CO-3, Tamil Nadu Agricultural University, Coimbatore
4.	CA 5	K-1, Agricultural Experimental Station, Kovilpatti
5.	CA 6	K-2, Agricultural Experimental Station, Kovilpatti
6.	CA 8	Jwalamukhi, College of Agriculture, Vellayani
7.	CA 9	Jwalasakhi, College of Agriculture, Vellayani
8.	CA 11	Ujjwala, College of Horticulture, Vellanikkara
9.	CA 12	College of Horticulture, Vellanikkara
10.	CA 13	College of Horticulture, Vellanikkara
11.	CA 14	LCA-334, College of Horticulture, Vellanikkara
12.	CA 15	College of Horticulture, Vellanikkara
13.	CA 16	LCA-324, College of Horticulture, Vellanikkara
14.	CA 18	Regional Agricultural Research Station, Ambalavayal
15.	CA 20	RHRC-16-5, College of Horticulture, Vellanikkara
16.	CA 21	College of Horticulture, Vellanikkara
17.	CA 22	College of Horticulture, Vellanikkara
18.	CA 23	College of Horticulture, Vellanikkara
19.	CA 24	College of Horticulture, Vellanikkara
20.	CA 25	College of Horticulture, Vellanikkara
21.	CA 28	Pant C-1, GBPAU, Punjab
22.	CA 29	KDCS-210,College of Horticulture, Vellanikkara

Contd.....

Sl. No.	Accession No.	Source
23.	CA 32	Regional Agricultural Research Station, Ambalavayal
24.	CA 34	Pusa Jwala, Indian Agrl. Research Institute, New Delhi
25.	CA 36	Aryanadu, Thiruvananthapuram
26.	CA 37	Aryanadu, Thiruvananthapuram
27.	CA 38	Aryanadu, Thiruvananthapuram
28.	CA 39	Neyyatinkara, Thiruvananthapuram
29.	CA 55	Veliyam, Kollam
30.	CA 59	Anchal, Kollam
31.	CA 60	Neyyatinkara, Thiruvananthapuram
32.	CA 64	Neyyatinkara, Thiruvananthapuram
33.	CA 81	Neyyatinkara, Thiruvananthapuram
34.	CA 82	Anchal, Kollam
35.	CA 83	Ayoor, Kollam
II *C. frutescens*		
36.	CF 30	College of Horticulture, Vellanikkara
37.	CF 40	College of Horticulture, Vellanikkara
38.	CF 41	Neyyatinkara, Thiruvananthapuram
39.	CF 42	Neyyatinkara, Thiruvananthapuram
40.	CF 43	Aryanadu, Thiruvananthapuram
41.	CF 44	Aryanadu, Thiruvananthapuram
42.	CF 45	Aryanadu, Thiruvananthapuram
43.	CF 46	Vellayani, Thiruvananthapuram
44.	CF 47	Ambalathara, Thiruvananthapuram
45.	CF 48	Peroorkada, Thiruvananthapuram

Contd.....

Sl. No.	Accession No.	Source
46.	CF 49	Local, Thiruvananthapuram
47.	CF 50	Local, Thiruvananthapuram
48.	CF 51	Anchal, Kollam
51.	CF 54	Veliyam, Kollam
52.	CF 56	Mavelikkara, Alapuzha
53.	CF 57	Mavelikkara, Alapuzha
54.	CF 58	Anchal, Kollam
55.	CF 61	Anchal, Kollam
III *C. chinense*		
56.	CC 62	Local, Thiruvananthapuram
57.	CC 63	Vellayani, Thiruvananthapuram
58.	CC 65	Aryanadu, Thiruvananthapuram
59.	CC 66	Aryanadu, Thiruvananthapuram
60.	CC 67	Veliyam, Kollam
61.	CC 68	Veliyam, Kollam
62.	CC 69	Anchal, Kollam
63.	CC 70	Anchal, Kollam
64.	CC 71	Neyyatinkara, Thiruvananthapuram
65.	CC 72	Neyyatinkara, Thiruvananthapuram
66.	CC 73	Varkala, Thiruvananthapuram
67.	CC 74	Ayoor, Kollam
68.	CC 75	Mavelikkara, Alapuzha
69.	CC 76	College of Horticulture, Vellanikkara
70.	CC 77	College of Horticulture, Vellanikkara

Four separate experiments were carried out in 25, 50 and 75 per cent shade along with open condition and the performance of genotypes was evaluated.

Statistical details:

Design	: RBD
Replications	: 2
Treatments	: 70
Plot size	: 5 x 5 m
No. of plants / plot	: 10

The seedlings were transplanted 45 days after sowing. The crop received timely management practices as per Package of Practices Recommendations of Kerala Agricultural University (KAU, 1996). Black high density polyethylene net, fabricated for 25, 50 and 75 per cent light intensity, was used. The nets were spread at a height of 2.50 m from ground level and supported on G.I. pipes and teak wood poles of 6.50 cm diameter. Care was taken to avoid natural shade in the experimental area.LI-COR-LI-188 B Quantum Radiometer with a photometric sensor was used to measure the light intensity inside the net.

3.1.1 Observations

Five plants were selected randomly from each genotype and observations on the following quantitative characters were recorded. Five mature leaves from the top of the main branches were selected for recording observations on leaf characters. Ten fruits were selected at random for recording observations on fruit characters.

1. Plant height (cm)

The height of plant from ground level to the tip of the plant at final harvest was measured and average worked out.

2. Internodal length (cm)

Length between two nodes just below the first branching was taken.

3. Stem girth (cm)

The girth of main stem at 15 cm above soil surface was taken, at final harvest.

4. Leaf area (cm^2)

Leaf area was measured by using a leaf area meter.

5. Petiole length (cm)

The petiole length of the leaf was measured.

6. Height of node to first flower (cm)

The height from ground level to the node to first flower was measured.

7. Node to first flower

The node at which the first flower developed was observed.

8. Days to first flower

Number of days from sowing to first flowering of plants was computed.

9. Fruits per plant

Total number of fruits produced per plant was counted.

10. Fruit length (cm)

Measured as the distance from pedicel attachment to the apex of the fruit using twine and scale.

11. Fruit girth (cm)

Measured at the widest point using twine and scale.

12. Fruit weight (g)

Ten fruits were weighed and mean weight recorded.

13. Yield per plant (g plant^{-1})

Total weight of the fruits harvested from a plant was recorded.

14. Incidence of mite

The performance of genotypes was monitored for the intensity of symptoms caused by chilli mite *Polyphagotarsonemus latus.*

A scoring procedure with a 0 - 5 scale was adopted based on the extent of damage to the plants (Plate 1) :

0 - no incidence
1 - mild (25 per cent)
3 - medium (50 per cent)
5 - severe (75 per cent)

3.1.2 Statistical analysis

The collected data were subjected to the analysis of variance to test the significant difference among the genotypes under each shade level for various traits as per Panse and Sukhatme (1978). Pooled analysis was done to test the significant difference among different shade levels. Variability for different

Plate 1. Scoring scale for incidence of mite

quantitative characters were estimated for chilli genotypes grown under open and 25 per cent shade as suggested by Burton (1952). Expected genetic advance at 5 per cent intensity of selection was calculated using the formula suggested by Johnson *et al.* (1955). Correlation of various biometrical characters was undertaken as per the procedure suggested by Singh and Choudhary (1979).

Based on the performance under shade and the yield pattern one genotype each for shade tolerance and shade susceptibility was selected in all the three species of *C. annuum, C. frutescens* and *C. chinense* for further studies.

3.2 Physiological basis of shade tolerance

The selected shade tolerant and shade susceptible genotypes of *C. annuum, C. frutescens* and *C. chinense* were grown both in open and 50 per cent shade during November 1998 to May 1999. Observations were recorded on the following characters during the growth, flowering and fruiting stages of the plant.

3.2.1 Leaf area index (LAI)

The leaf area was measured using LI 3100 leaf area meter and LAI was worked out based on the method suggested by Williams (1946).

$$LAI = \frac{\text{Total leaf area of a plant } (cm^2)}{\text{Ground area occupied } (cm^2)}$$

3.2.2 Specific leaf weight (SLW)

The SLW was calculated using the formula reported by Pearce *et. al.*,(1968) and expressed in g cm^{-2}.

$$SLW = \frac{\text{Leaf dry weight}}{\text{Leaf area}}$$

3.2.3 Crop growth rate (CGR)

The CGR was calculated using the formula of Watson (1958) and expressed in g m^{-2} day^{-1}

$$CGR = NAR \times LAI$$

3.2.4 Relative growth rate (RGR)

The RGR is the rate of increase in dry weight per unit dry weight per unit time expressed in g g^{-1} day^{-1}. It was calculated by the formula suggested by Williams (1946).

$$RGR = \frac{\log_e w_2 - \log_e w_1}{(t_2 - t_1)}$$

where,

w_1 and w_2 = plant dry weight at time t_1 and t_2 respectively

$(t_2 - t_1)$ = time interval in days

3.2.5 Net assimilation rate (NAR)

The RGR refers to the change in dry weight of the plant per unit leaf area per unit time. The procedure suggested by Watson (1958) and modified later by Buttery (1970) was used for calculating NAR and expressed in g m^{-2} day^{-1}.

$$NAR = \frac{(w_2 - w_1)}{(t_2 - t_1)\,(A1 + A2)}$$

where,

w_1 and w_2 = dry weights of whole plant at t_1 and t_2 respectively

A1 and A2 = leaf area indices at t_1 and t_2 respectively

$(t_2 - t_1)$ = time interval in days

3.3 Anatomical basis of shade tolerance

Selected shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* were grown both in open and 50 per cent shade during November 1998 to May 1999.

For leaf anatomical studies, third leaf from the top was taken at the fag end of the canopy cover for hand sectioning with fine razor. Middle portion of leaf lamina was sectioned to examine nature of anatomical differences as influenced by shade in the genotype. Each section was taken from an individual leaf and each leaf from an individual plant.

Measurements were taken to investigate various anatomical differences in leaf thickness, stomatal frequency, dimensions of upper and lower epidermis and palisade mesophyll as followed by Dhopte *et al.* (1991).

3.4 Biochemical basis of shade tolerance

The chemical constituents of selected shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense*, grown both in open and 50 per cent shade during November 1998 to May 1999 were analysed. The constituents estimated were photosynthetic pigments, capsaicin, oleoresin, ascorbic acid, carotenoids, proline and total phenol.

3.4.1 Photosynthetic pigments

The photosynthetic pigments *viz.*, chlorophyll-a, chlorophyll-b and total chlorophyll were estimated at vegetative, flowering and fruiting stages in the selected genotypes (Arnon, 1949).

Procedure

Five hundred milligrams of leaf sample was weighed and the leaf tissues were then ground with 10 ml of 80 per cent acetone using a pestle and mortar. The homogenate was centrifuged at 3000 rpm for 10 minutes. The supernatant was collected and made up to 25 ml with 80 per cent acetone. The OD value of the extract was measured at 663 nm and 645 nm using 80 per cent acetone as the blank in the spectrophotometer. The amount of the pigment was calculated using the following formulae and expressed as milligram of pigments per gram of fresh leaf.

Total chlorophyll : $20.2(\text{OD at } 645) + 8.02(\text{OD at } 663) \times \frac{V}{1000 \times w}$ mg g^{-1}

Chlorophyll a : $12.7(\text{OD at } 663) - 2.69(\text{OD at } 645) \times \frac{V}{1000 \times w}$ mg g^{-1}

Chlorophyll b : $22.9(\text{OD at } 645) - 4.68(\text{OD at } 663) \times \frac{V}{1000 \times w}$ mg g^{-1}

where,

V = final volume of chlorophyll extract in 80 % acetone

W = fresh weight of tissue extracted

3.4.2 Capsaicin

Capsaicin content of selected shade tolerant and shade susceptible genotypes of *C.annuum, C. frutescens* and *C. chinense* grown in open and 50 per cent shade was determined by Folin - Dennis method. The pungent principle reacts with Folin - Dennis reagent to give a bluish complex which was estimated colorimetrically (Mathew *et al.*, 1971).

Reagents

Folin - Dennis Reagent
Aqueous sodium carbonate solution (25 %)
Acetone

Procedure

The fruits harvested at red ripe stage were dried in a hot air oven at 50^0 C and powdered finely in a mixer grinder. Five hundred milligrams of each of the samples was weighed into test tubes. Added 10 ml acetone to it and kept overnight. Aliquots of 1 ml were pipetted into 100 ml conical flasks, added 25 ml of Folin - Dennis reagent and allowed to stand for 30 minutes. Added 25 ml of freshly prepared sodium carbonate solution and shook vigorously. The volume was made up to 100 ml with distilled water and the optical density was determined after 30 minutes at 725 nm against reagent blank (1 ml acetone + 25 ml Folin - Dennis reagent + 25 ml aqueous sodium carbonate solution) using a UV spectrophotometer.

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

3.4.3 Oleoresin

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

Procedure

Chilli fruits harvested at red ripe stage were dried in a hot air oven at 50^0 C, powdered finely in a mixer grinder. Two grams of chilli powder was weighed and packed in filter paper and placed in a Soxhlet apparatus. Two hundred ml of acetone was taken in the round bottom flask of the apparatus and heated in a water bath. The temperature was maintained at the boiling point of solvent. After complete extraction (7 to 8 h), the solvent was evaporated to dryness under vacuum.

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

$$\text{Oleoresin (\%)} = \frac{\text{weight of oleoresin x 100}}{\text{weight of sample}}$$

3.4.4 Ascorbic Acid

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

Reagents

3 % Metaphosphoric acid (HPO_3)
Ascorbic acid (standard)
2,6 - dichlorophenolindophenol dye

Procedure

Five grams of fresh fruits was extracted in an acid medium (3 % HPO_3) and titrated against 2,6-dichlorophenolindophenol dye to a pink colour which persisted for at least five seconds. Ascorbic acid content of the sample was calculated using the formula :

$$\left.\begin{array}{l}\text{Ascorbic acid content}\\ \text{in mg / 100 g fresh fruit}\end{array}\right\} \frac{\text{Titre x dye factor x volume made up x 100}}{\text{Aliquot of extract taken x weight of sample taken}}$$

3.4.5 Carotenoids

Carotenoids present in the fruits of selected genotypes were extracted using acetone and its optical density measured at 450 nm.

Procedure

One hundred milligrams of fresh fruit was cut into small pieces and homogenised in a blender with acetone. The homogenate was transferred into a volumetric flask and made up to 25 ml and kept overnight in dark. The optical density was measured at 450 nm (Jensen, 1978). The carotenoids present in the extract was calculated using the formula :

$$C = \frac{D \times f \times V \times 100}{2500}$$

where

C	=	Total amount of carotenoids in mg
D	=	Absorbance at 450 nm in a 1 cm cell
F	=	dilution factor
V	=	Volume of the original extract in ml
2500	=	Average extinction coefficient of the pigments

3.4.6 Proline

Selected shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* grown both in open and 50 per cent shade were analysed for the proline content during vegetative, flowering and fruiting stages.

Proline present in the leaves of selected genotypes was extracted using sulphosalicylic acid. The extracted proline was made to react with ninhydrin in acidic condition to form a red colour and the intensity was read at 520 nm (Sadasivam and Manikam, 1992).

Reagents

Acid ninhydrin
Aqueous sulphosalicylic acid (3 %)
Glacial acetic acid
Toluene
Proline

Procedure

One gram of the leaf sample was cut into small pieces and homogenized in a blender with 10 ml of 3% aqueous sulphosalicylic acid.

Filtered the homogenate. Took 2 ml of filtrate in a test tube and added 2 ml of glacial acetic acid and 2 ml acid ninhydrin. It was heated in the boiling water for one hour, then placed in an ice bath. Added 4 ml toluene to the reaction mixture and stirred. Separated the toluene layer and measured the colour intensity at 520 nm.

Amount of proline in the samples was calculated from a standard curve of pure proline and was expressed as micromoles per gram tissue.

$$\mu \text{ moles per g tissue} = \frac{\mu\text{g proline / ml x ml toluene x 5}}{115.5 \text{ g of sample}}$$

3.4.7 Phenols

Selected shade tolerant and shade susceptible genotypes grown both in open and in 50 per cent shade were analysed for the total phenol content during the fruiting stage. Total phenols were estimated by Folin - Ciocalteau method (Sadasivam and Manikam, 1992). The intensity of blue colour developed was read at 650 nm in a spectrophotometer.

Reagents

Ethanol (80 %)
Folin - Ciocalteau reagent
Sodium Carbonate (20 %)
Standard (100 mg catechol in 100 ml water; diluted 10 times for a working standard)

Procedure

One hundred milligrams of leaf sample was cut into small pieces and homogenised in a blender with 10 ml of 80% ethanol. The homogenised material was centrifuged at 3000 rpm for 10 minutes. Evaporated the supernatant to dryness. Dissolved the residue in 10 ml of distilled water. Pipetted out 0.2 ml of the aliquot into test tubes and added 5 ml of water, 0.5 ml of Folin - Ciocalteau reagent and 2 ml of 20 per cent sodium carbonate solution. Placed the tubes in a boiling water for exactly one minute and cooled and measured the absorbance at 650 nm against a reagent blank (5 ml water + 0.5 ml Folin - Ciocalteau reagent + 2 ml 20 % sodium carbonate solution) using a UV spectrophotometer.

The total phenol content was calculated from a standard curve of catechol and was expressed as mg / g of sample.

$$\text{Total phenol content in mg / g tissue} = \frac{\mu\text{g standard x absorbance of sample}}{\text{Absorbance of standard}}$$

3.5 Genetic basis of shade tolerance

3.5.1 Experimental materials

The experimental materials comprised of selfed progenies of the shade tolerant and shade susceptible genotype of *C. annuum, C. frutescens* and *C. chinense* for developing F1, F2, BC1 and BC2 generations.

3.5.2 Development of F1s

The experiment was laid out during June to October 1998. The crop was maintained as per the package of practices described earlier in chapter 3.1...

Shade tolerant genotype (P_1) was crossed with shade susceptible genotype (P_2) in each species of *C. annuum, C. frutescens* and *C. chinense* to study genetic basis of tolerance to shade in chilli.

3.5.3. Development of segregating generations

During November 1998 to May 1999, the parents and F1 of all the three species *C. annuum, C. frutescens* and *C. chinense* were grown in the crossing block. All the cultural practices were followed as described previously. The F1s were back crossed with both the parents to obtain BC1 and BC2 generation seeds and selfed to obtain F2 generation seeds.

3.5.4 Evaluation of six generations

The six generations *viz.*, P1, P2, F1, F2, BC1 and BC2 of the three species were evaluated in 50 per cent shade during November 1999 to May 2000. The experiment was laid out in a randomised block design with five replications. There were 30 plants each in P1, P2 and F1 and 100 plants each in F2, BC1 and BC2 per replication in each species. Plants received the same cultural practices as described earlier.

$m = \bar{F}2$

$d = \bar{B}1 - \bar{B}2$

$h = \bar{F}1 - 4\bar{F}2 - ½\bar{P}1 - ½\bar{P}2 + 2\bar{B}1 + 2\bar{B}2$

$i = 2\bar{B}1 + 2\bar{B}2 - 4\bar{F}2$

$j = \bar{B}1 - ½\bar{P}1 - \bar{B}2 + ½\bar{P}2$

$l = \bar{P}1 + \bar{P}2 + 2\bar{F}1 + 4\bar{F}2 - 4\bar{B}1 - 4\bar{B}2$

The variances of these parameters were calculated as follows :

$V(m) = V\bar{F}2$

$V(d) = V\bar{B}1 + V\bar{B}2$

$V(h) = V\bar{F}1 + 16\ V\bar{F}2 + ¼\ V\bar{P}1 + ¼\ V\bar{P}2 + 4V\bar{B}1 + 4V\bar{B}2$

$V(i) = 4V\bar{B}1 + 4V\bar{B}2 + 16\ V\bar{F}2$

$V(j) = V\bar{B}1 + ¼\ V\bar{P}1 + V\bar{B}2 + ¼\ V\bar{P}2$

$V(l) = V\bar{P}1 + V\bar{P}2 + 4V\bar{F}1 + 16\ V\bar{F}2 + 16\ V\bar{B}1 + 16\ V\bar{B}2$

where

m = mean
d = additive effect
h = dominance effect
i = additive x additive interaction
j = additive x dominance interaction
l = dominance x dominance interaction

The above genetic parameters were tested for significance using 't' test.

3.5.5 Statistical analysis

The data on yield under 50 per cent shade showed a normal distribution in F2 generation indicating quantitative inheritance and therefore scaling test and generation mean analysis were carried out.

(i) Scaling test

The presence of non allelic interaction was detected by scaling tests proposed by Mather (1949). Estimates of additive (D) and dominance (H) components of genetic variance were made using the mean and variances of six generations *viz.*, P1, P2, F1, F2, BC1 and BC2.

$$A = 2\bar{B}1 - \bar{P}1 - \bar{F}1$$

$$V(A) = 4\,V(\bar{B}1) + V(\bar{P}1) + V(\bar{F}1)$$

$$B = 2\bar{B}2 - \bar{P}2 - \bar{F}1$$

$$V(B) = 4V(\bar{B}2) + V(\bar{P}2) + V(\bar{F}1)$$

$$C = 4\bar{F}2 - 2\bar{F}1 - \bar{P}1 - \bar{P}2$$

$$V(C) = 16\,V(\bar{F}2) + 4V(\bar{F}1) + V(\bar{P}1) + V(\bar{P}2)$$

$$D = 2\bar{F}2 - \bar{B}1 - \bar{B}2$$

$$V(D) = 4V(\bar{F}2) + V(\bar{B}1) + V(\bar{B}2)$$

Significance was tested by ABCD scaling test.

(ii) Generation mean analysis

In the presence of non-allelic interaction six parameter model as suggested by Hayman (1958) was used :

RESULTS

4. RESULTS

The experiment entitled 'Genetic analysis of shade tolerance in chilli (*Capsicum* spp.)' was carried out in the Department of Olericulture, College of Agriculture, Vellayani during the period of 1997 to 2000.

Experimental data recorded during the course of investigation were subjected to statistical analysis and are presented under the following heads.

4.1. Characterization of chilli genotypes for shade tolerance

4.2. Physiological basis of shade tolerance

4.3. Anatomical basis of shade tolerance

4.4. Biochemical basis of shade tolerance

4.5. Genetic basis of shade tolerance

4.1 Characterization of chilli genotypes for shade tolerance

4.1.1. Plant height

Significant variation among genotypes of *C. annuum, C. frutescens* and *C. chinense* for plant height was observed under different levels of shade (Table 2). The plant height in all the genotypes showed an increasing trend with increased shade levels. Maximum plant height of 74.86 cm was recorded in plants grown under 75 per cent shade compared to 47.05 cm in the open.

Among *C. annuum*, the genotype CA 39 registered maximum plant height under open, 25 and 75 per cent shade with 69.18 cm, 73.88 cm and

89.18 cm respectively. CA 15 was the tallest plant (84.13 cm) under 50 per cent shade. CA 39 was on par with CA 15 and CA 14 under open (68.13 cm and 67.05 cm) and 25 per cent shade (72.88 cm and 71.75 cm) respectively. CA 15 was taller than CA 14 (79.38 cm) and CA 39 (77.18 cm) under 50 per cent shade. In 75 per cent shade CA 39 was on par with CA 29 (89.18 cm), CA 14 (89.10 cm), CA 15 (88.25 cm), CA 55 (88.18 cm) and CA 1 (87.63 cm) respectively.

CA 32 was the shortest plant under all shade levels with 27.43 cm, 29.71 cm, 39.47 cm and 54.75 cm under open, 25, 50 and 75 per cent shade levels respectively.

In *C. frutescens*, CF 49 was the tallest in open (61.22 cm) and 75 per cent shade (95.68 cm). Under 25 and 50 per cent shade, maximum plant height was recorded by CF 47 with 72.94 cm and 82.50 cm respectively. CF 46 was the shortest under all shade levels. Plant heights were 37.05 cm, 42.27 cm, 43.63 cm and 46.43 cm in open, 25, 50 and 75 per cent shade respectively.

Among genotypes of *C. chinense*, CC 67 (59.10 cm), CC 62 (72.55 cm), CC 63 (77.68 cm) and CC 62 (91.00 cm) were the tallest plants in open, 25, 50 and 75 per cent shade respectively. Plants were shortest in CC 66 (43.00 cm), CC 71 (51.97 cm), CC 76 (61.93 cm) and CC 76 (73.21 cm) in open, 25, 50 and 75 per cent shade respectively.

Significant variation for plant height among different shade levels was recorded in *C. annuum*, *C. frutescens* and *C. chinense*. Among *C. annuum*, CA 15 had maximum pooled mean for plant height (78.35 cm) which was on par with CA 39 (77.36 cm) and CA 14 (76.82 cm). Minimum pooled mean was observed in CA 32 (37.84 cm).

Among *C. frutescens*, CF 49 had a maximum pooled mean (77.94 cm) and CF 46 minimum (42.35 cm). CC 62 had a maximum pooled mean (74.80 cm) and CC 71 minimum (59.03 cm) among *C. chinense*.

4.1.2. Internodal length

Variation in internodal length was observed only among genotypes of *C. annuum* under all shade levels (Table 3). However significant variation was observed among different levels of shade for internodal length in *C. annuum*, *C. frutescens* and *C. chinense*. The internodal length increased with an increase in levels of shade. Maximum internodal length was observed under 75 per cent shade. Overall mean of the internodal length due to shade level was maximum under 75 per cent (3.51 cm) followed by 3.22 cm under 50 per cent shade. Minimum internodal length was recorded in plants grown in open condition (2.59 cm).

Internodes were longest in genotypes CA 18, CA 38 and CA 64 with 2.75 cm and shortest in CA 6 and CA 24 with 2.25 cm in open. Under 25 per cent shade, the range of internodal length was from 2.85 cm to 3.15 cm, maximum being in CA 2. In 50 per cent shade, maximum internodal length was recorded by CA 16 (3.45 cm) and minimum by CA 39 (3.05 cm). Under 75 per cent shade, maximum internodal length was registered by CA 14 and CA 28 with 3.85 cm each and minimum by CA 32 (3.30 cm).

Table 2. Characterization of chilli genotypes for shade tolerance : plant height (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	37.00	56.88	69.43	87.63	62.74
CA 2	48.96	59.13	66.43	84.88	64.85
CA 3	39.38	55.68	59.54	74.67	57.32
CA 5	39.13	43.75	48.63	54.18	46.42
CA 6	40.38	59.18	68.91	78.18	61.66
CA 8	36.88	43.88	47.50	59.38	46.91
CA 9	39.93	55.63	54.30	58.68	52.14
CA 11	41.68	61.55	65.38	70.30	59.73
CA 12	38.98	43.93	49.05	54.20	46.54
CA 13	39.93	59.43	59.80	61.00	55.04
CA 14	67.05	71.75	79.38	89.10	76.82
CA 15	68.13	72.88	84.13	88.25	78.35
CA 16	59.00	69.30	73.92	85.00	71.81
CA 18	35.93	45.50	49.13	54.21	46.19
CA 20	41.04	62.84	65.88	78.13	61.97
CA 21	38.25	57.55	60.50	60.38	54.17
CA 22	41.38	56.38	62.54	74.18	58.62
CA 23	45.92	54.68	60.13	69.18	57.48
CA 24	33.96	52.89	55.18	58.88	50.23
CA 25	47.55	59.50	60.68	62.04	57.44
CA 28	35.00	49.71	52.00	59.43	49.04
CA 29	40.43	63.04	70.54	89.18	65.80
CA 32	27.43	29.71	39.47	54.75	37.84
CA 34	30.68	38.84	61.79	78.39	52.43
CA 36	42.50	48.23	45.37	55.30	47.85
CA 37	54.18	63.88	69.43	82.55	67.51
CA 38	39.00	41.00	49.13	58.05	46.80
CA 39	69.18	73.88	77.18	89.18	77.36
CA 55	46.88	62.88	76.80	88.18	68.69
CA 59	35.18	53.93	60.18	64.3	53.40
CA 60	41.38	46.04	58.63	63.00	52.26
CA 64	40.93	51.29	54.43	57.38	51.01
CA 81	39.21	43.39	53.88	58.18	48.67
CA 82	42.47	46.88	63.63	72.82	56.45
CA 83	42.93	57.00	66.88	71.30	59.53

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	46.93	52.55	54.96	56.68	52.78
CF 40	44.30	48.43	49.30	52.93	48.74
CF 41	57.55	61.05	66.68	73.72	64.75
CF 42	52.47	64.50	67.50	70.29	63.69
CF 43	53.49	59.30	63.13	73.21	62.28
CF 44	54.25	64.37	73.09	84.77	69.12
CF 45	57.80	60.00	70.92	81.87	67.65
CF 46	37.05	42.27	43.63	46.43	42.35
CF 47	56.50	72.94	82.50	91.34	75.82
CF 48	59.38	70.21	78.25	89.46	74.33
CF 49	61.22	72.92	81.92	95.68	77.94
CF 50	51.42	67.42	74.89	90.93	71.17
CF 51	51.00	70.13	76.47	93.50	72.78
CF 52	49.25	65.05	71.50	90.84	69.16
CF 53	50.75	63.15	67.10	83.54	66.14
CF 54	47.92	58.83	64.92	77.46	62.28
CF 56	47.43	51.55	62.72	81.47	60.79
CF 57	47.63	55.79	65.00	78.80	61.81
CF 58	46.30	54.42	62.30	74.50	59.38
CF 61	50.88	56.74	74.75	80.30	65.67
C. chinense					
CC 62	59.00	72.55	76.63	91.00	74.80
CC 63	52.50	71.65	77.68	89.88	72.93
CC 65	51.68	63.63	76.25	84.88	69.11
CC 66	43.00	64.13	72.55	75.50	63.80
CC 67	59.10	67.46	76.63	87.18	72.59
CC 68	49.29	65.42	69.25	77.63	65.40
CC 69	48.75	56.37	67.18	84.46	64.19
CC 70	51.09	63.34	74.18	89.25	69.47
CC 71	47.55	51.97	63.25	73.34	59.03
CC 72	49.04	59.40	66.60	75.13	62.54
CC 73	50.38	62.43	69.75	83.09	66.41
CC 74	51.60	59.25	72.88	81.25	66.25
CC 75	51.38	56.75	64.80	73.67	61.65
CC 76	51.92	52.38	61.93	73.21	59.86
CC 77	46.34	53.48	68.75	83.55	63.03
Mean (over shade level)	47.05	57.77	64.75	74.86	61.11
SE ± M	1.377	1.268	1.322	1.685	0.711
CD (0.05)	3.894	3.586	3.739	4.765	1.971

Among the genotypes of *C. frutescens* and *C. chinense* there was no significant difference for internodal length under different shade levels.

4.1.3 Stem girth

Significant difference was observed among the genotypes of *C. annuum*, *C. frutescens* and *C. chinense* for stem girth under all the shade levels (Table 4). A reduction in the stem girth was noticed with an increase in the shade level. Maximum stem girth was recorded from plants grown in open condition. Overall mean in stem girth due to shade level was maximum in open (4.37 cm) followed by 25 per cent shade (3.88 cm). Minimum stem girth was recorded from plants grown under 75 per cent shade (3.00 cm).

Among genotypes of *C. annuum*, CA 39 recorded maximum stem girth in open, 50 and 75 per cent shade with 4.80 cm, 3.65 cm and 3.05 cm respectively. Under 25 per cent shade maximum stem girth was observed in CA 25 (4.05 cm) which was on par with CA 81 (3.90 cm), CA 39 (3.85 cm), CA 20 (3.80 cm), CA 82 (3.75 cm), CA 16 (3.75 cm) and CA 55 (3.75 cm).

CA 39 was on par with CA 25 (4.65 cm) and CA 15 (4.65 cm) in open and with CA 82 (3.55 cm) and CA 81 (3.50 cm) under 50 per cent shade. CA 39 was on par with CA 81 (3.00 cm), CA 82 (2.95 cm) and CA 38 (2.90 cm) under 75 per cent shade.

Minimum stem girth was recorded in CA 32 in open and 25 per cent shade with 2.80 cm and 2.35 cm respectively. But at 50 per cent shade it was minimum in CA 12 (2.10 cm) which was on par with CA 32 (2.15 cm), CA 9 (2.20 cm) and CA 2 (2.40 cm). Under 75 per cent shade CA 3 recorded (2.00

Table 3. Characterization of chilli genotypes for shade tolerance : internodal length (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	2.55	2.90	3.30	3.70	3.11
CA 2	2.50	3.15	3.30	3.60	3.14
CA 3	2.45	3.00	3.25	3.70	3.10
CA 5	2.60	2.90	3.25	3.40	3.04
CA 6	2.25	3.00	3.15	3.35	2.94
CA 8	2.55	3.00	3.20	3.40	3.04
CA 9	2.50	2.95	3.20	3.45	3.03
CA 11	2.40	2.90	3.20	3.45	2.99
CA 12	2.45	3.00	3.25	3.45	3.04
CA 13	2.45	2.85	3.25	3.40	2.99
CA 14	2.50	2.95	3.40	3.85	3.18
CA 15	2.50	3.00	3.30	3.75	3.14
CA 16	2.70	3.00	3.45	3.70	3.21
CA 18	2.75	2.95	3.20	3.35	3.06
CA 20	2.45	2.90	3.25	3.40	3.00
CA 21	2.50	2.95	3.20	3.65	3.08
CA 22	2.40	2.90	3.25	3.55	3.03
CA 23	2.50	3.00	3.25	3.80	3.14
CA 24	2.25	2.95	3.30	3.80	3.08
CA 25	2.50	3.00	3.25	3.75	3.13
CA 28	2.45	2.90	3.30	3.85	3.13
CA 29	2.50	3.00	3.35	3.70	3.14
CA 32	2.50	3.00	3.10	3.30	2.98
CA 34	2.60	2.95	3.25	3.65	3.11
CA 36	2.65	3.00	3.25	3.77	3.17
CA 37	2.55	3.00	3.20	3.80	3.14
CA 38	2.75	3.00	3.15	3.80	3.18
CA 39	2.65	3.00	3.05	3.60	3.08
CA 55	2.65	2.90	3.25	3.60	3.10
CA 59	2.50	2.95	3.35	3.50	3.08
CA 60	2.35	2.90	3.35	3.60	3:05
CA 64	2.75	2.85	3.15	3.70	3.11
CA 81	2.70	2.85	3.40	3.80	3.19
CA 82	2.55	2.85	3.30	3.70	3.10
CA 83	2.55	2.85	3.30	3.75	3.11

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	2.60	2.95	3.25	3.45	3.06
CF 40	2.65	3.00	3.15	3.30	3.03
CF 41	2.65	3.05	3.20	3.35	3.06
CF 42	2.45	3.00	3.25	3.35	3.01
CF 43	2.55	2.90	3.20	3.40	3.01
CF 44	2.55	3.00	3.30	3.50	3.09
CF 45	2.45	2.95	3.20	3.45	3.01
CF 46	2.55	3.05	3.25	3.45	3.08
CF 47	2.65	2.95	3.20	3.45	3.06
CF 48	2.55	2.95	3.20	3.45	3.04
CF 49	2.45	2.90	3.15	3.45	2.99
CF 50	2.55	2.90	3.15	3.45	3.01
CF 51	2.70	3.05	3.20	3.50	3.11
CF 52	2.45	2.95	3.15	3.40	2.99
CF 53	2.65	3.05	3.20	3.45	3.09
CF 54	2.45	3.10	3.20	3.50	3.06
CF 56	2.65	2.95	3.20	3.45	3.06
CF 57	2.55	3.00	3.25	3.35	3.04
CF 58	2.45	3.05	3.25	3.35	3.03
CF 61	2.45	3.05	3.20	3.30	3.00
C. chinense					
CC 62	2.45	2.95	3.20	3.35	2.99
CC 63	2.95	3.00	3.25	3.40	3.15
CC 65	2.90	3.00	3.15	3.45	3.13
CC 66	2.95	3.00	3.15	3.35	3.11
CC 67	2.85	2.95	3.17	3.35	3.08
CC 68	2.75	3.05	3.15	3.45	3.10
CC 69	2.75	2.90	3.20	3.45	3.08
CC 70	2.70	3.00	3.05	3.30	3.01
CC 71	2.80	3.05	3.10	3.35	3.08
CC 72	2.80	3.05	3.25	3.35	3.11
CC 73	2.75	3.00	3.10	3.35	3.05
CC 74	2.75	2.95	3.05	3.40	3.04
CC 75	2.85	3.00	3.15	3.40	3.10
CC 76	2.75	2.85	3.05	3.25	2.98
CC 77	2.75	2.95	3.05	3.45	3.05
Mean (over shade level)	2.59	2.97	3.22	3.51	3.07
SE ± M	0.068	0.059	0.051	0.070	0.031
CD (0.05)	0.193	0.167	0.143	0.197	0.086

cm) the lowest stem girth and was on par with CA 9 (2.00 cm), CA 12 (2.05 cm), CA 11 (2.10 cm), CA 34 (2.20 cm), CA 36 (2.20 cm), CA 32 (2.20 cm), CA 2 (2.25 cm), CA 24 (2.25 cm) and CA 59 (2.25 cm).

