

GENETIC STUDIES IN BELL PEPPER
(*Capsicum annuum* L. var. *grossum* Sendt.)

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University of Agricultural Sciences, Dharwad
in partial fulfilment of the requirements for the
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in

HORTICULTURE

By

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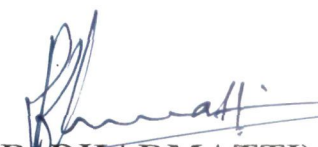
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*This is to certify that the thesis entitled "GENETIC STUDIES IN BELL PEPPER (*Capsicum annuum* L. var. *grossum* Sendt.)" submitted by **Miss NANDADEVI** for the degree of **DOCTOR OF PHILOSOPHY** in **HORTICULTURE** to the University of Agricultural Sciences, Dharwad, is a record of research work carried out by her during the period of her study in this university, under my guidance and supervision, and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.*

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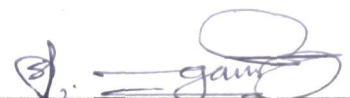

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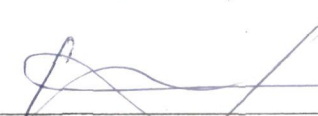
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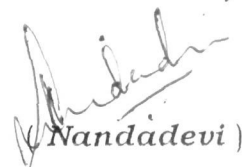
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(Nandadevi)

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Introduction

I. INTRODUCTION

The genus *Capsicum* belongs to the family Solanaceae originated in the new world and may have been simultaneously domesticated in several places in central and south America (Pickersgill, 1971). The domesticated peppers could be broadly classified into sweet and hot types based on their level of pungency. The bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.; $2n=2x=24$) is commonly known as sweet pepper, capsicum or green pepper. They differ from common hot peppers in size and shape of the fruits, capsaicin content and usage. Bell pepper is one of the highly remunerative vegetables cultivated in most parts of the world especially in temperate regions of central and south America and European countries.

The immature fruits are used in the preparation of stuffings, pizza and burger. It imparts delicate taste and pleasant flavour to the cuisine. Nutritionally, bell peppers are rich in vitamins particularly, vitamin A (180 IU) and vitamin C.

In the world, the area and production for bell peppers is merged with that of hot peppers. Annual world production in the year 2000 amounted to 1.88 million metric tonnes from an area of 1450 thousand hectares. India's contribution was estimated to be 49 thousand metric tonnes from an area of 5 thousand hectares (FAO, 2000). Within India, Karnataka has an area of 4,057 hectares with production of 39,503 tonnes (Anonymous, 2002a). Belgaum (843 ha), Haveri (571 ha), Kolar (460 ha) and Mandya (433 ha) districts of Karnataka possess highest area under this crop.

The bell pepper in India is grouped under non-traditional category of vegetables (Kalloo and Pandey, 2002). They are mainly cultivated

during *rabi* and *kharif* seasons in Karnataka, Maharashtra, Tamil Nadu, Himachal Pradesh and hilly areas of Uttar Pradesh.

In global vegetable market Holland is the major exporter of bell peppers. While it meets the requirements of Indian expatriates in South East Asia, Gulf countries and to some extent in UK (Kalloo and Pandey, 2002).

In India bell pepper possess narrow spectrum of variability (Arya and Saini, 1976a and Mulge, 1992). The systematic collection of natural variability has not been made. The breeders, therefore, face the dilemma of crop improvement with reduced variability. Thus, the first task of the breeder is to build up a collection and evaluation of germplasm. The present research was concentrated on to know the variability by including different groups of cultivated pepper genotypes (hot peppers, paprika types and local cultivars along with popularly grown large fruited bell pepper).

The study of germplasm was based on a few morphological characteristics controlled by number of genes may not provide an accurate indication of the genetic divergence (Dogget, 1988). Ideally, the study of polymorphism is best done at the level of arrangement of nucleotides in DNA, the primary source of all biological information. At this level seemingly identical accessions could display enormous difference if only we could employ appropriate DNA profiling techniques. Randomly amplified polymorphic DNA (RAPD) is one such method (Williams *et al.*, 1990) of identifying polymorphism that can be used to elicit information on genetic difference among individual of a population, between lines or germplasm. In this investigation the selected genotypes

belonging to different morphometric groupings and their reaction to powdery mildew disease was considered to know the polymorphism by RAPD markers.

Basically bell pepper is a cool season tropical crop and lacks adaptability to varied environmental conditions (Yoon *et al.*, 1989). Thus, an understanding of genotypic and environmental (GxE) responses is essential for developing suitable varieties or hybrids. Therefore, proper test plot to represent a target environment as well as breeding strategy which incorporate GxE analysis is necessary (Smith and Zobel, 1991).

The production and cultivation of bell pepper is hampered by serious disease like powdery mildew which causes severe defoliation and deterioration in fruit quality and yield (Gohokar and Peshney, 1981). However, meager scientific work has been done to know the effect of powdery mildew disease on reproductive biology. Therefore, the study was conducted on to know the effect of the disease on pollen viability of the crop which might be one of the reasons for yield loss due to the infection.

Further, to combat the disease in-built resistance is only the solution. Hence, screening for disease tolerance within existing cultivated local germplasm would be an appropriate strategy for immediate solution.

In Karnataka, several local types are popular, well adapted and tolerant to disease like powdery mildew. Despite their wide adaptability most of these local types (*viz.*, Tarihal Local and Ranebennur Local) have smaller fruit size with high pungency making their demand limited to choosy consumers. Hence, improvement is very much essential for the enhancement of economic returns of the marginal farmers.

Evaluation and assessing for variability available in pepper germplasm alone cannot keep up the pace of making advances in

production levels of bell pepper. The highly conserved linkage groups need to be broken to realise the potential variability which in turn would give better scope to the breeder for making selections. Thus, development of an effective capsicum breeding programme depends upon elucidating the genetic nature and magnitude of quantitatively inherited traits and estimation of the pre-potency of parents in cross combinations. The information generated in the process is used to understand the magnitude of heterosis of F_1 hybrids. This knowledge helps in exploiting the economically heterotic hybrid for commercial purpose and also in identification of potential hybrids to get transgressive segregants.

By looking to the commercial importance and consumer preference (fruit shape, level of pungency, disease resistance etc.) some of the bell pepper and hot pepper genotypes including local cultivars were used in the present investigation for hybridization programme.

Mutagenesis, as an alternative to hybridization offers an opportunity to improve the local cultivars for higher yields and fruit quality parameters. Significant increase in yield in bell pepper has been reported by Kamannavar (1981) using gamma rays. Hence, the study was carried out to improve the local cultivar 'Tarihal Local' through use of gamma rays.

To achieve the above requirements an attempt has been made to improve bell pepper crop with the following objectives.

1. To estimate the extent of variability and divergence in pepper genotypes over seasons for various characters
2. To study molecular polymorphism among selected pepper genotypes by RAPD-PCR technique

3. To investigate the per cent pollen sterility in selected pepper genotypes caused by powdery mildew disease incidence
4. To estimate the magnitude of heterosis and combining ability effects
5. To study the inheritance of fruit shape and isolation of transgressive segregants
6. To screen the promising mutants of 'Tarihal Local' for fruit quality parameter

Review of Literature

II. REVIEW OF LITERATURE

Bell pepper or sweet pepper (*Capsicum annuum* var. *grossum*) is one of the most important solanaceous vegetable crops grown worldwide under field and glasshouse conditions. The cultivation of bell pepper is mostly confined to temperate regions. Only few introductions (*viz.*, California Wonder, Yolo Wonder) are acclimatized to tropical conditions. Although there are considerable reports available on variability in bell pepper, the spectrum of variability was narrow with low mean values. This is the main reason for non-availability of varieties in India. However, involvement of exotic types and local types along with chilli in hybridization programme would enhance the scope for improvement in bell pepper. Therefore, an attempt has been made in this chapter to review the literature on variability studies, genotype x environment (G x E) interaction, divergence studies, molecular polymorphism studies, pollen viability studies. Reviews on heterosis and combining ability experiments, inheritance and isolation of transgressive segregants and mutation experiments in bell pepper are collected and presented here. Wherever, literature was inadequate on aforesaid aspects in bell pepper, efforts are made to include work on chilli and other related crops.

2.1 GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE

A critical estimate and study on genetic variability is pre-requisite for initiating appropriate breeding procedures in any crop improvement programmes. This demands wide range of variability in a population.

The degree to which variability of a character may be transmitted to the progeny is referred to as its heritability. According to Hanson *et al.* (1956) heritability in broadsense is the ratio of genotypic variance to total variance in non-segregating population. A high heritability is not always accompanied by genetic advance but in the presence of fixable (additive)

gene effects high genetic advance should be expected (Panse, 1957). Genetic advance under selection is the improvement in the mean genotypic value of the selected families over base population. This depends upon the genetic variability of the existing population, the heritability of character under selection and the intensity of selection.

2.1.1 Plant height

High per cent of genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) estimates were reported in chilli genotypes by Gaddagimath (1992), Sharma and Roy (1995) and Kataria *et al.* (1997) while low per cent was noticed by Ram and Lal (1992) and Hiremath (1997) for plant height.

High heritability and genetic advance over mean was noticed by Kataria *et al.* (1997) and Sreelathakumary and Rajamony (2002) in chilli. While moderate (Raju *et al.*, 1984) and high (Arya and Saini, 1977) heritability was observed in bell pepper.

2.1.2 Plant spread

In chilli high magnitude of GCV and PCV was reported by Ahmed *et al.* (1990), Warade *et al.* (1996) and Nandadevi and Hosamani (2003a). Whereas, Basavaraj (1997) reported low GCV and PCV in chilli.

High per cent of heritability and genetic advance was revealed by Basavaraj (1997) while, lower magnitude of genetic advance was noticed by Kataria *et al.* (1997) in chilli.

2.1.3 Number of primary branches

Ibrahim *et al.* (2001) reported medium to high per cent of GCV (15.10%), PCV (19.46%), heritability (19.46%) and genetic advance as per cent mean (166.11%) for number of primary branches. Shaik (2002)

reported low per cent of GCV and PCV, heritability and genetic advance for the trait in chilli. Whereas, high per cent of variability, heritability and genetic advance in chilli was observed by Nandadevi and Hosamani (2003a).

2.1.4 Number of secondary branches

High heritability observed for number of secondary branches by Nair *et al.* (1984) in chilli. Moderate per cent of heritability and genetic advance for the trait in chilli was reported by Basavaraj (1997).

2.1.5 Days to 50 per cent flowering

Very low GCV and PCV was reported by Varalakshmi and Haribabu (1991), Shirsat (1994), Giritammannavar (1995), Kataria *et al.* (1997), Hiremath (1997) and Shaik (2002) in chilli. While, high variability was noticed for days to 50 per cent flowering by Nair *et al.* (1984) in chilli.

Medium to high heritability and genetic advance was noticed by Kataria *et al.* (1997), Hiremath (1997) and Shaik (2002) in chilli. Whereas, in bell pepper high heritability and moderate heritability was noticed by Arya and Saini (1976b) and Thakur and Gill (1980) respectively. Low variability was reported by Chang (1977) for days to 50 per cent flowering in bell pepper.

2.1.6 Average fruit weight

Arya and Saini (1977) reported higher magnitude of GCV, PCV, heritability and genetic advance for average fruit weight. While, low heritability was noticed by Thakur and Gill (1980) in bell pepper.

High variability, heritability and genetic advance as per cent mean was recorded by Munshi and Behra (2000), Sreelathakumary and Rajamony (2002) and Nandadevi and Hosamani (2003a) in chilli.

2.1.7 Fruit length

Munshi and Behra (2000); Ibrahim *et al.* (2001) and Sreelathakumary and Rajamony (2002) have proved moderate to high magnitude of GCV, PCV, heritability and genetic advance for the expression of fruit length in chilli. Whereas, low variability was noticed by Chang (1977) in bell pepper.

2.1.8 Fruit width

High magnitude of variability and heritability was noticed for fruit width in bell pepper (Raju *et al.*, 1984). While, in chilli moderate to high variability, heritability and genetic advance was reported by Khadi (1983), Ibrahim *et al.* (2001) and Sreelathakumary and Rajamony (2002) in chilli.

2.1.9 Fruit shape index

Wide range of fruit shapes within *Capsicum annuum* have been observed by Greenleaf (1985) and Anand *et al.* (1987a). High variability and heritability estimate for fruit shape index was reported by Zhan (1992) in bell pepper.

2.1.10 Locules per fruit

Naik (1999) noticed low variability among parents and F_1 hybrids in bell pepper for locules per fruit. Whereas, high variability was noticed by Srivastava *et al.* (1998) and Sajjan (2001) in tomato for locules per fruit.

2.1.11 Pericarp thickness

Greater genetic variability was expressed in bell pepper for pericarp thickness (Arya and Saini, 1976 a, b and Gvozdenovic, 1989) while, Chang (1977) reported lower variability in bell pepper. Similarly, in chilli Rani *et al.* (1996) recorded higher variability and Natarajan *et al.* (1993) reported

lower variability with high heritability and genetic advance for pericarp thickness.

2.1.12 Pedicel length

Moderate to high heritability was reported by Shaik (2002), Basavaraj (1997) and Pawade *et al.* (1995) for pedicel length in chilli. While, high variability with high genetic advance was noticed by Gaddagimath (1985) and Basavaraj (1997) in chilli. Shaik (2002) reported low per cent of variability and genetic advance in chilli.