Among the genotypes of *C. frutescens*, CF 52 had maximum stem girth of 4.75 cm, 4.40 cm and 4.00 cm in open, 25 and 50 per cent shade respectively while CF 57 recorded 3.55 cm under 75 per cent shade.

CF 30 recorded minimum stem girth of 3.95 cm both in open and 25 per cent shade. A minimum stem girth of 3.20 cm was observed in CF 48 under 50 and 2.90 cm in CF 61 under 75 per cent shade.

In *C. chinense*, maximum stem girth was recorded by CC 63 with 6.05 cm, 6.00 cm and 5.35 cm in open, 25 and 50 per cent shade respectively while CC 65 had maximum stem girth of 4.70 cm under 75 per cent shade. Minimum stem girth was recorded by CC 62 with 4.30 cm, 3.90 cm, 3.55 cm and 3.05 cm in open, 25, 50 and 75 per cent shade respectively.

The performance of genotype varied significantly among different shade levels also in *C. annuum*, *C. frutescens* and *C. chinense*. CA 39 had a maximum pooled mean for stem girth (3.84 cm) which was superior to CA 81 (3.63 cm) and CA 82 (3.59 cm). Minimum pooled mean was observed in CA 32 (2.38 cm) which was on par with CA 12 (2.51 cm).

Among *C. frutescens*, maximum pooled mean for stem girth was registered by CF 52 (4.13cm) and lowest by CF 30 (3.48 cm). Among *C. chinense*, CC 63 had maximum (5.44 cm) CC 62 had minimum (3.70 cm).

Table 4. Characterization of chilli genotypes for shade tolerance: stem girth (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	3.95	2.95	2.90	2.35	3.04
CA 2	4.00	2.85	2.40	2.25	2.88
CA 3	3.85	3.35	2.65	2.00	2.96
CA 5	3.45	3.00	2.70	2.40	2.89
CA 6	3.95	3.05	2.75	2.75	3.13
CA 8	4.05	3.05	2.90	2.75	3.19
CA 9	3.90	2.90	2.20	2.00	2.75
CA 11	3.50	3.00	2.75	2.10	2.84
CA 12	3.45	2.45	2.10	2.05	2.51
CA 13	3.75	3.10	2.65	2.35	2.96
CA 14	4.10	3.45	2.90	2.40	3.21
CA 15	4.65	3.50	2.65	2.50	3.33
CA 16	4.30	3.75	3.05	2.50	3.40
CA 18	4.30	3.60	3.10	2.55	3.39
CA 20	4.00	3.80	2.70	2.55	3.26
CA 21	3.70	3.10	2.50	2.45	2.94
CA 22	3.60	3.60	2.70	2.60	3.13
CA 23	4.30	3.70	3.10	2.70	3.45
CA 24	3.40	2.90	2.50	2.25	2.76
CA 25	4.65	4.05	2.95	2.60	3.56
CA 28	3.80	3.30	3.00	2.70	3.20
CA 29	3.85	2.90	2.50	2.45	2.93
CA 32	2.80	2.35	2.15	2.20	2.38
CA 34	3.05	2.65	2.55	2.20	2.61
CA 36	3.90	3.10	2.80	2.20	3.00
CA 37	3.70	3.15	2.70	2.55	3.03
CA 38	4.35	3.50	3.10	2.90	3.46
CA 39	4.80	3.85	3.65	3.05	3.84
CA 55	4.05	3.75	2.90	2.65	3.34
CA 59	3.65	3.05	2.50	2.25	2.86
CA 60	4.10	3.65	3.00	2.70	3.36
CA 64	4.05	3.30	3.00	2.85	3.30
CA 81	4.10	3.90	3.50	3.00	3.63
CA 82	4.10	3.75	3.55	2.95	3.59
CA 83	3.90	3.65	2.55	2.35	3.11

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	3.95	3.70	3.30	2.95	3.48
CF 40	4.05	4.05	3.70	3.15	3.74
CF 41	4.35	4.15	3.90	3.15	3.89
CF 42	4.35	3.95	3.70	3.15	3.79
CF 43	4.15	3.90	3.60	3.10	3.69
CF 44	4.35	4.15	3.45	2.95	3.73
CF 45	4.55	4.20	3.35	3.00	3.78
CF 46	4.35	3.95	3.30	2.95	3.64
CF 47	4.30	4.05	3.40	3.00	3.69
CF 48	4.30	3.85	3.20	3.00	3.59
CF 49	4.35	4.05	3.25	2.95	3.65
CF 50	4.35	4.05	3.60	2.95	3.74
CF 51	4.70	4.25	3.90	3.45	4.08
CF 52	4.75	4.40	4.00	3.35	4.13
CF 53	4.65	4.20	3.75	3.45	4.01
CF 54	4.60	4.25	3.70	3.30	3.96
CF 56	4.52	4.15	3.80	3.40	3.97
CF 57	4.70	4.35	3.95	3.55	4.14
CF 58	4.55	4.15	3.55	2.95	3.80
CF 61	4.35	3.95	3.60	2.90	3.70
C. chinense					
CC 62	4.30	3.90	3.55	3.05	3.70
CC 63	6.05	6.00	5.35	4.37	5.44
CC 65	5.85	5.55	5.30	4.70	5.35
CC 66	6.00	5.90	5.35	4.10	5.34
CC 67	5.95	5.70	5.30	4.40	5.34
CC 68	5.20	4.85	4.50	4.10	4.66
CC 69	4.70	4.30	4.25	3.65	4.23
CC 70	5.15	4.50	4.50	3.75	4.48
CC 71	5.65	5.20	4.90	4.30	5.01
CC 72	5.45	4.90	4.80	4.10	4.81
CC 73	5.10	4.30	4.20	3.55	4.29
CC 74	5.25	4.60	4.35	4.05	4.56
CC 75	5.35	4.80	4.65	4.10	4.73
CC 76	5.25	4.90	4.70	4.05	4.73
CC 77	5.15	4.80	4.60	3.95	4.63
Mean (over shade level)	4.37	3.88	3.43	3.00	3.67
SE ± M	0.117	0.113	0.119	0.109	0.057
CD (0.05)	0.330	0.318	0.337	0.307	0.158

4.1.4 Leaf Area

Significant difference for leaf area was observed among the genotypes in *C. annuum*, *C. frutescens* and *C. chinense* under all the shade levels (Table 5). An increase in the leaf area was noticed with an increase in the shade level in all the genotypes. Maximum leaf area was registered in plants grown under 75 percent shade. Overall mean in leaf area due to shade level was maximum under 75 per cent (45.57 cm^2) followed by 50 per cent (39.51 cm^2) shade. Minimum leaf area was recorded from plants grown in open.

In open CA 39 registered maximum leaf area (19.38 cm^2) which was on par with CA 38 (18.86 cm^2), CA 64 (18.22 cm^2), CA 37 (18.03 cm^2), CA 81 (16.84 cm^2) and CA 55 (16.78 cm^2). CA 39 also registered maximum leaf area of 38.31 cm^2, 42.09 cm^2, 49.22 cm^2 under 25, 50 and 75 per cent shade respectively and was superior to other genotypes under these shade levels.

Minimum leaf area was recorded in CA 22 in open and 25 per cent shade with 6.30 cm^2 and 7.88 cm^2 respectively. In open, CA 22 was on par with CA 12 (6.31 cm^2), CA 5 (6.66 cm^2), CA 13 (7.24 cm^2), CA 2 (8.66 cm^2) and CA 23 (8.88 cm^2) while CA 22 was not par with other genotypes under 25 per cent shade. Under 50 and 75 per cent shade CA 6 recorded minimum leaf of 12.58 cm^2 and 14.41 cm^2 respectively. Under 50 per cent shade CA 6 was on par with CA 12 (13.73 cm^2) and CA 22 (13.85 cm^2). Under 75 per cent shade CA 6 was on par with CA 12 (15. 04 cm^2).

Among genotypes of *C. frutescens*, CF 58 had maximum leaf area in open (35.03 cm^2) which was on par with CF 51 (34.93 cm^2), CF 50 (34.21 cm^2), CF 52 (34.18 cm^2), CF 49 (32.52 cm^2), CF 57 (32.20 cm^2) and CF 48

(32.14 cm^2). Under 25, 50 and 75 per cent shade, CF 51 had maximum leaf area with 53.00 cm^2, 63.16 cm^2 and 67.84 cm^2 respectively. CF 51 was superior to other genotypes under 25 and 50 per cent shade while was on par with CF 57 (65.77 cm^2) in 75 per cent shade.

Minimum leaf area was recorded in CF 54 under 25, 50 and 75 shade with 33.66 cm^2, 40.14 cm^2 and 51.34 cm^2 respectively. CF 54 was on par with CF 61 (34.21 cm^2) under 25 per cent shade and with CF 30 (52.74 cm^2) and CF 40 (53.21 cm^2) under 75 per cent shade. In open, CF 61 registered minimum leaf area of 25.49 cm^2 which was on par with CF 43 (27.11 cm^2), CF 47 (27.95 cm^2), CF 46 (28.05 cm^2) and CF 40 (28.13 cm^2).

In *C. chinense*, maximum leaf area was registered by CC 62 with 44.53 cm^2 in open and CC 66 with 60.24 cm^2 under 25 per cent shade. CC 63 registered maximum leaf area of 81.76 cm^2 and 87.56 cm^2 under 50 and 75 per cent shade respectively. Minimum leaf area was observed in CC 72 with 31.02 cm^2, 41.23 cm^2, 48.74 cm^2 and 51.41 cm^2 in open, 25, 50 and 75 per cent shade respectively.

The performances of genotypes varied significantly among different shade levels in *C. annuum*, *C. frutescens* and *C. chinense*. Among *C. annuum*, maximum pooled mean for leaf area of 37.25 cm^2 was recorded in CA 39 which was superior to CA 38 (32.14 cm^2). Minimum pooled mean was registered by CA 22 (11.51 cm^2) which was on par with CA 12 (11.83 cm^2) and CA 6 (12.15 cm^2).

Among *C. frutescens*, maximum pooled mean for leaf area was recorded in CF 51 (54.73 cm^2) and minimum in CF 54 (38.80 cm^2). It was maximum in CC 63 (68.18 cm^2) and minimum in CC 72 (43.10 cm^2) among *C. chinense*.

4.1.5 Petiole length

Significant difference among the genotypes and between different shade levels was observed in all the three species for petiole length (Table 6). An increase in the petiole length was observed with an increase in the shade level. Maximum petiole length was recorded in plants grown under 75 per cent shade level. Overall mean of petiole length due to shade was maximum under 75 per cent (5.71 cm) followed by 50 per cent (5.25 cm) shade. Minimum petiole length was recorded from plants grown in open (3.56).

In open CA 11 registered maximum petiole length of 5.10 cm, which was on par with CA 37 and CA 38 with 4.90 cm each. Minimum petiole length was recorded from CA 5 (2.05 cm) and CA 6 (2.10 cm).

Maximum petiole length was recorded by CA 82 (6.85 cm) under 25 per cent shade which was on par with CA 11 (6.75 cm) and CA 29 (6.70 cm). Minimum petiole length was observed in CA 32 (3.10 cm) which was on par with CA 2 (3.10 cm), CA 12 (3.10 cm) and CA 1 (3.25 cm).

Under 50 per cent shade CA 29 had the highest petiole length (7.00 cm) which was on par with CA 82 (6.90 cm) followed by CA 11 (6.70 cm) and CA 38 (6.70 cm). Lowest petiole length was recorded in CA 2 and CA 32 (3.50 cm each) which was on par with CA 18 and CA 12 (3.70 cm each).

Under 75 per cent shade CA 39 had the highest petiole length (7.70 cm) which was superior to other genotypes followed by CA 38 (7.30 cm) and

Table 5. Characterization of chilli genotypes for shade tolerance : leaf area (cm^2)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	11.05	13.69	17.14	20.82	15.68
CA 2	8.66	13.70	16.91	20.85	15.03
CA 3	10.21	14.02	17.15	22.45	15.96
CA 5	6.66	12.02	15.28	17.61	12.89
CA 6	9.77	11.83	12.58	14.41	12.15
CA 8	15.45	22.12	24.77	26.93	22.32
CA 9	12.82	20.46	22.55	25.02	20.21
CA 11	14.75	28.01	30.47	31.89	26.28
CA 12	6.31	12.22	13.73	15.04	11.83
CA 13	7.24	16.63	19.24	24.02	16.78
CA 14	11.62	14.06	20.71	29.08	18.87
CA 15	9.96	13.56	21.18	28.87	18.39
CA 16	14.14	15.59	21.46	26.05	19.31
CA 18	10.56	13.35	18.68	23.75	16.59
CA 20	15.22	26.65	31.00	33.02	26.47
CA 21	10.38	21.10	26.05	33.21	22.69
CA 22	6.30	7.88	13.85	18.00	11.51
CA 23	8.88	15.76	19.43	37.42	20.37
CA 24	9.79	15.91	19.09	23.95	17.19
CA 25	12.64	20.32	22.05	24.47	19.87
CA 28	15.60	18.01	19.63	21.90	18.79
CA 29	15.58	23.21	24.93	27.99	22.93
CA 32	11.35	16.08	19.29	23.54	17.57
CA 34	11.83	15.42	17.09	19.21	15.89
CA 36	15.93	29.85	34.87	41.49	30.54
CA 37	18.03	28.89	35.17	38.94	30.26
CA 38	18.86	31.47	35.77	42.44	32.14
CA 39	19.38	38.31	42.09	49.22	37.25
CA 55	16.78	20.88	28.21	34.29	25.04
CA 59	12.45	18.96	24.20	32.05	21.92
CA 60	12.22	23.76	25.01	27.23	22.06
CA 64	18.22	31.03	33.18	36.96	29.85
CA 81	16.84	30.69	34.45	37.53	29.88
CA 82	15.20	21.75	26.58	31.42	23.74
CA 83	16.08	22.37	24.19	26.33	22.24

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	30.97	38.93	44.87	52.74	41.88
CF 40	28.13	40.47	46.08	53.21	41.97
CF 41	31.60	39.04	45.35	54.87	42.72
CF 42	31.75	39.41	47.08	59.04	44.32
CF 43	27.11	36.81	47.85	58.10	42.47
CF 44	29.84	43.07	54.22	58.50	46.41
CF 45	30.99	37.88	47.20	56.02	43.02
CF 46	28.05	38.99	54.17	57.19	44.60
CF 47	27.95	39.09	53.62	59.47	45.03
CF 48	32.14	39.05	49.07	59.18	44.86
CF 49	32.52	43.21	51.90	58.03	46.42
CF 50	34.21	43.72	57.38	61.50	49.20
CF 51	34.93	53.00	63.16	67.84	54.73
CF 52	34.18	43.69	57.70	62.81	49.60
CF 53	31.69	41.18	45.71	58.64	44.31
CF 54	30.04	33.66	40.14	51.34	38.80
CF 56	28.53	38.01	46.20	57.64	42.60
CF 57	32.20	44.99	55.00	65.77	49.49
CF 58	35.03	43.68	51.19	60.68	47.65
CF 61	25.49	34.21	43.20	59.76	40.67
C. chinense					
CC 62	44.53	57.95	77.42	80.80	65.18
CC 63	43.21	60.18	81.76	87.56	68.18
CC 65	42.00	49.19	64.16	70.84	56.55
CC 66	35.01	60.24	77.39	85.73	64.59
CC 67	42.08	46.34	59.17	71.26	54.71
CC 68	42.22	55.57	69.01	73.12	59.98
CC 69	42.47	52.19	58.97	62.50	54.03
CC 70	37.63	46.29	58.03	60.88	50.71
CC 71	33.67	42.70	54.54	59.64	47.64
CC 72	31.02	41.23	48.74	51.41	43.10
CC 73	35.27	44.86	53.74	62.56	49.11
CC 74	35.37	45.39	54.30	63.61	49.67
CC 75	35.06	47.67	51.48	61.56	48.94
CC 76	41.97	52.98	62.59	68.98	56.63
CC 77	41.82	58.93	65.51	69.97	59.06
Mean (over shade level)	23.53	32.48	39.51	45.57	35.27
SE $\pm$ M	1.069	0.775	0.65	0.794	0.418
CD (0.05)	3.023	2.193	1.837	2.247	1.159

CA 29 (7.10 cm). Lowest petiole length was recorded in CA 18 (3.80 cm) which was on par with CA 32 (3.90 cm) and CA 12 (4.00 cm).

In *C. frutescens*, CF 44 and CF 50 registered maximum petiole length (3.75 cm each) in open. CF 51 had maximum petiole length of 4.90 cm, 5.15 cm and 5.50 cm under 25, 50 and 75 per cent shade respectively. CF 30 registered minimum petiole length of 3.05 cm, 3.70 cm and 4.55 cm in open, 25 and 50 per cent shade respectively. Under 75 per cent shade CF 48 had minimum petiole length of 4.85 cm.

Among genotypes of *C. chinense*, CC 63 had longest petioles with 4.50 cm, 6.70 cm, 7.70 cm and 7.80 cm in open, 25, 50 and 75 per cent shade respectively. Minimum petiole length of 3.50 cm was recorded by CC 71 in open. CC 69 had a minimum length of 4.70 cm in 25 per cent shade. CC 68 registered minimum length of 5.70 cm and 6.20 cm under 50 and 75 per cent shade respectively.

Maximum pooled mean for petiole length was registered by CA 11(6.39 cm) which was superior to other genotypes followed by CA 29 and CA 38 with 6.25 cm each. Minimum pooled mean was observed in CA 18 (3.33 cm) and CA 32 (3.34 cm).

Among *C. frutescens*, maximum pooled mean for petiole length was recorded in CF 51 (4.81 cm) which was on par with CF 50(4.75 cm). Minimum pooled mean was registered by CF 30 with 4.11 cm.

Maximum pooled mean for petiole length of 6.68 cm was observed in CC 63 and minimum in CC 68 and CC 69 (5.15 cm) in *C. chinense*.

Table 6. Characterization of chilli genotypes for shade tolerance: petiole length (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	2.85	3.25	5.25	5.70	4.26
CA 2	2.50	3.10	3.50	5.05	3.54
CA 3	3.30	5.15	5.30	6.10	4.96
CA 5	2.05	4.70	4.95	5.20	4.23
CA 6	2.10	4.00	4.15	4.20	3.61
CA 8	2.70	5.45	5.50	5.80	4.86
CA 9	2.50	3.60	4.50	4.80	3.85
CA 11	5.10	6.75	6.70	7.00	6.39
CA 12	2.90	3.10	3.70	4.00	3.43
CA 13	2.80	5.50	5.70	6.95	5.24
CA 14	4.05	4.45	4.60	5.00	4.53
CA 15	4.30	4.50	4.75	5.20	4.69
CA 16	3.10	3.45	4.30	4.95	3.95
CA 18	2.50	3.30	3.70	3.80	3.33
CA 20	3.10	4.25	4.35	4.45	4.04
CA 21	3.55	4.90	5.15	5.70	4.83
CA 22	3.25	3.70	4.10	5.30	4.09
CA 23	3.90	4.15	4.50	5.20	4.44
CA 24	3.45	3.50	3.80	4.70	3.86
CA 25	3.10	5.10	5.10	5.10	4.60
CA 28	4.10	4.90	5.40	5.90	5.08
CA 29	4.20	6.70	7.00	7.10	6.25
CA 32	2.85	3.10	3.50	3.90	3.34
CA 34	3.25	3.65	3.90	4.70	3.88
CA 36	3.25	3.65	5.60	5.90	4.60
CA 37	4.90	5.25	5.60	5.80	5.39
CA 38	4.90	6.10	6.70	7.30	6.25
CA 39	3.90	5.70	6.20	7.70	5.88
CA 55	3.70	5.50	5.65	5.90	5.19
CA 59	3.30	3.70	4.45	5.90	4.34
CA 60	3.35	4.70	4.90	6.90	4.96
CA 64	3.85	5.90	6.30	6.20	5.56
CA 81	4.50	5.90	6.20	6.50	5.78
CA 82	4.25	6.85	6.90	7.00	6.25
CA 83	3.10	4.30	5.50	5.75	4.66

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	3.05	3.70	4.55	5.15	4.11
CF 40	3.15	3.75	4.70	5.25	4.21
CF 41	3.35	4.10	4.85	5.25	4.39
CF 42	3.40	4.15	4.90	5.10	4.39
CF 43	3.60	4.25	4.85	5.30	4.50
CF 44	3.75	4.30	4.85	5.45	4.59
CF 45	3.65	4.40	4.80	5.30	4.54
CF 46	3.30	4.15	4.75	5.10	4.33
CF 47	3.55	4.60	4.85	5.20	4.55
CF 48	3.50	4.35	4.65	4.85	4.34
CF 49	3.55	4.35	4.70	5.25	4.46
CF 50	3.75	4.75	5.15	5.35	4.75
CF 51	3.70	4.90	5.15	5.50	4.81
CF 52	3.50	4.75	4.90	5.35	4.63
CF 53	3.70	4.80	5.05	5.30	4.71
CF 54	3.50	4.65	5.05	5.35	4.64
CF 56	3.45	4.80	4.85	5.10	4.55
CF 57	3.25	4.70	5.05	5.30	4.58
CF 58	3.45	4.70	4.95	5.27	4.59
CF 61	3.45	4.75	5.05	5.15	4.60
C. chinense					
CC 62	3.75	4.85	6.45	7.15	5.55
CC 63	4.50	6.70	7.70	7.80	6.68
CC 65	4.20	5.70	6.60	6.70	5.80
CC 66	4.30	5.65	6.75	7.30	6.00
CC 67	4.10	5.40	6.05	6.30	5.46
CC 68	3.85	4.85	5.70	6.20	5.15
CC 69	3.75	4.70	5.80	6.35	5.15
CC 70	3.85	5.10	5.70	6.30	5.24
CC 71	3.50	5.15	5.90	6.75	5.33
CC 72	3.70	5.00	5.90	6.35	5.24
CC 73	3.75	5.15	6.05	6.40	5.34
CC 74	4.10	5.30	6.00	6.45	5.46
CC 75	4.00	4.90	6.10	6.55	5.39
CC 76	3.90	4.90	5.90	6.25	5.24
CC 77	3.95	4.90	5.80	6.45	5.28
Mean (over shade level)	3.56	4.70	5.25	5.71	4.81
SE ± M	0.082	0.092	0.079	0.112	0.046
CD (0.05)	0.233	0.261	0.222	0.318	0.128

4.1.6 Height of node to first flower

Significant variation among the genotypes for node height to first flower was observed under all the shade levels (Table 7). An increase in the height of node to first flower was noticed with increase in shade levels.

CA 39 had maximum node height to first flower in open, 25, 50 and 75 per cent shade with 30.63 cm, 32.50 cm, 37.00 cm and 47.13 cm respectively. In open CA 39 was on par with CA 82 (28.38 cm) while in 25 per cent shade CA 39 was on par with CA 82 (31.21 cm), CA 25 (30.90 cm) and CA 15 (29.75 cm). In 50 per cent shade CA 39 was on par with CA 14 (35.30 cm), CA 82 (34.63 cm), CA 15 (34.50 cm) and CA 25 (34.38 cm). Under 75 per cent shade CA 39 was on par with CA 14 (43.38 cm).

Minimum height to first flowering node was noted in CA 8 in open and 25 per cent shade with 15.00 cm and 16.29 cm respectively. Under 50 per cent shade CA 34 (18.88 cm) and 75 per cent shade CA 64 (20.34 cm) recorded the minimum.

In *C. frutescens*, maximum height was recorded in CF 58 (30.34 cm) in open. Under 25 and 50 per cent shade, CF 56 had the maximum height with 31.82 cm and 38.99 cm respectively. CF 52 recorded the maximum height (43.23 cm) under 75 per cent shade.

Minimum height to first flowering node was in CF 40 in open and 25 per cent shade with 24.15 cm and 24.63 cm while CF 30 had minimum height under 50 and 75 per cent shade with 26.38 cm and 30.55 cm respectively.

Among genotypes of *C. chinense*, maximum height to first flowering node was registered by CC 65 (30.74 cm) in open. Under 25, 50 and 75 per cent shade, CC 63 had the maximum height with 31.39 cm, 38.10 cm, and 44.88 cm respectively.

Minimum node height to first flower was in CC 62 in open and 25 per cent shade with 26.55 cm and 26.42 cm while CC 66 had minimum height under 50 and 75 per cent shade with 31.18 cm and 36.60 cm respectively.

The performance of genotypes varied significantly among different shade levels also in *C. annuum*, *C. frutescens* and *C. chinense*. Maximum pooled mean for node height to first flower was recorded in CA 39 (36.82 cm) and minimum in CA 34 (18.43 cm) which was on par with CA 18 (19.06 cm), CA 32 (19.18 cm), CA 38 (19.20 cm), CA 8 (20.01 cm) and CA 12 (20.13 cm). In the *C. frutescens*, maximum pooled mean for height of node to first flower was observed in CF 56 (34.99 cm) and minimum in CF 46 (27. 09 cm). In *C. chinense*, maximum was registered by CC 63 (36.19 cm) and minimum by CC 62 (31.48 cm).

4.1.7 Node to first flower

Significant variation among genotypes in node to first flower was observed under all the shade levels in *C. annuum* (Table 8). An increase in the number of node to first flower with an increase in shade level was observed.

Node number to first flower was lower in CA 34 (9.25) in open, which was on par with CA 9 (9.92). In 25 per cent shade CA 9 (9.46) had flowers in the lower node which was on par with CA 34 (10.13). CA 36 recorded lower node number under 50 and 75 per cent shade with 10.13 and 10.09 respectively.

Table 7. Characterization of chilli genotypes for shade tolerance: height of node to first flower (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	24.00	28.23	32.13	35.33	29.92
CA 2	23.96	27.45	27.50	29.54	27.11
CA 3	17.88	23.36	25.88	28.75	23.97
CA 5	19.38	22.00	24.13	27.13	23.16
CA 6	19.88	24.38	26.96	29.88	25.28
CA 8	15.00	16.29	22.88	25.88	20.01
CA 9	15.63	16.71	26.00	30.70	22.26
CA 11	23.63	27.13	29.00	30.75	27.63
CA 12	16.75	18.67	20.84	24.25	20.13
CA 13	21.88	25.38	28.13	31.64	26.76
CA 14	27.63	28.87	35.30	43.38	33.80
CA 15	26.63	29.75	34.50	41.86	33.19
CA 16	18.38	20.88	25.00	26.60	22.72
CA 18	16.13	18.88	19.57	21.67	19.06
CA 20	20.13	23.17	24.00	27.29	23.65
CA 21	21.63	22.50	31.50	34.25	27.47
CA 22	23.00	25.63	28.50	33.00	27.53
CA 23	18.38	23.00	25.63	28.85	23.97
CA 24	20.00	23.80	26.80	30.00	25.15
CA 25	26.38	30.90	34.38	34.17	31.46
CA 28	17.84	21.46	24.00	29.50	23.20
CA 29	21.00	24.84	25.64	27.40	24.72
CA 32	15.46	16.71	20.88	23.68	19.18
CA 34	15.50	17.84	18.88	21.50	18.43
CA 36	21.00	20.75	22.74	25.68	22.54
CA 37	20.00	21.50	22.75	26.84	22.77
CA 38	16.63	18.88	20.00	21.29	19.20
CA 39	30.63	32.50	37.00	47.13	36.82
CA 55	20.13	21.75	25.63	28.63	24.04
CA 59	22.88	25.13	26.63	35.50	27.54
CA 60	19.25	20.13	22.00	23.00	21.10
CA 64	17.25	18.52	19.25	20.34	18.84
CA 81	17.00	18.00	20.25	21.70	19.24
CA 82	28.38	31.21	34.63	35.25	32.37
CA 83	24.88	25.63	27.50	28.63	26.66

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	25.55	27.00	26.38	30.55	27.37
CF 40	24.15	24.63	28.23	32.25	27.32
CF 41	27.54	29.80	33.92	35.69	31.74
CF 42	27.69	28.42	32.09	36.69	31.22
CF 43	27.66	30.21	35.30	38.14	32.83
CF 44	26.46	27.50	32.15	36.67	30.70
CF 45	26.82	27.60	32.05	37.14	30.90
CF 46	24.49	25.20	26.47	32.18	27.09
CF 47	27.92	29.29	36.05	39.38	33.16
CF 48	27.88	30.32	36.25	40.39	33.71
CF 49	28.75	29.49	36.08	43.04	34.34
CF 50	28.50	29.80	36.75	40.30	33.84
CF 51	29.05	31.13	37.14	41.00	34.58
CF 52	27.05	29.55	38.97	43.23	34.70
CF 53	27.18	31.20	38.20	41.42	34.50
CF 54	27.50	31.44	38.56	42.45	34.99
CF 56	28.69	31.82	38.99	40.45	34.99
CF 57	29.65	30.49	38.80	37.72	34.17
CF 58	30.34	30.35	37.80	40.00	34.62
CF 61	28.62	30.10	36.23	39.25	33.55
C. chinense					
CC 62	26.55	26.42	32.75	40.20	31.48
CC 63	30.39	31.39	38.10	44.88	36.19
CC 65	30.74	31.35	38.10	42.63	35.71
CC 66	28.50	27.99	31.18	36.60	31.07
CC 67	29.09	29.32	33.88	41.38	33.42
CC 68	30.29	29.70	36.62	40.18	34.20
CC 69	29.60	28.29	35.56	38.93	33.10
CC 70	27.55	30.65	37.65	42.70	34.64
CC 71	29.55	30.80	35.40	41.25	34.25
CC 72	29.39	30.25	35.98	42.25	34.47
CC 73	29.25	30.90	37.25	42.18	34.90
CC 74	28.97	28.68	35.13	41.18	33.49
CC 75	29.80	29.75	35.24	39.83	33.66
CC 76	29.78	28.97	35.21	40.89	33.71
CC 77	30.13	31.13	35.00	40.50	34.19
Mean (over shade level)	24.50	26.32	30.65	34.49	28.99
SE ± M	1.037	1.266	1.163	1.467	0.622
CD (0.05)	2.933	3.581	3.288	4.150	1.723

The genotype CA 39 had flowers in the upper node in open, 25, 50 and 75 per cent shade with 20.88, 20.88, 21.50 and 22.13 respectively. CA 39 was significantly superior to CA 11 and CA 25 in open (19.00, 18.25) and 25 (18.56 and 18.70) per cent shade respectively. CA 39 was on par with CA 11 under 50 (20.76) and 75 (21.00) per cent shade.

The performance of genotype was found to vary significantly under different shade levels. Minimum pooled mean for node to first flower was in CA 34 (10.03) and maximum in CA 39 (21.35).

No significant variation among genotypes in node to first flower was observed both in *C. frutescens* and *C.* chinense under any shade level. However there was significant variation among different shade levels in both these species.

Among *C. frutescens*, minimum pooled mean for node to first flower was recorded in CF 48 (21.19) and maximum in CF 43 (22.67). In *C. chinense*, minimum was registered by CC 70 (19.60) and maximum by CC 62 (21.25).

4.1.8 Days to first flower

Significant variation among genotypes for days to first flower was observed under all the shade levels in *C. annuum* (Table 9). An increase in the number of days for the first flower was observed with an increase in the shade level.

Table 8. Characterization of chilli genotypes for shade tolerance: node to first flower

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	14.50	14.46	15.34	15.42	14.93
CA 2	15.34	15.37	16.00	16.88	15.90
CA 3	13.50	14.63	14.63	14.84	14.40
CA 5	10.67	11.50	11.59	11.38	11.29
CA 6	13.75	14.38	14.63	14.55	14.33
CA 8	10.30	10.17	11.00	12.63	11.03
CA 9	9.92	9.46	12.84	13.88	11.53
CA 11	19.00	18.56	20.76	21.00	19.83
CA 12	11.55	11.88	11.75	11.90	11.77
CA 13	12.50	12.88	13.63	13.75	13.19
CA 14	16.88	17.17	17.00	17.75	17.20
CA 15	17.38	17.67	17.88	18.25	17.80
CA 16	14.13	14.88	14.13	15.57	14.68
CA 18	10.50	10.34	11.08	12.50	11.11
CA 20	12.34	12.59	12.84	13.21	12.75
CA 21	17.63	17.30	17.13	17.20	17.32
CA 22	12.75	13.38	13.50	13.70	13.33
CA 23	11.88	11.88	12.00	12.10	11.97
CA 24	11.10	11.98	11.88	12.34	11.83
CA 25	18.25	18.70	18.63	18.83	18.60
CA 28	14.50	14.60	14.88	15.10	14.77
CA 29	16.50	16.84	16.96	17.38	16.92
CA 32	10.75	10.50	11.34	11.50	11.02
CA 34	9.25	10.13	10.25	10.50	10.03
CA 36	10.47	10.64	10.13	10.09	10.33
CA 37	10.50	10.58	10.50	10.50	10.52
CA 38	10.75	10.50	11.13	11.92	11.08
CA 39	20.88	20.88	21.50	22.13	21.35
CA 55	14.13	14.38	14.63	14.75	14.47
CA 59	15.13	15.13	15.63	15.92	15.45
CA 60	11.88	12.63	12.75	13.25	12.63
CA 64	11.00	10.75	10.88	11.00	10.91
CA 81	10.75	10.88	11.25	13.25	11.53
CA 82	14.50	14.50	15.00	15.50	14.88
CA 83	15.88	16.42	16.50	16.63	16.36

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	20.93	21.21	22.40	23.55	22.02
CF 40	20.55	23.79	21.88	23.25	22.37
CF 41	21.00	21.93	22.25	24.18	22.34
CF 42	20.63	21.47	21.92	22.93	21.74
CF 43	21.00	22.42	23.29	23.96	22.67
CF 44	20.80	21.79	21.43	22.94	21.74
CF 45	20.93	21.55	21.75	23.33	21.89
CF 46	20.68	21.43	22.29	22.93	21.83
CF 47	20.79	21.29	21.92	23.30	21.83
CF 48	20.54	20.79	21.42	22.00	21.19
CF 49	20.93	21.55	22.00	22.92	21.85
CF 50	20.92	21.29	21.54	23.30	21.76
CF 51	20.84	21.29	22.55	23.47	22.04
CF 52	20.43	20.90	21.92	23.29	21.64
CF 53	20.43	20.97	21.29	23.25	21.49
CF 54	20.97	21.63	22.93	24.38	22.48
CF 56	20.75	20.55	22.43	23.05	21.70
CF 57	20.97	21.02	21.88	23.43	21.83
CF 58	20.13	20.96	21.49	22.38	21.24
CF 61	20.43	21.00	21.79	24.05	21.82
C. chinense					
CC 62	20.38	20.50	21.35	22.75	21.25
CC 63	18.55	19.97	20.08	22.05	20.16
CC 65	18.63	19.55	19.97	24.02	20.54
CC 66	18.92	19.92	20.59	24.00	20.86
CC 67	18.32	19.42	19.52	22.71	19.99
CC 68	18.63	19.55	19.75	24.25	20.55
CC 69	19.00	20.43	21.17	22.92	20.88
CC 70	18.47	18.63	18.98	22.30	19.60
CC 71	18.92	19.88	20.46	22.94	20.55
CC 72	18.63	19.88	21.54	23.32	20.84
CC 73	18.75	19.55	20.30	23.24	20.46
CC 74	18.88	19.38	20.38	22.75	20.35
CC 75	19.29	19.93	21.20	23.45	20.97
CC 76	18.93	18.97	19.79	22.42	20.03
CC 77	18.88	19.50	20.78	23.05	20.55
Mean (over shade level)	16.69	17.18	17.68	18.85	17.60
SE ± M	0.365	0.644	0.577	0.613	0.280
CD (0.05)	1.033	1.821	1.632	1.735	0.777

Among the genotypes, CA 22 was earlier in flowering. It took 20.13, 21.00, 22.80 and 24.98 days for the first flowering in open, 25, 50 and 75 per cent shade respectively.