2.1.13 Seed weight per fruit

Singh and Singh (1970) observed lower magnitude of variability and heritability in *Capsicum* for seed weight per fruit. Whereas, Thangaraj and Muthukrishnan (1992) reported significant variation for seed weight in chilli. However, higher per cent of variability and heritability with moderate genetic advance was recorded by Basavaraj (1997) in chilli for seed weight.

2.1.14 Number of seeds per fruit

Narasimharaju (1979) suggested high magnitude of GCV and PCV for number of seeds per fruit in bell pepper, while, Raju *et al.* (1984) reported moderate to high heritability estimates in bell pepper.

High GCV, PCV, heritability and genetic advance estimates was noticed for number of seeds by many workers (Natarajan *et al.*, 1993; Warade *et al.*, 1996; Basavaraj, 1997 and Nandadevi and Hosamani, 2003a) in chilli.

2.1.15 Ascorbic acid content

Many scientists observed higher magnitude of heritability and genetic advance (Khadi, 1983; Gaddagimath, 1985; Bhagyalakshmi *et al.*, 1990 and Kumar *et al.*, 1993) in chilli for ascorbic acid content.

Pu *et al.* (1992) recorded that ascorbic acid content ranged from 100.00 to 356.40 milligram per 100 gram in 665 varieties of *Capsicum*. Significant variation was noticed by Khadi *et al.* (1987) and Rani (1994) in the fruits of green pepper.

2.1.16 Total soluble solids

Naidu (1993) reported low to moderate PCV and GCV and high heritability with moderate genetic advance in tomato. While, Patil (1996) reported low variability with moderate heritability and low genetic advance as per cent mean in tomato for total soluble solids.

2.1.17 Number of fruits per plant

The high variability in bell pepper for number of fruits was noticed by Arya and Saini (1977), Narasimharaju (1979) and Vandana Pandey *et al.* (2002).

Similarly, Raju *et al.* (1984) recorded higher magnitude of variability, heritability and genetic advance estimates for number of fruits per plant in bell pepper.

The high estimates of variability, heritability and genetic advance was reported by many researchers (Kataria *et al.*, 1997; Munshi and Behra, 2000 and Sreelathakumary and Rajamony, 2002) in chilli.

2.1.18 Fruit yield per plant

Arya and Saini (1977), Narasimharaju (1979) and Raju *et al.* (1984) reported higher per cent of GCV and PCV for fruit yield per plant in bell pepper. Whereas, low heritability was reported by Thakur and Gill (1980) in bell pepper for fruit yield.

Yield per plant is an important economic trait. High variability, heritability and genetic advance in chilli was reported by many workers

(Rani *et al.*, 1996; Kataria *et al.*, 1997 and Nandadevi and Hosamani, 2003a) in chilli whereas, Basavaraj (1997) recorded low variability and genetic advance with moderate to high variability in chilli for fruit yield per plant.

2.2 GENOTYPE AND ENVIRONMENT (G x E) INTERACTION

The evaluation of germplasm and assessment of the nature of variability forms the pre-requisite in any crop improvement programme. In most of the cases the nature and quantum of variability are studied by evaluating the genotypes in one season. In such cases the estimation of genotypic variances are biased, as genotype x environment (G x E) interaction is involved. There are limited references on the estimation of genetic variability in *Capsicum* spp. over seasons or locations.

Singh and Singh (1976) reported that additive, dominance and environmental variances as well as G x E interaction in varying proportions for number of branches, fruit length, fruit thickness and fruit number in F₁, F₂, BC₁ and BC₂ of *Capsicum annuum* L.

Significant G x E interaction for quantitative characters was noticed by Lohithaswa *et al.* (2001a) in 55 genotypes of chilli. While, Patel *et al.* (2001) reported that the environmental estimates of mean square due to genotype x years was highly significant for all the traits. Thus, indicating varied response of the genotype to different environments.

Higher magnitude of variance due to G x E (Vg x e) interaction component for fruit stalk length, seeds per pod and fruit yield per plant was noticed by Shaik (2002) in chilli. Shaik (2002) also reported lower magnitude of variability over two seasons compared to individual seasons.

Wani *et al.* (2003) in stability analysis study in hot peppers revealed that G x E (linear) component was non-significant for ascorbic acid content while, it was significant for fruit yield.

2.3 GENETIC DIVERGENCE

The magnitude of divergence between two groups under consideration is provided by D^2 statistic developed by Mahalanobis (1936). It considers the variation produced by any character and their consequent effect that it bears on other characters.

The technique in the form of generalized distance was first used by Mahalanobis (1936), in an anthropometric survey of the united province in India.

Murthy and Pavate (1962) observed that D^2 analysis can be extended to the situations where overlapping species need to be discriminated. It is also utilized when the discrimination at sub-species level is needed. Thus, the technique was subsequently used in different vegetable crops.

Gill *et al.* (1982) reported that genetic diversity of parents was positively related to heterosis in F_1 in sweet pepper. Khadi (1983) recorded positive heterosis in the hybrids whose parents were in same cluster.

However, Shifriss and Sacks (1980) reported that heterosis was not related to diversity in the cross between sweet pepper and hot pepper.

Sundaram *et al.* (1980) grouped 50 varieties of chillies into seven clusters. The main contributing characters were number of branches and number of fruits per fruit towards genetic diversity. While, Warade *et al.* (1997) grouped 60 cultivars of chilli into nine clusters.

Shaik (2002) observed that Byadgi kaddi, Byadgi dabbi, Dyavnur kaddi and Dyavnur dabbi, close derivatives of Byadgi chilli were grouped under different clusters.

Twenty chilli genotypes were clustered into six groups (Senapati *et al.*, 2003) where, cluster I was largest with maximum of 13 genotypes.

A comparison of cluster means for different characters indicated considerable differences between clusters for all the traits (Sundaram *et al.*, 1980; Varalakshmi and Haribabu, 1991; Warade *et al.*, 1997; Shaik, 2002 and Senapati *et al.*, 2003) in chilli.

2.4 MOLECULAR POLYMORPHISM IN *Capsicum* spp.

The evolutionary relationships among and within the cultivated species have been investigated in several studies by using molecular markers (Prince *et al.*, 1992 and Lefebvre *et al.*, 1993). The studies demonstrated that level of variation among domesticated peppers was lower than that of wild peppers. The variation among large fruited pepper was limited when compared with that of domesticated pungent peppers as reported by Prince *et al.* (1992) and Paran *et al.* (1998).

Wang *et al.* (1996) subjected diverse pepper accessions to Random Amplified Polymorphic DNA (RAPD) markers analysis and divided into four groups for classification of *Capsicum* spp. Wang *et al.* (1997) reported that RAPD markers were used for detection of polymorphism and assessment of levels of genetic variation within population of chilli.

Paran *et al.* (1998) employed Random Amplified Polymorphic DNA (RAPD) and Amplified Fragment Length Polymorphic (AFLP) markers to reveal variation in *Capsicum annuum* (bell peppers and hot peppers).

Pawar (2000) reported that cultivars Sankeshwar showed maximum polymorphism followed by Byadgi Dabbi and Byadgi Kaddi. While, minimum genetic distance was recorded between two cultivars of chilli (Byadgi Dabbi and Byadgi Kaddi).

A study was conducted by Buso *et al.* (2003) by using 17 random primers to analyze the genetic variability and phylogenetic relationships. It was reported that in the first group *C. annuum*, *C. frutescens* and *C.*

chinense accessions presented high relative similarity, while the *C. baccatum* var. *praetermissum* accessions constituted in another group.

2.5 POWDERY MILDEW DISEASE

Powdery mildew in capsicum [*Leveillula taurica* (Lev.) Arnaud] has become serious problem. The fungus causes yellowish necrotic lesions on upper surface of leaf and white powdery covering on lower surface of leaf (Dixon, 1978). Deterioration of fruit size and yield was reported by Gohokar and Peshney (1981).

The mycelium of *L. taurica* grows intercellularly within the host tissue (Molot *et al.*, 1990).

Powdery mildew disease causes heavy yield loss ranging from 14.2 per cent to 19.6 per cent (Shivaprakash *et al.*, 1976).

2.5.1 Genetics of powdery mildew resistance

The powdery mildew resistance was controlled by three genes (Anand *et al.*, 1987⁽⁹⁾ and Daubeze *et al.*, 1995) with additive gene action between loci and high heritability. Whereas, Hiremath (1997) observed low GCV and heritability coupled with low genetic advance.

Krishna Murthy and Deshpande (1997a) observed powdery mildew resistance was dominant and polygenically controlled in capsicum.

2.5.2 Fungal parasitism on pollen

The loss in the viability of pollen was noticed by Nair (1979) when the plants were infected with air borne fungi. The scientist opined that the sterility was due to protoplasm consumption or due to hyphal penetration into the pollen grains which draws nutrients from protoplasm by means of haustoria leading to sterility of the pollen.

These facts are important when one considers the air borne fungal spores which causes powdery mildew, rust *etc.* But, there is hardly any information available about the role of such spores on reproductive biology of the plant. However, reports are available on effect on pollen grains in response to fungus which produce pathotoxins (*viz.*, fusaric acid) (Balashova *et al.*, 1992; Golyshikina and Gigadlo, 2000 and Ravikumar and Patil, 2002).

2.6 HETEROSIS

Two inbred lines were crossed, the *per se* performance of the F_1 may be superior to mid parental value. This superiority over mean is called as heterosis. The magnitude of heterosis depends on accumulation of favourable dominant alleles in the F_1 population. If the parental populations differ from each other for favourable dominant alleles, the magnitude of heterosis will be proportionally higher. This relationship is evidenced in the basic formula for heterosis (Falconer, 1981).

$$\text{Heterosis in } F_1 = \sum dy^2$$

Where,

d = Magnitude of dominance

y = Difference between the parental population for allelic frequencies at the locus

The earlier workers revealed the possibility of exploitation of heterosis in bell pepper and hot pepper with respect to various qualitative, quantitative and stress related characters.

2.6.1 Seedling characters

Mulge and Anand (1997) reported average heterosis upto 54 per cent and heterobeltiosis (123.50%) in bell pepper for seedling height.

2.6.2 Plant height

The maximum heterosis of 65.50 per cent and 59.10 per cent over mid parent and better parent was reported respectively in cross combination Arka Mohini x PMR-28 by Mulge (1992) in bell pepper for plant height. Thomas and Peter (1988) revealed significant favourable heterosis in inter varietal hybrid evaluation of six bell pepper and six hot pepper types. While, Joshi *et al.* (1995) in bell pepper and Mishra *et al.* (1989) in chilli reported very low magnitude of heterosis for the trait. Naik (1999) reported that none of the crosses were heterotic in bell pepper for plant height.

2.6.3 Plant spread

The magnitude of heterosis over mid parent and better parent ranged from -12.45 (Belcod Local x California Wonder) to 32.31 per cent (Belcod Local x Arka Gaurav) and 17.97 to 28.34 per cent, respectively in bell pepper (Naik, 1999).

The positive significant heterosis was observed by Ahmed *et al.* (1998) and Nandadevi (1999) in chilli.

2.6.4 Number of primary branches

A significant and positive heterobiltiosis was reported by Joshi and Singh (1980) and Joshi (1986) in bell pepper. Whereas, Mishra *et al.* (1976) reported negative heterosis over better parent for number of primary branches in bell pepper.

Patel *et al.* (2001) reported heterosis over mid parent ranged from -20.42 to 28.14 per cent in chilli for number of primary branches.

2.6.5 Number of secondary branches

Sharma and Saini (1977) indicated low order of heterosis for number of secondary branches. While, Mulge (1992) reported significant positive heterobeltiosis in most of the crosses in bell pepper.

2.6.6 Days to 50 per cent flowering

Earliness in flowering is expressed as negative heterosis and was an established manifestation of heterosis among bell pepper hybrids and in chilli hybrids.

Many scientists observed high heterosis for early flowering in *Capsicum annuum* by Allah *et al.* (1975), Milkova and Daskalov (1977), Ahmed *et al.* (1998) and Patel *et al.* (2001). Miranda *et al.* (1988) reported heterosis in the range of 9.00 to 109.20 per cent over better parent for days to flowering in bell pepper.

2.6.7 Average fruit weight

The average fruit weight is an important component of yield. Positive heterosis for fruit weight was recorded by Joshi and Singh (1980), Joshi (1986), Miranda and DeCosta (1988) and Mulge (1992) in bell pepper.

Similarly, in chilli positive heterosis was noticed by Patel *et al.* (1997) and Rao and Reddy (1998). While, Lohithaswa *et al.* (2001b) and Nandadevi and Hosamani (2003b) reported higher magnitude of negative heterosis in chilli.

2.6.8 Fruit length

Joshi and Singh (1980) observed significant heterosis (12.80%) in bell pepper hybrids for fruit length. In heterosis study Joshi and Singh

(1987) identified Yolo Wonder x HC 201 as the best heterotic hybrid. Similarly, Verma and Sharma (1998) have also reported heterosis for this trait in bell pepper.

Contrary to the above findings, Kaul and Sharma (1988) reported dominance of negative heterosis in bell pepper for fruit length.

2.6.9 Fruit width

Thomas and Peter (1988) in bell pepper reported positive heterosis (101.80%) for fruit width. Joshi *et al.* (1995) noticed higher *per se* performance of F₁'s in comparison to the *per se* values of their parents in bell pepper for fruit width.

Whereas, negative heterosis was reported for fruit width by Kaul and Sharma (1988) and Naik (1999) in bell pepper.

2.6.10 Fruit shape index

Thakur *et al.* (1987) was in the opinion that F₁ means for fruit shape index were significantly superior to mid parent value and there were three crosses (Yolo Wonder x Bighart, KL; Bjala Kapiya x Vinedale and Vinedale x Bighart, KL) superceded the respective better parents in bell pepper.

Significant heterosis in positive direction has been evidenced by Chadha and Kumar (2001) and Kulkarni (2003) in tomato for fruit shape index.

2.6.11 Locules per fruit

Mulge (1992) reported negative heterosis (desirable) whereas Naik (1999) noticed that none of the hybrids were significantly heterotic over mid and better parent in bell pepper for locules per fruit. Negative

heterosis was recorded by Dharmatti (1995), Kulkarni (1999) and Sajjan (2001) in tomato for locules per fruit.

2.6.12 Pericarp thickness

The selection against thick pericarp has been important for improving the digestibility of fresh market pepper (Fisher, 1992). Whereas, most of the scientists have emphasized on thicker pericarp with positive heterosis (Joshi *et al.*, 1995 and Naik, 1999 in bell pepper and Ahmed *et al.*, 1998 in chilli).

2.6.13 Pedicel length

In chilli, heterosis for pedicel length was reported by Bhat (1981), Khadi (1983) and Gaddagimath (1985) over better parent. Naik (1999) reported that out of 15 crosses one and four hybrids of bell pepper were significantly heterotic in positive direction over mid parent and better parent respectively.

2.6.14 Seed weight per fruit

Positive heterobeltiosis was reported by Pradeepkumar *et al.* (1993) and Mulge and Anand (1998) in bell pepper for seed weight per fruit.

2.6.15 Number of seeds per fruit

Naik (1999) recorded that the range of heterosis to the tune of -16.51 to 29.45 per cent over mid parent and -61.34 to 46.25 over better parent in bell pepper for number of seeds per fruit. Mishra *et al.* (1989 and 1991) opined significant positive heterosis in bell pepper for this trait. Whereas, in chilli negative heterosis for the trait was noticed by Nair *et al.* (1984).

2.6.16 Ascorbic acid content

The magnitude of average heterosis exhibited for ascorbic acid was 13.10 per cent as revealed by Vandana Pandey *et al.* (2002) in bell pepper. Further, it was reported that Yolo Wonder x CW-51 exhibited maximum heterosis of 14.21 per cent over check in bell pepper.

The heterosis over mid parent ranged from -16.95 to 31.36 per cent in chilli (Basavaraj, 1997).

2.6.17 Total soluble solids

Total soluble solids (TSS) are related to yield of concentrated product.

The positive heterosis was observed for reducing the non-reducing sugars in chilli (Basavaraj, 1997). Similar results were observed for soluble solids by Dhatt *et al.* (2001) and Sajjan (2001) in tomato.

Dharmatti (1995) reported heterosis for TSS which ranged from -100 to 68.11 per cent over commercial check. Whereas, Chadha and Kumar (2001) noticed negative heterosis for this trait in tomato.

2.6.18 Number of fruits per plant

Number of fruits per plant is an important component of yield. Manifestation of heterosis for this character was very much apparent in bell pepper with the works of Shifriss and Sacks (1980), Kaul and Sharma (1988), Depestre and Espionosa (1988), Mulge (1992), Naik (1999) and Vandana Pandey *et al.* (2002).

Significant negative heterosis has also been reported for number of fruits per plant (Mishra *et al.*, 1976 and Bhat, 1981) in chilli.

2.6.19 Fruit yield per plant

Heterosis for yield is common phenomenon in the crop, though the degree of heterosis varies widely which can be attributed to the variation in the potentialities of parent chosen for crossing programme.

Several workers have observed positive heterosis for fruit yield in bell pepper (Shifriss and Sacks, 1980; Joshi and Singh, 1980; Thomas and Peter, 1988; Kaul and Sharma, 1988; Miranda *et al.*, 1988; Joshi *et al.*, 1995; Mulge and Anand, 1997 and Vandana Pandey *et al.*, 2002).

Kaul and Sharma (1988) observed 25 to 34 per cent heterobeltiosis in bell pepper. The range of heterosis over better parent was 7.00 to 54.70 per cent in the studies of Miranda *et al.* (1988). Whereas Verma and Sharma (1998) recorded higher fruit yield per plant in the cross combination CW x Bonali. Vandana Pandey *et al.* (2002) recorded 61.11 per cent heterosis in bell pepper.

Contrary to the above findings, few scientists have reported negative heterosis for fruit yield in hot pepper (Gaddagimath, 1985 and Lakshmi *et al.*, 1988). While, significant positive heterosis was observed in diallel crosses of chilli (Nandadevi and Hosamani, 2003b).

2.7 COMBINING ABILITY

The general combining ability (*gca*) effect coming from the two parents, the specific combining ability (*sca*) effect arising from the interaction between the genotypes of the two parents, determines the performance of the progeny developed by crossing such parents. This is represented as

$$X - \bar{X} = gca_p + gca_q + sca_{pq}$$

Where,

X = True mean of cross between P and Q

$\bar{X}$ = Mean of all crosses

The popular line x tester analysis developed from the concept of North Carolina Designs is helpful in determining the *gca* and *sca* effects. Thus, it is possible to estimate the potentiality of the crosses and also to apportion the course for this superiority in terms of *gca* and *sca* effects.

The *gca* reflects the breeding value of parental genotype concerned and helps in identifying genotypes to be used for developing superior populations. The *sca* effect represents the non reliable component of the genotype value arising due to the contribution from dominance deviation and interaction deviation (Patil, 1995). Hence, if the *sca* effect is the main cause for superiority of a cross, it is inferred that superiority of this cross cannot be fixed through selection. In pursuit of rendering a genetic improvement in vegetable crops, the vegetable breeder, must possess an adequate knowledge of combining ability and allied genetic parameters. Such knowledge has been steadily increasing in bell pepper and reports are available on bell pepper and chilli have been summarised below.

2.7.1 Seedling characters

Mulge and Anand (1997) identified high *gca* effect in the study for seedling characters, also possessed high *gca* effects for yield and yield components.

2.7.2 Plant height

Higher *gca* effect was noticed for plant height by Joshi and Singh (1987) in California Wonder, Bullnose and HC-201.

The results of combining ability studies carried out by Kaul and Sharma (1988) noticed higher ratio of GCA variance to SCA variance in bell pepper. Contrary to this Mulge (1992) and Ahmed *et al.* (2003) in bell pepper and Basavaraj (1997) in chilli recorded high SCA variance than GCA variance, indicating predominance of non additive gene effects. Joshi

and Singh (1987) noticed both additive and non additive gene effect in bell pepper for plant height.

2.7.3 Plant spread

Dominance variance was predominant for plant spread (Naik, 1999) in bell pepper while, Khadi (1983), Jagdeesh (1995) and Nandadevi *et al.* (2003) reported that both additive and non additive gene effects controlling this trait in chilli.

2.7.4 Number of primary branches

Sharma and Saini (1977) observed higher GCA variance than SCA variance, for number of primary branches in bell pepper. While, Mulge (1992) and Ahmed *et al.* (2003) gave importance to SCA variance for the trait in bell pepper. High and significant *gca* as well as *sca* effects have been reported for number of primary branches by Milkova (1984) in bell pepper.

2.7.5 Number of secondary branches

Higher magnitude of GCA variance than SCA variance was observed by Sharma and Saini (1977) and Mulge (1992) in bell pepper. While, Naik (1999) observed that the parent Arka Gaurav as best combiner in bell pepper for number of secondary branches.

2.7.6 Days to 50 per cent flowering

High SCA variance for 50 per cent flowering in bell pepper was reported by Mulge (1992) and Verma and Sharma (1998). Significant GCA and SCA variance was recorded by Milkova (1984) and Joshi and Singh (1987) indicating both additive and non additive gene effect in bell pepper. However, Dolgikh and Sviridova (1983) and Ahmed *et al.* (2003) reported

significant GCA variance in bell pepper indicating predominance of additive gene effects.

2.7.7 Average fruit weight

Many scientists (Milkova, 1984; Miranda *et al.*, 1988; Miranda and DeCosta, 1988 and Gvozdenovic *et al.*, 1996) reported high GCA variance for average fruit weight in bell pepper. Whereas, Mulge and Anand (1997) and Ahmed *et al.* (2003) observed higher magnitude of SCA variance in bell pepper. Naik (1999) suggested the non additive gene effects in control of average fruit weight in bell pepper.

Joshi and Singh (1987) in bell pepper reported significance GCA and SCA variance for the trait under consideration.

2.7.8 Fruit length

High GCA variance indicated the importance of additive gene effects for fruit length was recorded by Kaul and Sharma (1988) and Miranda *et al.* (1988) in bell pepper. While, Mulge (1992) in bell pepper recorded high SCA variance. Joshi and Singh (1987) and Ahmed *et al.* (2003) suggested both additive and non additive gene effects in bell pepper for fruit length.

2.7.9 Fruit width

Significant GCA and SCA variance was observed for fruit width by Kaul and Sharma (1988) and Miranda and DeCosta (1988) in bell pepper. While, Nandadevi *et al.* (2003) indicated importance of both additive and non additive gene effects in chilli.

Ahmed *et al.* (2003) observed higher magnitude of GCA variance in bell pepper for fruit width. Whereas, Mulge (1992) suggested operation of non additivity for fruit width in bell pepper.

2.7.10 Fruit shape index

Thakur *et al.* (1987) suggested that relative magnitude of dominance effect contributed more towards genetic variance than additive effect for fruit shape index in bell pepper.

Sajjan (2001) and Kulkarni (2003) observed predominance of SCA variance in tomato hybrids while, Dundi (1991) reported that GCA variance was in higher magnitude than SCA variance in tomato.

2.7.11 Locules per fruit

Naik (1999) reported high GCA variance for locules per fruit, whereas, Mulge (1992) recorded predominance of non additive gene effect for locules per fruit in bell pepper.

Patil (1997) and Kulkarni (2003) revealed importance of additive gene effects governing locules per fruit in tomato. While, Dharmatti (1995) and Sajjan (2001) observed preponderance of non additivity for this trait in tomato.

2.7.12 Pericarp thickness

Thakur *et al.* (1987) and Naik (1999) suggested that importance of additive component in bell pepper for pericarp thickness. Whereas, Ahmed *et al.* (2003) reported both additivity and non additivity for the trait under study in bell pepper. Mulge (1992) suggested higher SCA variance than GCA variance indicating predominance of non additive gene effect controlling pericarp thickness in bell pepper.

2.7.13 Pedicel length

High SCA variance for pedicel length was observed in bell pepper by Mulge (1992) and Naik (1999). In chilli, similar results were revealed by Basavaraj (1997) and Nandadevi and Hosamani (2003b).

2.7.14 Seed weight per fruit

Variance due to specific combining ability was higher than the variance due to general combining ability for seed weight in chilli fruits (Nandadevi *et al.*, 2003). While, Bhagyalakshmi *et al.* (1991) stated that equal magnitude of both GCA and SCA variance in chilli for seed weight.

2.7.15 Number of seeds per fruit

Basavaraj (1997) and Naik (1999) reported the preponderance of dominant variance than additive variance for number of seeds in chilli fruits and bell pepper respectively. Importance of both GCA and SCA variance was recorded by Bhagyalakshmi *et al.* (1991) and Gaddagimath (1992) in chilli for number of seeds per fruit.

2.7.16 Ascorbic acid content

Vandana Pandey *et al.* (2002) recorded that CW-51 and Sel-2 were good general combiners while, the cross Yolo Wonder x CW-51 as good specific combiner for ascorbic acid content in bell pepper.

Gaddagimath (1992) and Bhagyalakshmi *et al.* (1991) recorded predominance of SCA variance. Khadi (1983) reported the preponderance of additive gene effect for ascorbic acid content in chilli.

2.7.17 Total soluble solids (TSS)

Reducing sugars are predominantly controlled by non-additive gene effects, whereas, non-reducing sugars were controlled by additive gene effects (Basavaraj, 1997) in chilli.

The results obtained by Patil (1997) and Sharma *et al.* (1999) revealed importance of additive gene effect for TSS in tomato. On the contrary Pradeepkumar *et al.* (1997) and Kulkarni (2003) noticed preponderance of non additive gene effects for the trait in tomato.

2.7.18 Number of fruits per plant

Significant GCA and SCA variances for number of fruits per plant in bell pepper was observed by Sharma and Saini (1977), Dolgikh and Sviridova (1983), Milkova (1984), Joshi and Singh (1987) and Kaul and Sharma (1988). Whereas, Mulge (1992) and Ahmed *et al.* (2003) reported predominance of SCA variance in bell pepper indicating the dominance of non additivity for the character.

2.7.19 Fruit yield per plant

The studies of Mulge and Anand (1997), Verma and Sharma (1998), Vandana Pandey *et al.* (2002) and Ahmed *et al.* (2003) observed high SCA variance indicating the non additive gene effect in controlling yield per plant in bell pepper. While, Dolgikh and Svirodova (1983) and Kaul and Sharma (1988) observed high GCA variance for yield in bell pepper suggesting predominance of additive gene effects.

Vandana Pandey *et al.* (2002) reported Arka Basanth, EC-114360 and Bullnose as good combiners Naik (1999) observed Arka Gaurav and California Wonder had significant and high *gca* effects among the parents.