Flowering was late in CA 15 in open, 25 and 50 per cent shade with 35.68, 35.38 and 35.88 days respectively. Under 75 per cent shade, CA 14 had maximum days (38.18) to first flower. In open condition CA 15 was superior to CA 14 (33.50) but under 25 per cent it was on par with CA 14 (33.89). Under 50 per cent shade CA 15 was on par with CA 14 (35.83) and CA 39 (34.50). In 75 per cent shade CA 14 was on par with CA 15 (38.05), CA 3 (38.00), CA 9 (37.00), CA 29 (36.63), CA 25(36.38) and CA 39 (36.30).

The performances of genotype varied significantly with different shade levels also. Among *C. annuum*, CA 22 had a minimum pooled mean of 22.23 days to first flower and CA 15 maximum (36.25).

In *C. frutescens*, significant variation among genotypes was observed under 25, 50 and 75 per cent shade and between different shade levels. The genotype CF 43 was early in flowering under 25 per cent shade (51.32) and CF 40 under 50 and 75 per cent shade with 51.35 and 53.68 days respectively. The genotype CF 45 took more days to first flower under 25, 50 and 75 per cent shade with 55.00, 55.68 and 59.05 days respectively. Minimum pooled mean of 52.06 days to first flower was registered in CF 40 and maximum in CF 45 (55.76).

Significant variation for days to first flower was observed among genotypes under all shade levels in *C. chinense* and between different shade levels. The genotype, CC 63 was earlier in flowering in open, 25 and 50 per cent shade with 49.38, 49.88 and 54.13 days respectively. In 75 per cent shade, CC 71 had the minimum days to first flower (58.25). The genotype CC 66 was late in flowering under 25, 50 and 75 per cent shade and took 56.55, 60.68 and 64.55 days respectively for first flowering. In open CC 62 had the maximum days to first flower (54.85). CC 63 had a minimum pooled mean of 52.96 and CC 66 a maximum of 59.12 days to first flower.

4.1.9 Fruits per plant

Significant difference was observed among the genotypes for fruits per plant in *C. annuum*, *C. frutescens* and *C. chinense* under all the shade levels (Table 10). As the shade level increased from 25 to 75 per cent, the fruits per plant were found decreased in all the genotypes. No significant variation was observed for fruits per plant among open and 25 per cent shade.

In *C. annuum*, CA 13 had maximum fruits in open and 25 per cent shade with 125.00 and 139.00 respectively. In open CA 13 was on par with CA 23 (121.05) while at 25 per cent shade, CA 13 was superior to the following CA 28 (123.18). Under 50 per cent shade, CA 28 had maximum fruits (100.13) which was on par with CA 25 (97.30). CA 21 recorded maximum fruits under 75 per cent shade (83.68) which was on par with CA 25 (82.68).

Minimum fruits per plant was recorded by CA 32 in all the shade levels with 16.10, 17.13, 13.63 and 13.18 fruits in open, 25, 50 and 75 per cent shade respectively.

Table 9. Characterization of chilli genotypes for shade tolerance: days to first flower

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	26.80	27.22	31.80	34.30	30.03
CA 2	28.38	29.05	31.58	35.38	31.10
CA 3	28.39	29.44	32.55	38.00	32.10
CA 5	24.92	26.70	30.98	34.18	29.20
CA 6	26.56	26.38	31.68	34.88	29.88
CA 8	25.13	24.58	27.08	33.13	27.48
CA 9	24.50	24.88	33.47	37.00	29.96
CA 11	29.63	30.52	31.29	31.88	30.83
CA 12	24.69	24.88	27.28	35.13	28.00
CA 13	22.80	23.50	26.38	31.30	26.00
CA 14	33.50	33.89	35.83	38.18	35.35
CA 15	35.68	35.38	35.88	38.05	36.25
CA 16	24.93	25.45	30.96	34.08	28.86
CA 18	29.37	30.54	31.90	33.75	31.39
CA 20	25.00	25.43	31.58	34.68	29.17
CA 21	27.04	28.94	30.13	34.93	30.26
CA 22	20.13	21.00	22.80	24.98	22.23
CA 23	28.05	29.19	31.29	33.00	30.38
CA 24	28.25	27.92	30.00	32.77	29.74
CA 25	28.43	28.88	31.05	36.38	31.19
CA 28	26.10	26.93	30.20	33.30	29.13
CA 29	30.70	31.13	33.80	36.63	33.07
CA 32	24.13	25.13	33.18	34.38	29.21
CA 34	23.43	24.43	27.80	30.38	26.51
CA 36	26.13	27.47	28.48	32.45	28.63
CA 37	23.55	24.70	31.68	34.55	28.62
CA 38	24.94	25.38	28.15	33.18	27.91
CA 39	30.88	31.38	34.50	36.30	33.27
CA 55	30.99	31.63	33.43	35.55	32.90
CA 59	30.55	31.93	33.25	35.03	32.69
CA 60	33.00	33.22	33.87	35.30	33.85
CA 64	31.03	31.38	31.88	32.38	31.67
CA 81	29.88	30.93	31.63	34.18	31.66
CA 82	33.55	33.60	34.13	35.55	34.21
CA 83	29.78	31.03	32.68	35.00	32.12

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	50.63	51.63	53.30	54.55	52.53
CF 40	51.43	51.77	51.35	53.68	52.06
CF 41	52.13	52.45	53.75	54.38	53.18
CF 42	51.93	52.50	54.38	55.18	53.50
CF 43	51.13	51.32	52.43	53.93	52.20
CF 44	52.38	53.05	55.25	56.68	54.34
CF 45	52.30	55.00	56.68	59.05	55.76
CF 46	51.70	52.65	53.13	54.48	52.99
CF 47	51.85	54.02	54.97	55.80	54.16
CF 48	52.07	52.87	55.95	56.96	54.46
CF 49	52.63	54.70	56.33	58.25	55.48
CF 50	52.13	53.38	54.55	59.00	54.77
CF 51	51.43	52.93	53.13	54.13	52.91
CF 52	52.00	52.65	54.05	55.55	53.56
CF 53	51.68	51.63	54.01	56.93	53.56
CF 54	53.63	54.00	54.82	55.93	54.60
CF 56	51.88	53.25	55.28	57.18	54.40
CF 57	51.85	53.20	53.53	55.55	53.53
CF 58	52.13	51.55	52.45	55.45	52.90
CF 61	51.63	52.38	53.05	55.20	53.07
C. chinense					
CC 62	54.85	55.55	59.58	60.65	57.66
CC 63	49.38	49.88	54.13	58.45	52.96
CC 65	54.18	55.18	57.25	60.00	56.65
CC 66	54.68	56.55	60.68	64.55	59.12
CC 67	51.43	53.45	69.08	60.38	58.59
CC 68	62.63	53.38	57.33	61.43	58.69
CC 69	51.88	53.80	57.68	60.90	56.07
CC 70	52.75	52.68	57.05	60.63	55.78
CC 71	51.63	52.88	55.44	58.25	54.55
CC 72	52.88	53.85	58.68	61.23	56.66
CC 73	52.05	55.78	59.18	61.08	57.02
CC 74	52.50	54.08	56.00	61.35	55.98
CC 75	52.25	53.60	59.15	60.25	56.31
CC 76	52.63	54.67	58.65	61.05	56.75
CC 77	52.50	54.88	59.10	61.87	57.09
Mean (over shade level)	39.98	40.87	43.51	46.15	42.63
SE ± M	0.566	0.553	0.550	0.690	0.296
CD (0.05)	1.601	1.565	1.556	1.951	0.821

In *C. frutescens*, maximum fruits were recorded in CF 51 in open, 25, 50 and 75 per cent shade with 219.20, 220.55, 171.18 and 120.55 fruits respectively. CF 51 was superior to other genotypes under all the shade levels. Minimum fruits were recorded in CF 61 (102.15), CF 46 (98.63), CF 43 (76.93) and CF 42 (57.63) in open, 25, 50 and 75 per cent shade respectively.

Among genotypes of *C. chinense*, maximum fruits were registered in CC 63 in open, 25 and 50 per cent shade with 41.13, 44.05 and 31.13 fruits respectively. CC 70 had the highest fruits under 75 per cent shade (20.30). CC 66 had minimum fruits of 19.05, 20.68, 13.50 and 9.88 in open, 25, 50 and 75 per cent shade respectively.

The performance of genotype varied significantly among different shade levels in the three species. Maximum pooled mean for fruits per plant was observed in CA 28 (103.35) and minimum in CA 32 (15.01) among *C. annuum*. In *C. frutescens*, maximum pooled mean for fruits per plant was recorded in CF 51 (182.87) and minimum in CF 61 (86.39). Maximum pooled mean for fruits per plant was registered by CC 63 (33.97) and minimum in CC 66 (15.78) among *C. chinense*.

4.1.10 Fruit length

Significant difference among the genotypes for fruit length of *C. annuum*, *C. frutescens* and *C. chinense* was observed under all the shade levels (Table 11).

Among *C. annuum*, maximum fruit length was registered by CA 38 in all the shade levels with 15.85 cm, 16.00 cm, 15.35 cm and 15.30 cm in open,

Table 10. Characterization of chilli genotypes for shade tolerance: fruits per plant

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	31.68	30.15	24.50	21.18	26.88
CA 2	34.13	34.05	29.63	28.05	31.47
CA 3	35.30	37.50	33.00	27.13	33.23
CA 5	34.05	32.43	26.63	24.58	29.42
CA 6	33.77	36.05	31.55	28.55	32.48
CA 8	49.93	44.18	34.05	33.38	40.39
CA 9	46.15	35.80	31.13	27.10	35.05
CA 11	58.33	53.05	41.05	34.49	46.73
CA 12	44.30	41.37	33.60	27.05	36.58
CA 13	125.00	139.00	74.18	69.05	101.81
CA 14	30.42	25.13	21.27	16.88	23.43
CA 15	29.88	25.63	21.53	16.63	23.42
CA 16	30.48	30.35	24.88	20.55	26.57
CA 18	24.33	24.05	20.55	19.48	22.10
CA 20	58.05	67.63	53.05	33.55	53.07
CA 21	111.20	111.15	91.18	83.68	99.30
CA 22	47.50	47.50	35.23	31.55	40.45
CA 23	121.05	123.00	77.63	60.25	95.48
CA 24	34.00	37.38	27.55	23.48	30.60
CA 25	108.00	116.68	97.30	82.68	101.17
CA 28	115.05	123.18	100.13	75.05	103.35
CA 29	75.18	76.25	65.18	49.13	66.44
CA 32	16.10	17.13	13.63	13.18	15.01
CA 34	19.93	21.43	15.13	18.00	18.62
CA 36	35.92	43.10	27.25	23.55	32.46
CA 37	31.20	29.75	19.13	13.38	23.37
CA 38	26.87	28.13	23.43	19.88	24.58
CA 39	26.20	24.30	16.50	14.75	20.44
CA 55	49.53	45.00	39.00	36.11	42.41
CA 59	38.05	39.18	27.25	26.05	32.63
CA 60	31.13	33.25	27.38	23.55	28.83
CA 64	26.82	23.00	16.63	17.38	20.96
CA 81	19.93	20.88	16.93	16.11	18.46
CA 82	45.30	47.13	31.39	25.18	37.25
CA 83	37.18	38.83	37.18	34.05	36.81

Contd….

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	123.15	126.88	84.20	74.18	102.10
CF 40	113.60	106.05	85.55	63.55	92.19
CF 41	108.55	101.48	82.05	64.88	89.24
CF 42	115.70	114.05	77.68	57.63	91.27
CF 43	106.20	100.38	76.93	63.13	86.66
CF 44	115.55	107.33	87.13	58.50	92.13
CF 45	111.98	108.63	84.68	62.55	91.96
CF 46	122.65	98.63	84.55	62.63	92.12
CF 47	126.63	122.60	104.55	76.18	107.49
CF 48	128.23	121.05	87.45	75.25	103.00
CF 49	123.05	116.13	79.08	70.38	97.16
CF 50	209.85	194.13	136.55	110.63	162.79
CF 51	219.20	220.55	171.18	120.55	182.87
CF 52	204.40	202.38	134.73	105.13	161.66
CF 53	118.70	116.63	109.63	84.63	107.40
CF 54	114.93	124.82	91.80	81.05	103.15
CF 56	121.00	103.50	81.68	65.18	92.84
CF 57	141.63	127.63	90.18	67.05	106.62
CF 58	103.10	101.25	82.18	67.38	88.48
CF 61	102.15	99.13	77.63	66.63	86.39
C. chinense					
CC 62	28.18	29.88	19.68	13.78	22.88
CC 63	41.13	44.05	31.13	19.55	33.97
CC 65	31.68	26.63	18.05	14.68	22.76
CC 66	19.05	18.68	13.50	9.88	15.28
CC 67	38.28	38.32	30.18	17.63	31.10
CC 68	36.88	34.63	30.00	18.38	29.97
CC 69	36.05	35.50	27.05	17.63	29.06
CC 70	36.30	35.00	25.55	20.30	29.29
CC 71	31.63	33.04	24.13	18.50	26.83
CC 72	34.05	35.18	24.93	19.20	28.34
CC 73	35.60	35.63	25.05	19.50	28.95
CC 74	30.75	31.55	24.60	16.25	25.79
CC 75	32.73	30.88	26.25	14.55	26.10
CC 76	28.85	30.05	22.68	15.88	24.37
CC 77	29.88	31.73	22.07	14.88	24.64
Mean (over shade level)	68.62	67.26	51.14	40.89	56.98
SE ± M	2.861	2.205	2.247	2.174	1.194
CD (0.05)	8.093	6.237	6.356.	6.148	3.310

25, 50 and 75 per cent shade respectively. CA 38 was superior to other genotypes under all the shade levels (Plate 2a).

Fruits were shorter in CA 2 with 2.45 cm, 2.55 cm, 2.45 cm and 2.50 cm under open, 25, 50 and 75 per cent shade respectively (Plate 2b).

Among *C. frutescens* genotypes, maximum fruit length was recorded in CF 51 with 4.30 cm, 4.30 cm, 4.25 cm and 4.25 cm in open, 25, 50 and 75 per cent shade respectively. The genotype CF 51 was on par with CF 52 and CF 50 (4.05 cm each) in open whereas CF 51 was on par with CF 52 (4.15 cm) only in 25 per cent shade. Under 50 and 75 per cent shade CF 51 was on par with CF 52 (4.10 cm, 4.15 cm), CF 50 (4.05 cm, 4.10 cm) and CF 53 (4.05 cm each) respectively. The genotype CF 46 had shortest fruit under all the shade levels with 2.05 cm each (Plate 3).

In *C. chinense*, longest fruit was in CC 63 with 6.10 cm, 6.05 cm, 6.00 cm and 5.90 cm in open, 25, 50 and 75 per cent shade respectively. CC 63 was superior to other genotypes under all the shade levels (Plate 4). CC 76 had shorter fruit in open (3.05 cm) and 75 per cent shade (3.05). The genotype CC 62 had minimum fruit length in 25 (2.95 cm) and 50 per cent shade (3.05 cm).

In *C. annuum*, *C. frutescens* and *C. chinense* there was no significant variation for fruit length among different shade levels.

4.1.11 Fruit girth

Significant variation among genotypes for fruit girth was observed under all shade levels in *C. annuum*, *C. frutescens* and *C. chinense* (Table 12).

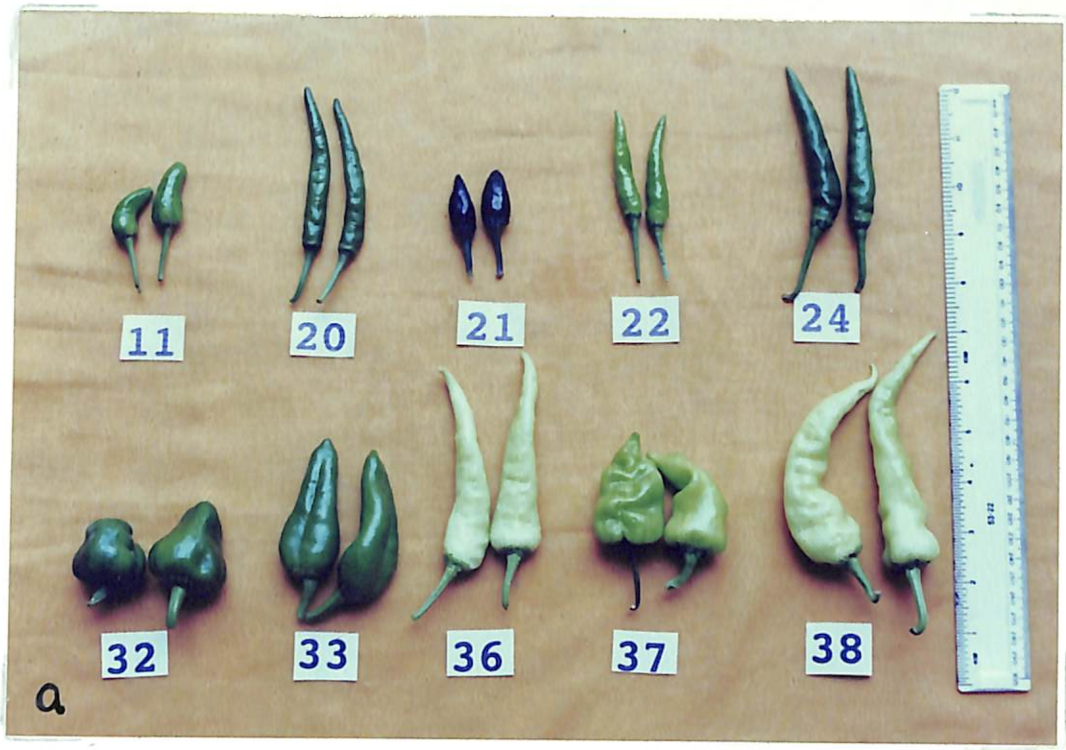

Plate 2 a & b Variability in fruit size and shape of *C. annuum*

Plate 3. Variability in fruit size and shape of *C. frutescens* and *C. chinense*

Plate 3. Variability in fruit size and shape of *C. frutescens* and *C. chinense*

Table 11. Characterization of chilli genotypes for shade tolerance: fruit length (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	6.55	6.45	6.35	6.40	6.44
CA 2	2.45	2.55	2.45	2.50	2.49
CA 3	5.45	5.50	5.45	5.45	5.46
CA 5	5.75	5.90	5.65	5.65	5.74
CA 6	5.90	5.90	6.00	5.90	5.93
CA 8	9.00	9.10	9.05	9.00	9.04
CA 9	8.60	8.65	8.55	8.45	8.56
CA 11	6.15	6.15	6.10	6.10	6.13
CA 12	6.45	6.45	6.45	6.45	6.45
CA 13	5.90	5.90	5.85	5.90	5.89
CA 14	5.95	6.15	5.95	6.05	6.03
CA 15	5.55	5.75	5.80	5.80	5.73
CA 16	7.15	7.10	7.20	7.30	7.19
CA 18	8.95	8.75	9.05	9.05	8.95
CA 20	7.70	7.80	7.90	7.80	7.80
CA 21	4.05	4.10	4.30	4.00	4.11
CA 22	6.60	6.25	6.20	6.10	6.29
CA 23	3.95	4.05	4.10	4.10	4.05
CA 24	6.80	7.00	6.90	7.00	6.93
CA 25	3.30	3.40	3.35	3.25	3.33
CA 28	4.85	4.95	4.90	4.90	4.90
CA 29	6.05	6.15	6.15	6.15	6.13
CA 32	3.95	3.85	3.75	3.65	3.80
CA 34	7.10	8.10	7.80	7.70	7.68
CA 36	9.85	9.85	10.00	9.75	9.86
CA 37	8.35	8.75	8.50	8.65	8.56
CA 38	15.85	16.00	15.35	15.30	15.63
CA 39	7.70	7.90	8.10	8.05	7.94
CA 55	5.30	5.20	5.20	5.10	5.20
CA 59	5.15	5.00	4.95	5.10	5.05
CA 60	5.10	5.15	5.20	5.10	5.14
CA 64	11.10	10.90	11.00	11.25	11.06
CA 81	11.10	11.10	11.20	11.10	11.13
CA 82	5.05	5.10	5.20	5.10	5.11
CA 83	5.10	5.10	5.30	5.05	5.14

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	2.10	2.20	2.25	2.10	2.16
CF 40	2.25	2.20	2.30	2.30	2.26
CF 41	2.35	2.40	2.45	2.40	2.40
CF 42	2.85	2.95	2.90	3.05	2.94
CF 43	3.30	3.10	3.20	3.25	3.21
CF 44	3.60	3.55	3.55	3.60	3.58
CF 45	2.75	2.80	2.85	2.80	2.80
CF 46	2.05	2.05	2.05	2.05	2.05
CF 47	3.10	3.15	3.20	3.20	3.16
CF 48	3.80	3.80	3.85	3.80	3.81
CF 49	3.65	3.65	3.75	3.80	3.71
CF 50	4.05	4.00	4.05	4.10	4.05
CF 51	4.30	4.30	4.25	4.25	4.28
CF 52	4.05	4.15	4.10	4.15	4.11
CF 53	3.95	4.00	4.05	4.05	4.01
CF 54	3.25	3.30	3.35	3.40	3.33
CF 56	3.75	3.80	3.85	3.90	3.83
CF 57	3.75	3.70	3.65	3.75	3.71
CF 58	3.70	3.65	3.65	3.75	3.69
CF 61	2.45	2.35	2.40	2.50	2.43
C. chinense					
CC 62	3.05	2.95	3.05	3.15	3.05
CC 63	6.10	6.05	6.00	5.90	6.01
CC 65	4.05	4.00	3.95	3.90	3.98
CC 66	3.90	3.95	3.85	3.85	3.89
CC 67	4.00	4.05	3.95	3.90	3.98
CC 68	3.25	3.30	3.35	3.40	3.33
CC 69	4.25	4.25	4.15	4.05	4.18
CC 70	5.05	5.00	4.95	4.90	4.98
CC 71	5.45	5.35	5.20	5.05	5.26
CC 72	4.20	4.30	4.25	4.25	4.25
CC 73	4.05	4.15	4.10	4.05	4.09
CC 74	4.20	4.05	4.05	4.00	4.08
CC 75	3.30	3.25	3.35	3.20	3.28
CC 76	3.05	3.15	3.10	3.05	3.09
CC 77	4.45	4.55	4.50	4.35	4.46
Mean (over shade level)	5.16	5.19	5.18	5.16	5.17
SE ± M	0.089	0.095	0.109	0.098	0.049
CD (0.05)	0.252	0.267	0.308	0.278	NS

In *C. annuum* maximum fruit girth was in CA 37 in open, 25, 50 and 75 per cent shade with 10.35cm, 9.75 cm, 9.80 cm and 9.10 cm respectively. Under all these shade levels CA 37 was superior to other genotypes in respect of fruit girth. Minimum fruit girth was observed in CA 24 (3.10 cm) in open, CA 28 under 25 (3.00 cm) and 50 per cent (3.05 cm) and CA 83 under 75 per cent (3.05 cm) shade.

Among genotypes of *C. frutescens*, maximum fruit girth was registered by CF 51 in open, 25, 50 per cent shade with 3.10 cm, 3.30 cm and 3.20 cm respectively. CF 50 had the maximum girth (3.30 cm) under 75 per cent shade. Minimum fruit girth was observed in CF 46 in open, 25 and 50 per cent shade with 1.50 cm, 1.55 cm and 1.50 cm respectively. CF 45 had the minimum girth (1.75 cm) under 75 per cent shade.

Among the genotypes of *C. chinense*, maximum fruit girth was observed in CC 63 with 9.85 cm, 10.10 cm, 10.00 cm and 9.90 cm in open, 25, 50 and 75 per cent shade respectively. CC 63 was on par with CC 66 (9.65 cm) in open and with CC 65 under 50 (9.75 cm) and 75 per cent shade (9.65 cm) respectively. Under 25 per cent shade, CC 63 was superior to other genotypes. Minimum fruit girth was registered by CC 69 in open (3.95 cm), 25 (4.05 cm) and 50 per cent shade (3.95 cm). The genotype CC 68 had minimum girth under 75 per cent shade (4.05 cm).

No significant variation for fruit girth was observed among different shade levels in *C. annuum*, *C. frutescens* and *C. chinense*.

Table 12. Characterization of chilli genotypes for shade tolerance: fruit girth (cm)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	4.25	4.05	4.05	4.00	4.09
CA 2	6.05	6.1	6.05	6.15	6.09
CA 3	3.25	3.15	3.05	3.10	3.14
CA 5	3.25	3.15	3.05	3.85	3.33
CA 6	4.55	4.60	4.45	5.25	4.71
CA 8	6.45	6.65	5.95	6.00	6.26
CA 9	6.45	6.30	6.05	4.80	5.90
CA 11	3.80	3.65	3.60	3.40	3.61
CA 12	3.30	3.50	3.55	3.60	3.49
CA 13	3.65	3.85	3.65	4.55	3.93
CA 14	5.70	5.80	5.65	5.10	5.56
CA 15	4.60	4.70	4.65	5.40	4.84
CA 16	6.30	6.35	6.40	7.15	6.55
CA 18	8.15	8.20	8.10	5.60	7.51
CA 20	3.75	4.00	3.70	3.80	3.81
CA 21	3.90	4.15	3.85	4.35	4.06
CA 22	4.20	4.50	4.35	4.35	4.35
CA 23	4.65	4.40	4.50	4.10	4.41
CA 24	3.10	3.60	3.90	3.90	3.63
CA 25	4.65	4.10	4.30	3.70	4.19
CA 28	3.15	3.00	3.05	3.30	3.13
CA 29	3.35	3.45	3.50	3.65	3.49
CA 32	8.15	8.00	7.90	7.30	7.84
CA 34	7.80	6.85	6.55	7.20	7.10
CA 36	8.10	8.20	8.20	9.10	8.40
CA 37	10.35	9.75	9.80	9.10	9.75
CA 38	8.50	8.15	8.05	7.30	8.00
CA 39	6.40	6.25	6.10	5.20	5.99
CA 55	4.20	4.25	4.30	4.45	4.30
CA 59	4.35	4.45	4.45	3.95	4.30
CA 60	3.15	3.20	3.25	5.10	3.68
CA 64	7.30	7.35	7.10	7.35	7.28
CA 81	7.40	7.40	7.30	5.20	6.83
CA 82	3.30	3.35	3.25	3.75	3.41
CA 83	4.15	4.15	4.20	3.05	3.89

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	1.95	2.05	2.00	2.05	2.01
CF 40	2.10	2.15	2.25	2.30	2.20
CF 41	2.05	2.15	2.25	2.10	2.14
CF 42	2.05	2.25	2.20	2.20	2.18
CF 43	1.75	1.85	2.05	2.00	1.91
CF 44	1.65	1.75	1.80	1.85	1.76
CF 45	1.65	1.75	1.75	1.75	1.73
CF 46	1.50	1.55	1.50	1.85	1.60
CF 47	2.10	2.20	2.25	2.40	2.24
CF 48	2.60	2.45	2.55	2.75	2.59
CF 49	2.95	3.15	3.20	3.05	3.09
CF 50	2.95	3.10	3.00	3.10	3.04
CF 51	3.10	3.30	3.20	3.15	3.19
CF 52	3.05	3.10	3.05	2.90	3.03
CF 53	2.30	2.55	2.70	2.70	2.56
CF 54	2.75	2.75	2.65	2.80	2.74
CF 56	2.85	2.80	2.80	2.80	2.81
CF 57	2.75	2.85	2.80	2.60	2.75
CF 58	2.40	2.40	2.55	2.60	2.49
CF 61	2.25	2.25	2.45	2.65	2.40
C. chinense					
CC 62	5.90	6.05	6.20	8.10	6.56
CC 63	9.85	10.10	10.00	9.90	9.96
CC 65	9.55	9.70	9.75	9.65	9.66
CC 66	9.65	9.75	9.50	9.75	9.66
CC 67	4.10	4.05	3.95	4.15	4.06
CC 68	4.00	4.05	4.05	4.05	4.04
CC 69	3.95	4.05	3.95	5.90	4.46
CC 70	8.10	7.90	8.00	7.35	7.84
CC 71	6.35	6.45	6.50	6.85	6.54
CC 72	7.25	7.10	7.20	7.30	7.21
CC 73	6.65	7.05	7.15	7.25	7.03
CC 74	6.95	7.15	7.20	6.05	6.84
CC 75	4.55	4.70	4.80	5.15	4.80
CC 76	5.55	5.55	5.70	6.15	5.74
CC 77	6.30	6.35	6.60	9.30	7.14
Mean (over shade level)	4.70	4.73	4.71	4.78	4.73
SE $\pm$ M	0.097	0.100	0.087	0.094	0.239
CD (0.05)	0.276	0.282	0.245	0.267	NS

4.1.12 Fruit weight

Significant variation was observed among genotypes of *C. annuum*, *C. frutescens* and *C. chinense* for fruit weight under all the shade levels (Table 13).

Among *C. annuum*, maximum fruit weight was registered by CA 38 with 16.40 g, 16.25 g, 15.75 g and 15.75 g in open, 25, 50 and 75 per cent shade respectively. Under all these shade levels CA 38 was superior to other genotypes.

Minimum fruit weight was registered by CA 21 in open, 25, and 75 per cent shade with 2.55 g, 2.55 g and 2.50 g respectively. CA 13 had the minimum weight (2.40 g) under 50 per cent shade. CA 21 was on par with CA 13 (2.55 g) and CA 23 (3.00 g) in open and with CA 13 (2.65 g) and CA 23 (3.00 g) under 25 per cent shade.

In *C. frutescens*, maximum fruit weight was registered by CF 51 (1.98 g) in open and 75 per cent shade (2.06 g). Under 50 and 75 per cent shade, maximum weight was recorded by CF 50 (2.06 g) and (2.04 g) respectively. Minimum fruit weight was recorded by CF 46 with 0.50 g each in open, 25 and 75 per cent shade and 0.52 g under 50 per cent shade.

Among genotypes of *C. chinense*, CC 63 had the maximum fruit weight in open, 25, 50 and 75 per cent shade with 7.02 g, 7.05 g, 7.01g and 7.02 g respectively. CC 63 was superior to other genotypes. Minimum weight was recorded by CC 67 with 3.13 g, 3.16 g, 3.25 g and 3.35 g in open, 25, 50 and 75 per shade respectively.

There was no significant difference among different shade levels for fruit weight in *C. annuum*, *C. frutescens* and *C. chinense*. Maximum pooled mean for fruit weight was observed in CA 38 (16.04 g), CF 50 (2.00 g) and CC 63 (7.03 g). Minimum pooled mean was observed in CA 21 (2.54 g), CF 46 (0.51 g) and CC 67 (3.22 g).

4.1.13 Yield per plant

There was significant variation among genotypes for yield in *C. annuum*, *C. frutescens* and *C. chinense* under all the shade levels (Table 14). Significant variation was also observed among different shade levels for yield in all the three species. The yield was found to decrease with increasing levels of shade from 25 to 75 per cent. No significant variation was observed for yield per plant among open and 25 per cent shade. Overall mean of yield in open (183.62 g) was on par with that at 25 per cent shade (181.82 g).

The genotype CA 38 had maximum yield under all shade levels with 382.88 g, 397.38 g, 310.13 g and 250. 65 g respectively in open, 25, 50 and 75 per cent shade. In open and 25 per cent shade, CA 38 was superior to other genotypes. Under 50 per cent shade, CA 38 was on par with CA 25 (296.40 g) and under 75 per cent it was on par with CA 36 (241.05 g).

Minimum yield was in CA 32 in open (73.75 g) and by CA 39 under 25 (87.60 g), 50 (72.80 g) and 75 (71.05 g) per cent shade.

CA 38 had the maximum pooled yield (335.26 g) followed by CA 25 (297.28 g) and CA 32 the minimum (85.97 g). CA 32 was on par with CA 39 (89.52 g) and CA 15 (102.80 g).

Table 13. Characterization of chilli genotypes for shade tolerance: fruit weight (g)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	3.90	4.10	4.05	4.00	4.01
CA 2	3.50	3.65	3.85	3.60	3.65
CA 3	4.90	4.85	4.90	4.90	4.89
CA 5	4.60	4.90	4.90	4.75	4.79
CA 6	5.10	5.00	5.25	5.25	5.15
CA 8	6.25	6.35	5.90	6.10	6.15
CA 9	6.38	6.38	6.50	6.40	6.42
CA 11	5.75	6.45	6.35	6.60	6.29
CA 12	4.05	4.25	3.95	3.95	4.05
CA 13	2.55	2.65	2.40	2.60	2.55
CA 14	4.65	4.70	4.95	4.90	4.80
CA 15	4.50	4.60	4.90	4.90	4.73
CA 16	4.65	4.80	4.90	4.85	4.80
CA 18	10.50	10.60	10.00	10.05	10.29
CA 20	4.90	4.95	5.00	5.30	5.04
CA 21	2.55	2.55	2.55	2.50	2.54
CA 22	4.35	4.45	4.60	4.85	4.56
CA 23	3.00	3.00	3.00	2.90	2.98
CA 24	5.90	6.15	6.10	6.05	6.05
CA 25	3.60	3.70	3.45	3.95	3.68
CA 28	3.10	3.15	3.19	3.20	3.16
CA 29	3.40	3.25	2.80	2.85	3.08
CA 32	10.75	10.80	10.25	10.10	10.48
CA 34	7.25	7.10	7.40	8.10	7.46
CA 36	9.90	9.45	9.85	9.45	9.66
CA 37	10.90	11.90	10.35	11.13	11.07
CA 38	16.40	16.25	15.75	15.75	16.04
CA 39	6.00	5.25	5.95	5.75	5.74
CA 55	4.65	5.00	4.90	5.05	4.90
CA 59	5.10	5.30	5.40	4.65	5.11
CA 60	6.75	7.10	5.85	5.75	6.36
CA 64	10.25	10.65	10.30	10.03	10.31
CA 81	10.75	10.95	10.50	10.55	10.69
CA 82	5.25	5.30	5.13	5.13	5.20
CA 83	4.70	5.05	4.85	4.75	4.84

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	0.76	0.81	0.83	0.81	0.80
CF 40	0.91	0.90	0.95	0.90	0.92
CF 41	0.75	0.85	0.85	0.83	0.82
CF 42	0.87	0.89	0.94	0.90	0.90
CF 43	1.10	1.17	1.23	1.21	1.18
CF 44	1.59	1.64	1.64	1.67	1.64
CF 45	1.46	1.51	1.49	1.56	1.51
CF 46	0.50	0.50	0.52	0.50	0.51
CF 47	1.05	1.09	1.02	1.10	1.07
CF 48	1.38	1.39	1.47	1.45	1.42
CF 49	1.95	2.05	1.94	1.98	1.98
CF 50	1.93	2.06	2.04	1.95	2.00
CF 51	1.98	1.99	1.94	2.06	1.99
CF 52	1.88	1.91	1.89	1.88	1.89
CF 53	1.80	1.71	1.79	1.78	1.77
CF 54	1.73	1.69	1.67	1.69	1.70
CF 56	1.74	1.74	1.74	1.69	1.73
CF 57	1.74	1.71	1.79	1.71	1.74
CF 58	1.78	1.77	1.76	1.81	1.78
CF 61	1.60	1.67	1.63	1.73	1.66
C. chinense					
CC 62	5.10	5.10	5.30	5.30	5.20
CC 63	7.02	7.05	7.01	7.02	7.03
CC 65	5.93	6.00	6.04	5.98	5.99
CC 66	6.36	6.28	6.20	6.47	6.33
CC 67	3.13	3.16	3.25	3.35	3.22
CC 68	3.83	3.54	3.30	3.36	3.51
CC 69	3.18	3.58	3.25	3.47	3.37
CC 70	4.85	4.77	4.65	4.62	4.72
CC 71	5.25	5.51	5.15	5.09	5.25
CC 72	4.45	4.45	4.65	4.61	4.54
CC 73	3.95	3.80	3.78	3.80	3.83
CC 74	4.30	4.20	4.30	4.23	4.26
CC 75	4.30	4.23	4.18	4.13	4.21
CC 76	5.18	5.05	5.43	5.35	5.25
CC 77	4.88	4.89	4.65	4.76	4.80
Mean (over shade level)	4.44	4.50	4.55	4.47	4.49
SE ± M	0.161	0.162	0.156	0.180	0.082
CD (0.05)	0.455	0.457	0.440	0.507	NS

Among *C. frutescens*, maximum yield was recorded by CF 51 under all the shade levels with 262.63 g, 262.80 g, 206.13 g and 160.65 g in open, 25, 50 and 75 per cent shade respectively. CF 51 was on par with CF 50 in open (253.88 g), under 50 per cent shade (200.00 g) and 75 per cent shade (149.35 g) while CF 51 was on par with CF 52 in 25 per cent shade (250.58 g) respectively.