2.8 INHERITANCE PATTERN OF FRUIT SHAPE AND ISOLATION OF TRANSGRESSIVE SEGREGANTS

Thakur *et al.* (1987) while studying 28 F₁'s, F₂'s and back cross generations reported duplicate epistasis for fruit shape index in bell pepper.

Sahoo and Mishra (1990) stated that outstanding expression of fruit yield were observed in transgressive segregants in chilli.

Bhat (1981) revealed positive residual heterosis for fruit yield in chilli. Similar results were recorded by Khadi (1983). Patil (1990) observed

higher fruit yield in F₂ population of chilli indicating the possibility of exploiting F₂'s for commercial purpose.

On the contrary, Krishna Murthy and Despande (1997b) noticed that segregating generation had lesser mean chilli yield over their corresponding better parent performance. Hiremath (1997) reported that the 42 F₂ crosses of chilli expressed higher magnitude of significant SCA and GCA variance for fruit yield and fruit weight indicating broader variability in the material.

The results showed transgressive segregation for most of the traits and further suggested fruit weight was quantitatively inherited in F₂ progeny of hot pepper (Wang *et al.*, 2003).

2.9 MUTAGENESIS IN *CAPSICUM ANNUUM*

The work carried out regarding mutation breeding in *Capsicum annum* is very meagre however, few reports are quoted in this on mutation of *Capsicum annum*.

Kamannavar (1981) reported various types of chlorophyll and viable mutations in M₂ population of four *Capsicum* varieties. Bell pepper showed highest chlorophyll and viable (larger leaves, fruit modifications) mutants compared to chilli varieties. Further, noticed that days to flower was earlier at 10 KR and 20 KR of gamma irradiation.

Raghuvanshi and Singh (1982) studied the effect of mutagen on chilli cultivar NP-46-A which was subjected to 20 KR gamma rays and 0.5 per cent EMS. They observed higher percentage of small blunt fruits (1.41%) and broad fruits (1.08) respectively. Similarly, induced mutation in chilli crop was studied by Venkatrajah and Subhash (1985) and Venkateshwaralu (1988).

Mehta *et al.* (1999) observed considerable variability induced by chemical mutagenic treatments and differential varietal and character response was noticed with respect to early flowering, leaf shape, fruit shape and plant height in chilli.

High variability for quantitative characters like number of fruits per plant and fruit yield per plant was evidenced by Ramalingam (1977), Kamannavar (1981) and Mehta *et al.* (1999) in *Capsicum*.

'MDU-L' is a mutant variety released from India which has higher yielding potential and improved fruit quality (Daskalov, 1986) in chilli.

Material and Methods

III. MATERIAL AND METHODS

The investigation on genetic studies in bell pepper was undertaken during *rabi* 2000 to *kharif* 2003 at Olericulture Unit, Department of Horticulture, University of Agricultural Sciences, Dharwad. The details of the material used for the study, experimental designs adopted and statistical procedures followed are out lined in this chapter.

3.1 LOCATION AND CLIMATE

Geographically Dharwad is located at 15°26' north latitude, 76°07' east longitude at an attitude of 678 m above the mean sea level. Olericulture Unit of Department of Horticulture, Dharwad is situated in the agro-climatic zone VIII. The average annual rainfall of last 50 years (1950-2000) is 778.48 m, fairly well distributed form April to November.

The mean monthly maximum temperature range from 26.80°C-35.7°C while, mean monthly minimum temperature range between 14.37° and 23.67°C. The relative humidity (RH) fluctuates between 57.60 and 88.00 per cent. The detail of weather data are presented in Appendix I.

3.2 EXPERIMENTAL SITE

The field experiments were conducted at Olericulture Unit, Department of Horticulture, University of Agricultural Sciences, Dharwad. The type of soil is red soil (inceptisol). The physical and chemical properties of the soil are presented in Appendix II.

3.3 EXPERIMENT I: EVALUATION OF GERMPLASM OVER SEASONS AND SCREENING FOR POWDERY MILDEW DISEASE INCIDENCE DURING RABI 2000

A set of 25 genotypes (Appendix III) consisting of large fruited bell peppers, paprika type, hot peppers and local cultivars were maintained at Olericulture Unit, Department of Horticulture, University of Agricultural

Sciences, Dharwad were evaluated for variability, divergence and genotype x environment (G x E) interaction.

The genotypes were evaluated and simultaneously selfed under field conditions during *rabi* 2000 and *kharif* 2001 in Randomised Block Design (RBD). The details of the experiment is stated below.

Treatments	: Twenty five genotypes
Replications	: Three
Spacing	: 60 cm x 45 cm
Plot size	: 2.4 m x 1.5 m

3.4 EXPERIMENT II: RANDOM AMPLIFIED POLYMORPHIC DNA (RAPD) MOLECULAR CHARACTERIZATION

3.4.1 Plant material

Thirteen genotypes belonging to different morphometric groupings and disease reaction to powdery mildew disease incidence (tolerant to susceptible category) from the pool of 25 genotypes were selected based on evaluation over two seasons (Table 1).

Each of the 13 genotypes chosen represent different fruit shape, level of pungency and reaction towards powdery mildew disease incidence. Thus genotypes included large fruited bell peppers, hot peppers, paprika type and local cultivars. Nine of these 13 genotypes were used as parent material in crossing programme in the investigation. The characteristics of the 13 genotypes are presented in Table 1.

Seedlings were raised in Olericulture Unit, Department of Horticulture University of Agricultural Sciences, Dharwad. One plant in all the 13 genotypes were analysed for variability at RAPD level at Institute of Agri-Biotechnology, University of Agricultural Sciences, Dharwad.

Table 1. Characteristics of 13 pepper genotypes

Genotypes	Fruit shape	Level of pungency	Powdery mildew disease reaction
California Wonder	Blocky	Mild pungent	Susceptible
Yolo Wonder	Blocky	Mild pungent	Susceptible
Belgaum Local	Blocky	Mild pungent	Susceptible
Arka Gaurav	Blocky	Mild pungent	Susceptible
Tarihal Local	Round	High pungent	Tolerant
Ranebennur Local	Round	High pungent	Tolerant
4080-25	Companulate	Pungent	Moderately susceptible
4080-15	Companulate	Pungent	Susceptible
KTPI-19	Triangular	Mild pungent	Susceptible
Goa Local	Companulate	Pungent	Moderately susceptible
Chilli Yellow	Elongate	Pungent	Tolerant
Guntur Local	Elongate	Pungent	Susceptible
PMR-57/88/k	Elongate	Pungent	Tolerant

3.4.2 DNA extraction

Fresh leaves were used for DNA extraction by following the procedure of Krishna and Jawali (1997).

- 2-3 young leaves from one month old seedling were collected, washed and then dipped in 70 per cent ethyl alcohol for one minute for disinfection.
- The leaves were rinsed in sterile distilled water and crushed in chilled pestle and mortar by adding 1 ml of extraction buffer (Appendix IV).
- The extract was transferred to sterile microfuge tubes and 100 μ l SDS (20%) was added to each tube. The contents were mixed well and incubated in water bath at 65°C for 15 minutes.
- 200 μ l of potassium acetate (5 M) was added to each tube and mixed thoroughly. The contents were cooled on ice for 10 minutes and spun at 5000 rpm for 5 minutes at 4°C.
- To the supernatant, 200 μ l of ammonium acetate (10 M) was added, mixed well and allowed to stand on ice for 15 minutes. The contents were centrifuged at 13,000 rpm for 5 minutes at 4°C.
- The supernatant was taken in fresh tube and 600 μ l of isopropanol was added to each tube to precipitate nucleic acids.
- The tubes were kept at -20°C for 30 minutes and were centrifuged at 14,000 rpm for 5 minutes at 4°C to pellet the nucleic acids.
- The supernatant was discarded, the pellet was air dried., washed with 70 per cent ethyl alcohol and air dried again by keeping tubes open in laminar air flow cabinet.
- The dried pellet was dissolved in 100 μ l of TE (T₁₀E₁) buffer and incubated at 60°C for 10 minutes.

- The DNA content was quantified using UV spectrophotometer at λ 260 nm and λ 280 nm. The DNA was diluted using T₁₀E₁ buffer to get final DNA concentration of 10 ng/ μ l.

3.4.3 RAPD-PCR

A. Materials

1. Template DNA

Source - Crude DNA extracts from leaves of 13 genotypes

2. Random primers (Kit C and D of decamer primers)

Source - Operon Technologies Inc. Alameda, USA

3. Taq DNA polymerase with 10 x Taq assay buffer

Source - M/S Bangalore Genei Pvt. Ltd. Bangalore

4. dNTPS: dNTPS mix was obtained from M/S Bangalore Genei Pvt. Ltd. Bangalore

5. Chemicals: Molecular biology grade were obtained from Hi-Media, Mumbai.

6. Thermocycler: Master cycler gradient ^R of eppendorf AG, Barkhausenweg 1, 22339 Hamburg, Germany was used for cyclic amplification of DNA.

B. Reaction mix

One primer at a time was used to search molecular polymorphism in 13 genotypes by RAPD-PCR assay, with DNA from 13 plants of pepper cultivars as templates. The master mix required for 13 reactions was prepared afresh to avoid handling errors (Appendix V). The master mix was distributed to 13 tubes (24 μ l per tube) and 1 μ l of the template DNA from the respective plants was added to make the total reaction volume to

25 μ l. The amplification mixture in each tube was overlaid with 20 μ l mineral oil to avoid evaporation.

C. PCR-amplification

The PCR amplification was done by following method proposed by Castrillo and Brooks (1998) with certain modifications.

Stage	Step	Temperature (°C)	Duration (min.)	Number of cycles	
I	1	Denaturation	94	5	1
II	1	Denaturation	94	1	40
	2	Annealing	35	1	
	3	Extension	72	2	
III	1	Extension	72	5	1
	2	Dump	4	-	-

After the completion of 42 cycles, the samples were held at 4°C, in the thermal cycler. All the contents were loaded onto the agarose gels (Appendix VI) for electrophoresis.

D. Separation of amplified products by agarose gel electrophoresis

The amplified product were separated on 1 per cent agarose gel using tris borate EDTA buffer (pH 8.3) along with λ /Hind III + ϕ x 174/Hae III as marker.

3.5 EXPERIMENT III: POLLEN VIABILITY STUDIES

3.5.1 Plant material

The pollen viability study was carried out on 13 selected genotypes of pepper.

3.5.2 Inoculation

The conidial spores from powdery mildew infected leaves were inoculated by dusting on to the healthy leaves of 15 days old seedling of each genotypes under glasshouse conditions.

3.5.3 Observations recorded

Three plants (five flowers per plant) were randomly selected from each of the infected genotypes to study per cent pollen sterility in powdery mildew infected plants. Acetocarmine staining method was followed (Giri and Mishra, 1990) for pollen viability test.

$$\text{Per cent pollen sterility} = \frac{\text{Number of sterile pollen}}{\text{Total number of pollen}} \times 100$$

3.6 EXPERIMENT IV: DEVELOPMENT OF F₁ HYBRID AND THEIR EVALUATION

Inbred lines of nine divergent parents (including bell and hot peppers) were selected from evaluated genotypes and crossed in line x tester mating design. This involves three females (lines) and six males (testers). The salient features of the parents and standard check (Indira) which were used in the study are given in Table 2.

3.6.1 Crossing programme

Flower buds from female parents were emasculated and bagged a day prior to their opening and pollinated with the pollens of identified male parents the next morning. Crossed flowers were tagged for easy identification.

Selfing was ensured by bagging the flower buds of parental genotypes and F₁s (to get F₂'s). Seeds were extracted from red ripe fruits.

3.6.2 Evaluation of F₁ hybrids

The evaluation of 18 F₁ hybrids along with their parents and standard check for various traits was taken up during *kharif* 2002. The details of the experiment are as under.

Table 2. Salient features of the parental genotypes of pepper

Sl. No.	Parents	Source	Features
Female			
1.	California Wonder	NBPGR, New Delhi	Introduction from USA, plants are vigorous, upright, prolific, fruits 3-4 lobed, smooth with medium thick fleshed. Yield about 120-150 q/ha in 125-140 days after transplanting. Susceptible to powdery mildew disease.
2.	Arka Gaurav	IIHR, Bangalore	Selection from variety 'Golden Cal Wonder' with medium to large blocky erect fruits, dark green, thick fleshed and 3-4 lobed. Suitable for <i>rabi</i> and <i>kharif</i> season. Yield 180-250 q/ha. Bacterial wilt resistant.
3.	Yolo Wonder	NBPGR, New Delhi	Prolific, late with green, blocky, drooping fruits. Thick fleshed with 3-4 lobed, yield upto 100-125 q/ha
Males			
1.	Tarihal Local	Germplasm pool of Horticulture Dept., UAS, Dharwad.	Local variety, popular around Dharwad (Karnataka). Fruits are pendent, green fruits, highly pungent and have more ridges and round shaped. Late flowering and tolerant to powdery mildew disease.
2.	4080-15	KRCCH, Arabhavi	Plants are compact, fruits are pendent, long pediceled, 5-6 cm long with sunken blossom end of the fruits. Slightly ridged, pungent and medium green coloured.
3.	KTPI-19	Regional Research Station, Katrain, H.P.	A paprika variety developed at RRS Katrain, the fruits are big, thick fleshed non pungent with high colour value. Susceptible to most of the diseases.

Table 2. Contd.....