Minimum yield was in CF 46 under all shade levels. The yield were 65.88 g, 61.33 g, 57.28g and 51.05 g in open, 25, 50 and 75 per cent shade level respectively which was on par with CF 41 in open (86.38 g), under 50 per cent (70.65 g) and 75 per cent shade (61.55).

CF 51 had the maximum pooled yield (224.80 g) followed by CF 50 (209.51 g) and minimum in CF 46 (58.84 g).

Among genotypes of *C. chinense*, maximum yield was observed in CC 63 under all the shade levels with 217.25 g, 221.65 g, 150.25 g and 95.25 g in open, 25, 50 and 75 per cent shade respectively. CC 63 was superior in yield compared to other genotypes in open, 25 and 50 per cent shade whereas CC 63 was on par with CC 72 (92.63 g), CC 71 (91.20 g) and CC 70 (90.55 g) under 75 per cent shade.

Minimum yield was observed in CC 66 under all shade levels. The yields were 101.13 g, 99.23 g, 71.63 g and 50.55 g under open, 25, 50 and 75 per cent shade respectively.

CC 63 had the maximum pooled mean (171.10 g) and CC 66 (80.63 g) the minimum.

Table 14. Characterization of chilli genotypes for shade tolerance: yield per plant (g)

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	120.38	119.13	85.38	83.88	102.19
CA 2	116.63	111.25	100.63	89.15	104.42
CA 3	153.00	160.50	119.15	100.90	133.39
CA 5	145.00	123.00	103.15	89.65	115.20
CA 6	157.63	177.63	151.75	140.80	156.95
CA 8	273.13	243.00	185.38	180.40	220.48
CA 9	282.55	215.38	187.75	172.98	214.67
CA 11	316.25	319.13	207.05	168.70	252.78
CA 12	172.75	176.00	145.38	107.88	150.50
CA 13	319.38	340.60	187.85	150.25	249.52
CA 14	124.25	104.50	95.40	91.18	103.83
CA 15	117.63	106.38	97.15	90.05	102.80
CA 16	129.75	126.75	114.38	102.90	118.45
CA 18	219.65	233.15	206.38	182.80	210.50
CA 20	271.63	302.68	248.80	150.25	243.34
CA 21	251.75	263.13	223.05	170.40	227.08
CA 22	175.13	173.88	142.08	133.20	156.07
CA 23	359.98	341.85	211.55	147.80	265.30
CA 24	171.38	176.13	147.05	116.90	152.87
CA 25	339.75	354.13	296.40	198.85	297.28
CA 28	333.88	321.75	269.75	180.25	276.41
CA 29	244.05	230.30	180.10	136.35	197.70
CA 32	73.75	102.63	84.45	83.05	85.97
CA 34	102.13	109.68	108.90	144.13	116.21
CA 36	320.38	367.88	248.13	241.05	294.36
CA 37	297.30	304.13	153.00	127.68	220.53
CA 38	382.88	397.38	310.13	250.65	335.26
CA 39	126.63	87.60	72.80	71.05	89.52
CA 55	202.50	178.38	152.93	147.85	170.42
CA 59	182.63	180.13	152.55	147.80	165.78
CA 60	202.25	214.25	184.50	165.35	191.59
CA 64	206.50	207.75	172.83	167.85	188.73
CA 81	199.13	202.95	165.23	170.15	184.37
CA 82	201.25	215.25	140.33	145.50	175.58
CA 83	170.13	145.30	145.30	147.65	152.10

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	95.63	101.75	71.15	70.25	84.70
CF 40	108.13	104.88	79.13	73.25	91.35
CF 41	86.38	85.75	70.65	61.55	76.08
CF 42	112.13	108.33	77.78	63.10	90.34
CF 43	120.13	117.00	92.38	78.13	101.91
CF 44	151.80	151.13	118.65	91.85	128.36
CF 45	150.13	156.80	131.35	95.55	133.46
CF 46	65.68	61.33	57.28	51.05	58.84
CF 47	117.88	115.88	98.10	86.45	104.58
CF 48	164.63	168.83	125.38	109.00	141.96
CF 49	190.50	182.65	152.50	136.10	165.44
CF 50	253.88	234.80	200.00	149.35	209.51
CF 51	262.63	262.80	206.13	160.65	223.05
CF 52	252.05	250.58	184.38	143.05	207.52
CF 53	204.50	202.85	139.88	109.55	164.20
CF 54	200.25	172.73	138.18	120.45	157.90
CF 56	192.68	177.38	137.13	100.25	151.86
CF 57	181.75	184.40	136.98	102.05	151.30
CF 58	182.00	178.60	143.63	121.00	156.31
CF 61	156.88	153.78	126.05	113.95	137.67
C. chinense					
CC 62	130.25	131.38	99.63	70.65	107.98
CC 63	217.25	221.65	150.25	95.25	171.10
CC 65	169.05	170.68	97.75	79.55	129.26
CC 66	101.13	99.23	71.63	50.55	80.63
CC 67	122.88	122.45	73.25	51.10	92.42
CC 68	117.63	114.75	75.85	60.05	92.07
CC 69	112.63	113.88	97.15	69.53	98.30
CC 70	165.25	164.28	113.13	90.55	133.30
CC 71	147.95	159.38	121.65	91.20	130.04
CC 72	147.88	155.40	114.25	92.63	127.54
CC 73	136.63	135.75	94.13	69.65	109.03
CC 74	131.53	130.25	105.55	69.00	109.08
CC 75	137.25	126.08	107.58	60.30	107.80
CC 76	148.13	150.63	121.20	74.05	123.50
CC 77	142.15	151.13	102.65	67.85	115.72
Mean (over shade level)	183.62	181.82	140.41	116.05	155.47
SE ± M	5.908	6.811	5.916	5.151	2.988
CD (0.05)	16.670	19.217	16.691	14.534	8.282

4.1.14 Incidence of mite

Incidence of mite *Polyphagotarsonemus latus* was observed at varying intensities in different genotypes. The symptoms appeared as curling of leaves and production of clusters of small leaves by the axillary bud.

The genotypes were scored for incidence of mite on a 0 - 5 scale. Significant difference was observed among the genotypes for incidence of mite in *C. annuum*, *C. frutescens* and *C. chinense* (Table 15) under all the shade levels.

Maximum incidence was seen in CA 32 under all shade levels with a mean score of 2.17 in open and 25 per cent shade, 1.93 under 50 per cent and 1.90 under 75 per cent shade. CA 32 was superior to other genotypes. The genotype CA 2 was completely free from the attack.

Among genotypes of *C. frutescens*, maximum incidence was in CF 47 in open, 50 and 75 per cent shade with a score of 1.20, 1.05 and 1.10 respectively. In 25 per cent shade CF 48 had the maximum (1.05) incidence. Minimum incidence was observed in CF 30 with a score of 0.32 in open and 0.20 under 25, 50 and 75 per cent shade.

In *C. chinense*, maximum incidence was observed in CC 69 in open (1.03) and 25 per cent shade (0.95). The genotype CC 75 had maximum score (0.83) under 50 per cent shade and in CC 72 (0.88) at 75 per cent shade. Minimum incidence was seen in CC 67 under all shade levels with 0.25, 0.23, 0.23 and 0.18 in open, 25, 50 and 75 per cent shade respectively.

There was significant difference among different levels of shade for incidence of mite in *C. annuum*, *C. frutescens* and *C. chinense*. CA 32 had a maximum pooled mean (2.04) and minimum by CA 2 (zero). Maximum pooled mean for incidence of mite was recorded by CF 47 (1.07), CC 69 (0.82) and minimum CF 30 (0.23) and CC 67 (0.22).

4.1.15 Estimation of variability and genetic parameters

The variability parameters like genotypic and phenotypic variances, coefficients of variation at genotypic and phenotypic levels, heritability in broad sense, genetic advance and genetic advance as percentage of mean were estimated for chilli genotypes grown under open and 25 per cent shade and presented in Table 16 and 17.

Wide variation was observed in phenotypic and genotypic variances among characters both in open and 25 per cent shade. Maximum values of genotypic (5402.42 and 5746.73) and phenotypic (5472.24 and 5839.52) variances were recorded for yield per plant in open and 25 per cent shade respectively. Internodal length exhibited the least phenotypic (0.03 and 0.04) and genotypic (0.02 and 0.03) variances in open and 25 per cent shade respectively.

The values for genotypic coefficient of variation (GCV) and Phenotypic coefficient of variation (PCV) ranged from 5.26 to 72.15 and 6.45 to 72.39 in open and 5.43 to 71.65 and 6.80 to 71.79 under 25 per cent shade respectively. The estimates of GCV and PCV were the highest for fruits per plant in open (72.15 and 72.39) and 25 per cent shade (71.65 and 71.79). The least GCV and PCV were recorded for internodal length (5.26 and 6.45) in open and 5.43 and 6.80 under 25 per cent shade respectively.

Table 15. Characterization of chilli genotypes for shade tolerance: incidence of mite

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. annuum					
CA 1	0.98	0.85	0.58	0.73	0.79
CA 2	0.00	0.00	0.00	0.00	0.00
CA 3	1.05	1.03	1.00	1.00	1.02
CA 5	1.68	1.55	1.58	1.61	1.61
CA 6	1.29	1.13	1.00	1.00	1.11
CA 8	1.71	1.63	1.58	1.55	1.62
CA 9	1.58	1.50	1.33	1.35	1.44
CA 11	1.18	1.00	0.91	0.91	1.00
CA 12	1.18	1.05	1.00	0.98	1.05
CA 13	1.05	0.85	0.95	0.93	0.95
CA 14	1.05	0.98	0.93	0.95	0.98
CA 15	1.18	1.05	0.87	0.93	1.01
CA 16	1.08	0.98	0.84	0.88	0.95
CA 18	1.18	1.05	1.03	1.00	1.07
CA 20	1.29	1.25	1.00	1.00	1.14
CA 21	1.29	1.24	1.00	1.00	1.13
CA 22	0.95	1.00	1.00	0.78	0.93
CA 23	1.10	0.98	0.90	0.90	0.97
CA 24	1.63	1.58	1.33	1.10	1.41
CA 25	1.15	1.00	0.95	1.00	1.03
CA 28	1.08	0.95	0.95	1.00	1.00
CA 29	1.17	1.05	1.00	0.98	1.05
CA 32	2.17	2.17	1.93	1.90	2.04
CA 34	1.88	1.78	1.53	1.68	1.72
CA 36	0.95	0.79	0.71	0.55	0.75
CA 37	1.08	1.00	0.93	0.93	0.99
CA 38	0.68	0.61	0.61	0.30	0.55
CA 39	1.13	1.00	0.84	0.90	0.97
CA 55	1.08	1.00	0.83	0.90	0.95
CA 59	0.82	0.73	0.50	0.65	0.68
CA 60	1.00	0.85	0.93	0.93	0.93
CA 64	1.13	1.00	0.98	0.93	1.01
CA 81	0.95	0.71	0.66	0.60	0.73
CA 82	1.20	1.00	1.00	0.83	1.01
CA 83	0.82	0.73	0.63	0.55	0.68

Contd....

Treatments	Levels of shade				
	Open	25 %	50 %	75 %	Mean
C. frutescens					
CF 30	0.32	0.20	0.20	0.20	0.23
CF 40	0.48	0.42	0.29	0.29	0.37
CF 41	0.95	0.80	0.63	0.70	0.77
CF 42	0.85	0.68	0.48	0.23	0.56
CF 43	0.93	0.58	0.48	0.44	0.61
CF 44	0.95	0.80	0.68	0.53	0.74
CF 45	0.63	0.53	0.50	0.53	0.55
CF 46	0.80	0.69	0.55	0.48	0.63
CF 47	1.20	0.91	1.05	1.10	1.07
CF 48	1.05	1.05	0.78	0.87	0.94
CF 49	1.03	1.02	0.95	0.90	0.98
CF 50	0.95	0.88	0.78	0.83	0.86
CF 51	1.08	1.03	1.08	0.92	1.03
CF 52	1.03	0.95	0.92	0.88	0.95
CF 53	0.95	0.88	0.63	0.63	0.77
CF 54	0.80	0.71	0.39	0.53	0.61
CF 56	0.87	0.78	0.87	0.68	0.80
CF 57	0.79	0.75	0.64	0.68	0.72
CF 58	0.71	0.55	0.39	0.28	0.48
CF 61	0.95	0.73	0.71	0.68	0.77
C. chinense					
CC 62	0.38	0.25	0.39	0.28	0.33
CC 63	0.38	0.28	0.28	0.28	0.31
CC 65	0.48	0.48	0.42	0.38	0.44
CC 66	0.28	0.25	0.25	0.23	0.25
CC 67	0.25	0.23	0.23	0.18	0.22
CC 68	0.71	0.45	0.47	0.47	0.53
CC 69	1.03	0.95	0.70	0.58	0.82
CC 70	0.92	0.89	0.70	0.68	0.80
CC 71	0.78	0.72	0.72	0.48	0.68
CC 72	0.88	0.68	0.81	0.73	0.78
CC 73	0.80	0.73	0.55	0.47	0.64
CC 74	0.58	0.55	0.48	0.51	0.53
CC 75	0.85	0.78	0.83	0.66	0.78
CC 76	0.45	0.23	0.23	0.28	0.30
CC 77	0.55	0.46	0.53	0.48	0.51
Mean (over shade level)	0.96	0.86	0.77	0.75	0.84
SE ± M	0.064	0.048	0.048	0/054	0.027
CD (0.05)	0.181	0.135	0.137	0.154	0.075

Table 16. Variability parameters for biometrical characters in chilli genotypes in open condition

Characters	Mean ± SE	Genotypic variance	Phenotypic variance	GCV	PCV	Heritability	Genetic advance	Genetic advance as % of mean
Plant height	47.05 ± 1.38	73.52	77.31	18.22	18.69	95.09	17.22	36.61
Internodal length	2.59 ± 0.07	0.02	0.03	5.26	6.45	66.59	0.23	8.85
Stem girth	4.37 ± 0.12	0.45	0.47	15.30	15.76	94.26	1.34	30.60
Leaf area	23.53 ± 1.07	137.04	139.33	49.75	50.16	98.36	23.92	101.63
Petiole length	3.56 ± 0.08	0.36	0.38	16.75	17.06	96.34	1.21	69.75
Height of node to first flower	24.50 ± 1.04	23.05	25.20	19.60	20.49	91.47	9.46	38.60
Node to first flower	16.69 ± 0.37	15.36	15.63	23.48	23.68	98.27	8.00	47.94
Days to first flower	39.98 ± 0.57	158.33	158.97	31.48	31.54	99.60	25.87	64.58
Fruits per plant	68.62 ± 2.86	2450.56	2461.93	72.15	72.39	99.34	101.64	148.14
Fruit length	5.16 ± 0.09	6.00	6.01	47.45	47.52	99.74	5.04	97.63
Fruit girth	4.70 ± 0.09	5.33	5.35	49.12	49.21	99.65	4.75	101.02
Fruit weight	4.44 ± 0.16	8.85	8.90	66.99	67.18	99.41	6.11	137.57
Yield per plant	183.62 ± 5.91	5402.42	5472.24	40.03	40.29	98.72	150.44	81.93
Reaction to mite attack	0.96 ± 0.06	0.14	0.14	38.40	39.54	84.32	0.74	76.82

Table 17. Variability parameters for biometrical characters in chilli genotypes under 25 per cent shade

Characters	Mean ± SE	Genotypic variance	Phenotypic variance	GCV	PCV	Heritability	Genetic advance	Genetic advance as % of mean
Plant height	57.77 ± 1.27	86.41	89.62	16.09	16.39	96.41	18.80	32.53
Internodal length	2.97 ± 0.06	0.03	0.04	5.43	6.80	68.43	0.26	9.58
Stem girth	3.88 ± 0.11	0.64	0.66	20.58	20.98	96.17	1.61	41.56
Leaf area	32.48 ± 0.78	208.91	210.11	44.51	44.63	99.43	29.69	91.41
Petiole length	4.70 ± 0.09	0.77	0.79	18.70	18.91	97.85	1.79	38.09
Height of node to first flower	26.32 ± 1.27	19.52	22.73	16.78	18.11	85.89	8.43	32.04
Node to first flower	17.18 ± 0.43	16.92	17.75	23.95	24.53	95.33	8.27	48.17
Days to first flower	40.87 ± 0.55	164.28	164.90	31.36	31.42	99.63	26.35	64.46
Fruits per plant	67.25 ± 2.20	2322.63	2352.34	71.65	71.79	99.58	99.07	147.28
Fruit length	5.19 ± 0.09	6.11	6.13	47.62	47.69	99.71	5.08	97.82
Fruit girth	4.73 ± 0.09	5.10	5.12	47.73	47.83	99.61	4.64	98.12
Fruit weight	4.50 ± 0.16	9.06	9.11	66.84	67.04	99.42	6.18	99.42
Yield per plant	181.82 ± 6.81	5746.73	5839.52	41.53	41.86	98.41	154.92	84.86
Reaction to mite attack	0.86 ± 0.04	0.14	0.15	43.85	44.56	96.86	0.76	88.89

High magnitudes of GCV and PCV were displayed by fruit weight (66.69 and 67.18) and leaf area (49.75 and 50.16) and lower values by stem girth (15.30 and 15.76) and petiole length (16.75 and 17.06) in open. Under 25 per cent shade high magnitudes of GCV and PCV were displayed by fruit weight (66.84 and 67.04) and fruit girth (47.73 and 47.83) whereas it was low for plant height (16.09 and 16.39) and height of node to first flower (16.78 and 18.11).

Heritability in the broad sense varied from 66.59 for internodal length to 99.74 for fruit length in open (Fig. 1). Similar results were observed under 25 per cent shade with variation in the heritability from 68.43 for internodal length to 99.71 for fruit length (Fig. 2). In general heritability estimates in open and 25 per cent shade were high for most of the characters *viz.* fruit girth (99.65% and 99.61%), days to first flower (99.60% and 99.63%), fruit weight (99.41% and 99.42%), fruits per plant (99.34% and 99.58%), yield (98.72% and 98.41%) and leaf area (98.36% and 99.43%) respectively.

Genetic advance was the highest for yield (150.44 and 154.92) and the lowest for internodal length (0.23 and 0.26) in open and 25 per cent shade respectively.

The expected genetic advance ranged from 8.85 for internodal length to 148.14 for fruits per plant in open. Under 25 per cent shade the range was from 9.58 for internodal length to 147.28 for fruits per plant.

High heritability combined with high GCV and expected genetic advance was observed for fruits per plant and fruit weight under both shade

Fig. 1. Heritability and genetic advance (as percentage of mean) of characters in chilli genotypes in open condition

X1	Plant height
X2	Internodal length
X3	Stem girth
X4	Leaf area
X5	Petiole length
X6	Height of node to first flower
X7	Node to first flower
X8	Days to first flower
X9	Fruits per plant
X10	Fruit length
X11	Fruit girth
X12	Fruit weight
X13	Yield per plant
X14	Incidence of mite

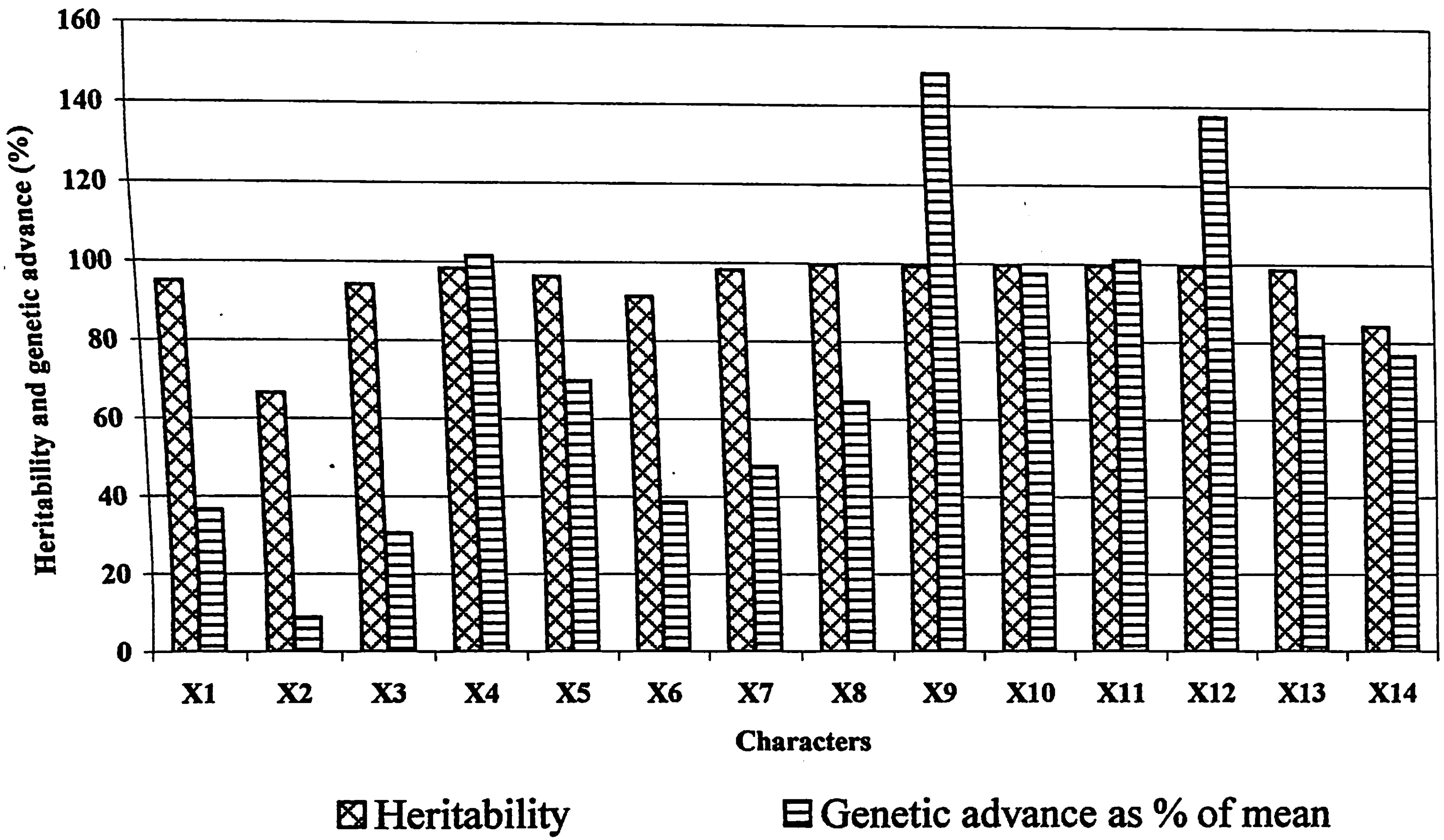

Fig. 1 Heritabilty and genetic advance (as percentage of mean) of characters in chilli genotypes in open condition

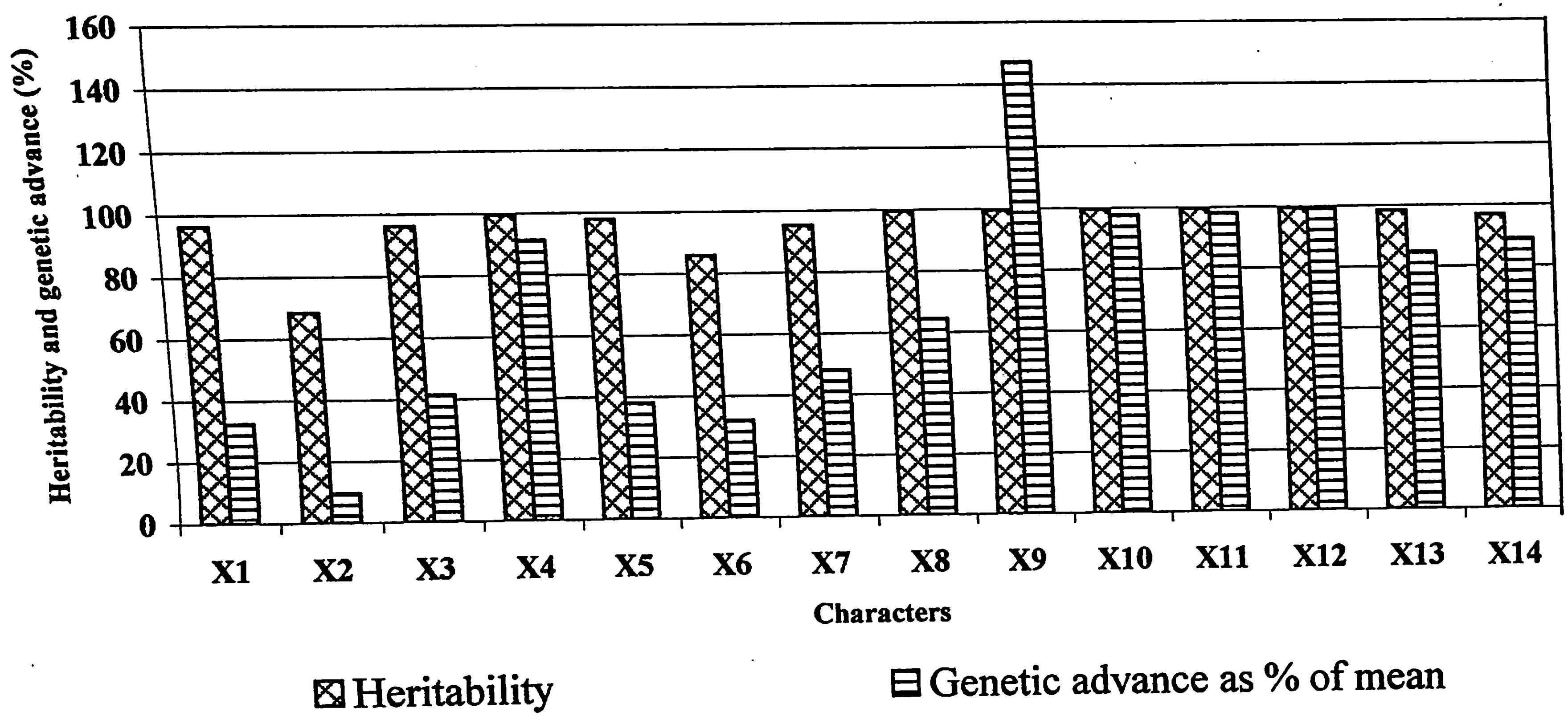

Fig. 2 Heritability and genetic advance (as percentage of mean) of characters in chilli genotypes under 25 per cent shade

levels. High heritability with low genetic advance was observed for internodal length and stem girth.

The phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlation coefficients were estimated for 14 characters in open and 25 per cent shade (Table 18, 19 and 20).

A significant positive correlation was observed for fruits per plant, fruit length and fruit weight at genotypic and phenotypic levels under both shade levels. Association of plant height, leaf area, height of node to first flower and days to first flower had significant negative phenotypic and genotypic correlation with yield in open and 25 per cent shade.

Fruit length had maximum positive correlation with yield (r_g = 0.484 and 0.485), followed by fruit weight (r_g =0.308 and0.362) and fruits per plant (r_g = 0.233 and 0.248) in open and 25 per cent shade respectively.

Based on the performance under shade and the yield pattern one genotype each for shade tolerance and shade susceptibility was selected in all the three species. In *C. annuum*, the genotype CA 38 recorded maximum yield under all the shade levels and selected as shade tolerant (Plate 4a). The genotype CA 39 had minimum yield under all the shade levels and selected as shade susceptible (Plate 4b). The per cent increase in characters like plant height, internodal length, leaf area and leaf petiole in 25 per cent shade was minimum in CA 38 compared to CA 39 (Fig. 3). In 25 per cent shade CA 38 recorded per cent increase in fruits and yield per plant whereas a per cent decrease was observed for these characters in CA 39. In *C. frutescens*, CF 51 had the highest yield under all shade levels and selected as the shade tolerant

Table 18. Phenotypic correlation among biometrical characters of chilli genotypes in open and 25 per cent shade

Sl. No.	Character		Plant height	Inter-nodal length	Stem girth	Leaf area	Petiole length	Height of node to first flower	Node to first flower	Days to first flower	Fruits per plant	Fruit length	Fruit girth	Fruit weight	Yield per plant	Incidence of mite
		-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Plant height	P *	1.0000	0.1792	0.4921	0.4705	0.3257	0.6347	0.6105	0.5125	0.1678	-0.3159	-0.0944	-0.3423	-0.2528	-0.3922
		P **	1.0000	0.1047	0.4030	0.3598	0.2019	0.5872	0.5314	0.3765	0.2467	-0.2910	-0.0769	-0.3959	-0.1172	-0.3161
2	Internodal length	P *		1.0000	0.6391	0.5003	0.3236	0.3116	0.1609	0.3712	-0.2392	0.0632	0.4717	0.2109	-0.1797	-0.3751
		P **		1.0000	0.1248	0.1287	-0.1375	0.1914	0.2094	0.1834	0.0620	-0.1813	0.0442	-0.1252	-0.1294	-0.1179
3	Stem girth	P *			1.0000	0.7491	0.3815	0.6946	0.5447	0.6891	-0.0200	-0.2532	0.2381	-0.1334	-0.1718	0.6169
		P **			1.0000	0.7981	0.3892	0.6211	0.6119	0.7506	0.0657	-0.3515	0.1713	-0.2092	-0.2113	-0.6206
4	Leaf area	P *				1.0000	0.3720	0.7449	0.7328	0.9141	0.2263	-0.4528	-0.0115	-0.3118	-0.3107	-0.5799
		P **				1.0000	0.3546	0.5669	0.7006	0.8719	0.1962	-0.3706	0.0732	-0.2366	-0.2246	-0.5745
5	Petiole length	P *					1.0000	0.3111	0.2435	0.2612	-0.0650	0.1248	0.2510	0.2180	0.1862	-0.3063
		P **					1.0000	0.2312	0.1329	0.1476	-0.0455	0.1855	0.2147	0.1906	0.2964	-0.1894
6	Height of node to first flower	P *						1.0000	0.8514	0.8039	0.2703	-0.6023	-0.1962	-0.5167	-0.3558	-0.5578
		P **						1.0000	0.8025	0.7011	0.3192	-0.5953	-0.2522	-0.5718	-0.2814	-0.5036
7	Node to first flower	P *							1.0000	0.8586	0.5207	-0.7188	-0.4325	-0.7000	-0.3625	-0.5235
		P **							1.0000	0.8607	0.4741	-0.7338	-0.4182	-0.7150	-0.4148	-0.5434
8	Days to first flower	P *								1.0000	0.3795	-0.6373	-0.2432	-0.5264	-0.4286	-0.5606
		P **								1.0000	0.3452	-0.6460	-0.2127	-0.5314	-0.4308	-0.5716
9	Fruits per plant	P *									1.0000	-0.4410	-0.6439	-0.6627	0.2343	-0.0408
		P **									1.0000	-0.4300	-0.6317	-0.6454	0.2482	-0.0521
10	Fruit length	P *										1.0000	0.5284	0.8231	0.4808	0.3245
		P **										1.0000	0.5221	0.8198	0.4807	0.3437
11	Fruit girth	P *											1.0000	0.7810	0.1295	-0.0228
		P **											1.0000	0.7597	0.1443	-0.0017
12	Fruit weight	P *												1.0000	0.3074	0.2157
		P **												1.0000	0.3611	0.2354
13	Yield per plant	P *													1.0000	0.2011
		P **													1.0000	0.1772
14	Incidence of mite	P *														1.0000
		P **														1.0000

P * Phenotypic correlation in open condition P ** Phenotypic correlation under 25 % shade

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Table 19. Genotypic correlation among biometrical characters of chilli genotypes in open and 25 per cent shade

Sl. No.	Character	-	Plant height 1	Inter-nodal length 2	Stem girth 3	Leaf area 4	Petiole length 5	Height of node to first flower 6	Node to first flower 7	Days to first flower 8	Fruits per plant 9	Fruit length 10	Fruit girth 11	Fruit weight 12	Yield per plant 13	Incidence of mite 14
1	Plant height	G *	1.0000	0.2428	0.5287	0.4840	0.3435	0.6827	0.6315	0.5249	0.1682	-0.3241	-0.0948	-0.3558	-0.2652	-0.4082
		G **	1.0000	0.2325	0.4038	0.3665	0.2139	0.6259	0.5498	0.3824	0.2539	-0.2967	-0.0791	-0.4055	-0.1169	-0.3216
2	Internodal length	G *		1.0000	0.8060	0.6183	0.4012	0.4049	0.2218	0.4507	-0.280	0.0813	0.5803	0.2486	-0.2152	-0.4609
		G **		1.0000	0.4273	0.4345	-0.4163	0.5675	0.7548	0.6656	0.2222	-0.6451	0.1684	-0.4831	-0.4747	-0.4788
3	Stem girth	G *			1.0000	0.7806	0.4043	0.7390	0.5595	0.7115	-0.0226	-0.2620	0.2447	-0.1372	-0.1830	-0.6505
		G **			1.0000	0.8160	0.4054	0.6554	0.6371	0.7659	0.0666	-0.3586	0.1744	-0.2152	-0.2173	-0.6279
4	Leaf area	G *				1.0000	0.3811	0.7894	0.7471	0.9236	0.2289	-0.4562	-0.1118	-0.3130	-0.3149	-0.5973
		G **				1.0000	0.3590	0.6150	0.7214	0.8757	0.1965	-0.3712	0.0740	-0.2379	-0.2265	-0.5860
5	Petiole length	G *					1.0000	0.3341	0.2563	0.2681	-0.0676	0.1269	0.2557	0.2238	0.1871	-0.3108
		G **					1.0000	0.2624	0.1428	0.1491	-0.0469	0.1871	0.2182	0.1923	0.2994	-0.1954
6	Height of node to first flower	G *						1.0000	0.8922	0.8430	0.2793	-0.6277	-0.2057	-0.5427	-0.3750	-0.6025
		G **						1.0000	0.8825	0.7539	0.3460	-0.6411	-0.2708	-0.6184	-0.3023	-0.5265
7	Node to first flower	G *							1.0000	0.8675	0.5269	-0.7268	-0.4373	-0.7066	-0.3696	-0.5412
		G **							1.0000	0.8838	0.4843	-0.7514	-0.4280	-0.7323	-0.4298	-0.5597
8	Days to first flower	G *								1.0000	0.3820	-0.6395	-0.2437	-0.5290	-0.4304	-0.5762
		G **								1.0000	0.3464	-0.6474	-0.2134	-0.5341	-0.4341	-0.5808
9	Fruits per plant	G *									1.0000	-0.4429	-0.6468	-0.6675	0.2331	-0.0395
		G **									1.0000	-0.4310	-0.6345	-0.6490	0.2480	-0.0513
10	Fruit length	G *										1.0000	0.5299	0.8274	0.4843	0.3368
		G **										1.0000	0.5234	0.8232	0.4852	0.3510
11	Fruit girth	G *											1.0000	0.7851	0.1306	-0.0270
		G **											1.0000	0.7634	0.1452	-0.0012
12	Fruit weight	G *												1.0000	0.3081	0.2202
		G**												1.0000	0.3620	0.2420
13	Yield per plant	G *													1.0000	0.2059
		G **													1.0000	0.1808
14	Incidence of mite	G *														1.0000
		G **														1.0000

G * Genotypic correlation in open condition   G ** Genotypic correlation under 25 % shade

Table 20. Environmental correlation among biometrical characters of chilli genotypes in open and 25 per cent shade

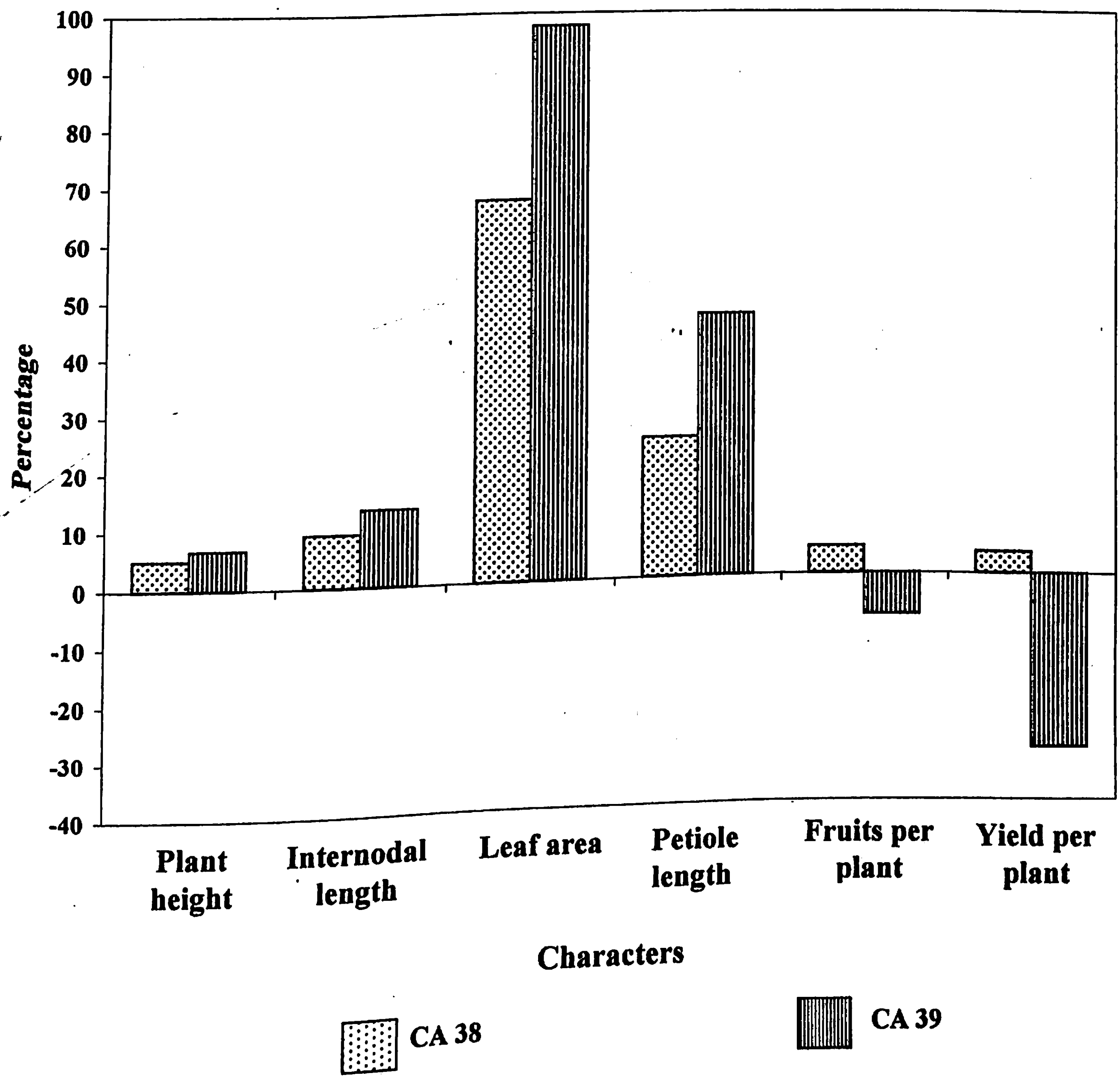
Sl. No.	Character		Plant height	Inter-nodal length	Stem girth	Leaf area	Petiole length	Height of node to first flower	Node to first flower	Days to first flower	Fruits per plant	Fruit length	Fruit girth	Fruit weight	Yield per plant	Incidence of mite
		-	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Plant height	E *	1.0000	-0.1094	-0.160	0.0860	-0.0716	-0.0394	-0.0047	0.1226	0.2357	-0.0162	-0.1660	0.2147	0.1639	-0.1057
		E **	1.0000	0.2322	0.3823	0.0675	-0.2084	0.2473	0.1062	0.1501	-0.1630	-0.0139	0.0496	0.0757	-0.1383	-0.1567
2	Internodal length	E *		1.0000	0.0033	-0.0005	0.0210	-0.0263	-0.2448	0.1133	-0.2472	-0.1045	-0.0297	0.1949	-0.0794	-0.0712
		E **		1.0000	0.0541	0.1411	-0.1764	0.1316	-0.0377	0.0286	0.0217	-0.0994	-0.0292	0.0902	-0.0052	0.0644
3	Stem girth	E *			1.0000	-0.0808	-0.0830	0.1208	0.1968	-0.0157	0.0943	0.0713	0.0640	-0.0343	0.1744	-0.0623
		E **			1.0000	0.0138	-0.1404	0.3468	0.0453	0.0720	0.0448	-0.0272	0.0513	0.0880	0.0029	-0.4209
4	Leaf area	E *				1.0000	0.0425	-0.1017	-0.1084	-0.0157	0.0036	-0.1423	0.0325	-0.2406	-0.0272	-0.1503
		E **				1.0000	0.0444	-0.0502	-0.1113	0.0615	0.1370	-0.2566	-0.0880	-0.0126	-0.0508	0.0442
5	Petiole length	E *					1.0000	-0.0446	-0.2371	-0.1146	0.0710	0.0411	0.0367	-0.0717	0.1725	-0.2209
		E **					1.0000	-0.1693	-0.1593	0.0497	0.0906	0.0876	-0.0783	0.0794	0.1419	0.0337
6	Height of node to first flower	E *						1.0000	0.1427	-0.0386	0.1729	-0.1817	0.0082	0.0363	0.0160	0.0263
		E **						1.0000	0.0476	0.1639	-0.0322	-0.1022	-0.0748	-0.0107	-0.0746	-0.3513
7	Node to first flower	E *							1.0000	0.0277	0.0069	0.1244	0.0426	-0.1513	0.1049	-0.0760
		E **							1.0000	-0.0494	0.1563	-0.1085	-0.0829	-0.1290	0.0546	-0.1436
8	Days to first flower	E *								1.0000	-0.0886	0.0436	-0.1088	-0.0040	-0.2504	-0.1387
		E **								1.0000	0.0431	-0.2386	-0.0249	0.0289	-0.1245	-0.0924
9	Fruits per plant	E *									1.0000	-0.0353	-0.0880	0.1020	0.3757	-0.1358
		E **									1.0000	-0.1291	0.0500	0.0689	0.3370	-0.1503
10	Fruit length	E *										1.0000	0.0286	-0.2080	0.0506	-0.1801
		E **										1.0000	0.1509	0.0422	0.0151	-0.1315
11	Fruit girth	E *											1.0000	-0.0859	-0.0120	0.2389
		E **											1.0000	0.0053	0.0720	-0.0486
12	Fruit weight	E *												1.0000	0.2558	0.1342
		E **												1.0000	0.3143	-0.1547
13	Yield per plant	E *													1.0000	0.0896
		E **													1.0000	0.0283
14	Incidence of mite	E *														1.0000
		E **														1.0000

E * Environmental correlation in open condition   E ** Environmental correlation under 25 % shade

Plate 4 a. Shade tolerant genotype of *C. annuum* – CA 38

Plate 4 b. Shade susceptible genotype of *C. annuum* – CA 39

Fig. 3 Biometrical characters of shade tolerant and shade susceptible genotypes of *C. annuum* under 25 % shade (% difference over open condition)



genotype (Plate 5a) and CF 46 recorded lowest yield in all the shade levels and selected as shade susceptible genotype (Plate 5b). The genotype CC 63 of *C. chinense* recorded maximum yield under all shade levels and selected as the shade tolerant (Plate 6a) and minimum yield was recorded by CC 66 and selected as the shade susceptible genotype (Plate 6b).

4.2 Physiological basis of shade tolerance

4.2.1 Leaf area index (LAI)

The data on leaf area index were significant both among genotypes and between different shade levels (Table 21). The LAI increased steadily up to fruiting stage and then declined in the harvesting stage.

Both shade tolerant and susceptible genotypes recorded maximum LAI when grown in open compared to 50 per cent shade. Shade tolerant genotypes of *C. annuum*, *C. frutescens* and *C. chinense* had higher LAI than shade susceptible genotypes at all levels. Maximum LAI was registered by all the genotypes at fruiting stage and minimum at vegetative stage. Shading during vegetative and flowering stages had greater influence on the per cent reduction of LAI whereas shading during fruiting and harvesting stages had lesser influence on the per cent reduction (Figure 4).

In the case of *C. annuum*, maximum LAI was observed in shade tolerant genotype CA 38 at fruiting stage both in open (1.489) and 50 per cent shade (1.460). However minimum LAI was observed in CA 39 (shade susceptible genotype) at vegetative stage both in open (0.382) and 50 per cent shade (0.260).

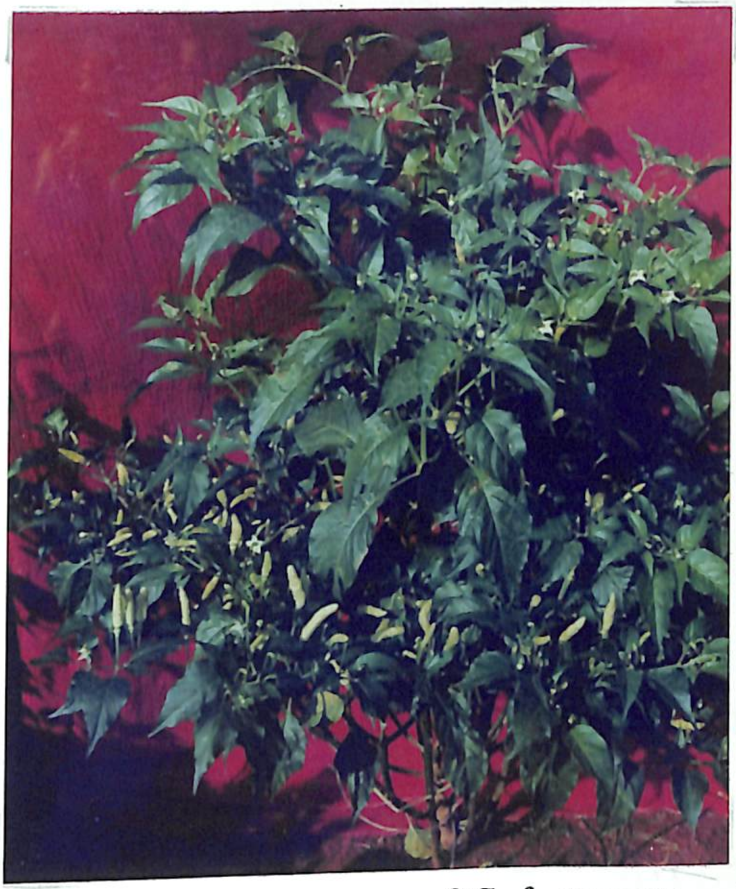


Plate 5 a. Shade tolerant genotype of *C. frutescens* – CF 51

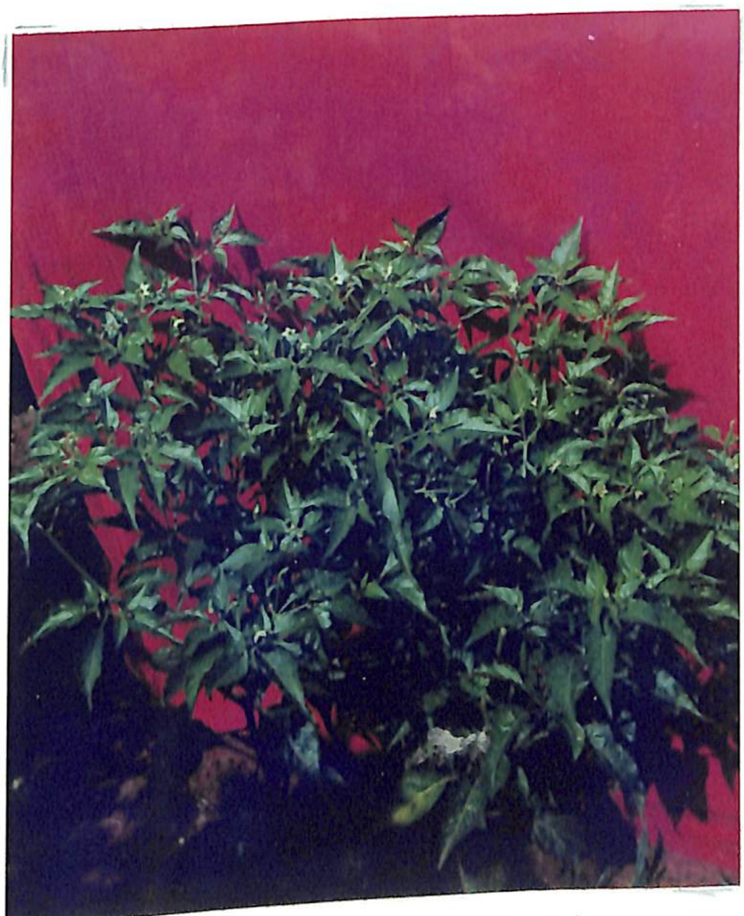


Plate 5 b. Shade susceptible genotype of *C. frutescens* – CF 46

Plate 6 a. Shade tolerant genotype of *C. chinense* – CC 63

Plate 6 b. Shade susceptible genotype of *C. chinense* – CC 66

Similarly in *C. frutescens*, shade tolerant genotype CF 51 had the highest LAI at fruiting stage both in open (2.410) and 50 per cent shade (2.030) and minimum in shade susceptible CF 46 with a value of 0.658 in open and 0.415 under 50 per cent shade during vegetative stage.

In the case of *C. chinense*, maximum LAI was recorded during fruiting stage. The shade tolerant genotype CC 63 recorded the highest value both in open condition (2.520) and in 50 per cent shade (2.260). However the shade susceptible genotype CC 66 recorded the lowest value in open (0.604) as well as in 50 per cent shade (0.534) during vegetative stage.

4.2.2 Specific leaf weight (SLW) (g cm^{-2})

The data on SLW indicated statistical significance among different genotypes at all growth stages in both open and 50 per cent shade (Table 22). The values increased progressively up to fruiting stage and decreased towards harvesting stage in all the genotypes both in open and 50 per cent shade.

A decreasing trend in SLW was observed in 50 per cent shade compared to open in all the genotypes. Maximum SLW was registered during fruiting stage and minimum during vegetative stage. Shading during all the growth stages had greater influence on the per cent reduction of SLW (Fig. 5).

In *C. annuum*, maximum SLW was observed in shade tolerant genotype CA 38 during fruiting stage both in open (3.680) and 50 per cent shade (1.699) and minimum in shade susceptible genotype CA 39 with values of 2.105 in open and 0.992 under 50 per cent shade.

In the case of *C. frutescens*, maximum SLW was recorded during fruiting stage and minimum during vegetative stage. The shade tolerant genotype CF 51 recorded highest SLW both in open (4.499) and 50 per cent shade (2.483). The shade susceptible CF 46 had the lowest values both in open (3.802) and 50 per cent shade (1.542). In *C. chinense*, the shade tolerant genotype CC 63 had the highest value under open (4.914) and 50 per cent shade (2.302).

4.2.3 Crop growth rate (CGR) (g m $^{-2}$ day^{-1})

Significant difference between genotypes was observed at all the growth stages both in open and 50 per cent shade (Table 23). As such a decrease in CGR was noticed in all shade tolerant and susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* grown under 50 per cent shade than in open (Fig. 6).

In *C. annuum*, the highest CGR was observed in shade tolerant genotype CA 38 during the period between fruiting and harvesting stage both in open (3.073) and 50 per cent shade (1.580). The shade susceptible genotype CA 39 had the minimum value of 0.062 in open and 0.024 under 50 per cent shade during the period between vegetative and flowering phase.

In *C. frutescens*, the shade tolerant genotype CF 51 had the maximum CGR both in open (5.844) and 50 per cent shade (1.458) during the period between fruiting and harvesting stage. However minimum CGR was noticed in shade susceptible genotype CF 46 during the period between vegetative and

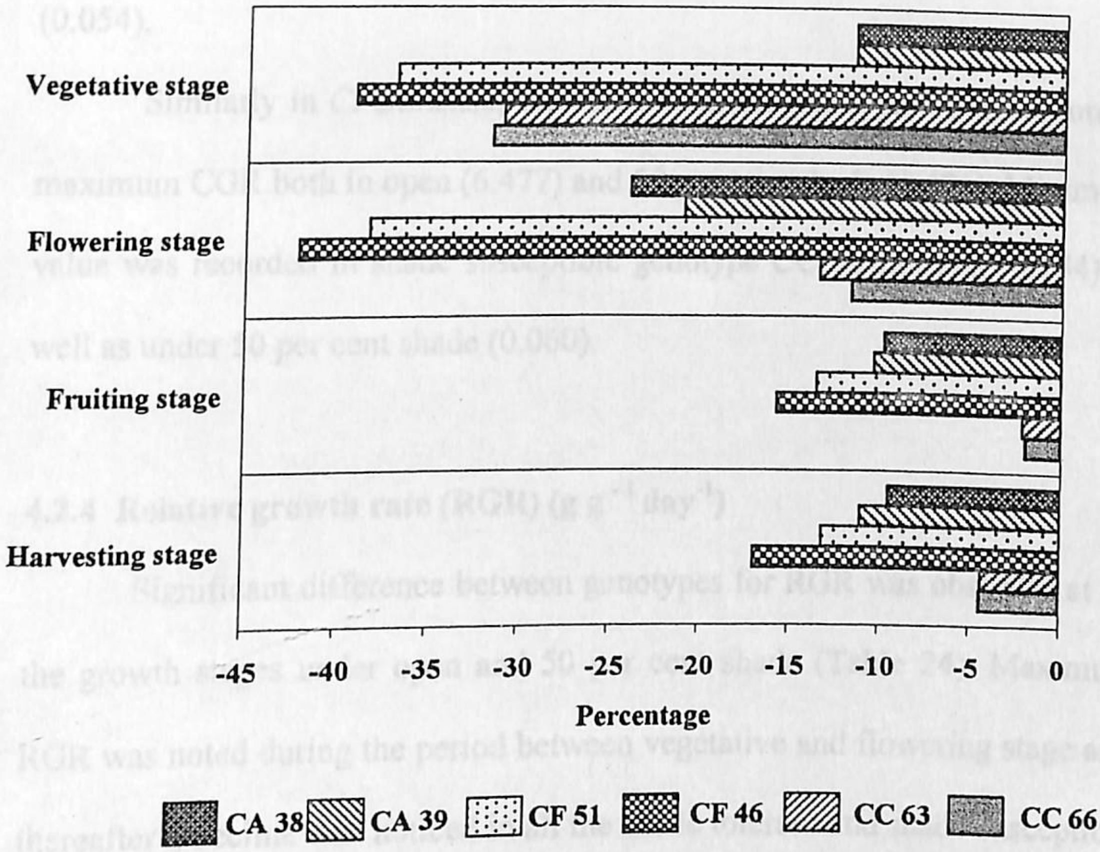
Table 21. Leaf area index of shade tolerant and shade susceptible genotypes of chilli

Genotypes	Vegetative stage		Flowering stage		Fruiting stage		Harvesting stage	
	Shade	Open	Shade	Open	Shade	Open	Shade	Open
CA 38	0.274	0.471	1.193	1.350	1.460	1.489	1.300	1.360
CA 39	0.260	0.382	1.078	1.245	1.379	1.409	1.240	1.296
CF 51	0.418	0.687	1.033	1.785	2.030	2.410	1.928	2.321
CF 46	0.415	0.658	1.033	1.674	1.924	2.230	1.828	2.105
CC 63	0.581	0.657	1.209	1.530	2.260	2.520	2.140	2.405
CC 66	0.534	0.604	1.125	1.480	2.151	2.384	2.031	2.244
SEM ±	0.0038	0.0053	0.0081	0.0029	0.0056	0.0059	0.0061	0.0083
CD (0.05)	0.0122	0.0167	0.0255	0.0093	0.0176	0.0187	0.0194	0.0261

Table 22. Specific leaf weight of shade tolerant and shade susceptible genotypes of chilli (g cm^{-2})

Genotypes	Vegetative stage		Flowering stage		Fruiting stage		Harvesting stage	
	Shade	Open	Shade	Open	Shade	Open	Shade	Open
CA 38	1.168	2.294	1.272	2.193	1.699	3.680	1.510	3.221
CA 39	0.992	2.105	1.224	2.120	1.626	3.679	1.492	3.157
CF 51	1.722	3.849	2.439	4.472	2.483	4.499	2.306	4.215
CF 46	1.542	3.802	2.412	4.480	2.458	4.487	2.295	4.127
CC 63	1.239	3.428	2.249	4.837	2.302	4.914	2.175	4.690
CC 66	1.273	3.470	2.133	4.786	2.300	4.820	2.181	4.609
SEM ±	0.0033	0.0095	0.0045	0.0082	0.0017	0.0111	0.0094	0.0105
CD (0.05)	0.0104	0.0299	0.0140	0.0258	0.0053	0.0350	0.0295	0.0330

Fig. 4 Leaf area index of shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)



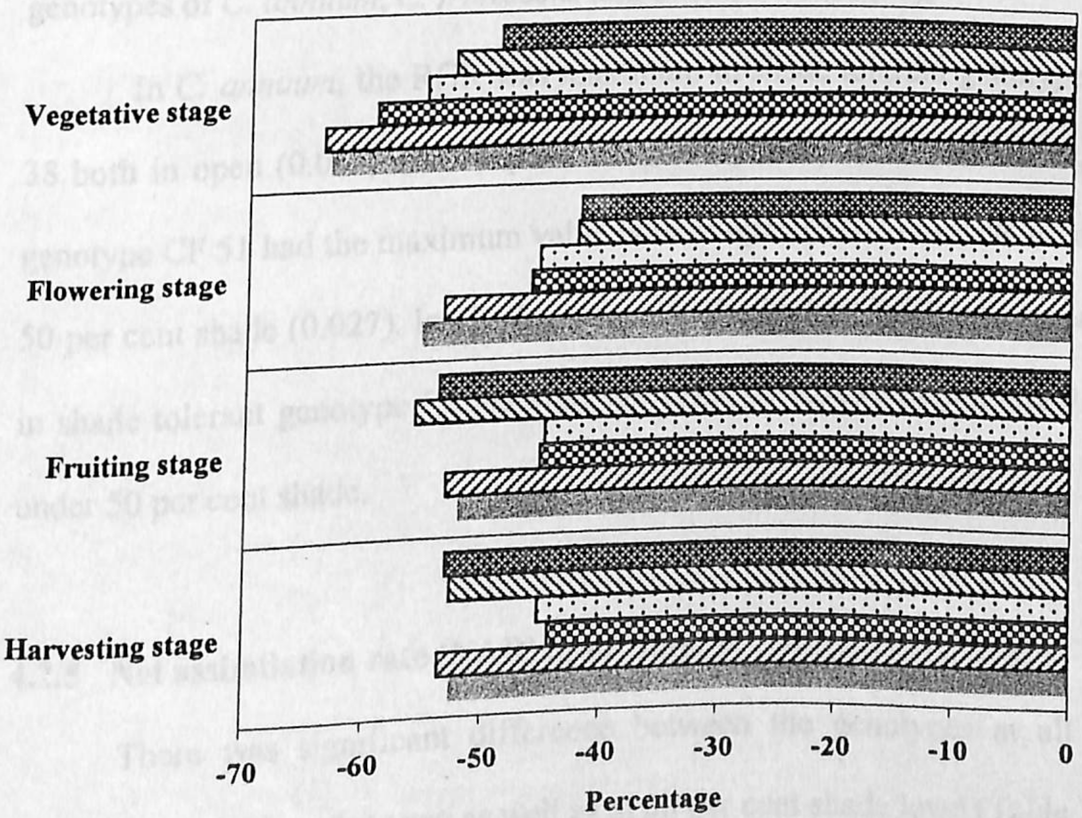


Fig. 5 Specific leaf weight of shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)

flowering stages both in open (0.248) as well as under 50 per cent shade (0.054).

Similarly in *C. chinense*, the shade tolerant genotype CC 63 recorded maximum CGR both in open (6.477) and 50 per cent shade (1.476). Minimum value was recorded in shade susceptible genotype CC 66 in open (0.184) as well as under 50 per cent shade (0.060).

4.2.4 Relative growth rate (RGR) (g g^{-1} day^{-1})

Significant difference between genotypes for RGR was observed at all the growth stages under open and 50 per cent shade (Table 24). Maximum RGR was noted during the period between vegetative and flowering stage and thereafter a decline was noticed in all the shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* (Fig. 7).

In *C. annuum*, the RGR was maximum in shade tolerant genotype CA 38 both in open (0.047) and 50 per cent shade (0.046). In *C. frutescens*, the genotype CF 51 had the maximum value both in open (0.041) as well as under 50 per cent shade (0.027). In *C. chinense*, also the highest RGR was recorded in shade tolerant genotype CC 63 with the value of 0.049 in open and 0.033 under 50 per cent shade.

4.2.5 Net assimilation rate (NAR) (g m^{-2} day^{-1})

There was significant difference between the genotypes at all the growth stages both under open as well as at 50 per cent shade level (Table 25). In all the genotypes maximum NAR was observed during the period between

Table 23. Crop growth rate of shade tolerant and shade susceptible genotypes of chilli ($g\ m^{-2}\ day^{-1}$)

Genotypes	Growth stages					
	Vegetative to flowering		Flowering to fruiting		Fruiting to harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.030	0.063	0.412	0.806	1.580	3.073
CA 39	0.024	0.062	0.324	0.738	1.225	1.937
CF 51	0.058	0.248	0.721	1.167	1.458	5.844
CF 46	0.054	0.248	0.683	1.070	1.321	5.185
CC 63	0.069	0.214	0.875	0.982	1.476	6.477
CC 66	0.060	0.184	0.748	0.919	1.362	6.028
SEM ±	0.0027	0.0023	0.0047	0.0091	0.0102	0.0087
CD (0.05)	0.0085	0.0073	0.0148	0.0286	0.0322	0.0275

Table 24. Relative growth rate of shade tolerant and shade susceptible genotypes of chilli ($g\ g^{-1}\ day^{-1}$)

Genotypes	Growth stages					
	Vegetative to flowering		Flowering to fruiting		Fruiting to harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.046	0.047	0.015	0.017	0.020	0.025
CA 39	0.041	0.042	0.013	0.016	0.017	0.019
CF 51	0.027	0.041	0.013	0.026	0.017	0.026
CF 46	0.026	0.037	0.011	0.024	0.016	0.024
CC 63	0.033	0.049	0.018	0.033	0.017	0.035
CC 66	0.022	0.039	0.018	0.029	0.017	0.033
SEM ±	0.0012	0.0015	0.0011	0.0009	0.0010	0.0013
CD (0.05)	0.0036	0.0047	0.0036	0.0028	0.0032	0.0041

Fig. 6 Crop growth rate of shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)

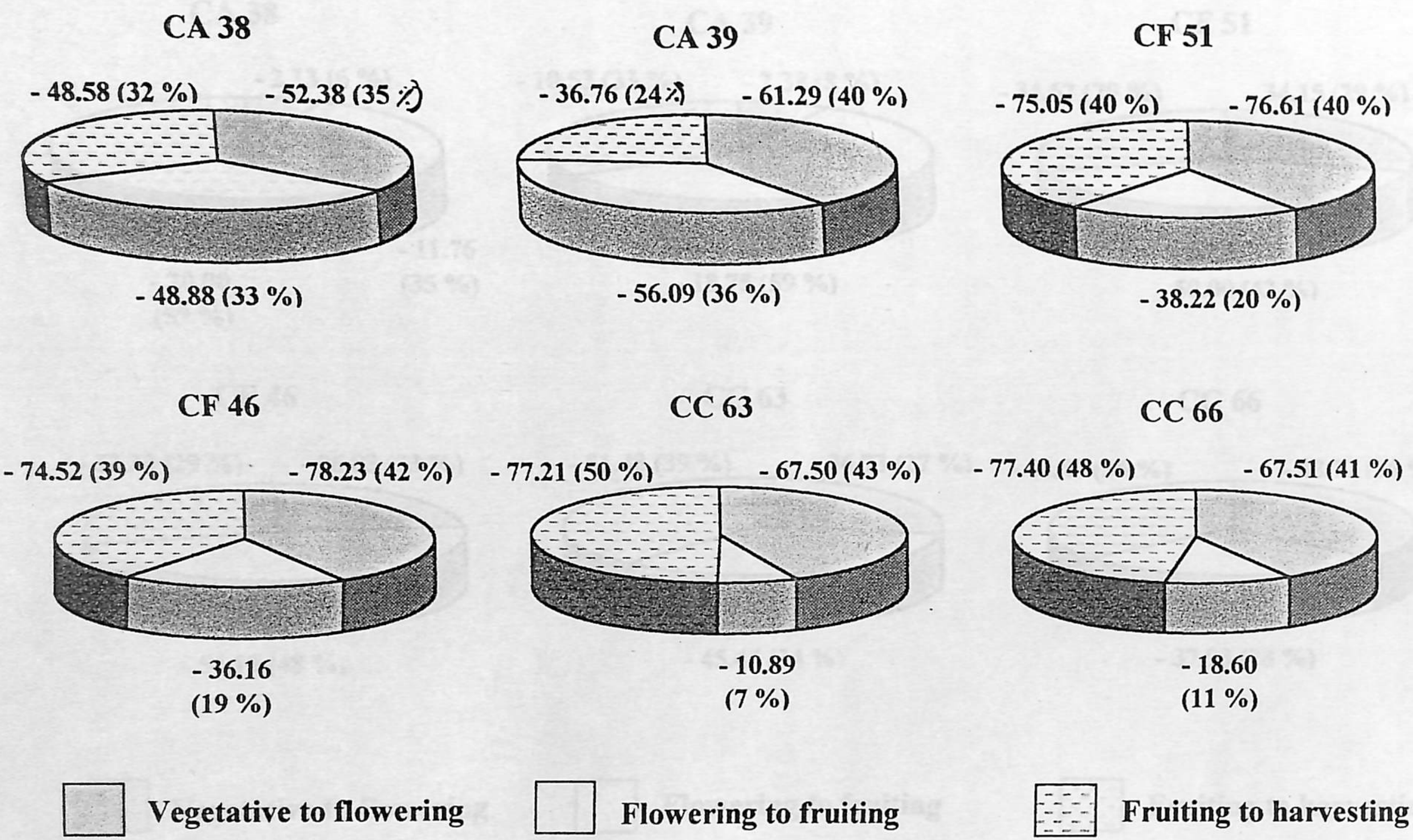
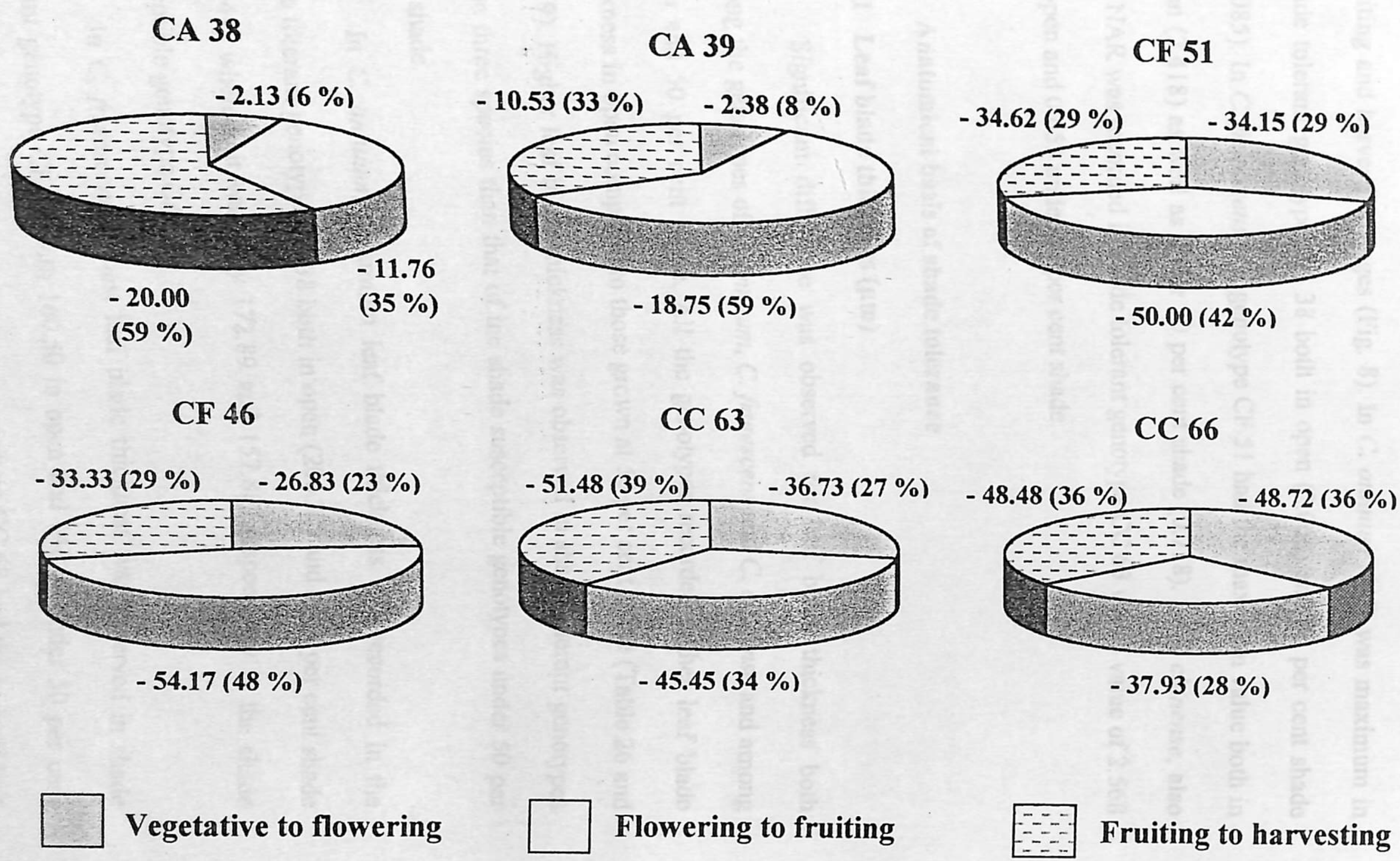


Fig. 7 Relative growth rate of shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)



fruiting and harvesting stages (Fig. 8). In *C. annuum* NAR was maximum in shade tolerant genotype CA 38 both in open (2.064) and 50 per cent shade (1.085). In *C. frutescens*, the genotype CF 51 had the maximum value both in open (2.418) as well as under 50 per cent shade (0.718). In *C. chinense*, also the NAR was recorded in shade tolerant genotype CC 63 with a value of 2.568 in open and 0.653 under 50 per cent shade.