Sl. No.	Parents	Source	Features
4.	Chili Yellow	Germplasm pool, Dept. of Horticulture, UAS, Dharwad	Plants are medium to tall stature. Anthers are yellow coloured, fruits are slender and elongate dark green, leaves are dark greened. Tolerant to powdery mildew disease. Highly pungent.
5.	Goa Local	Germplasm pool, Dept. of Horticulture, UAS, Dharwad	Local variety of coastal area, plants are vigorous, upright fruits light green, companulate to triangular shaped, tolerant to powdery mildew disease.
6.	Guntur Local	Germplasm pool, Dept. of Horticulture, UAS, Dharwad	Plants are tall, dense and fruits are long (7.00-8.00 cm) with 0.52 mg capsaicin/gram of fruit, high yielding potential.
	Standard check		
1.	Indira	Sandoz seed company	It is a commercial hybrid released from 'Sandoz' seed company. High yielding, glossy and dark green blocky fruits. Susceptible to powdery mildew disease

Treatments	: Three females + six males + 18 F ₁ 's and standard check Indira)
Replication	: Three
Design	: RBD
Spacing	: 60 cm x 45 cm
Date of sowing in nursery	: 20 th May 2002
Date of transplanting in mainfield	: 15 th June 2002

3.7 EXPERIMENT V: INHERITANCE PATTERN OF FRUIT SHAPE AND ISOLATION OF TRANSGRESSIVE SEGREGANTS

Out of 18 F₁ hybrids obtained by L x T mating design, three F₁ hybrids were selected and selfed to get F₂ population. Details of the experiment is as follows:

Treatments	: Three F ₂ population + Three F ₁ population of • Arka Gaurav x 4080-15 (250 plants) • Arka Gaurav x Tarihal Local (256 plants) • Yolo Wonder x KTPI-19 (250 plants)
Spacing	: 60 cm x 45 cm in separate blocks for parents F ₁ 's and F ₂ 's along with standard check
Season	: <i>Kharif</i> 2003

Chi-square test was employed to find out inheritance pattern of fruit shape.

To isolate transgressive segregants the plants having required fruit shape index, average fruit weight and fruit yield per plant were compared with better parent and standard check. The plants having higher magnitude over better parent and standard check for aforesaid characters were counted and per cent transgressive segregants with respect to average fruit weight and fruit yield per plant were calculated.

3.8 EXPERIMENT VI: INDUCTION OF MUTATION TO IMPROVE 'TARIHAL LOCAL' CULTIVAR OF BELL PEPPER

3.8.1 Material

The seeds of Tarihal local were treated with different doses of gamma rays at Bhaba Atomic Research Centre (BARC), Trombay, Mumbai.

3.8.2 Details of the experiment

Number of seeds irradiated	: 1000 per treatment
Treatments	: Three (T_1 , T_2 and T_3) + control (unirradiated)
Doses used	: 10 kilorads (KR) (T_1), 15 KR (T_2) and 20 KR (T_3)
Mutagen	: Acute gamma irradiation

3.8.3 Studies in M_2 generation

The M_2 generation was raised by pooling all the seeds in each treatment from 30 randomly selected plants of M_1 population and the seeds were thoroughly mixed. The crop was grown during *kharif* 2003 with a spacing of 60 cm x 45 cm in separate blocks for each treatment. The detailed observations on following mutant types were recorded.

- A. Chlorophyll mutants: Chlorophyll mutants were scored from sixth to fifteenth day old seedlings in M_2 generation.
- B. Viable mutants: Viable mutants deviating from the control plants which are not lethal were recorded upto harvest. The viable mutants such as leaf shape, fruit shape and days to flowering were compared with the control (without irradiation).

3.8.4 Estimation of mutation frequency

The frequency of both chlorophyll and viable mutations were estimated as follows:

$$\text{Mutation frequency (\%)} = \frac{\text{Number of mutations}}{\text{Total number of plants scored}} \times 100$$

3.8.5 Quantitative characters

Seventy five random plants were selected from each treatment and observations were recorded on number of fruits per plant and fruit yield per plant on individual plant basis.

3.9 CULTURAL PRACTICES

3.9.1 Raising of seedlings

The seeds of all the genotypes were sown in raised nursery beds in the Olericulture Unit, Department of Horticulture, University of Agricultural Sciences, Dharwad. Recommended cultural practices were undertaken to raise the seedlings (Anonymous, 2002b).

3.9.2 Field preparation and layout of the experiment

The experimental plots were ploughed and brought to fine tilth. Twenty five tonnes of FYM and 50 per cent of N (75 kg/ha) and entire P_2O_5 (75 kg/ha) and K_2O (50 kg/ha) was incorporated in the soil before transplanting. The experiment was laidout during *rabi* and *kharif* seasons of 2000-2003.

3.9.3 Transplanting and after care

The 45 days old seedlings were transplanted to the main field with spacing of 60 x 45 cm. After one month of transplanting top dressing was

done with remaining 50 per cent N (75 kg/ha). Irrigation was carried out once in four days depending on weather conditions and recommended plant protection measures were taken (Anonymous, 2002b).

3.10 OBSERVATIONS RECORDED

Five plants were randomly selected in each replication per treatment for recording the observations in case of Experiment I and Experiment IV. Whereas, observations were recorded on individual plant basis in F_2 and M_2 populations.

A. Quantitative descriptions

3.10.1 Seedling height

Seedling height of F_1 's was recorded in centimeters (cm), one month after sowing and mean was worked out.

3.10.2 Root length

Root length of F_1 's was recorded in centimeters (cm), one month after sowing and mean was worked out.

3.10.3 Plant height

Plant height was measured in centimeters (cm) at the time of first harvest and average was used for computation.

3.10.4 Plant spread

Measurement were made in east-west and north-south directions and the average was calculated to obtain plant spread in centimeters (cm).

3.10.5 Number of primary branches

Number of primary branches per plant on the main stem at final harvest were counted and mean was calculated.

3.10.6 Number of secondary branches

The number of secondary branches arising from primary branches at final harvest was counted.

3.10.7 Days to 50 per cent flowering

Number of days taken from the date of transplanting for 50 per cent of population to flower was recorded and the mean was worked out.

3.10.8 Average fruit weight

Average weight of the five randomly selected fruits from second harvest was recorded in grams (g).

3.10.9 Fruit length

Fruit length was measured in centimeters (cm) with the help of vernier calipers and the mean was calculated.

3.10.10 Fruit width

Maximum width of fruit was measured in centimeters (cm) using vernier calipers and average was worked out.

3.10.11 Fruit shape index

The polar (L) and equatorial diameter (D) of the fruits was measured with the help of vernier calipers. The shape index was calculated by the formula L/D .

3.10.12 Locules per fruit

Number of locules was counted by cutting the fruit transversely in the middle and the average was calculated.

3.10.13 Pericarp thickness

The pericarp thickness was measured in centimeters (cm) with the help of vernier caliper and the mean was computed.

3.10.14 Pedicel length

Length of pedicel was measured in centimeters (cm) and the mean was recorded.

3.10.15 Seed weight per fruit

Fresh seeds of each fruit were weighed in grams (g) and average was calculated.

3.10.16 Number of seeds per fruit

The seed number was counted from each fruit and average was worked out.

3.10.17 Ascorbic acid content

Ascorbic acid content in each fruit was analysed using the method suggested by Ranganna (1977) and expressed in milligrams/100 gram fresh weight (mg/100 g).

3.10.18 Total soluble solids (TSS)

A drop of juice was used to record the TSS (°brix) with the help of Erna hand refractometer at ambient temperature. Read value corrected according to table for temperature correction of the reading.

3.10.19 Number of fruits per plant

Total number of fruits harvested from all the pickings were pooled and average number of fruits was calculated.

3.10.20 Fruit yield per plant

Fruit weight per plant was recorded in kilograms (kg) for green fruits from each plant and mean was computed.

3.10.21 Per cent powdery mildew disease index

All the plants in each of the entries for each replication were scored for powdery mildew disease using the score card given below. Observations were recorded at first picking.

Score	Description	Number of plants in the category
0	Plant completely free from the disease	X ₁
1	Upto 25% of plants affected	X ₂
2	Upto 25-50% of plants affected	X ₃
3	Upto 50-75% of plants affected	X ₄
4	>75% of plants affected	X ₅

(Mulge, 1992)

Powdery mildew disease index (PMDI) was computed for each entry with the following formula and expressed in percentage.

$$\text{PMDI} = \frac{0 \times X_1 + 1 \times X_2 + 2 \times X_3 + 3 \times X_4 + 4 \times X_5}{4 \times (X_1 + X_2 + X_3 + X_4)} \times 100$$

B. Qualitative descriptions

3.10.22 Leaf shape

Leaf shape was recorded at vegetative growth stage (Srivastava *et al.*, 2001).

3.10.23 Fruit shape

Fruit shape was recorded at near maturity stage of plants (Srivastava *et al.*, 2001).

3.10.24 Pungency

The green fruits were evaluated for pungency by organoleptic method. The arbitrary score 1 to 4 given as below.

Score	Degree of pungency
1	Mild pungent
2	Moderately pungent
3	Pungent
4	Highly pungent

3.11 STATISTICAL ANALYSIS AND INTERPRETATION OF THE DATA

3.11.1 Evaluation of genotypes for variability and genotype x environment (G x E) interaction

3.11.1.1 Analysis of variance (ANOVA)

Replication wise mean values of genotypes were used for performing the analysis of variance both in *rabi* (R) and *kharif* (K) seasons. The ANOVA for G x E interaction was constituted by pooling the values of R and K.

The structure of ANOVA is as follows

Source of variation	Individual seasons			
	d.f.	MSS	Expected MSS	Cal.f
Replication	(r-1)	M ₁		(M ₁ /M ₃)
Genotype	(g-1)	M ₂	$\sigma^2e + \sigma^2g$	(M ₂ /M ₃)
Error	(r-1)(g-1)	M ₃	σ^2e	
Total	(rg-1)			
Pooled environment				
Replication	(r-1)	M ₁		
Environment (E)	(e-1)	M ₂	$\sigma^2e + \sigma^2gy + rg\sigma^2g$	
Genotype (G)	(g-1)	M ₃	$\sigma^2e + r\sigma^2gy + ry\sigma^2g$	(M ₃ /M ₅)
G x E	(e-1)(g-1)	M ₄	$\sigma^2e + r\sigma^2gy$	(M ₄ /M ₅)
Error	(r-1)(gy-1)	M ₅	σ^2e	
Total	(rgy-1)			

Where, r, g and y represent number of replications, genotypes and year respectively.

3.11.1.2 Estimation of genotypic and phenotypic variances

Genotypic and phenotypic variance were computed based on the expected mean sum of squares (MSS) from the ANOVA table as follows:

1. Variances for individual seasons

$$V_g = \frac{M_2 - M_3}{r} \quad V_e = M_3$$

$$V_p = V_g + V_e$$

Where,

V_g = Genotypic variance

V_p = Phenotypic variance

V_e = Environmental variance

2. Variances for pooled environment

$$V_e = M_5$$

$$V_g = \frac{M_3 - M_4}{ry}$$

$$V_{g \times e} = \frac{M_4 - M_5}{r}$$

$$V_p = V_e + V_g + V_{ge}$$

Where,

V_{ge} = Variance due to genotype and seasons

3.11.1.3 Genotypic (GCV) and phenotypic (PCV) coefficient of variations

Genotypic (GCV) and phenotypic (PCV) coefficient of variation were worked out as suggested by Burton (1952) and are as follows:

$$\text{GCV (\%)} = \frac{\sqrt{\text{Genotypic variance } (\sigma^2_g)}}{\text{General mean of the character } (\bar{x})} \times 100$$

$$\text{PCV (\%)} = \frac{\sqrt{\text{Phenotypic variance } (\sigma^2_p)}}{\text{General mean of the character } (\bar{x})} \times 100$$

3.11.1.4 Heritability in broad sense

Heritability coefficient (h^2) was computed for each character as ratio of genotypic variance to the total variance as suggested by Hanson *et al.* (1956).

$$h^2 = \sigma^2_g / \sigma^2_p \times 100$$

3.11.1.5 Genetic advance

Genetic advance (GA) for each character was computed by adopting the formula given by Johnson *et al.* (1955).

$$\text{GA} = (h^2) (k) \sigma_p$$

Where,

h^2 = heritability coefficient

k = selection differential which is equal to 2.06 at 5 per cent intensity

σ_p = phenotypic standard deviation of the trait

3.11.1.6 Genetic advance over mean (GAM)

$$\text{GAM} = \frac{\text{GA}}{\bar{X}} \times 100$$

Classification of GCV, PCV, heritability and genetic advance values

Genetic components	Range			Reference
	Low (%)	Medium (%)	High (%)	
GCV and PCV	0-10	10-20	>20	Shivasubramanian and Menon (1973)
Heritability	0-30	30-60	>60	Robinson <i>et al.</i> (1949)
Genetic advance	0-10	10-20	>20	Johnson <i>et al.</i> (1955)

3.11.2 Genetic diversity

3.11.2.1 Mahalanobis's D² analysis

Mahalanobis (1936) D² statistic was used for assessing the genetic divergence between different populations. The D² analysis was carried out using the mean values of two seasons combined for each trait recorded. Mahalanobis generalised distance (D²) between any two population is given by the formula.

$$D^2 = \sum \sum \lambda_{ij} \sigma_i \sigma_j$$

Where,

D² = Square of generalised distance

λ_{ij} = Reciprocal of common dispersal matrix

$$\sigma_i = (\mu_{i1} - \mu_{i2})$$

$$\sigma_j = (\mu_{j1} - \mu_{j2})$$

μ = General mean

Since the formula for computation requires inversion of higher order determinant, transformation of the original correlated under standardized character mean (X_s) to standardized uncorrelated variable (Y_s) was done to simplify the computational procedure. The D² values were obtained as the sum of squares of the differences between pairs of corresponding uncorrelated (Y_s) values of any two genotypes (Rao, 1952).