4.3 Anatomical basis of shade tolerance

4.3.1 Leaf blade thickness (μm)

Significant difference was observed for leaf blade thickness both among the genotypes of *C. annuum*, *C. frutescens* and *C. chinense* and among open and 50 per cent shade. All the genotypes recorded higher leaf blade thickness in open compared to those grown at 50 per cent shade (Table 26 and Fig. 9). Higher leaf blade thickness was observed in shade tolerant genotypes of the three species than that of the shade susceptible genotypes under 50 per cent shade.

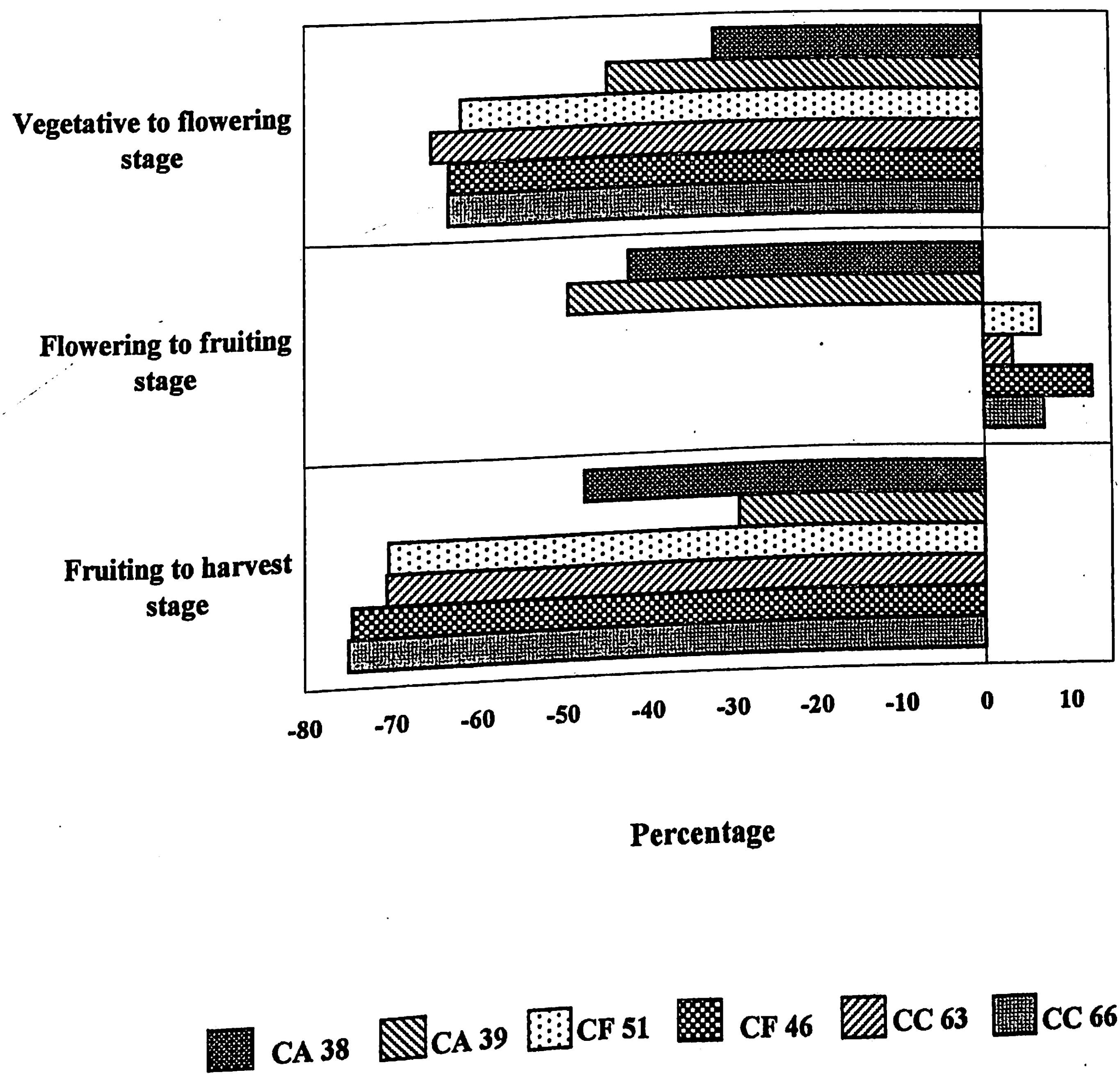
In *C. annuum*, maximum leaf blade thickness was recorded in the shade tolerant genotype CA 38 both in open (206.30) and at 50 per cent shade (161.41) whereas it was only 172.89 and 157.88 respectively in the shade susceptible genotype CA 39.

In *C. frutescens* highest leaf blade thickness was observed in shade tolerant genotype CF 51 with 160.50 in open and 146.00 under 50 per cent shade. In *C. chinense* the shade tolerant genotype CC 63 had the highest leaf

Table 25. Net assimilation rate of shade tolerant and shade susceptible genotypes of chilli ($g\ m^{-2}\ day^{-1}$)

Genotypes	Growth stages					
	Vegetative to flowering		Flowering to fruiting		Fruiting to harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.109	0.160	0.345	0.596	1.085	2.064
CA 39	0.091	0.164	0.301	0.596	0.975	1.376
CF 51	0.138	0.361	0.698	0.654	0.718	2.418
CF 46	0.131	0.377	0.661	0.639	0.685	2.325
CC 63	0.120	0.326	0.724	0.642	0.653	2.568
CC 66	0.112	0.305	0.665	0.621	0.633	2.530
SEM ±	0.0046	0.0039	0.0050	0.0045	0.0082	0.0044
CD (0.05)	0.0146	0.0122	0.0157	0.0142	0.0258	0.0138

Fig. 8 Net assimilation rate of shade tolerant and shade susceptible genotypes of chilli (% difference over open condition)



blade thickness in open and 50 per cent shade with 172.33 and 159.24 respectively.

4.3.2 Stomatal frequency (No. mm^{-2})

There was significant variation for stomatal frequency both among the genotypes and among the two shade levels. All the genotypes grown in the open had more stomates per unit area of leaves than those grown under 50 per cent shade (Plate 7).

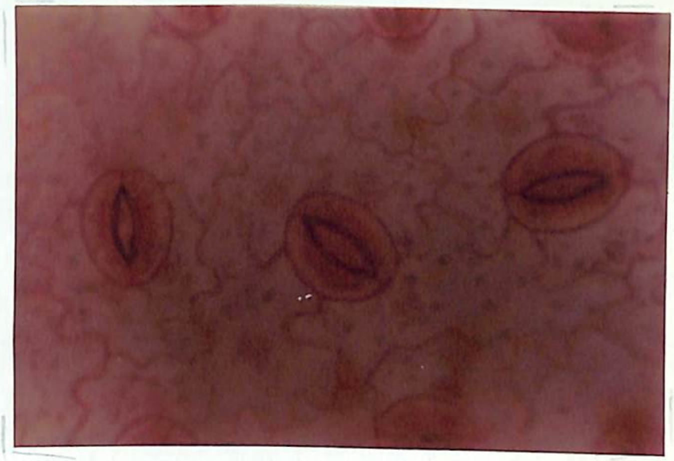
The shade tolerant genotype CA 38 of *C. annuum* had maximum stomates per unit area in the open (16.99) as well as under 50 per cent shade (14.60). In *C. frutescens*, the stomatal frequency ranged from 12.67 under 50 per cent shade to 14.80 in open .In *C. chinense*, maximum stomates per unit area was observed in the genotype CC 66 with 12.53 in open and 12.26 under 50 per cent shade.

4.3.3 Upper epidermal cell thickness (μm)

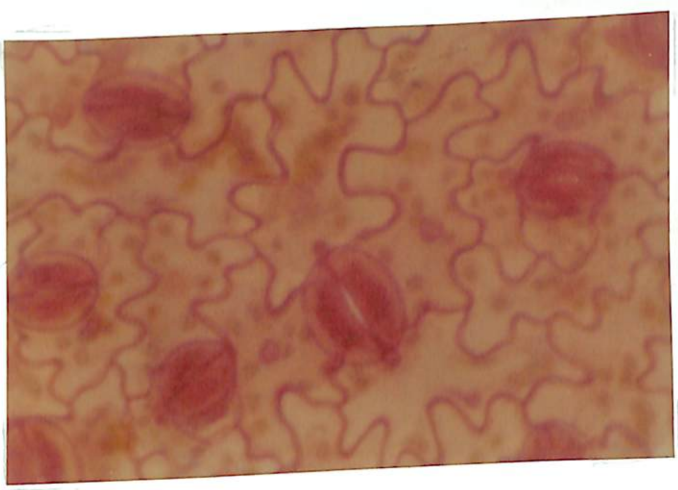
Significant difference in upper epidermal cell thickness existed both among genotypes and between the shade levels. All the genotypes grown in the open had thicker upper epidermal cell than those grown under 50 per cent shade.

In *C. annuum*, the maximum upper epidermal thickness was observed in shade tolerant genotype CA 38 both in open (14.15) and 50 per cent shade (13.37). In *C. frutescens*, the shade tolerant genotype CF 51 had the maximum upper epidermal cell thickness with 13.85 in open and 9.98 under 50 per cent

CA 38

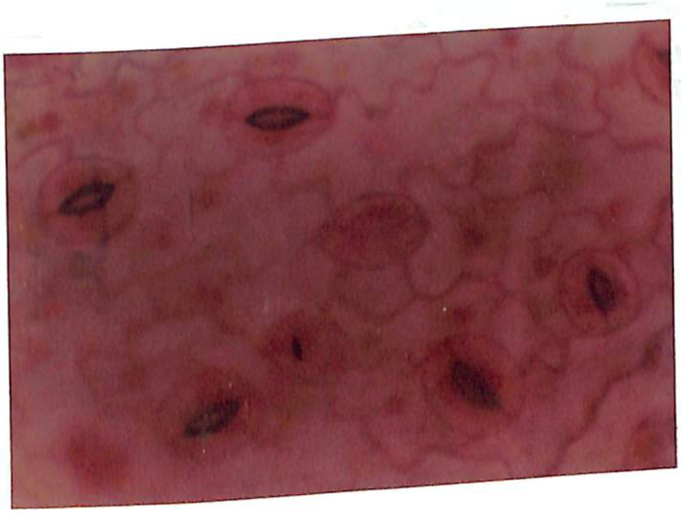


CA 39

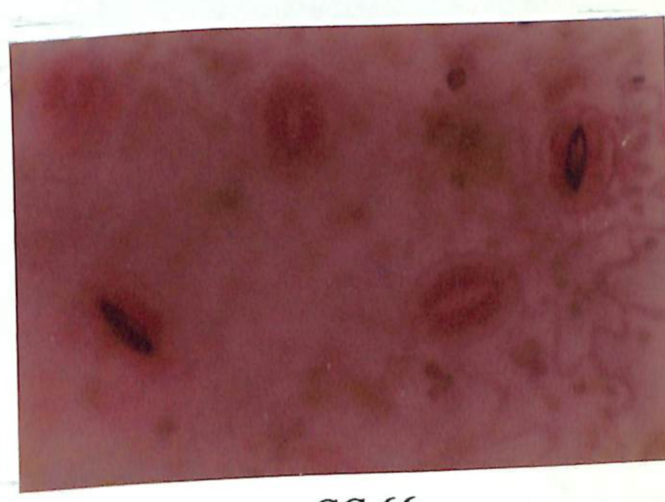


CF 51

C F 46



CC 63



CC 66

Plate 7. Stomatal frequency of shade tolerant and shade susceptible genotypes of chilli under 50 per cent shade

shade. In *C. chinense*, the shade susceptible genotype CC 66 registered the maximum upper epidermal cell thickness both in open 13.22 and 50 per cent shade 10.37.

4.3.4 Lower epidermal cell thickness (μm)

There was significant difference in lower epidermal cell thickness both among the genotypes and between the two shade levels. The lower epidermal cell thickness was more in genotypes grown under open compared to those grown under 50 per cent shade.

In *C. annuum*, the maximum lower epidermal cell thickness was observed in shade tolerant genotype CA 38 (10.84) in open and (9.56) 50 per cent shade. In *C. frutescens*, the lower epidermal cell thickness was maximum in CF 51 with 9.97 and 6.76 in open and 50 per cent shade respectively. In *C. chinense*, the shade susceptible genotype CC 66 had 12.85 and 10.30 in open and 50 per cent shade respectively.

4.3.5 Palisade mesophyll thickness (μm)

Significant difference in palisade mesophyll thickness existed both among genotypes and between the two shade levels. All the genotypes in the open had thicker palisade mesophyll than those in 50 per cent shade. Under shade all the shade tolerant genotypes had thicker palisade mesophyll compared to shade susceptible ones.

Maximum palisade mesophyll thickness was observed in shade tolerant *C. annuum* genotype CA 38 in open (80.47) and 50 per cent shade (61.19). In

C. frutescens, the shade tolerant CF 51 had a thickness of 45.87 and 41.07 and CC 63 the shade tolerant genotype of *C. chinense*, recorded a thickness of 64.36 and 48.26 in open and 50 per cent shade respectively.

4.3.6 Spongy mesophyll thickness (µm)

There was significant difference in spongy mesophyll thickness both among different genotypes and between the shade levels. All the genotypes in the open had thicker spongy mesophyll than those grown in 50 per cent shade.

In *C. annuum*, the maximum spongy mesophyll thickness was observed in shade susceptible genotype CA 39 with 93.18 and 70.84 in open and 50 per cent shade respectively. In *C. frutescens*, the shade tolerant CF51 had 66.89 and 51.52 and CC 63 the shade tolerant genotype of *C. chinense* had 106.19 and 103.01 in open and 50 per cent shade.

4.3.7 Vascular bundle thickness (µm)

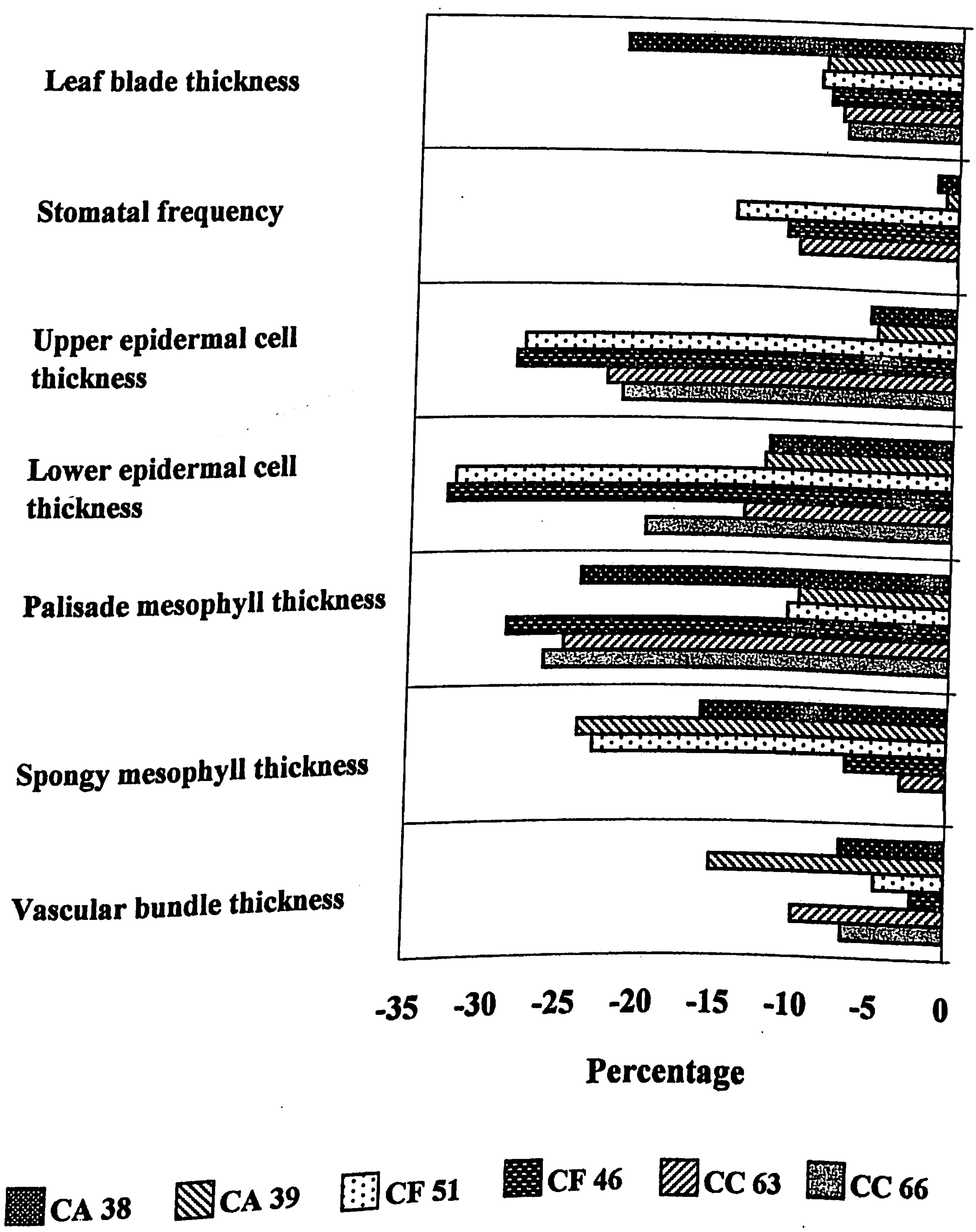
Significant difference in vascular bundle thickness existed among genotypes and between the two shade levels. All the genotypes had thicker vascular bundles in leaves in open compared to 50 per cent shade.

In *C. annuum*, CA 39 had the maximum vascular bundle thickness (151.75) in open whereas under shade CA 38 had the maximum (134.93). In *C. frutescens*, the highest vascular bundle thickness was observed in CF 46 (148.16) in open and 50 per cent shade (144.92). In *C. chinense*, CC 63 had the maximum vascular bundle thickness (196.40) in open whereas under shade CC 66 had the maximum (180.34).

Table 26. Anatomical characteristics of shade tolerant and shade susceptible genotypes of chilli

Genotypes	Leaf blade thickness (μm)		Stomatal frequency (No. mm^{-2})		Upper epidermal cell thickness (μm)		Lower epidermal cell thickness (μm)		Palisade mesophyll thickness (μm)		Spongy mesophyll thickness (μm)		Vascular bundle thickness (μm)	
	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open	Shade	Open
CA 38	161.41	206.30	14.60	16.99	13.37	14.15	9.56	10.84	61.19	80.47	67.62	80.47	134.93	144.86
CA 39	157.88	172.89	13.64	14.88	12.89	13.57	9.35	10.64	57.94	64.25	70.84	93.18	128.64	151.75
CF 51	146.00	160.50	12.67	14.80	9.98	13.85	6.76	9.97	41.07	45.87	51.52	66.89	135.24	141.68
CF 46	133.77	146.50	12.82	14.41	9.65	13.49	6.45	9.59	32.15	45.11	45.31	48.48	144.92	148.16
CC 63	159.24	172.33	10.33	11.51	9.96	12.86	10.64	12.29	48.26	64.36	103.01	106.19	177.10	196.40
CC 66	155.09	167.23	12.26	12.53	10.37	13.22	10.30	12.85	45.07	61.14	96.50	96.53	180.34	193.07
SEM ±	0.924	0.510	0.025	0.026	0.047	0.028	0.021	0.020	0.016	0.041	0.023	0.023	0.137	0.174
CD (0.05)	2.912	1.608	0.078	0.083	0.147	0.087	0.067	0.063	0.051	0.130	0.072	0.072	0.431	0.548

Fig. 9 Anatomical characteristics of shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)



4.4 Biochemical basis of shade tolerance

4.4.1 Chlorophyll (mg g^{-1})

Chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a / b ratio of shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* differed significantly between open and 50 per cent shade (Table 27 to 30). An increase in the content of chlorophyll a, chlorophyll b and total chlorophyll and a decrease in chlorophyll a / b ratio was observed in all the genotypes when grown under 50 per cent shade compared to open (Fig. 10 to 13).

In *C. annuum*, highest chlorophyll a and total chlorophyll was observed in shade tolerant genotype CA 38 during vegetative stage (0.534) and (1.159) under shade and chlorophyll b during flowering (0.660). In *C. frutescens*, highest chlorophyll a, b and total chlorophyll was registered by shade tolerant genotype CF 51 with 0.577, 0.773 and 1.350 respectively during vegetative stage under 50 per cent shade. Similarly in *C. chinense*, CC 63 recorded the highest chlorophyll a, b and total chlorophyll during vegetative stage with values 0.584, 0.716 and 1.300 respectively. In all the genotypes the chlorophyll a / b ratio was less in shade compared to open at all the growth stages.

4.4.2 Capsaicin (%)

No significant difference was observed for capsaicin content between open and 50 per cent shade in all the shade tolerant and shade susceptible

Table 27. Variation for chlorophyll a content in shade tolerant and shade susceptible genotypes of chilli (mg g^{-1})

Genotypes	Growth stages					
	Vegetative		Flowering		Harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.534	0.471	0.471	0.419	0.378	0.206
CA 39	0.509	0.457	0.439	0.406	0.365	0.227
CF 51	0.577	0.485	0.534	0.465	0.334	0.242
CF 46	0.570	0.488	0.521	0.464	0.330	0.268
CC 63	0.584	0.503	0.457	0.436	0.352	0.283
CC 66	0.572	0.498	0.451	0.432	0.335	0.298
SEM ±	0.0340	0.0033	0.0027	0.0027	0.0022	0.0027
CD (0.05)	0.0108	0.0103	0.0084	0.0084	0.0069	0.0084

Table 28. Variation for chlorophyll b content in shade tolerant and shade susceptible genotypes of chilli (mg g^{-1})

Genotypes	Growth stages					
	Vegetative		Flowering		Harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.625	0.538	0.660	0.520	0.576	0.301
CA 39	0.615	0.532	0.648	0.569	0.585	0.363
CF 51	0.773	0.533	0.739	0.552	0.601	0.346
CF 46	0.754	0.521	0.625	0.523	0.604	0.372
CC 63	0.716	0.540	0.662	0.510	0.586	0.424
CC 66	0.682	0.530	0.557	0.503	0.529	0.414
SEM ±	0.0046	0.0023	0.0022	0.0037	0.0034	0.0042
CD (0.05)	0.0145	0.0073	0.0071	0.0116	0.0107	0.0133

Table 29. Variation for total chlorophyll content in shade tolerant and shade susceptible genotypes of chilli (mg g^{-1})

Genotypes	Growth stages					
	Vegetative		Flowering		Harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	1.159	1.009	1.131	0.939	0.954	0.507
CA 39	1.124	0.989	1.087	0.975	0.950	0.590
CF 51	1.350	1.018	1.273	1.017	0.935	0.588
CF 46	1.324	1.009	1.146	0.987	0.934	0.640
CC 63	1.300	1.043	1.119	0.946	0.938	0.707
CC 66	1.255	1.028	1.008	0.935	0.864	0.712
SEM ±	0.0064	0.0038	0.0022	0.0038	0.0030	0.0014
CD (0.05)	0.0203	0.0121	0.0070	0.0121	0.0095	0.0043

Table 30. Variation for chlorophyll a / b content in shade tolerant and shade susceptible genotypes of chilli (mg g^{-1})

Genotypes	Growth stages					
	Vegetative		Flowering		Harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	0.854	0.875	0.714	0.806	0.656	0.684
CA 39	0.828	0.850	0.677	0.714	0.623	0.625
CF 51	0.746	0.919	0.723	0.842	0.556	0.700
CF 46	0.756	0.937	0.834	0.887	0.546	0.720
CC 63	0.816	0.931	0.690	0.855	0.601	0.667
CC 66	0.839	0.940	0.782	0.859	0.633	0.720
SEM ±	0.0049	0.0052	0.0039	0.0037	0.0032	0.0036
CD (0.05)	0.0142	0.0094	0.0087	0.0044	0.0061	0.0063

Fig. 10 Variation for chlorophyll a content in shade tolerant and shade susceptible genotypes of chilli (% increase over open condition)

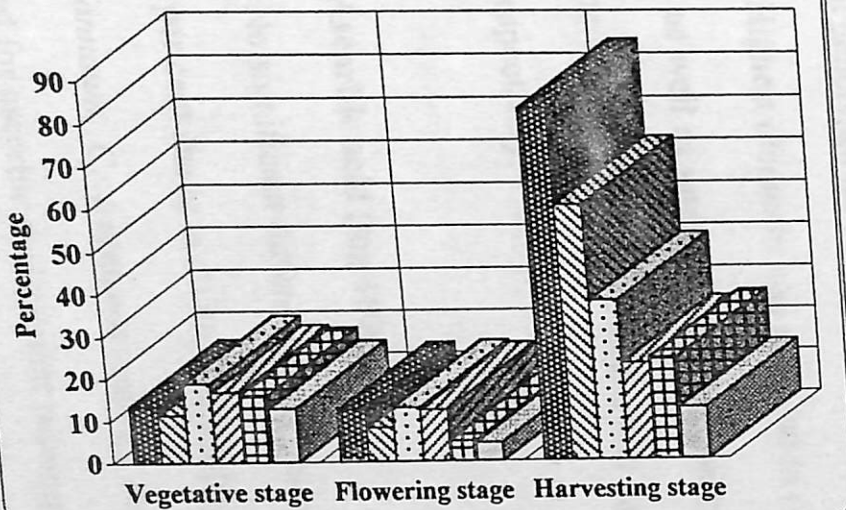


Fig. 11 Variation for chlorophyll b content in shade tolerant and shade susceptible genotypes of chilli (% increase over open condition)

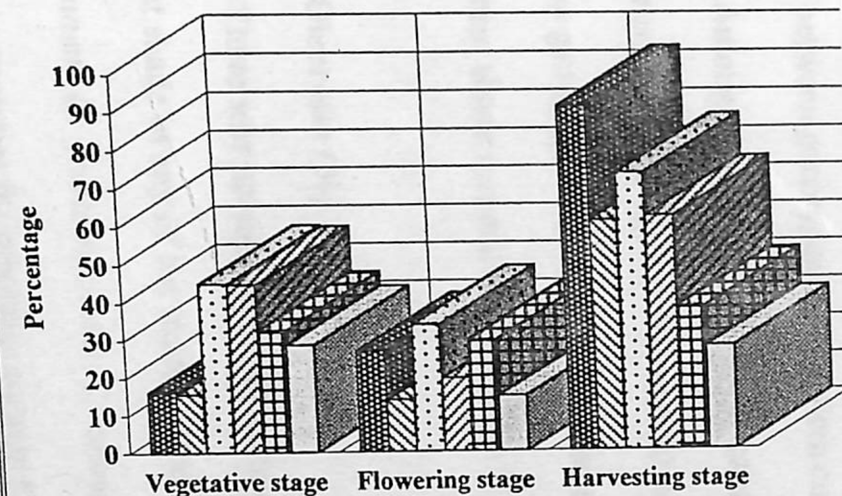


Fig. 12 Variation for total chlorophyll content in shade tolerant and shade susceptible genotypes of chilli (% increase over open condition)

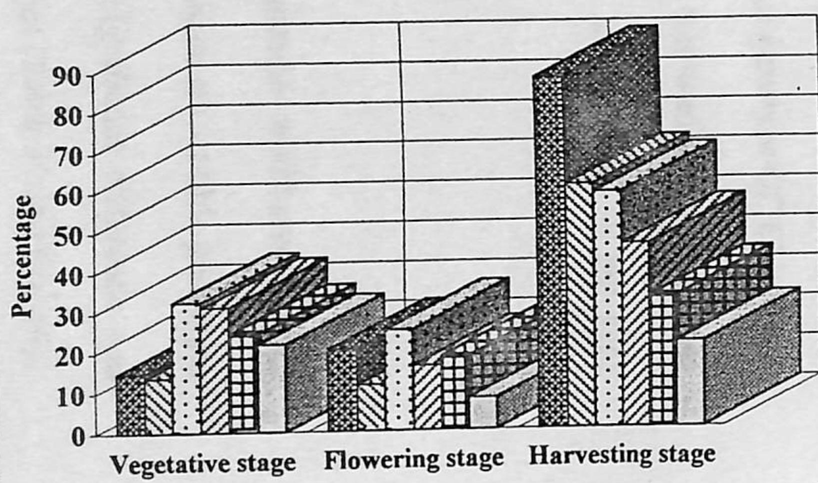
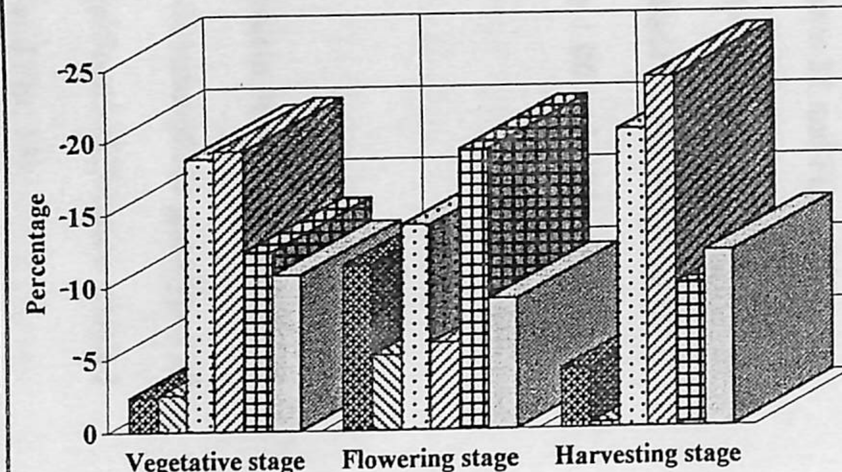


Fig. 13 Variation for chlorophyll a / b content in shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)



CA 38 CA 39 CF 46 CF 51 CC 63 CC 66

genotypes of *C. annuum*, *C. frutescens* and *C. chinense*. Significant difference existed between genotypes for capsaicin content (Table 31 and Fig. 14).

Among the genotypes tried capsaicin content was highest in *C. frutescens*, CF 46 in open (1.27) and 50 per cent shade (1.21) followed by *C. chinense* genotype CC 63 which recorded the values 1.06 and 1.01 in open and 50 per cent shade respectively.

4.4.3 Oleoresin (%)

There was no significant difference for oleoresin between open and 50 per cent shade in any of the shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense*. Significant difference existed between genotypes for oleoresin content (Table 31 and Fig. 15).

Highest oleoresin was recorded in *C. chinense* genotype CC 63 in open (23.35) as well as under 50 per cent shade (23.15) followed by *C. frutescens* genotype CF 46 which recorded 20.00 and 19.90 in open and 50 per cent shade respectively.

4.4.4 Ascorbic acid (mg $100g^{-1}$)

No significant difference was observed for ascorbic acid between open and 50 per cent shade in all the shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense*. Significant difference was observed for ascorbic acid content between genotypes (Table 31 and Fig. 16).

Highest ascorbic acid content was recorded from *C. frutescens* genotype CF 46 both in open and 50 per cent shade with values 116.09 and 116.88 respectively.

4.4.5 Carotenoid (%)

Carotenoid content of shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* differed significantly between open and 50 per cent shade. Significant difference in carotenoid content was also observed among the genotypes of three species (Table 31 and Fig. 17).

Highest carotenoid content was recorded in *C. frutescens* genotype CF 46 both in open (0.45) and 50 per cent shade (0.40) followed by *C. chinense* genotype CC 63 with 0.32 in open and 0.30 under 50 per cent shade respectively.

4.4.6 Proline (μg g^{-1})

Significant difference among genotypes of *C. annuum*, *C. frutescens* and *C. chinense* for proline content was observed at all the growth stages in open and 50 per cent shade (Table 32 and Fig. 18). An increase in the proline content was observed with growth stages in all the shade tolerant and shade susceptible genotypes. Highest proline content was recorded from plants grown in open condition in all the growth stages. Maximum proline was observed during harvesting stage.

In all the three species, the shade tolerant genotypes could maintain higher proline even under 50 per cent shade compared to shade susceptible genotypes. In *C. annuum*, the highest proline content was recorded in shade tolerant genotype CA 38 in open (2.211) and 50 per cent shade (2.013). Similarly in *C. frutescens* and *C. chinense*, the highest proline content was recorded in CF 51 (2.080 and 1.933) and CC 63 (2.089 and 1.922) in open and 50 per cent shade respectively.

4.4.7 Total phenol (mg g^{-1})

The total phenol content of shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* differed significantly between open and 50 per cent shade (Table 31 and Fig. 19). Maximum phenol content was observed in both shade tolerant and shade susceptible genotypes in open condition. In all the three species, the shade tolerant genotypes could maintain higher total phenol even under 50 per cent shade compared to shade susceptible genotypes.

In *C. annuum*, highest total phenol content was observed in shade tolerant genotype CA 38 both in open (4.86) and 50 per cent shade (3.36). Similarly in *C. frutescens* and *C. chinense* the highest total phenol content was recorded in CF 51 (5.04 and 4.32) and in CC 63 (4.28 and 2.66) in open and 50 per cent shade respectively.