3.11.2.2 Clustering of D^2 values

All the $n(n-1)/2$ D^2 values were clustered using Tocher's method described by Rao (1952).

3.11.2.3 Intra and inter cluster distance

The intra and inter cluster distance were calculated by the following formula described by Singh and Chaudhary (1979).

$$\text{Sum of intra cluster distance} = \frac{\sum D_i^2}{n}$$

Where,

$\sum D_i^2$ = Sum of distance between all possible combination of the entries included in the cluster.

n = Number of all possible combination

$$\text{Square of inter cluster distance} = \frac{\sum D_{ij}^2}{n_i n_j}$$

Where,

$\sum D_{ij}^2$ = Sum of distance between all possible combination ($n_i n_j$) of the entries included in the clusters

n_i = Number of entries in cluster i

n_j = Number of entries in cluster j

3.11.3 Heterosis and combining ability

3.11.3.1 Line x tester analysis

3.11.3.1.1 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) and test of significance for all the traits was carried out by using mean values is suggested by Panse and Sukhatme (1967).

ANOVA for parents and hybrids

Source of variation	Degrees of freedom (df)	Mean sum of square (MSS)
Replication	(r-1)	Mr
Parents (P)	(p-1)	Mp
Females (F)	(f-1)	Mf
Males (M)	(m-1)	Mm
Female vs male	1	Mfm
Hybrid (h)	(h-1)	Mw
Parents vs hybrids	1	Mph
Error	(r-1) (g-1)	Me

Where,

$$g = (m+f+mf); P = (m+f) \text{ and } h = mf$$

3.11.3.1.2 Estimation of heterosis

The magnitude of heterosis was estimated in relation to mid parent, better parent, best parent and standard check (SC) (Indira) values as percentage increase or decrease of F_1 's over their respective parents. The estimation of heterosis was carried out following methods of Turner (1953) and Hayes *et al.* (1955).

$$\text{a. Heterosis over mid parent (MP) (\%)} = \frac{F_1 - MP}{MP} \times 100$$

$$\text{b. Heterosis over better parent (BP) (\%)} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{c. Heterosis over best parent (BSP) (\%)} = \frac{F_1 - BSP}{BSP} \times 100$$

$$\text{d. Standard heterosis (\%)} = \frac{F_1 - SC}{SC} \times 100$$

Significance test was done by comparing the mean deviation with values of critical difference (CD) obtained separately from MP, BP, BSP and SC by using the following formula.

$$\text{CD for heterosis over MP} = \frac{\sqrt{3\text{EMS}}}{2r} \times \text{table 't' value}$$

$$\text{CD for heterosis over BP, BSP and SC} = \frac{\sqrt{2 \times \text{EMS}}}{r} \times \text{table 't' value}$$

Where,

r= number of replication

t= table 't' value at error degrees of freedom

EMS= Error mean sum of square

3.11.3.2 Combining ability analysis

3.11.3.2.1 Analysis of variance (ANOVA)

For combining ability analysis, only crosses were considered and analysed based on the line x tester analysis as proposed by Kempthorne (1957) and emphasised by Arunachalum (1974).

Source	Degrees of freedom (df)	Mean sum of square (MSS)	Expectation
Replication	(r-1)		
Lines (females)	(d-1)	M ₁	$\sigma^2e + \sigma^2dt + r\sigma^2d$
Testers (males)	(t-1)	M ₂	$\sigma^2e + \sigma^2dt + r\sigma^2t$
Line x testers	(d-1) (t-1)	M ₃	$\sigma e + \sigma^2dt$
Error	(r-1) (dt-1)	M ₄	σ^2e

Where,

d and t are number of line and testers respectively

COV (half sibs) and COV (full sibs) were estimated by equating the observed mean sum of squares to their expectations. Since number of lines and testers used were different, weighed average of COV (half sibs) was computed by deriving least square estimates as proposed by Arunachalum (1974). Least square estimates were derived as follows:

$$Y = \text{COV (half sibs)} = \frac{\frac{1}{2}[t(a+c-2b)+d(b+c-2a)]}{dt-t^2-d^2}$$

$$X = \text{COV (full sibs)} = \frac{[t(a+c-2b)+d(b+c-2a)-\frac{1}{2}[t^2(a+c)+d^2(b+c)-dt(a+b)]]}{dt-t^2-d^2}$$

Where,

$$a = \frac{M_2-M_4}{r} \quad b = \frac{M_1-M_4}{r} \quad c = \frac{M_3-M_4}{r}$$

The least square estimates of x and y were used to compute components of combining ability variance as follows:

$$\sigma^2_{gca} = y \text{ and } \sigma^2_{sca} = x-2y$$

3.11.3.2.2 Estimation of combining ability effects

The combining ability effects were estimated as follows:

a. General combining ability effects (*gca*) of i^{th} line

$$g_i = \frac{X_{i..}}{tr} - \frac{X_{...}}{dtr}$$

b. General combining ability effects (*gca*) of j^{th} line

$$g_j = \frac{X_{.j.}}{tr} - \frac{X_{...}}{dtr}$$

Where,

$X_{i..}$ = Total of i^{th} line over all testers and replications

$X_{.j.}$ = Total of j^{th} tester over all lines and replications

$$\frac{X_{...}}{dtr} = \text{Over all mean}$$

C. Specific combining ability effects (sca) due to ij^{th} cross

$$S_{ij} = \frac{X_{ij}}{r} - \frac{X_{...}}{dtr} - \frac{X_{.j}}{dr} - \frac{X_{i...}}{dtr}$$

Where,

X_{ij} = Total of ij^{th} cross over all the lines and replications

3.11.3.2.3 Standard errors of combining ability effects

The variance of different estimates was calculated by multiplying the error variance by their respective coefficients as shown below.

Error variance = M_4 = error mean sum of squares from ANOVA for combining ability

Variance of (g_i) lines = M_4/rd

Variance of (g_j) testers = M_4/rt

Variance of hybrids (S_{ij}) = M_4/r

The square root of variance of the estimates was used as standard error meant for testing the significance of combining ability analysis.

3.11.4 Chi-square test

Chi-square test was employed to test the segregation ratio for fruit shape (i.e., blocky fruit shape with $FSI \approx 1.30-1.5$). The statistic was computed using the formula given below.

$$\chi^2 = [(observed\ mean) - (expected\ mean)]^2 / expected\ mean$$

The chi-square value was compared with table chi-square at (1) degree of freedom for the significance. Non significance of chi-square value indicated the adequacy of additive dominance model.

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the experiments conducted during 2000-2003 at Olericulture Unit, Department of Horticulture, University of Agricultural Sciences, Dharwad on genetic studies in bell pepper are presented in this chapter.

4.1 EVALUATION OF GENOTYPES

Twenty-five genotypes of pepper comprised of large fruited bell peppers, hot peppers, paprika type and local cultivars were evaluated during *rabi* 2000 and *kharif* 2001.

These genotypes were subjected to variability, genotype x environment (G x E) interaction and genetic diversity studies. The screening for powdery mildew disease resistance among the varieties was taken up during *rabi* season as there was no incidence of the disease during *kharif* season. The results obtained are presented here.

4.1.1 Analysis of variance

Analysis of variance (ANOVA) for various character for individual seasons and pooled environment is presented in Table 3. The results indicated significant variation among the genotypes for all the characters in *rabi* season *kharif* season and over pooled environments. Highly significant variation was observed for most of the characters. The significant difference was noticed due to genotype x environment (G x E) interaction except for average fruit weight, locules per fruit, pericarp thickness and number of seeds per fruit which were statistically non-significant.

4.1.2 Genetic variability, genotype x environment (G x E) interaction

The mean values of all the genotypes tested for 19 characters are given in Appendix VII. Genetic variability including character mean,

Table 3. Analysis of variance for 19 characters for individual seasons and over seasons in pepper genotypes

Source of variance	Degree of freedom (df)			Plant height			Plant spread			Number of primary branches			Number of secondary branches			Days to 50 per cent flowering		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Replication	2	2	2	56.617	1.812	28.390	42.265	1.390	22.086	0.116	0.273	0.140	0.038	0.084	0.0261	0.254	2.111	0.0273
Genotype (G)	24	24	24	841.54**	1080.02**	1861.03**	369.272**	795.12**	938.360**	1.760**	4.21**	5.002**	9.161**	10.348**	18.977**	82.352**	3.111**	137.564**
Seasons (y)	-	-	1	-	-	3.016	-	-	240.920**	-	-	2.968**	-	-	2.777**	-	-	3.466**
G x Y	-	-	24	-	-	50.594**	-	-	223.476**	-	-	0.224**	-	-	0.314**	-	-	12.027**
Error	48	48	96	7.538	5.781	9.043	7.071	5.124	7.053	0.130	0.032	0.083	0.066	0.060	0.085	0.767	0.611	1.351
S.Em±				2.24	1.963	1.74	2.17	1.848	1.533	0.295	0.146	0.1667	0.209	0.199	0.168	0.715	0.831	0.671
CV%				4.66	4.05	5.08	6.17	4.96	5.98	11.83	5.36	9.05	4.18	3.84	4.67	2.39	2.75	

Source of variance	Degree of freedom (df)			Average fruit weight			Fruit length			Fruit width			Fruit shape index			Locules per fruit		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Replication	2	2	2	31.858	47.913	9.268	0.169	0.592	0.350	0.369	0.115	0.0963	0.102	0.0057	0.016	0.0017	0.011	0.0042
Genotype (G)	24	24	24	1085.62**	735.45**	1790.812**	21.17**	29.169**	47.96**	7.90**	5.65**	12.776**	21.896**	16.357**	36.966**	2.090*	2.119**	4.204**
Seasons (y)	-	-	1	-	-	405.374**	-	-	0.42	-	-	2.139**	-	-	0.296*	-	-	0.027*
G x Y	-	-	24	-	-	30.017*	-	-	2.364**	-	-	0.506**	-	-	1.504**	-	-	0.009
Error	48	48	96	12.337	21.44	16.914	0.107	0.040	0.071	0.073	0.023	0.049	0.145	0.089	0.123	0.015	0.007	0.008
S.Em±				2.87	3.78	2.375	0.267	0.164	0.154	0.222	0.12	0.127	0.311	0.243	0.202	0.100	0.067	0.601
CV%				17.46	27.48	22.27	5.373	3.23	4.34	8.83	4.94	6.85	13.71	11.15	12.83	3.996	2.62	3.36

* Significant at 5 per cent probability

** Significant at 1 per cent probability

RK - Over two seasons

Table 3. Contd.....

Source of variance	Degree of freedom (df)			Pericarp thickness			Pedicel length			Seed weight/fruit			Number of seeds/fruit			Ascorbic acid content		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Replication	2	2	2	0.0020	0.031	0.010	0.0065	0.020	0.0247	0.152	0.003	0.0171	687.81	7.000	1422.50	964.87	1285.00	1234.50
Genotype (G)	24	24	24	0.0819**	0.057**	0.126**	1.529**	1.614**	3.057**	12.99**	10.414**	20.874**	12670.969**	13093.973**	25443.6**	2949.80**	3498.28**	5194.60**
Seasons (Y)	-	-	1	-	-	0.025	-	-	0.215**	-	-	0.311*	-	-	313.927	-	-	12530.39**
G x Y	-	-	24	-	-	0.010	-	-	0.087**	-	-	0.349**	-	-	328.72	-	-	1115.54**
Error	48	48	96	0.0022	0.003	0.004	0.018	0.012	0.015	0.037	0.036	0.047	229.763	201.003	216.269	180.52	349.82	277.37
S.Em±				0.038	0.047	0.037	0.108	0.090	0.069	0.158	0.156	0.125	13.268	34.55	8.490	10.970	15.271	9.62
CV%				16.55	22.70	23.97	5.67	4.55	5.06	7.75	7.68	8.89	11.32	28.91	10.03	7.10	10.93	9.27

Source of variance	Degree of freedom (df)			Total soluble solids			Number of fruits/plant			Fruit yield/plant			Per cent powdery mildew index		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Replication	2	2	2	0.101	0.021	0.0207	15.312	2918.12	897.65	0.0048	0.034	0.339	2.968	-	-
Genotype (G)	24	24	24	3.299**	3.170**	6.435**	2948.50**	3686.22**	6505.122**	0.255**	0.199**	0.538**	423.74**	-	-
Seasons (Y)	-	-	1	-	-	0.992**	-	-	0.588	-	-	0.094*	-	-	-
G x Y	-	-	24	-	-	0.021*	-	-	470.397**	-	-	0.021**	-	-	-
Error	48	48	96	0.014	0.011	0.013	79.67	196.46	43.413	0.0098	0.0092	0.007	2.12	-	-
S.Em±				0.097	0.085	0.066	7.29	11.44	3.804	0.081	0.078	0.048	1.188	-	-
CV%				2.01	1.80	1.94	16.23	28.52	11.97	18.84	20.85	16.53	3.29	-	-

* Significant at 5 per cent probability

** Significant at 1 per cent probability

RK - Over two seasons

range, environmental, genotypic and phenotypic variances, genotypic and phenotypic coefficient of variability, heritability, genetic advance as per cent mean and G x E interaction for different characters are presented in Table 4.

4.1.2.1 Plant height

The plant height varied between 24.48 to 86.47 centimeters in *rabi* season and 24.66 to 88.64 centimeters in *kharif* season. The environmental variance was low (5.781) in *kharif* season compared to *rabi* season (7.538) and over two seasons (9.04). Similarly, the genetic variance was higher in *kharif* season (358.08) than in *rabi* season (278.00) and over two seasons (301.39). The variance due to genotypic and environment ($V_{g \times e}$) was 13.85.

The phenotypic coefficient of variation (PCV) recorded was 28.68, 32.14 and 30.50 per cent for *rabi* season, *kharif* season and over two seasons, respectively. The GCV observed was 28.30, 31.88 and 28.21 per cent in *rabi* season, *kharif* season and over two seasons, respectively. High magnitude of heritability and genetic advance as per cent mean was noticed in *kharif* season (98.40% and 65.14%) compared to *rabi* season and over two seasons.

4.1.2.2 Plant spread

The maximum plant spread was noticed in *kharif* season (45.67 cm) followed by *rabi* season (43.13 cm) and over two seasons (44.80 cm). Higher range of plant spread was noticed in *kharif* (22.53 to 85.27 cm). The environmental variance of 7.07, 5.12 and 7.05 was recorded in *rabi*, *kharif* and over two seasons, respectively. The phenotypic variance was higher in *rabi* season (198.34) and over two seasons (127.804) compared to *kharif* season (56.849) whereas, variance due to G x E was 72.41.

Table 4. Estimation of genetic parameters for 19 characters for individual seasons and over two seasons in pepper genotypes

Character	Plant height (cm)			Plant spread (cm)			Number of primary branches			Number of secondary branches			Days to 50 per cent flowering		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Mean	58.91	59.36	58.26	43.13	45.67	44.80	3.06	3.33	3.18	6.13	6.38	6.23	36.61	36.96	36.84
Range	25.48-86.47	24.66-88.64	25.06-88.36	25.40-70.53	22.53-85.27	29.27-75.43	2.00-5.13	2.07-6.07	2.13-5.60	4.00-11.93	4.07-12.47	4.07-12.20	31.00-52.00	29.00-48.33	30.67-50.17
Ve	7.538	5.781	9.043	7.071	5.124	7.053	0.130	0.032	0.083	0.066	0.060	0.085	0.767	0.611	1.351
Vg	278.00	358.08	301.739	120.733	51.725	119.147	0.551	3.389	0.796	3.032	3.429	3.111	27.195	3.000	22.702
Vgxy			13.85			72.414			0.047			0.076			3.559
Vp	285.538	363.861	224.632	127.804	56.849	198.341	0.681	0.879	0.926	3.098	3.489	3.272	27.962	3.611	27.612
PCV (%)	28.68	32.14	30.5	26.21	35.87	27.96	27.03	32.33	28.65	28.73	29.29	28.72	14.44	13.06	12.95
GCV (%)	28.30	31.88	28.21	25.48	35.53	26.37	24.20	31.89	26.94	28.42	29.03	28.44	14.24	12.77	12.80
h ² (%)	97.40	98.40	87.60	94.50	98.10	89.00	80.80	97.20	88.40	97.90	98.30	98.10	97.30	95.60	97.70
GAM (%)	57.53	55.14	54.39	51.01	72.50	51.23	44.77	64.86	52.20	57.91	59.25	58.11	28.91	25.70	26.06

Character	Average fruit weight (gm)			Fruit length (cm)			Fruit width (cm)			Fruit shape index			Locules per fruit		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Mean	20.12	16.85	18.39	6.09	6.20	6.14	3.27	3.08	3.20	2.78	2.67	2.73	3.09	3.11	3.10
Range	1.85-59.38	3.52-47.98	2.69-53.03	2.57-11.63	2.71-13.01	2.64-12.32	0.75-6.48	1.25-5.59	1.00-5.91	0.81-10.97	0.80-8.34	0.86-9.66	2.00-4.00	2.00-4.00	2.00-4.00
Ve	12.337	21.440	16.914	0.107	0.040	0.071	0.073	0.023	0.049	0.145	0.089	0.123	0.015	0.007	0.008
Vg	357.761	238.00	293.466	7.021	9.709	7.599	2.609	1.876	2.045	7.250	5.422	5.910	0.692	0.704	0.699
Vgxy			4.368			0.764			0.152			0.460			0.0003
Vp	370.098	259.44	314.748	7.128	9.749	8.434	2.689	1.899	2.246	7.395	5.511	6.493	0.707	0.711	0.707
PCV (%)	95.61	95.59	94.45	43.81	50.37	46.12	50.16	44.51	46.69	97.97	87.83	90.88	27.25	27.08	27.08
GCV (%)	94.00	91.55	93.44	43.48	50.26	46.04	49.47	44.23	45.96	97.01	87.12	90.70	26.96	26.96	26.96
h ² (%)	96.70	91.70	97.90	98.50	99.60	99.60	97.20	98.80	96.90	98.00	98.40	99.60	97.80	99.10	99.10
GAM (%)	190.41	180.65	190.43	89.00	103.39	74.79	100.31	90.91	93.12	196.76	178.28	186.81	54.69	55.31	55.16

Table 4. Contd.....

Character	Pericarp thickness (cm)			Pedicel length (cm)			Seed weight/fruit (g)			Number of seeds/fruit			Ascorbic acid content (mg/100g)		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Mean	0.28	0.25	0.27	2.35	2.43	2.40	2.50	2.49	2.44	145.24	148.09	146.95	189.21	171.17	180.05
Range	0.08 - 0.62	0.09 - 0.53	0.09 - 0.56	1.38 - 3.88	1.43 - 4.18	1.40 - 4.03	0.34 - 6.95	0.50 - 7.07	0.47 - 7.01	44.27 - 303.23	46.40 - 343.33	45.55 - 324.78	103.33 - 229.60	106.60 - 212.53	123.50 - 213.70
Ve	0.002	0.003	0.004	0.108	0.090	0.069	0.037	0.036	0.047	229.76	201.00	216.269	180.52	349.82	277.37
Vg	0.027	0.018	0.019	0.503	0.534	0.495	4.318	3.459	3.421	4147.07	4297.66	4185.81	923.09	1049.486	679.843
Vgxy	-	-	0.001	-	-	0.024	-	-	0.101	-	-	37.449	-	-	279.39
Vp	0.029	0.021	0.024	0.611	0.624	0.588	4.355	3.495	3.558	4376.83	4498.65	4439.565	1103.61	1399.306	1236.573
PCV (%)	60.23	57.79	56.47	30.69	30.42	30.13	83.59	75.23	76.81	45.55	45.27	45.07	17.56	21.63	17.31
GCV (%)	57.91	53.14	55.01	30.17	30.08	29.67	83.23	74.83	76.50	44.34	44.27	42.26	16.06	18.67	16.01
h ² (%)	92.50	84.60	94.90	96.60	97.80	97.00	99.10	99.30	99.20	94.80	95.50	87.90	83.60	74.50	85.50
GAM (%)	114.29	100.00	107.40	61.28	61.13	60.00	170.40	153.01	156.97	88.90	89.13	81.62	30.25	33.18	30.49

Character	Total soluble solids (*brix)			Number of fruits/plant			Fruit yield/plant (kg)			Powdery mildew index (%)		
	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK	Rabi (R)	Kharif (K)	RK
Mean	5.94	5.77	5.85	54.99	52.85	53.89	0.53	0.46	0.60	44.23	-	-
Range	4.00 - 7.67	4.00 - 7.53	4.00 - 7.60	17.30 - 133.07	13.40 - 127.87	18.45 - 111.55	0.28 - 1.71	0.26 - 1.55	0.28 - 1.60	24.02 - 60.50	-	-
Ve	0.014	0.011	0.013	79.672	196.465	43.413	0.0098	0.0092	0.007	2.12	-	-
Vg	1.095	1.053	1.069	956.278	1163.25	1076.951	0.082	0.063	0.086	140.54	-	-
Vgxy	-	-	2.667	-	-	142.328	-	-	0.005	-	-	-
Vp	1.067	1.064	3.749	1035.951	1359.715	1262.692	0.092	0.072	0.0978	142.66	-	-
PCV (%)	17.79	17.88	17.81	58.53	69.78	60.40	57.69	58.48	46.75	27.00	-	-
GCV (%)	17.63	17.79	17.74	56.24	64.54	58.26	54.52	54.64	46.97	26.80	-	-
h ² (%)	98.70	99.00	99.30	92.30	85.60	93.00	89.30	87.30	102.00	98.50	-	-
GAM (%)	36.03	36.39	36.41	111.29	122.97	115.75	105.66	106.52	31.72	54.80	-	-

The phenotypic coefficient of variance (PCV) recorded was 26.21, 35.87 and 27.96 per cent while, genotypic coefficient of variation (GCV) recorded was 25.48, 35.53 and 36.37 per cent in *rabi*, *kharif* and over two seasons, respectively. High heritability (98.10%) and genetic advance as per cent mean (72.50%) was recorded in *kharif* season compared to *rabi* season and pooled environment.

4.1.2.3 Number of primary branches

The highest number of primary branches was observed during *kharif* season (3.33) followed by pooled environment (3.18) while, the range was from 2.00 to 5.13 centimeters, 2.07 to 6.07 centimeters and 2.13 to 5.60 centimeters in *rabi* season, *kharif* season and pooled environment respectively. The environmental variance and genotypic variance was higher in *rabi* (0.13, 0.551) and *kharif* season (0.032, 3.389). While phenotypic variance was higher (0.93) over two seasons when compared with *rabi* and *kharif* seasons individually. The variance due to G x E was 0.047.

The highest PCV (32.33%), GCV (31.39%), heritability (97.20%) and genetic advance as per cent mean (64.86%) was observed in *kharif* season.

4.1.2.4 Number of secondary branches

In *kharif* season more number of secondary branches (6.38) were recorded compared to *rabi* season (6.13) and over two seasons (6.23). The environmental variance observed was 0.066 (*kharif*), 0.060 (*rabi*) and 0.085 (over two seasons). Both genotypic and phenotypic variances were higher (3.429; 3.489) in *rabi* season compared to *kharif* season and pooled environment.

The PCV (29.29%) and GCV (29.03%) were of higher magnitude in *kharif* season than in *rabi* and pooled seasons. Heritability (98.30%) and

genetic advance as per cent season (59.25%) were high in *kharif* and *rabi* seasons, respectively.

4.1.2.5 Days to 50 per cent flowering

Early 50 per cent flowering was noticed in *rabi* season (36.61) followed by pooled environment (36.84) and *kharif* season (36.96). The maximum range was observed in *rabi* season (31.00 to 52.00 days).

Genotypic (27.195) and phenotypic (27.962) variances were high in *rabi* season compared to *kharif* and over two seasons. Environmental variance was highest over pooled environment (1.351).

Highest PCV (14.44%), GCV (14.24%) and genetic advance as per cent mean (28.91%) was recorded in *rabi* season whereas, heritability was of higher value (97.70%) over pooled environment.

4.1.2.6 Average fruit weight

The maximum fruit weight (20.12 g) was recorded during *kharif* season while, the range was between 1.85 to 59.3 grams, 3.52 to 47.98 grams and 2.69 to 53.03 grams in *rabi*, *kharif* and over two seasons, respectively. The environmental variance observed was highest in *kharif* season (21.44) and lowest in *rabi* season (12.37). The genotypic (357.76) and phenotypic variance (370.10) was high in *rabi* season compared to *kharif* and pooled environment. Variance due to G x E was 4.37.

The variability due to phenotype and genotype was 95.61 (*rabi*), 95.59 (*kharif*) and 94.45 (over two seasons) and 94.00 (*rabi*), 91.55 (*kharif*) and 93.44 (over two seasons) per cent respectively. Heritability (97.90%) and genetic advance as per cent mean (190.43%) was highest over the pooled environment.

4.1.2.7 Fruit length

The average fruit length was varied from 2.57 to 11.63, 2.71 to 13.01 and 2.64 to 12.32 centimeters during *rabi*, *kharif* and over pooled environment, respectively. The highest fruit length was observed in *kharif* (6.20) season. The variance due to genotype (9.709) and phenotype (9.749) was high in *kharif* season. The genotype x environment variance was 0.76.

The PCV observed was 43.81, 50.37 and 46.12 per cent and GCV recorded was 43.48, 50.26 and 46.04 per cent for *rabi* season, *kharif* season and over two seasons, respectively. The heritability was high for *kharif* season (99.60%) compared to *rabi* season (98.50%) and over two seasons (99.60%). Similarly, the genetic advance as per cent mean recorded was 89.00 per cent for *rabi* season, 103.39 per cent for *kharif* season and 74.79 per cent over two seasons.

4.1.2.8 Fruit width

The average fruit width in *rabi*, *kharif* and over two seasons was 3.27, 3.08 and 3.20 centimeters with wide range of 0.75 to 6.48 centimeters, 1.25 to 5.59 centimeters and 1.00 to 5.91 centimeters, respectively.