4.5 Genetic basis of shade tolerance

Shade tolerant and shade susceptible genotypes selected one each from *C. annuum*, *C. frutescens* and *C. chinense* were used for producing F1, F2, BC1 and BC2 generations to study the inheritance of shade tolerance. The

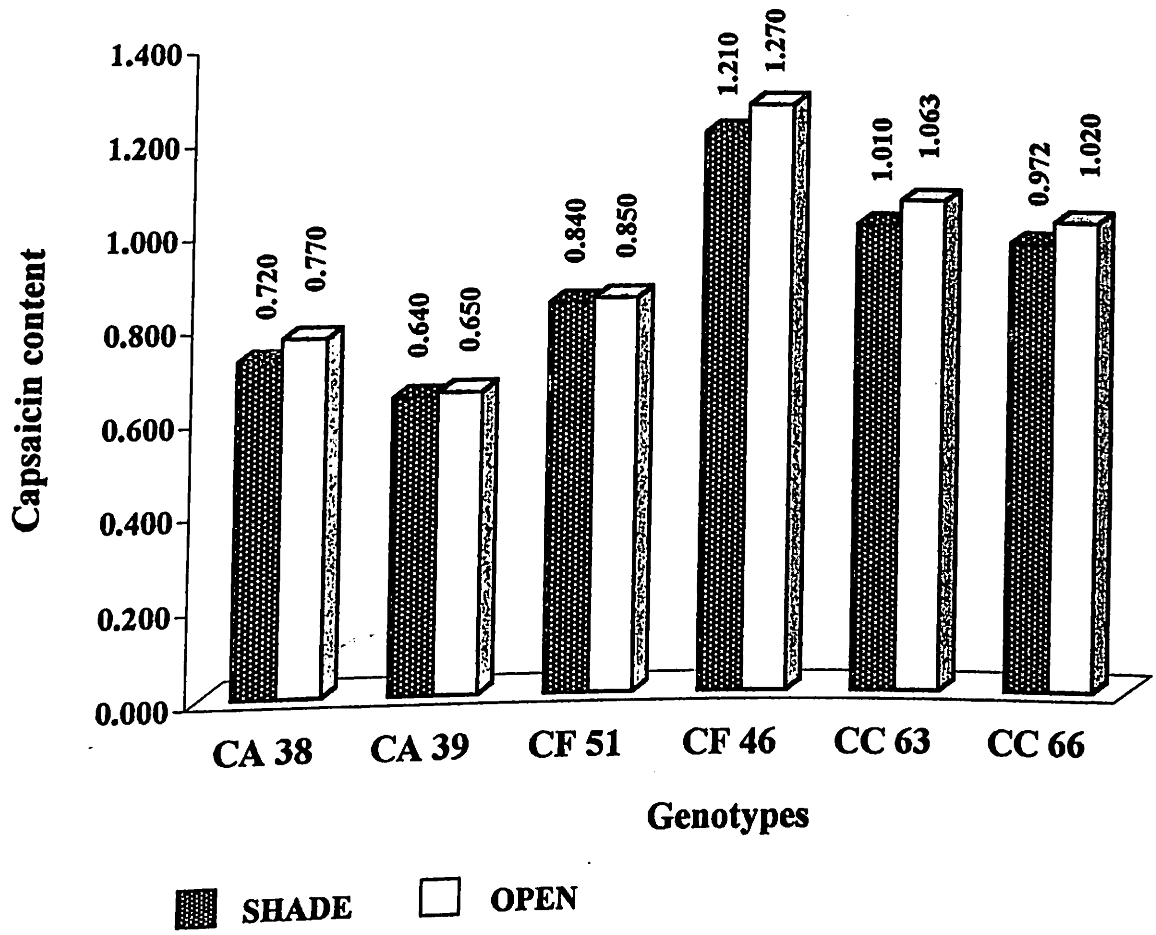
Table 31. Variation for capsaicin, oleoresin, ascorbic acid, carotenoid and total phenol content in shade tolerant and shade susceptible genotypes of chilli

Chemical constituents		Genotypes							
		CA 38	CA 39	CF 51	CF 46	CC 63	CC 66	SEM ±	CD (0.05)
Capsaicin (%)	Shade	0.72	0.64	0.84	1.21	1.01	0.97	0.0212	NS
	Open	0.77	0.65	0.85	1.27	1.06	1.02	0.0193	NS
Oleoresin (%)	Shade	12.13	12.26	17.00	19.90	23.15	19.35	0.0423	NS
	Open	12.24	12.40	17.63	20.00	23.35	19.50	0.0407	NS
Ascorbic acid (mg 100 g^{-1})	Shade	112.00	112.67	85.61	116.88	93.34	98.06	0.4995	NS
	Open	112.58	110.34	84.70	116.09	92.74	97.01	0.4183	NS
Carotenoid (%)	Shade	0.29	0.29	0.16	0.40	0.30	0.23	0.0024	0.0077
	Open	0.31	0.31	0.18	0.45	0.32	0.24	0.0026	0.0081
Total phenol (mg g^{-1})	Shade	3.36	3.24	4.32	4.20	2.66	2.64	0.0069	0.0217
	Open	4.86	4.80	5.04	4.92	4.28	4.08	0.0086	0.0272

Table 32. Variation for proline content in shade tolerant and shade susceptible genotypes of chilli (μg g^{-1})

Genotypes	Growth stages					
	Vegetative		Flowering		Harvesting	
	Shade	Open	Shade	Open	Shade	Open
CA 38	1.807	2.086	1.925	2.147	2.013	2.211
CA 39	1.688	2.017	1.890	2.111	1.984	2.178
CF 51	1.773	1.986	1.915	2.025	1.933	2.080
CF 46	1.526	1.953	1.811	1.970	1.910	2.049
CC 63	1.913	2.017	1.971	2.076	1.992	2.089
CC 66	1.810	2.010	1.936	2.019	1.976	2.026
SEM ±	0.0136	0.0051	0.0060	0.0047	0.0048	0.0033
CD (0.05)	0.0430	0.0160	0.0189	0.0148	0.0152	0.0105

Fig. 14 Variation for capsaicin content in shade tolerant and shade susceptible genotypes of chilli



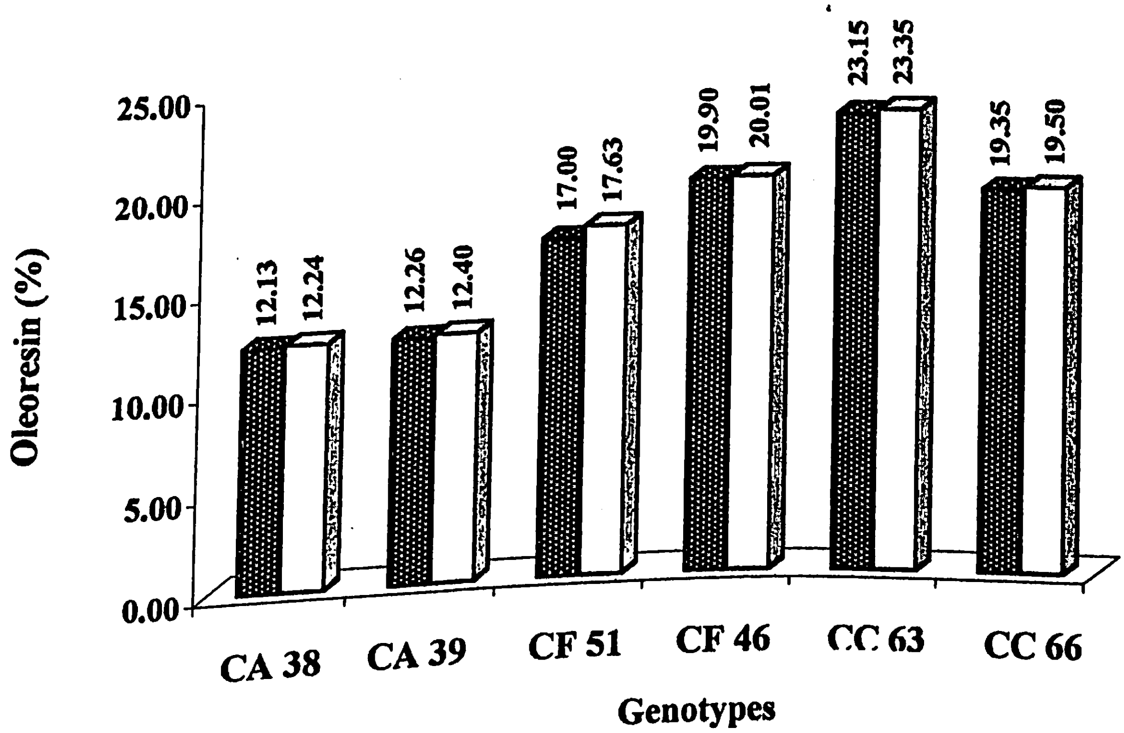
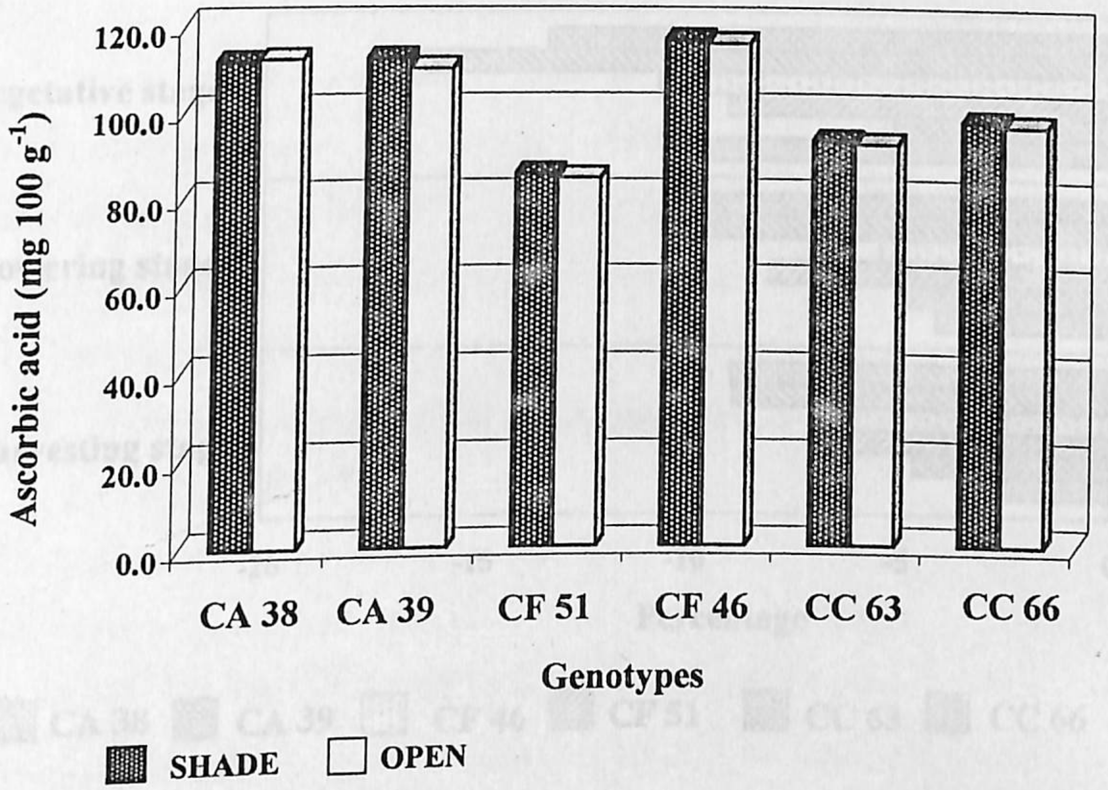


Fig. 15 Variation for oleoresin content in shade tolerant and shade susceptible genotypes of chilli

Fig. 16 Variation for ascorbic acid content in shade tolerant and shade susceptible genotypes of chilli



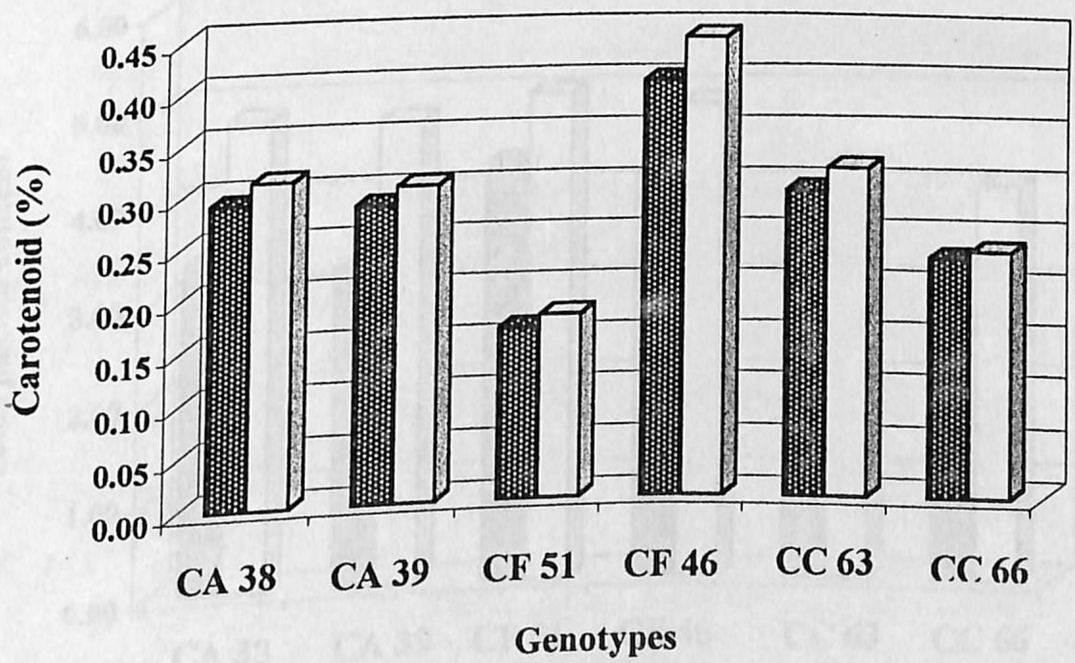
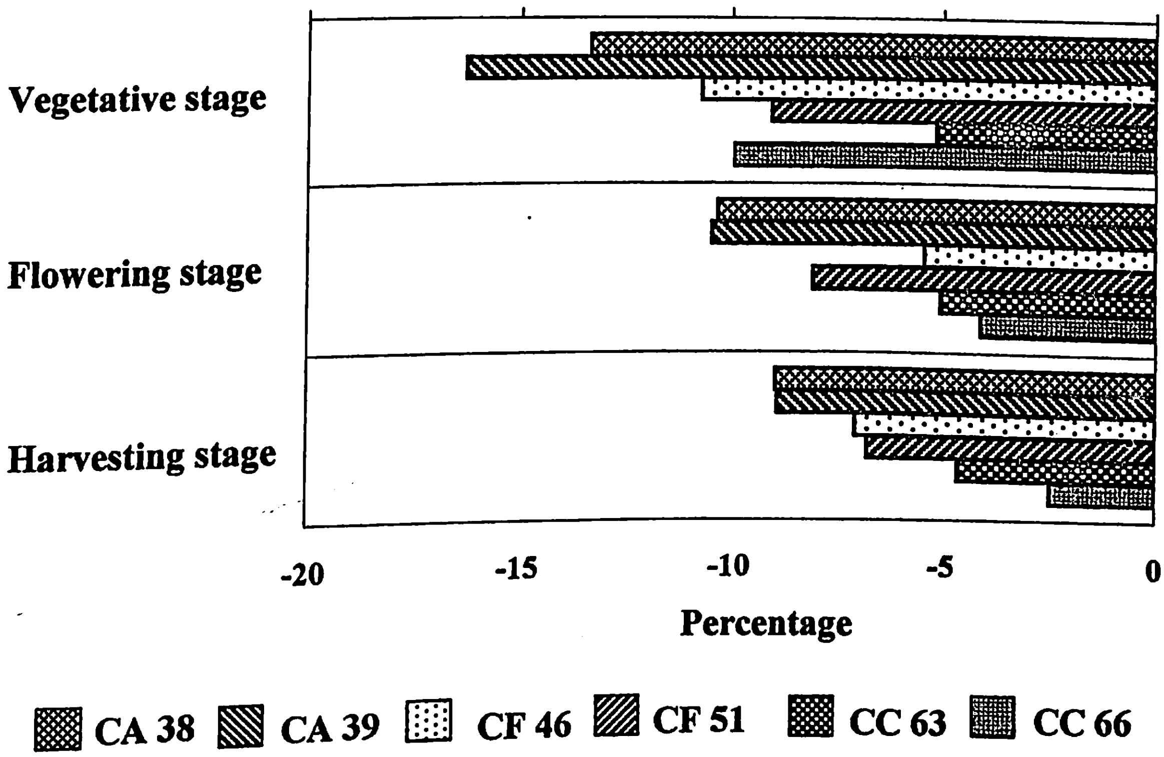


Fig. 17 Variation for carotenoid content in shade tolerant and shade susceptible genotypes of chilli

Fig. 18 Variation for proline content in shade tolerant and shade susceptible genotypes of chilli (% reduction over open condition)



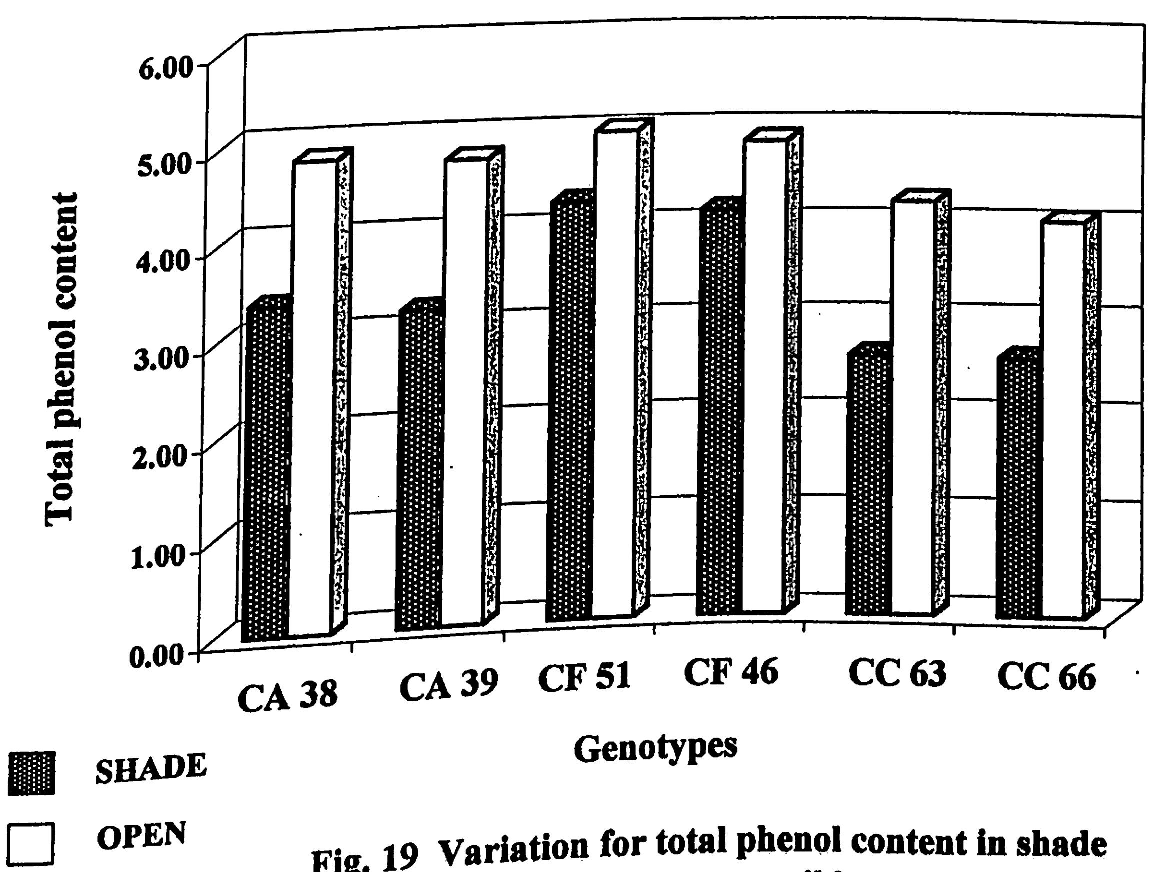


Fig. 19 Variation for total phenol content in shade tolerant and shade susceptible genotypes of chilli

mean values of fruit yield as an expression of shade response under 50 per cent shade of these three crosses, their F1s, F2s and back cross generations were recorded and presented in Table 33 and Plate 8 a to c.

The presence and type of non-allelic interactions were determined by ABCD scaling tests and presented in Table 34. The significance of scaling tests indicated the presence of non-allelic interactions for shade tolerance in the selected three parental crosses.

The generation means were partitioned into different components like mean effect (m), additive effect (d), dominance effect (h), additive x additive effect (i), additive x dominance effect (j) and dominance x dominance effect (l) and presented in Table 35.

Additive effects (d) were highly significant and positive in all the three crosses of shade tolerant and shade susceptible categories *viz.* CA 38 x CA 39 of *C. annuum* (108.00), CF 51 x CF 46 of *C. frutescens* (32.40) and CC 63 x CC 66 of *C. chinense* (31.40). Dominance effects (h) were highly significant and positive in CA 38 x CA 39 of *C. annuum* (179.50) and CF 51 x CF 46 of *C. frutescens* (39.29) crosses whereas it was non significant in CC 63 x CC 66 of *C. chinense* (28.90) cross.

When additive and dominance effects were compared, it was clear that additive effects made a major contribution to the inheritance of shade tolerance.

The estimates of the gene effects for i was significant and positive (86.40) whereas j (-29.50) and l (-226.20)) were significant and negative in CA 38 x CA 39 cross of *C. annuum.*

In CF 51 x CF 46 cross of *C. frutescens* the gene effect for i (-6.40) was non significant and j (-36.30) and l (-44.90) were significant and negative.

In CC 63 x CC 66 cross of *C. chinense* l was not significant (-2.60) whereas i (-83.60) and j (-53.30) though significant, were negative.

Table.33 Generation means for shade tolerance in chilli

Crosses	Generation means					
	P1	P2	F1	F2	BC1	BC2
CA 38 x CA 39	426	151	382	348	424	316
CF 51 x CF 46	238	101	215	207	221	189
CC 63 x CC 66	422	252	450	436	431	399

Table 34. Scaling tests for non allelic interactions of shade tolerance in chilli

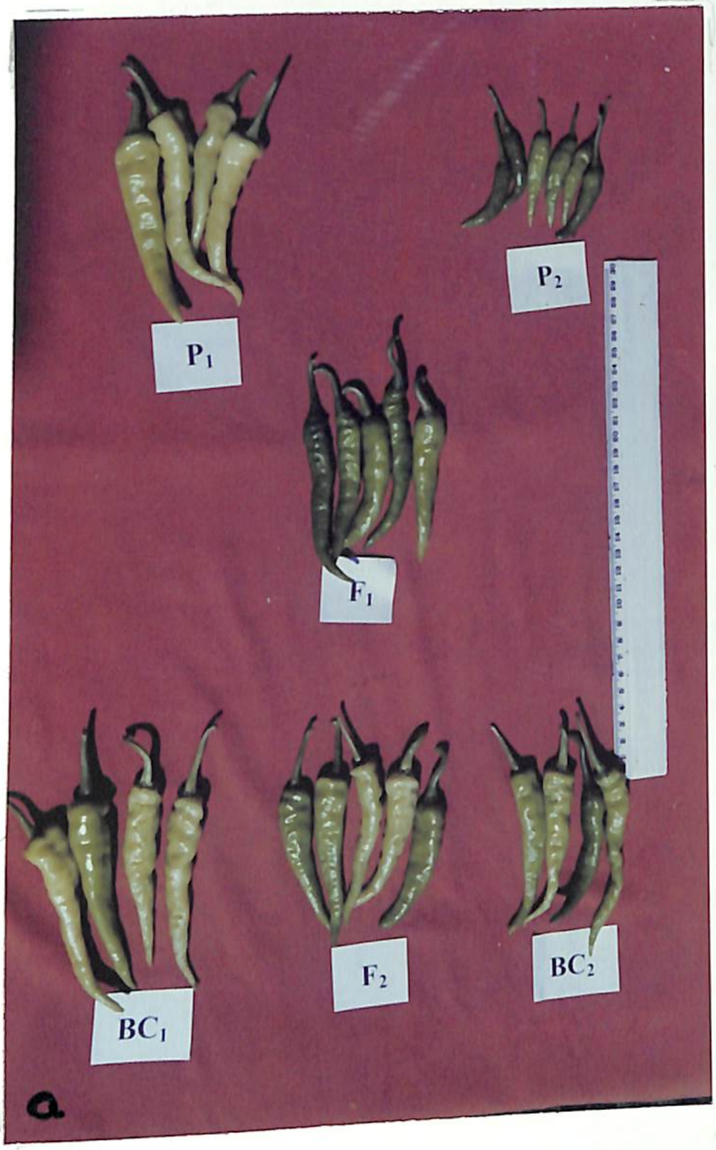
Crosses	A	B	C	D
CA 38 x CA 39	40.40**	99.40**	53.40**	- 43.20**
CF 51 x CF 46	- 11.00**	61.60**	57.00**	3.20
CC 63 x CC66	- 10.20	96.40**	169.80**	41.80**

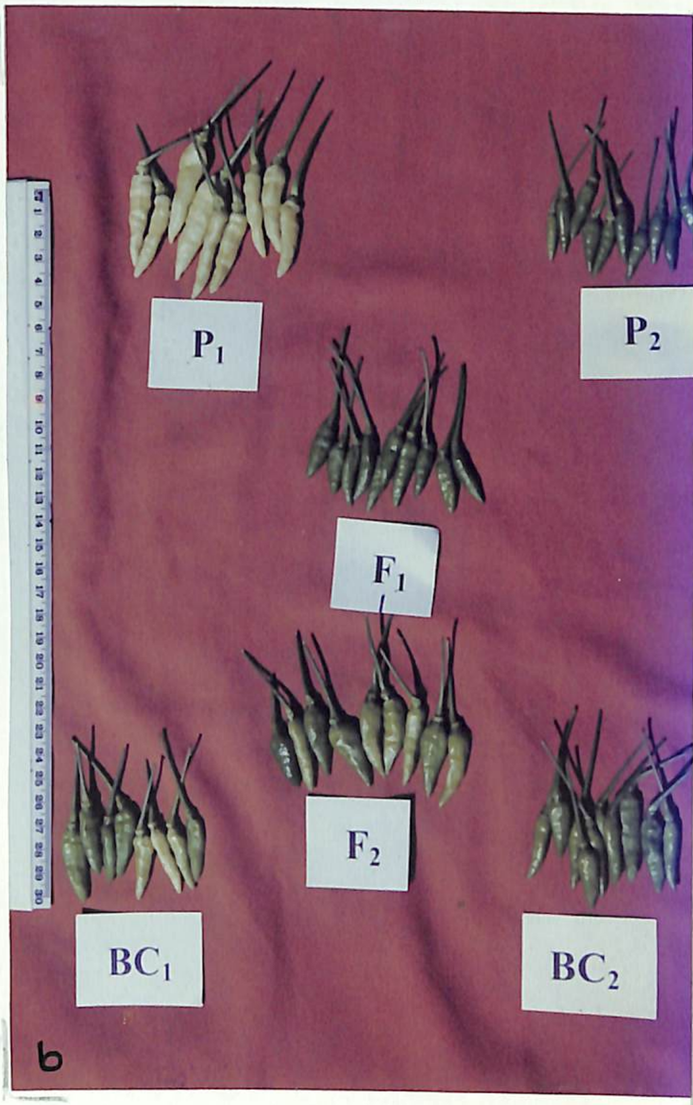
** Significant at 1 per cent level

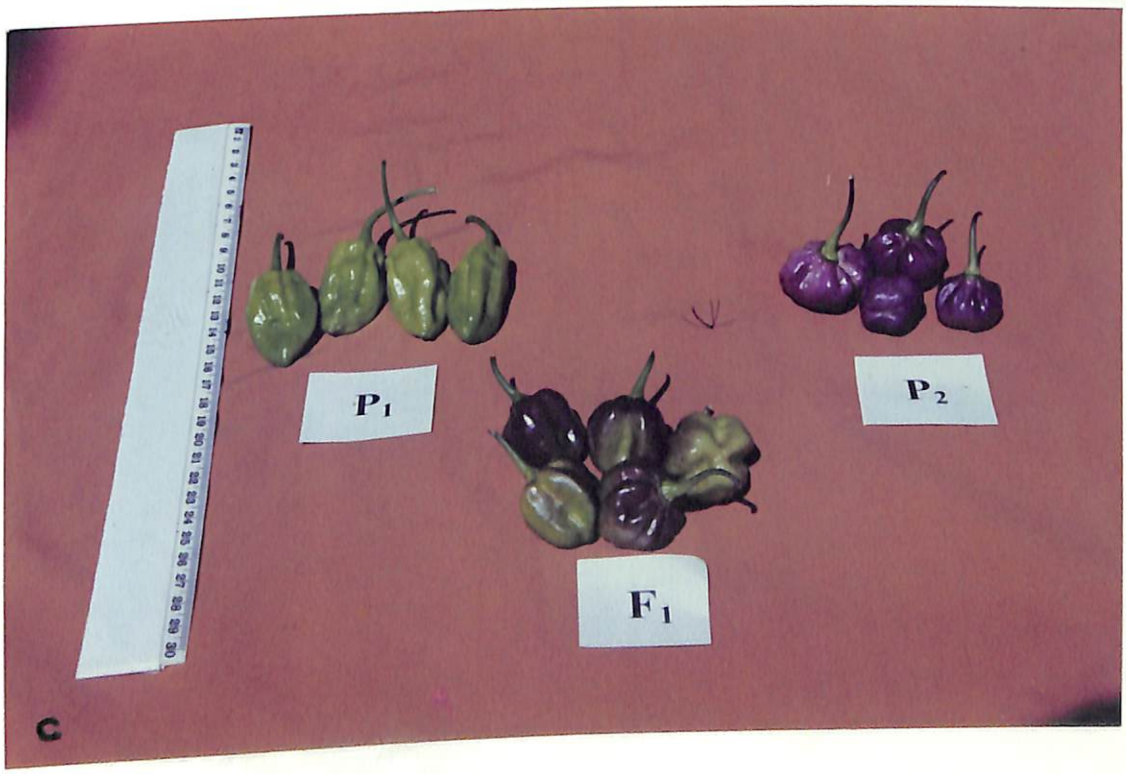
Table 35. Genetic parameters of shade tolerance in chilli

Crosses	Genetic parameters						Gene action
	m	d	h	i	j	l	
CA 38 x CA 39	348.40**	108.00**	179.50**	86.40**	- 29.50**	- 226.20**	Duplicate
CF 51 x CF 46	206.80**	32.40**	39.29**	- 6.40	- 36.30**	- 44.99**	Duplicate
CC 63 x CC 66	435.80**	31.40**	28.90	- 83.50**	- 53.30**	- 2.60	Duplicate

** Significant at 1 per cent level


P_1
P_2
F_1
BC_1
F_2
BC_2
a


P_1
P_2
F_1
F_2
BC_1
BC_2
b


P_1
P_2
F_1
c

DISCUSSION

5. DISCUSSION

The three important cultivated species of the genus *Capsicum* are *C. annuum*, *C. frutescens* and *C. chinense*. The cultivars of *C. annuum* are annual, early maturing and cultivated on an extensive scale. In contrast, *C. frutescens* and *C. chinense* are perennial with pungent fruits and cultivation is restricted mainly to homesteads. As the availability of open land for vegetables is meagre in Kerala, farmers utilize the interspaces of perennial crops in the homesteads for growing vegetables where shade is one of the yield limiting factors. Genotype(s) of chilli with ability to yield substantially even under shaded condition will be ideal for the homesteads of Kerala. Though it is a common crop of homesteads, most of the cultivars grown are evolved for the open conditions. They are low in yield and poor in quality under the homestead situation. Hence the present investigation was envisaged with the objectives of identifying promising genotype(s) suitable for shaded areas and analyzing the physiological, anatomical, biochemical and genetic aspects involved in its shade tolerance.

5.1.1 Characterization of chilli genotypes for shade tolerance

Growth and development of crop plants are influenced by the quantity, quality and duration of solar radiation as light energy is the main input of the photosynthetic process in green plants (Noggle and Fritz, 1979). Though different crop species have differential growth and yield response to light intensity during their ontogeny, higher growth and yield stability by way of some physiological, biochemical and molecular mechanisms of a crop under low light condition have great importance (Singh, 1994). In the present study, significant variation for plant height, internodal length and stem girth was observed both among genotypes of *C. annuum*, *C. frutescens* and *C. chinense* and among different shade levels. An increasing trend in plant height and internodal length was observed with an increase in shade level in all the genotypes (Table 2 and 3). The plants grown under open condition were shorter in all the three species. A gradual reduction in stem girth was observed with an increase in the shade (Table 4).

The increase in plant height under shade may be due to long internodal length as reported by Syed Kamaruddin (1983) and Smith *et al.* (1984) in tomato and Rylski and Spigelman (1986b) in sweet pepper. Dense shade caused etiolation effect on the plant. The increased internodal length under shade may be due to the increased availability of auxin, which was otherwise destroyed by higher light intensity. These results are in conformity with those obtained by Rylski (1986) in sweet pepper where he obtained greater plant height under 26 and 47 per cent shade levels as compared to those grown under normal light. Similar results were reported by Jung *et al.* (1994), Leonardi (1996) and Yinhua and Jianzhen (1998) in *Capsicum*. The results of the studies undertaken by Nagaota *et al.* (1979), Buitalar and Janse (1983), El-Abd *et al.* (1994) and Nasiruddin *et al.* (1995) in tomato are in line with the present findings.

The increased plant height may also be due to the strong apical growth in shaded plants, which prevented side shoot sprouting and further development. High irradiance may result in high rates of transpiration. The reduced height of chilli in open may definitely be due to the internal deficiencies of water and its consequent retardation of cell division and cell enlargement (Meyer *et al.*, 1973).

Significant variation for internodal length among genotypes under different shade levels was observed only in *C. annuum*. This may be an indication of the shade tolerance nature of the genotypes of *C. frutescens* and *C. chinense*.

The present study revealed that the stem girth in the plants under shade was slightly lower in all the genotypes than those under open condition. This reduction in stem girth may be due to etiolation effect of shade. It is inferred that when the light is cut off, there is more availability of auxin, which will help to increase the cell elongation. Moreover there would be more parenchymatous cells available due to the lack of oxidation of polyphenol, which will result in suberization (Thangam, 1998). This result is in conformity with the findings of Nagaota *et al.* (1979) and Smith *et al.* (1984) in tomato, who reported that plants grown in lower light intensities were taller with thinner stems.

Leaf modifications that influence photosynthesis will also alter the plant response to radiation stress. Significant variation for leaf area and petiole length was observed among genotypes of *C. annuum*, *C. frutescens* and *C. chinense* as well as among different shade levels in the present study (Table 5 and 6). An increase in leaf area and petiole length with an increase in shade level was observed in all the genotypes. Increase in leaf area under higher shade levels were brought about by minimizing the use of metabolites for other growth activities. Shade grown plants develop large leaf area, which allow more efficient capture of available light energy. In contrast, unshaded situation increases leaf thickness, which presumably leads to a larger internal volume for carbondioxide diffusion and a greater cellular volume to hold the photosynthetic apparatus (Bjorkman, 1981).

This finding is in conformity with the results reported by Smith *et al.* (1984), El-Abd *et al.* (1994) and Heuvelink and Marcelis (1996) in tomato and Yinhua and Jianzhen (1998) in *Capsicum.*

The increased leaf area under shade may perhaps be a plant adaptation to expose larger photosynthetic surface under limited illumination (Attridge, 1990). The retardation or cessation of cell enlargement acted in the case of plants with reduced height may be the reason here too for the reduced leaf area under open condition.

The present study revealed that petiole length under shade was slightly higher in all the genotypes than open condition. This increase in petiole length may obviously be due to competition under shade to capture maximum sunlight.

Flowering is an indication of the transition of vegetative phase to the reproductive phase in plants. Production of flowers with minimum number of days of growth as well as in the lower nodes of the plant is an indication of earliness in a crop. Significant difference for height of node to first flower, node number to first flower and days to first flower was observed in the present experiment among genotypes of *C. annuum*, *C. frutescens* and *C. chinense* under all the shade levels as well as between different shade levels (Table 7, 8 and 9). An increase in the height of node to first flower, number of node at which first flower produced and days for the first flower to open was found with an increase in the shade level. Increased plant height under shade might have resulted in increased height of node to first flower and the node number at which first flower was produced.

The attributes of elongation *viz.* plant height, internodal length, petiole length and height of node to first flower could be explained in terms of the pigment phytochrome. This exists in two forms, the red absorbing form (pr) and the far red absorbing form (pfr). In the open the pigment will be in the pfr form, which prevents elongation, and in shade, which mimics darkness, it is in pr form enhancing stem elongation.

The present study revealed that shading prolonged the days to first flowering in comparison to open. This may be due to increased and excessive vegetative growth by dense shading. Heavy shade may be resulted in increased days to first flowering. This is in conformity with the results of Jeon and Chung (1982) who reported that in chilli, number of days from sowing to flowering increased as the shade increased. Rylski and Spigelman (1986a) observed delay in fruit picking by about one month in sweet pepper when plants were grown in screen house. Similar results of prolonged flower production were also reported in tomato grown in shade (El-Gizawy *et al.*, 1993a; Thangam, 1998).

Flower initiation is controlled by C : N ratio. Delayed reproductive phase will be the result in shade where the C : N ratio is low. It is also assumed that the physiological shifting of the vegetative growth to the reproductive phase may be weak in shade due to the low solar radiation (Sagi *et al.*, 1979; Voican and Voican, 1982). Again, the shading might have reduced the net photosynthesis or interfered with the light controlled plant morphogenesis favouring vegetative development (Logendra *et al.*, 1990).

The environmental conditions under which a plant grows control the productivity of the plant to a great extent. As far as the fruit and yield characters are concerned, significant variation in fruits per plant and yield was observed in the present study among the genotypes under all shade as well as between different shade levels. As the shade level increased from 25 to 75 per cent the fruits per plant reduced obviously in all the three species (Table 10). This may be due to the poor fruit set coupled with high flower drop resulted by the reduced photosynthetic activity under shade. This result is in conformity with the results reported by Rylski and Spigelman (1986b) and Jung *et al.* (1994) in sweet pepper and Sagi *et al.* (1979), Picken (1984) and Thangam (1998) in tomato.

Carbohydrate shortage and high amount of ethylene production induce the abscission of reproductive organs. Wien and Turner (1989) opined that shading reduces the sugar concentration in the flower buds with an increase on ethylene production, which concomitantly enhanced flower bud abscission with less number of fruits per plant.

Significant difference for fruit length, fruit girth and fruit weight was observed only among the genotypes of *C. annuum*, *C. frutescens* and *C. chinense* under all the shade levels (Table 11, 12 and 13). However, there was no significant difference among the shade levels as far as the individual fruit characters are concerned. This indicates that fruit morphology is governed by the genetic architecture, which is not altered by the environment.

Yield is a complex character, which is the outcome of a number of genetic factors and environmental conditions. Reduced yield under the stress of shade is reported as a regular phenomenon in various tropical crops *viz.* vegetables (Nair, 1991), tomato (Yamashiti and Hayashi, 1994; and Francescangeli *et al.*, 1994a) and in pepper by Leonardi (1996).

The result of the present study revealed that yield per plant was reduced under shade in comparison to open condition (Table 14). The yield was found decreased with increased level of shade from 25 to 75 per cent. At the same time, there was no significant difference in yield between open and 25 per cent shade indicating the tolerance nature of the chilli towards mild shade. Similar increased yield under mild shade (10 – 30 per cent) has been reported in tomato (Smith *et al.*, 1984; El-Aidy, 1986 and El-Gizawy *et al.*, 1993b) and in pepper (Rylski and Spigelman, 1986b; Hou *et al.*, 1987; and Basuki and Asandhi, 1987 and Yinghua and Jianzhen, 1998).

The significant reduction in yield noted for the higher intensities of shade in the present study might be due to lower fruit set in addition to reduced photosynthetic activity especially under the dense shades (50 and 75 per cent). A considerable reduction in yield by shading was noticed in the present experiment. In summer time, one per cent reduction in light intensity imposed 0.36 per cent yield loss, because the rate of photosynthesis decreased with decreasing light intensity (Akimovo *et al.* 1986). Dense shade may reduce photosynthesis and yield by reducing the amount of light reaching the plant. There is a close relationship between photosynthesis and the absorption spectra of chlorophyll II (Noggle and Fritz, 1973). The same conclusion was quoted by Logendra *et al.* (1990). They reported that shading may have reduced net photosynthesis or interfered with light controlled plant morphogenesis favouring vegetative development.

The present study also projected the superior performance of chilli genotypes *viz.* CA 38 (*C. annuum*), CF 51 (*C. frutescens*) and CC 63 (*C. chinense*) in terms of yield which could be used in the further breeding programme to incorporate shade tolerance.

Mite attack in chilli is reported to be a serious one in tropical region of India and often causing 25 to 50 per cent yield loss (Kalloo, 1988). Some of the varieties with resistance to mite attack are Punjab Lal, LEC-1 and Goli Kalyanpur. In the present study, significant difference was observed among the genotypes for the incidence of mite in *C. annuum*, *C. frutescens* and *C. chinense* under all shade as well as between different shade levels (Table 15). Among the three species, less incidence was observed in *C. frutescens* and *C. chinense*. The incidence was at varying level and it ranged from 0 to 2.04. The genotype CA 2 of C. *annuum* was found free from the incidence of mite. This needs further investigation under artificial epizootic condition so as to utilize them for developing varieties with resistance to mite attack.

5.1.2 Variability and genetic parameters

Information on variability and heritability of plant characters and the association among yield and its component characters are of vital importance in any breeding programme. Partitioning of the variability into heritable and non-heritable components will enable to know the effectiveness of selection. In the present study, variability and genetic parameters were worked out in *C. annuum*, *C. frutescens* and *C. chinense* genotypes of chilli in open and 25 per cent shade (Table 16 and 17). The results obtained are discussed here.

Higher phenotypic and genotypic coefficients of variation were observed for fruits per plant, fruit weight, fruit length, fruit girth, yield and leaf area in both open and 25 per cent shade indicating the higher magnitude of variability for these traits. Internodal length had low phenotypic and genotypic coefficients of variation. High values of GCV have been reported both for fruit size (Arya and Saini, 1976; Rajput *et al.*, 1982; Nandi, 1992; Sarma and Roy, 1995; Sheela 1998) and for fruit length (Nandi, 1992; Pawade *et al.*, (1993).

High values of heritability were also observed in the present study for most of the characters in open and 25 per cent shade. The magnitude was found high for fruit length, fruit girth, days to first flower, fruit weight, yield and leaf area. High value of heritability was also reported earlier for fruit weight (Gopalakrishnan *et al.*, 1984; Choudhary *et al.*, 1985; Sheela, 1998), for fruit size and yield per plant (Arya and Saini, 1977) in chillies.

High heritability does not mean a high genetic advance for a particular quantitative character. Johnson *et al.*, (1955) reported that heritability estimates along with genetic gain would be more rewarding than heritability alone in predicting the consequential effect of selection to choose the best individual. The expected genetic advance was high in the present study for fruits per plant, fruit weight, fruit length, fruit girth, yield and leaf area both in open and 25 per cent shade (Fig. 1 and 2). High expected genetic advance was also reported earlier for fruit size, mean fruit weight, yield per plant and fruit length by Sheela (1998).

High heritability coupled with high genetic advance obtained in the present study for fruits per plant, fruit weight, fruit length, fruit girth, yield and leaf area both in open and 25 per cent shade can be considered as the favourable attributes for the improvement through selection. Similarly, the high heritability combined with high genetic advance could be treated as an indication of additive gene action and the consequent high-expected genetic gain from selection for these characters. High heritability in conjunction with high genetic advance reported for fruit size by Gopalakrishnan *et al.* (1984) and Sheela (1998) supports the present finding.

On the basis of the present study it is evident that characters *viz.* fruits per plant, fruit weight, fruit length and fruit girth deserve due weightage while formulating selection strategies for the improvement of yield in chilli in open and mild shade. These results tally very closely with the findings of Sheela (1998).

5.1.3 Correlation of characters

Selection for yield *per se* may not be effective since implicitly or explicitly "there may not be genes for yield *per se*, but rather for the various components, the multiplicative interaction of which results in the artifact of yield" (Grafius, 1956). This necessitates identification of appropriate component characters whose selection result in the improvement of complex characters like yield. A better understanding of the contribution of each trait in building up the genetic make up of the crop may be obtained through correlation studies. A study of correlations between yield and its components will be of great value in planning and evaluating breeding programme for incorporating shade tolerance.

A significant positive correlation of economic traits like fruits per plant, fruit length, fruit weight with yield was recorded suggesting that selection for these characters would lead to improvement in yield both in open and 25 per cent shade (Table 18, 19 and 20). This is in agreement with findings of Padda *et al.* (1970), Khurana *et al.* (1993), Ahmed *et al.* (1997) and Sheela (1998). Significant negative correlation was observed between yield and traits like plant height, leaf area, height of node to first flower and days to first flower. Negative correlation between yield and days to first flower was also reported by Rao *et al.* (1981) and Sheela (1998) in chilli.

Results indicated that yield as well as fruits per plant were significantly on par between open and 25 per cent shade and then decreased. The overall mean yields under 25, 50 and 75 per cent shade levels expressed as percentage of that in the open were 99, 76 and 63 per cent. Though the extent of decline in yield was significant at the intense shade level of 75 per cent, the crop still gave a substantial yield of 63 per cent at this shade intensity. As yield tends to be higher in certain genotypes under 25 per cent shade, chilli appears to fall in the category of shade loving plants. But the response of different genotypes to light intensity was variable. Under shaded conditions an increase in the characters like plant height, internodal length, leaf area and petiole length was recorded. In case, if the percentage of increase is not conspicuous due to shade in a genotype, we can assume that such genotype can tolerate shaded situation to a certain extent. The genotype CA 38 recorded a plant height of 39 cm and internodal length of 2.75 cm under open condition. The per cent increase in plant height was only 5.12 in CA 38 compared to 6.79 in CA 39 in 25 per cent shade (Fig. 3) which indicates the shade tolerance nature of CA 38. The per cent increase in internodal length was also less in CA 38 (9.09) compared to CA 39 (13.21) 25 per cent shade. The leaf area and petiole length also showed a similar trend in the per cent increase in 25 per cent shade. The per cent increase was less in leaf area (66.86) and petiole length (24.49) in CA 38 compared to CA 39 (97.68 and 46.15 respectively) in 25 per cent shade. The genotype CA 38 recorded per cent increase in fruits and yield per plant in 25 per cent shade whereas a per cent decrease was observed in CA 39 for fruits and yield per plant. The per cent increase was 4.69 and 3.79 for fruits per plant and yield in CA 38 while the genotype CA 39 had a per cent decrease of 7.25 and 30.82 for these characters in 25 per cent shade.

Considering all these characters into account CA 38 and CA 39 of *C. annuum* could be represented as the shade tolerant and shade susceptible genotypes respectively for further studies. Usually the genotypes of *C. frutescens* and *C. chinense* are grown in the homesteads and they have got a capacity to yield under shade. Hence genotypes with higher yield under shade were selected as the shade tolerant and genotypes with low yield were selected as the shade susceptible in both these species.

5.2 Physiological basis of shade tolerance

Growth analysis has been established as a standard method of estimating net photosynthetic production of plants and plant stands. Leaf area index (LAI) in the present study varied significantly among different genotypes at all the growth stages under open and 50 per cent shade (Table 21 and Fig. 4). The leaf area increased steadily up to fruiting stage and then declined in the harvesting stage. Maximum LAI was observed in open condition compared to 50 per cent shade. It is true in any crop that the rate of photosynthesis is higher when light infiltration is better. Under open condition, light is not a limiting factor resulting in better leaf development. Similar observations were made by Ajithkumar (1999) in ginger.

Shading during vegetative and flowering stages had greater influence in the per cent reduction of LAI whereas it had lesser influence during fruiting and harvesting stages. The study also proved that the shade tolerant genotypes CA 38, CF 51 and CC 63 were able to maintain higher LAI than the shade susceptible genotypes CA 39, CF 46 and CC 66 at all the growth stages under 50 per cent shade.

The finding that higher LAI as the characteristic of shade tolerant genotypes under shade in all the growth stages could have contributed to their higher productivity in the shade. This could be due to better photosynthesis in genotypes with higher LAI leading to increased crop productivity. The increase in LAI often influences total dry matter accumulation as reported by Mohandas (1989).

Growth efficiency is associated with leaf weight that mostly reflects leaf thickness. The Specific leaf weight (SLW) or leaf thickness was shown to be significantly correlated with photosynthetic rate per unit area serving as an index for rapid field selection for higher photosynthetic capacity. Specific leaf weight (SLW) varied significantly among different genotypes at all the growth stages under open and 50 per cent shade (Table 22 and Fig. 5). SLW was found to increase progressively up to fruiting stage and then declined towards the harvesting stage. Shading during all the growth stages had greater influence on the per cent reduction of SLW.

In the present study, maximum SLW was recorded under open condition compared to shade. Similar results were reported by Murty *et al.* (1973) in rice, Ramanujam and Jose (1984) in cassava, Yinghua and Jianzhen (1998) in capsicum and Ajithkumar (1999) in ginger. However the shade tolerant genotypes CA 38, CF 51 and CC 63 were able to maintain higher SLW than the shade susceptible genotypes CA 39, CF 46 and CC 66 at all the growth stages under 50 per cent shade.

CGR, RGR and NAR are the most important growth characteristics describing the production efficiency of assimilator apparatus. In the present experiment, significant difference was observed between genotypes for CGR, RGR and NAR at all the growth stages in open and 50 per cent shade.

Highest CGR was recorded in genotypes grown under open condition as reported by Ramadasan and Satheesan (1980) in turmeric and Ramanujan and Jose (1984) in cassava. This could be due to their higher LAI and SLW in the open condition. However the shade tolerant genotypes CA 38, CF 51 and CC 63 could maintain greater CGR values even under 50 per cent shade (Table 23 and Fig. 6). This could be due to their inherent genetic set up to tolerate the stress situation in the shade.

As such all the genotypes recorded maximum RGR during the period between vegetative and flowering stages (Table 24 and Fig. 7). Invariably all the genotypes recorded lesser RGR in 50 per cent shade than the open. However all the shade tolerant genotypes *viz.*, CA 38, CF 51 and CC 63 could maintain relatively higher RGR than the susceptible genotypes even under 50 per cent shade.

Under normal condition, vegetative growth is more during the early stage giving higher RGR as a result of utilization of the reserved food materials. As the plant enters reproductive stage, carbohydrate accumulation is dominant over utilization resulting in poor vegetative growth. Similar results were reported by Jung *et al.* (1994) in pepper.

In the present study, highest NAR values were recorded in plants grown under open condition (Table 25 and Fig. 8). However all the shade tolerant genotypes (CA 38, CF 51 and CC 63) maintained higher NAR values than the shade susceptible genotypes (CA 39, CF 46 and CC 66) even under

50 per cent shade. The higher NAR could have resulted primarily due to higher LAI in the shade tolerant genotypes. Loach (1970) indicated that the lower values of NAR in shade susceptible genotype might be accounted for their higher respiration rate through increased LAI causing heavy shading. These factors allowed a lower photosynthetic capacity per unit leaf area. Similar results of highest NAR under open condition were reported by Ramadasan and Satheesan (1980) in turmeric, Ramanujam and Jose (1984) in cassava Smith *et al.* (1984) cucumber and Laura *et al.* (1986) in sweet potato.

5.3 Anatomical basis of shade tolerance

Leaf growth and development is changed by high light intensities in such a way that there is an increase in the elongation of the palisade cells and an increase in the number of cells across the leaf section and in the average cell diameter. In the present study comparison of genotypes under different shade levels revealed that chilli genotypes grown in the open had thicker leaves. The palisade and spongy mesophyll cells, vascular bundles and upper and lower epidermal cells were also thicker with more number of stomates per unit area (Table 26 Fig. 9).

The leaf blade thickness is one of the important characters regulating the level of photosynthesis in plants. In the present study, the leaf thickness of the shade tolerant genotypes was comparatively higher than the shade susceptible genotypes. The per cent reduction in leaf thickness due to shade was higher in *C. annuum* genotype CA 38 (21.75%). This effect was marginal in *C. frutescens and C. chinense* the traditional shade tolerant species. Though the percentage reduction in leaf blade thickness was more in shade tolerant genotype CA 38, the higher leaf blade thickness under 50 per cent shade contributed for better yield even under shade condition. Based on the results of the present study, it is assumed that leaf blade thickness is one of the criteria governing the shade tolerance in chilli.

The increase in leaf blade thickness in chilli genotypes grown in the open may be due to the increase in the thickness of palisade and spongy mesophyll cells. This result is in conformity with the results of Fahl *et al.* (1994). They have reported that unshaded coffee leaves were 11 per cent thicker than shaded plants because of the increased size of palisade and spongy mesophyll cells. Similar results were also reported by Salisbury and Ross (1978) in cotton, Ramanujam and Jose (1984) in cassava, Ward and Woolhouse (1986) in maize, Ashton and Berlyn (1992) in Shorea species, Buisson and Lee (1993) in papaya and Yinghua and Jianzhen (1998) in pepper.

Though significant difference was observed for the stomatal frequency due to variation in genotype and shade, the percentage reduction due to shade was not found conspicuous.

All the chilli genotypes had more stomates per unit area when grown in open. The difference in stomatal frequency between leaves grown in open and 50 per cent shade can be an alteration caused by change in leaf size. The percentage reduction in stomatal frequency due to shade was minimum in *C. annuum*. Even within a reduction ranged from 11.03 to 14.39 per cent in *C. frutescens* they performed better in terms of growth and yield. Therefore, the role of stomatal frequency in terms of regulating shade tolerance could not be proved in the present study.

The results of Schoch (1972) in *C. annuum*, Ramanujam and Jose (1984) in cassava, Ashton and Berlyn (1992) in Shorea species and Buisson and Lee (1993) in papaya are in line with the present finding.

Regarding the upper and lower epidermal cell thickness, significant differences were observed among genotypes and between two shade levels. Genotypes grown in open recorded maximum thickness in upper and lower epidermal cells. The percentage reduction due to shade was more in *C. frutescens* and minimum in *C. annuum*. Examination of the genotypes revealed that the shade tolerant genotypes have thicker epidermal cells than the shade susceptible ones. This is in corroboration with the findings in the family Moraceae (Strauss-Debenedetti, 1989) and in other tropical species (Lee *et al.*, 1990).

Significant difference between genotypes and shade levels were observed in the present experiment for mesophyll cell thickness. Genotypes grown under open recorded maximum thickness in palisade mesophyll and spongy mesophyll cells. The per cent reduction of cell thickness due to shade varied from 9.74 to 28.72 for palisade mesophyll and 0.03 to 23.98 for spongy mesophyll. The palisade and spongy mesophyll cells in leaves grown under open condition were more in length. Under shade, reduced palisade parenchyma and spongy parenchyma were observed. Such phenomenon of palisade differentiation under different light habitat was also reported by Esau (1965). These observations are in conformity with Bidwell (1979). Shade leaves invest more of their energy in producing light harvesting pigments that allows limited amount of light striking them.

Significant difference in vascular bundle thickness was also existed in the present study both among genotypes and between shade levels. The vascular bundle of genotypes grown under shade was thinner compared to those grown in open condition. The per cent reduction due to shade was marginal in all the genotypes and ranged from 2.19 to 15.23.

5.4 Biochemical basis of shade tolerance

Radiation that penetrates the leaf can be absorbed by various components. Chloroplast pigments determine the extent of visible light absorption. In the present study, the contents of chlorophyll a, b and total chlorophyll differed significantly among the genotypes and between the shade levels. Higher contents of chlorophyll a, b and total chlorophyll and lower chlorophyll a / b ratio were noticed in all the genotypes under 50 per cent shade in comparison with the open (Table 27 to 30 and Fig. 10 to 13). Among the genotypes, shade tolerant CA 38, CF 51 and CC 63 had higher contents of chlorophyll a, b and total chlorophyll than the shade susceptible genotypes under 50 per cent shade. El-Gizawy *et al.* (1993 a) in tomato, Singh (1994) in okra and Yinghua and Jianzhen (1998) in pepper also observed that total chlorophyll content was invariably higher under reduced light conditions.

Janardhan and Murthy (1980) showed that the adaptability of rice cultivars to low light was associated with higher chlorophyll content. This was also true in the present investigation where the shade tolerant genotypes had higher total chlorophyll content than shade susceptible genotypes. Venkateswarlu *et al.* (1977) showed that there was a tendency to enrich the assimilatory system by increasing the chlorophyll content for more light absorption. The increase in chlorophyll content under shade was more prominent in chlorophyll b fraction leading to lower chlorophyll a / b ratio. The higher content of chlorophyll b and decreased ratio of chlorophyll a / b ratio under shade was the result of a shift in photosynthetic response from chlorophyll a to chlorophyll b (Chowdhury *et al.*, 1994). The chlorophyll b is considered to be the primary light harvesting pigment for photosystem II and hence largely responsible for the oxidation of cytochrome and water. Besides, it also enlarges photosystem I for better harness of the entire machinery and plays a dominant role under subdued light (Hale and Orcutt, 1987).

Pungency is considered as the most important quality trait in chillies. Capsaicin, the pungent principle of chillies, is a condensation product of 3-hydroxy, 4-methoxy benzylamine and decylenic acid. Capsaicin has significant physiological action and is used in many pharmaceutical and cosmetic preparations.

Significant variation was observed in the present study among genotypes for capsaicin content in open (0.65 to 1.27%) and under 50 per cent shade (0.64 to 1.21%) (Table 31 and Fig. 14). The degree of pungency among varieties varied considerably. This could probably be due to the presence of gene modifying factors for pungency and the ratio of placental tissue to seed and pericarp. A comparison of capsaicin content of the genotypes in the present study clearly indicated that genotypes of *C. frutescens* contained higher capsaicin than that of *C. chinense* and *C. annuum*. However the capsaicin content did not differ significantly between the two shade levels in all the genotypes. This indicates that the pungent principle is a genetic character, which is not altered by the environment. Similar results were reported by Bigotti (1974) and Jeon and Chung (1982) who reported that the capsaicin content was not affected by shade.

Oleoresin represents the total flavour extracts of ground spices and it consists of fixed oil, capsaicin, pigments, sugars and resin. The results of the present study indicated significant variation between genotypes for oleoresin content under 50 per cent shade and open condition (Table 31 and Fig. 15). A comparison of oleoresin content of the genotypes in the current investigation revealed that genotypes of *C. chinense* contained higher oleoresin than that of *C. frutescens* and *C. annuum*. However the shade levels did not exert any influence on the oleoresin content in any of the chilli genotypes. Similar to the case of capsaicin, the genetic set up of the plant determines the oleoresin content too, which is not influenced by the environment.

The nutritive value of chillies is largely determined by content of ascorbic acid. Significant variation in ascorbic acid content between genotypes both in open and 50 per cent shade was observed in the present study (Table 31 and Fig. 16). However the ascorbic acid content was not affected by the shade levels in any of the genotypes, suggesting that this character also is governed by the genetic set up rather than the management practices.

Similar results were reported by Bigotti (1974) in pepper. However, higher ascorbic acid in tomato under shading was reported by El-Gizawy *et al.*

(1993b) and Sharma and Tiwari (1993a) while lower ascorbic acid under shading by Nasiruddin *et al.* (1995) and Yanagi *et al.* (1995). This could be due to differential response of crops to shade levels with respect to quality parameters.

Colour is a prized quality characteristic of capsicums aesthetically rewarding with commercial importance. The principal colouring matter of chilli fruit is the carotenoid pigment. Capsanthin and capsorubin are the main pigments contributing red colour to chillies. Carotenoids play an important role in ripening of fruits and the ability to synthesize them is regulated by irradiation.

In the present study, a wide variation in total carotenoid content between genotypes under shade and open was observed (Table 31 and Fig. 17). The total carotenoid was found to range from 0.16 to 0.40% under shade and 0.17 to 0.45% in open condition. Carotenoid content differed significantly between the open and shade in the present study. Genotypes grown under open had significantly higher carotenoids compared to those grown under 50 per cent shade. In most crops, the carotenoid content increases with maturity when grown under open condition. Similar results were reported by Lopez *et al.* (1986) in *C. annuum* fruits. Shade inhibited formation of capsanthin, the major red pigment in maturing fruit.

The total phenol content of shade tolerant and shade susceptible genotypes of *C. annuum*, *C. frutescens* and *C. chinense* in the present study differed significantly between open and 50 per cent shade (Table 31 and Fig.

19). It was higher in genotypes grown under open condition compared to 50 per cent shade.

Shade tolerant genotypes *viz.*, CA 38, CF 51 and CC 63 had higher total phenol than shade susceptible genotypes. *viz.* CA 39, CF 46 and CC 66. Higher content of total phenols in shade tolerant genotypes of the present study suggest the role of phenols in imparting tolerance to shade. Similar results were reported by Smart *et al.* (1985) in *Vitis* sp.

Significant difference was also observed among the genotypes of *C. annuum, C. frutescens* and *C. chinense* for proline content at all the growth stages in open and 50 per cent shade (Table 32 and Fig. 18). High values were observed in genotypes grown in open condition. In all the three species studied, the shade tolerant genotypes CA 38, CF 51 and CC 63 could maintain higher proline even under 50 per cent shade compared to shade susceptible ones.

Proline accumulation has been shown to be an adaptive mechanism to stress tolerance. High proline content in open condition compared to shade may be due to water stress under high light intensities as reported by Hervieu *et al.* (1994) and Ajithkumar (1999) in ginger.

5.5 Genetic basis of shade tolerance

Breeding strategies for evolving shade tolerant varieties can be worked out only based on the inheritance of the gene(s) responsible. As a pre-requisite, the genetic basis of shade tolerance was studied in chilli using both shade tolerant and shade susceptible genotypes belonging to *C. annuum, C.*

frutescens and *C. chinense*. Generation mean analysis which provides the estimates of main gene effects (additive and dominance) and their digenic interactions, (additive x additive, additive x dominance and dominance x dominance) was carried out to unveil the mode of inheritance of shade tolerance in chilli. Further, attempts were also made to find out the type of epistasis in various crosses.

The present study revealed that the shade tolerance in chilli was governed by polygenes with recessive nature. The tolerance was found to be incompletely dominant over susceptibility resulting in interacting crosses. The significance of ABCD scaling test revealed non-allelic interactions in the crosses *viz.*, CA 38 x CA 39 of *C. annuum*, CF 51 x CF 46 of *C. frutescens* and CC 63 x CC 66 of *C. chinense* for shade tolerance (Table 34). This strongly projects the importance of epistasis on the genes governing shade tolerance in chilli genotypes.

Additive effects were highly significant in all the three species studied (Table 35). Dominance effect was significant only in the cross CA 38 x CA 39 of *C. annuum* and CF 51 x CF 46 of *C. frutescens*. In the interacting crosses, studies on gene effects for shade tolerance indicated the importance of both additive (d) and additive x additive (i) gene effects as well as dominance (h) and dominance x dominance (l) gene effects.

In crosses *viz.* CA 38 x CA 39 of *C. annuum* and CF 51 x CF 46 of *C. frutescens* dominance and dominance x dominance components of genetic variance were the major contributing factors for shade tolerance. While examining the type of epistasis involved in the inheritance of this character, it was found that the crosses exhibited duplicate type of epistasis. These results suggested that substantial gain for shade tolerance can possibly be manipulated through heterosis breeding in *C. annuum* and *C. frutescens*.

In the cross CC 63 x CC 66 of *C. chinense*, contribution of additive or additive x additive genetic variance was pronounced for shade tolerance and the improvement of this character can be done by selection in *C. chinense*.

This finding is in line with the results reported by Yongjian *et al.* (1998) in cucumber grown under shade.

To recapitulate the foregoing discussion, it is evident that *C. frutescens* and *C. chinense*, the two traditional species distributed in the homesteads of Kerala are the best source of shade tolerance. However, their horticultural traits never match to the consumer preference in large. In fact, this necessitates breeding in chilli for shade tolerance so as to evolve suitable types for the interspaces of perennial crops.

The present investigation suggests priority in characterization of the available genotypes of chilli in terms of physiological attributes (*viz.* LAI, SLW, CGR, RGR and RGR) and biochemical components (*viz.* chlorophyll a, chlorophyll b, total chlorophyll, total phenol and proline). Developing a database on these characters followed by a breeding strategy involving heterosis and selection, deserve priority. The shade tolerant cultivars *viz.* CA 38 (*C. annuum*), CF 51 (*C. frutescens*) and CC 63 (*C. chinense*) identified in the present study need special attention in terms of multi locational testing.

SUMMARY

6. SUMMARY

The present investigation entitled 'Genetic analysis of shade tolerance in chilli (*Capsicum* spp.)' was conducted at the Department of Olericulture, College of Agriculture, Vellayani during 1997 - 2000. The objectives were to identify superior genotype(s) of chilli with ability to yield better under shade and to analyse the physiological, anatomical, biochemical and genetic basis of shade tolerance.

The experimental material consisted of 70 diverse genotypes of chilli belonging to *C. annuum* (35), *C. frutescens* (20) and *C. chinense* (15). The performance of the genotypes was evaluated both in open as well as under 25, 50 and 75 per cent shade levels. Based on the yield pattern under shade, one genotype each for shade tolerance and shade susceptibility was selected in the three species of *C. annuum, C. frutescens* and *C. chinense* for further studies. The results obtained are summarised below.

Significant variation among the genotypes of *C. annuum, C. frutescens* and *C. chinense* was observed for plant height, internodal length, stem girth, leaf area, petiole length, days to first flower, node to first flower, height of node to first flower, fruits per plant, fruit length, fruit girth, fruit weight, yield and incidence of mite.

Significant variation among different shade levels was also observed for plant height, internodal length, stem girth, leaf area, petiole length, days to first flower node to first flower, height of node to first flower, fruits per plant, yield and incidence of mite.

Characters like plant height, internodal length, leaf area, petiole length, days to first flower, node to first flower and height of node to first flower were maximum under 75 per cent shade. Stem girth and incidence of mite were maximum in open condition. No significant difference was observed for fruits per plant and yield between open and 25 per cent shade. Fruit length, fruit girth and fruit weight did not vary significantly among different shade levels.

Maximum plant height was observed in genotype CA 39 of *C. annuum* in open, 25 and 75 per cent shade levels. CA 15 was the tallest plant under 50 per cent shade. CA 32 was the shortest under all the four levels of shade. In *C. frutescens* CF 49 and CF 47 registered maximum height while CF 46 was the shortest plant. CC 62 of *C. chinense* had the maximum plant height under 75 per cent shade and minimum in CC 76.

Internodal length increased with increase in levels of shade. Maximum internodal length was observed under 75 per cent shade and minimum in open. No significant variation was observed for internodal length among genotypes of *C. frutescens* and *C. chinense.* A reduction in stem girth was noticed with an increase in the shade level. Maximum stem girth was recorded from plants grown in open condition. Highest stem girth was observed in CA 39 of *C. annuum,* CF 52 of *C. frutescens* and CC 63 of *C. chinense* under different levels of shade.

An increase in leaf area and petiole length was noticed with an increase in the shade level in all the genotypes. Maximum leaf area and petiole length were registered in plants grown under 75 per cent shade. Genotype CA 39 of *C. annuum,* CF 51 of *C. frutescens* and CC 63 of *C. chinense* recorded more leaf area under 75 per cent shade.

Days to first flower increased with increase in shade level in all the genotypes. Among the genotypes of *C. annuum,* CA 22, *C. frutescens,* CF 43 and *C. chinense,* CC 63 were earlier in flowering.

An increase in height of node to first flower was observed with increase in shade levels. CA 39 of *C. annuum,* CF 52 of *C. frutescens* and CC 63 of *C. chinense* registered maximum height to first flowering node under 75 per cent shade.

Number of node to first flower was increased with increase in shade level in *C. annuum.* The genotype CA 39 had flowers in upper node under the four levels of shade. No significant variation among genotypes for node to first flower was observed in *C. frutescens* and *C. chinense.*

Significant difference for fruit length, fruit girth and fruit weight was observed among the genotypes of *C. annuum, C. frutescens* and *C. chinense* under all the shade levels. However no significant difference was observed for these characters under different shade levels indicating that the characters are controlled by genetic factors and not altered by environment.

Fruits as well as yield per plant decreased with increased levels of shade from 25 to 75 per cent in all the genotypes. No significant difference for fruits per plant and yield was observed between open and 25 per cent shade indicating the tolerance nature of chilli towards mild shade. Maximum fruits per plant were recorded in CA 13 of *C. annuum*, CF 51 of *C. frutescens* and CC 63 of *C. chinense.* The genotype CA 38 of *C. annuum* had maximum yield under all the shade levels and minimum in CA 39. In *C. frutescens* maximum yield was recorded by CF 51 and minimum by CF 46 and in *C. chinense* maximum and minimum yield were recorded by CC 63 and CC 66 respectively under all the shade levels.

Incidence of mite was maximum in CA 32 of *C. annuum* under the four levels of shade. The genotype CA 2 was completely free from the incidence. Among the three species, mild incidence was observed in *C. frutescens* and *C. chinense.*

High GCV and PCV were recorded for fruits per plant, fruit weight, fruit girth, fruit length, leaf area and yield in open and 25 per cent shade. Genetic advance was highest for yield and lowest for internodal length in open and 25 per cent shade. High heritability combined with high GCV and expected genetic advance was observed for fruits per plant, fruit weight, fruit girth, fruit length, leaf area and yield both in open and 25 per cent shade indicating the possibility of improvement of these characters through selection. A significant positive correlation was observed for fruits per plant, fruit length and fruit weight with yield at genotypic and phenotypic levels both in open and 25 per cent shade.

A marked increase of LAI was noticed up to fruiting stage followed by a decline at harvesting stage in all the six genotypes. CA 38, CF 51 and CC 63 were able to maintain higher LAI than CA 39, CF 46 and CC 66 in all the stages. SLW was found to decrease under shaded condition in all the six genotypes. The trends in CGR and RGR indicated higher values in CA 38, CF 51 and CC 63 in open and shaded conditions. The CGR values were maximum during the period between fruiting and harvesting stage whereas RGR during the period between vegetative and flowering stage. NAR decreased under shade in all the six genotypes. CA 38, CF 51 and CC 63 maintained higher NAR values than CA 39, CF 46 and CC 66 even under low light condition.

Genotypes grown in open had higher thickness in leaf blade, upper and lower epidermal cell, palisade and spongy mesophyll cell, vascular bundle and more stomates per unit area of leaves. Under 50 per cent shade, these characters were maximum in shade tolerant genotypes compared to shade susceptible ones.

The content of chlorophyll a, b and total chlorophyll increased in shade compared to open in all the six genotypes, and the increase was more pronounced in CA 38, CF 51 and CC 63 than that of CA 39, CF 46 and CC 66. The increase in chlorophyll content was more prominent in chlorophyll b fraction leading to a lower chlorophyll a / b ratio. A distinct reduction in the chlorophyll a/b ratio was recorded in all the genotypes under 50 per cent shade compared to open. The total phenol and proline content decreased under shade compared to open in all the six genotypes. However, the decrease was comparatively less in CA 38, CF 51 and CC 63. No significant variation was observed for capsaicin, oleoresin and ascorbic acid content between shade and open conditions. Carotenoid content was found higher in open condition in all the six genotypes. The higher amounts of total chlorophyll, proline and total phenol content of shade tolerant genotypes were ascribed for shade tolerance in chilli.

Inheritance studies on shade tolerance using three crosses of shade tolerant and shade susceptible genotypes of *C. annuum* (CA 38 x CA 39), *C. frutescens* (CF 51 x CF 46) and *C. chinense* (CC 63 x CC 66) revealed a polygenic system. Non-allelic interaction was present in three crosses. Additive, additive x additive, dominance and dominance x dominance types of gene action and duplicate type of epistasis were involved in the inheritance of shade tolerance.

The present investigation has enlarged the vision and understanding of the performance of chilli genotypes under shade conditions. The physiological, anatomical and biochemical attributes responsible and genetic mechanism of tolerance behaviour of chilli genotypes to shade have been amply brought out. It is hoped that the information generated will be useful in developing high yielding varieties in *C. annuum, C. frutescens* and *C. chinense* tolerant to shade.

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GENETIC ANALYSIS OF SHADE TOLERANCE IN CHILLI (*Capsicum* spp.)

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ABSTRACT OF THE THESIS

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ABSTRACT

Investigation on 'Genetic analysis of shade tolerance in chilli (*Capsicum* spp.)' was carried out in the Department of Olericulture, College of Agriculture, Vellayani, during 1997 – 2000 with the objective of identifying superior genotype(s) of chilli to yield better under shade and to analyse the physiological, anatomical, biochemical and genetic basis of shade tolerance.

Seventy genotypes of chilli belonging to *C. annuum*, *C. frutescens* and *C. chinense* collected from different parts of the country were initially evaluated under 25, 50 and 75 per cent shade in comparison with open condition for shade tolerance and yield. Plant height, internodal length, stem girth, leaf area, petiole length, days to first flower, node to first flower, height of node to first flower, fruits per plant, fruit length, fruit girth, fruit weight, yield and incidence of mite were found significantly different both among the genotypes and between different shade levels. High heritability combined with high GCV and expected genetic advance was observed for fruits per plant, fruit weight, fruit length, fruit girth, leaf area and yield under shade indicating the possibility of improvement of these characters through selection. A positive correlation was observed for fruits per plant, fruit length and fruit weight with yield at genotypic and phenotypic levels.

CA 38 of *C. annuum,* CF 51 of *C. frutescens* and CC 63 of *C. chinense* were identified as shade tolerant and CA 39 of *C. annuum,* CF 46 of *C. frutescens* and CC 66 of *C. chinense* as shade susceptible genotypes.

The shade tolerant genotypes were found to be superior in maintaining higher LAI, SLW, CGR, RGR and NAR under shade than shade susceptible ones. Genotypes grown under open had thicker leaves with more stomates per unit area. Anatomical attributes *viz.*, upper and lower epidermal cells, palisade and spongy mesophyll cells and vascular bundle thickness were maximum in open.

The increase in chlorophyll a, b and total chlorophyll under shade was prominent in shade tolerant genotypes than that of susceptible ones. A decreasing trend was observed in chlorophyll a / b ratio in all the genotypes due to prominent increase of chlorophyll b fraction. The shade tolerant genotypes were found to maintain higher proline and total phenol content under shade compared to shade susceptible genotypes. Capsaicin, oleoresin and ascorbic acid content did not vary significantly due to shade. Under open condition the genotypes recorded higher carotenoid content.

A polygenic system of inheritance with non-allelic interaction was revealed in shade tolerance. Duplicate type of epistasis with additive, additive x additive, dominance and dominance x dominance components of genetic variances could observe.