The environmental and genotypic variance was 0.073 and 2.609 respectively in *rabi* season, 0.023 and 2.876 respectively in *kharif* season and 0.049 and 2.045 respectively over two seasons. Variance due to genotype x environment (G x E) was 0.152.

The higher magnitude of PCV (50.16%), GCV (49.47%) and genetic advance as per cent mean (100.31%) was noticed in *rabi* season. While, heritability was high in *kharif* season (98.80%) when compared to *rabi* (97.20%) and over two seasons (96.90%).

4.1.2.9 Fruit shape index

The fruit shape index was ranged between 0.81 to 10.97, 0.80 to 8.34 and 0.86 to 9.66 in *rabi*, *kharif* and over two seasons, respectively. The variance due to environment (0.15) and genotype (7.25) was high in *rabi* season when compared with *kharif* and over two seasons. The variance due to G x E was 0.46.

The PCV and GCV were 97.97 and 97.01 per cent in *rabi* season, 87.83 and 87.12 per cent in *kharif* season and 90.88 and 90.70 per cent over two seasons. The heritability (99.60%) and genetic advance as per cent mean (196.76%) was highest over two seasons and in *rabi* season respectively.

4.1.2.10 Locules per fruit

The number of locules per fruit was ranged from 2.00 to 4.00 in all the seasons. The variance due to genotype (0.704) and phenotype (0.711) was high in *kharif* season. Whereas, environmental variance was high in *rabi* season (0.015).

The PCV (27.08), GCV (26.96%) and heritability (99.10) estimates were of equal magnitude for *kharif* season and over two seasons. While genetic advance as per cent mean was highest for *kharif* season (55.31%), over two seasons (55.16%) and *rabi* season (54.69%).

4.1.2.11 Pericarp thickness

The pericarp thickness was highest in *rabi* season (0.28 cm) compared to *kharif* (0.25 cm). The environmental variance observed was 0.002, 0.003 and 0.004, genotypic variance was 0.027, 0.018 and 0.019 and phenotypic variance was 0.029, 0.021 and 0.024 in *rabi* season, *kharif* season and over two seasons, respectively. The variance due to genotype x environment was 0.001.

The phenotypic (60.23%) and genotypic (53.91%) coefficient of variability was high in *rabi* season along with high heritability (92.50%) and genetic advance as per cent mean (114.29%) when compared with *kharif* season and over two seasons.

4.1.2.12 Pedicel length

The average pedicel length for *rabi* and *kharif* season was 2.35 and 2.43 centimeters respectively. The environmental variance was observed to be 0.108, 0.090 and 0.069 while, genotypic variance was 0.503, 0.534 and 0.495 and phenotypic variance was 0.611, 0.624 and 0.588 during *rabi*, *kharif* and over pooled seasons, respectively.

While considering two seasons separately higher per cent of PCV (30.69%) and GCV (30.17%) was observed during *rabi* season. The variability due to phenotype and genotype over two seasons was 30.13 and 29.67 respectively. Whereas, heritability (97.80%) and genetic advance as per cent mean (61.28%) was of higher magnitude in *kharif* and *rabi* seasons, respectively.

4.1.2.13 Number of seeds per fruit

The average number of seeds per fruit was 145.24, 148.09 and 146.95 in *rabi* season, *kharif* season and over two seasons, respectively. The environmental variance was high (229.76) in *rabi* season. While, genotypic variance was high (4297.66) in *kharif* season. The variance due to genotype x environment interaction was 37.49.

The PCV (45.55%) and GCV (44.34%) was high for *rabi* season whereas, heritability (95.50%) and genetic advance as per cent mean (89.13%) was of high magnitude for *kharif* season.

4.1.2.14 Seed weight per fruit

The average seed weight of 2.50, 2.49 and 2.44 grams was noticed in *rabi*, *kharif* and over two seasons, respectively. The environmental variance over two seasons (0.047) was highest compared to individual seasons. The variance due to genotype was of higher magnitude (4.318) in *rabi* seasons followed by *kharif* (3.459) season. High phenotypic variance of 4.355 was recorded in *rabi* season and variance due to G x E was 0.01.

The higher per cent of PCV (83.59%), GCV (83.23%) and genetic advance as per cent mean (170.40%) was recorded in *rabi* season compared to *kharif* season. While during *kharif* season high heritability was noticed (99.30%).

4.1.2.15 Ascorbic acid content

The *rabi* grown peppers have recorded higher amount of ascorbic acid content (189.21 mg/100 g) when compared to *kharif* grown pepper (171.17 mg/100 g). Whereas during *kharif* season environmental variance (349.82) was of higher magnitude in comparison with *rabi* season (180.52) and over two seasons (277.37). The variances due to genotype (1049.486) and phenotype (1399.306) were also high in *kharif* season. The G x E variance was 279.39.

Similarly, PCV (21.63%), GCV (18.67%) and genetic advance as per cent mean (33.18%) were recorded highest in *kharif* while, heritability (85.50%) showed higher magnitude over two seasons.

4.1.2.16 Total soluble solids

The total soluble solids was 5.94, 5.77 and 5.85 °brix during *rabi* season, *kharif* season and over two seasons. While the variance due to environment was in higher magnitude (0.014) in *rabi* season. Whereas

higher genotypic variance (1.095) and phenotypic variance (3.749) was noticed in *rabi* and over two seasons, respectively. The variance due to genotype x environment interaction was 2.667.

The coefficient variability due to phenotype and genotype was 17.79 and 17.63 per cent respectively in *rabi* season and was 17.88 and 17.79 per cent respectively in *kharif* season. While, over seasons PCV and GCV was 17.81 and 17.74 per cent respectively. The heritability (99.30%) and genetic advance as per cent mean (36.41%) was of higher magnitude over two seasons compared to individual seasons.

4.1.2.17 Number of fruits per plant

The number of fruits per plant was ranged from 17.30 to 133.07, 13.40 to 127.87 and 18.45 to 111.55 with an average of 54.99, 52.85 and 53.89 in *rabi* season, *kharif* season and over two seasons, respectively.

The environmental variance of 196.45 in *kharif* season was higher than *rabi* season (79.672) and over two seasons (43.413). Genotypic (1163.25) and phenotypic (1359.715) variances were high in *kharif* grown crop than during *rabi* and over two seasons. The variance due to G x E interaction was 142.328.

The PCV was recorded to be 58.53, 69.78 and 60.40 per cent, similar trend was noticed for GCV with the magnitude of 56.24, 64.54 and 58.26 per cent respectively for *rabi* season, *kharif* season and over two seasons.

The heritability recorded was high over pooled environment (93.00%) compared to *rabi* season (92.30%) and *kharif* season (85.60%). Whereas, high genetic advance as per cent mean was observed for *kharif* season (122.97%), over two seasons (115.70%) and *kharif* season (111.29%).

4.1.2.18 Fruit yield per plant

The highest fruit yield per plant was exhibited during *kharif* (0.53 kg) and over two seasons (0.60 kg/ha) and the range was from 0.28 to 1.71, 0.26 to 1.55 and 0.28 to 1.60 kilograms in *rabi* season, *kharif* season and over two seasons, respectively. The environmental variance was 0.098, 0.092 and 0.007. While, genotypic variance was 0.082, 0.063 and 0.086 and phenotypic variance was 0.092, 0.072 and 0.098 in *rabi*, *kharif* and over two seasons, respectively. The variance due to interaction (G x E) was 0.005.

The phenotypic coefficient of variability (46.75%) and heritability (102.00%) was highest over two seasons, compared to *rabi* and *kharif* seasons, whereas GCV (54.64%) and genetic advance as per cent mean (106.52%) was highest in *kharif* followed by *rabi* and over seasons.

4.1.2.19 Per cent powdery mildew index

The screening for powdery mildew disease was recorded only during *rabi* season. The disease incidence was ranged from 14.10 to 75.80 per cent with an average of 43.70 per cent. The environmental, genotypic and phenotypic variances were 2.12, 140.24 and 142.86 respectively.

The coefficient of variability due to phenotype and genotype was 27.00 and 26.80 per cent. Whereas, heritability and genetic advance as per cent mean was 98.50 and 54.80 per cent respectively.

4.1.3 Genetic diversity

The material used in the present study exhibited wide range of variability for all the character. The interesting features of this material was the greater variability observed in the fruit characters as observed in variability studies.

The study comprised of 25 genotypes and were subjected to D^2 statistics to assess the genetic diversity.

4.1.3.1 Contribution of each character towards total divergence

Genetic diversity was calculated by using pooled data of each character over two seasons (*rabi* and *khari*). Out of 19 characters (Table 5) studied number of seeds per fruit (55.00%) contributed maximum to the diversity followed by number of fruits per plant (21.67%), ascorbic acid content (15.33%), fruit weight (3.67%), plant height (2.67%), powdery mildew (1.00%) and plant spread (0.67%).

Twenty five genotypes were grouped under seven clusters (Fig. 1) following the method suggested by Tocher (Rao, 1952). Among seven clusters bell pepper genotypes were congregated in Cluster I. While, pungent types were grouped in Cluster II. The mild type paprika was grouped under Cluster III (Table 6).

The cluster II was largest comprising of nine genotypes followed by Cluster I with eight genotypes. While, the Cluster IV contains three genotypes which included local cultivars of northern transitional tract of Karnataka viz., Tarihal Local and Ranebennur Local. Cluster V contains two genotypes (4080-15, 4080-25). Remaining three clusters had one genotype each.

4.1.3.2 Group constellation

The inter cluster and intra cluster D^2 values are given in Table 7 for seven clusters. The maximum divergence ($D^2=279.88$) occurred between Cluster VI and VII.

The minimum distance was observed between Clusters II and III ($D^2=74.98$) indicated close relationship among the genotypes of these clusters.

Table 5. Contribution of different characters towards total divergence of pepper genotypes

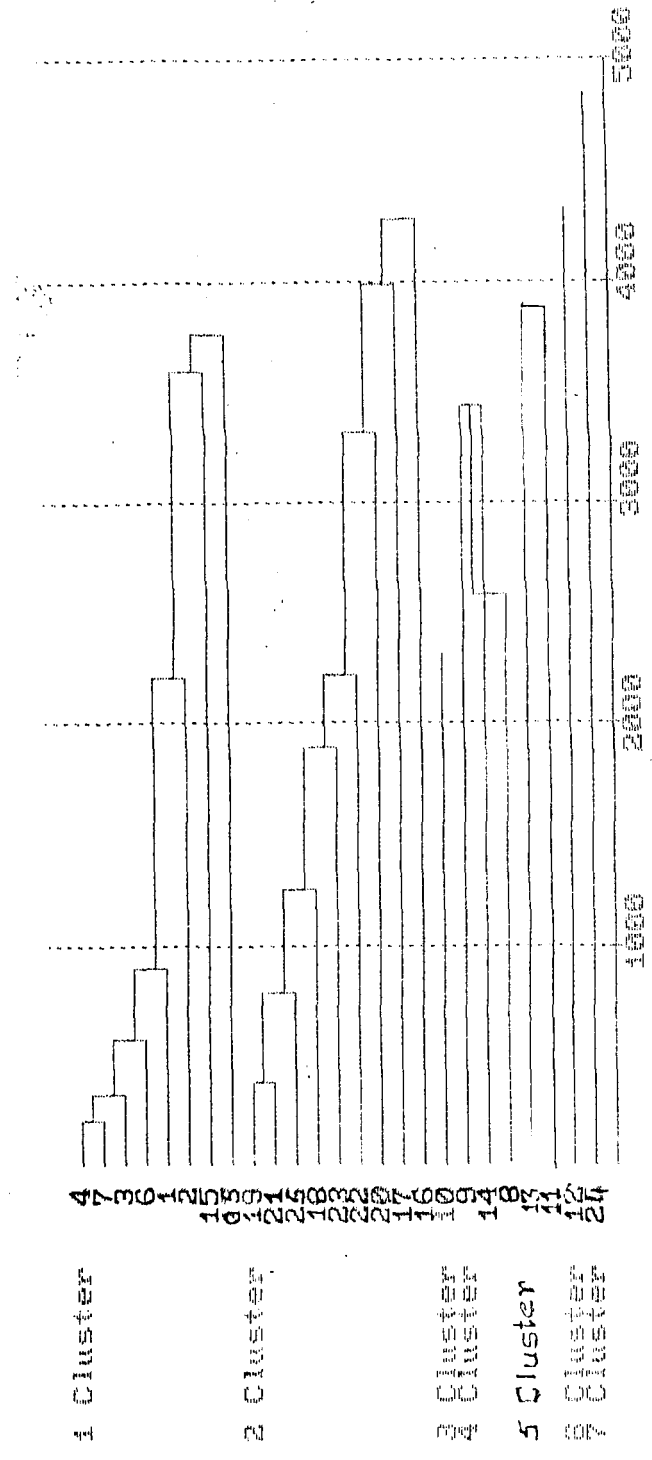
Characters	Per cent contribution
Plant height	2.67
Plant spread	0.67
Number of primary branches	0.00
Number of secondary branches	0.00
Days to 50 per cent flowering	0.00
Average fruit weight	3.67
Fruit length	0.00
Fruit width	0.00
Fruit shape index	0.00
Locules/fruit	0.00
Pericarp thickness	0.00
Pedicel length	0.00
Seed weight/fruit	0.00
Number of seed/fruit	55.00
Ascorbic acid content	15.33
Total soluble solids	0.00
Number of fruits/plant	21.67
Fruit yield/plant	0.00
Per cent powdery mildew disease index	1.00

Table 6. Grouping of pepper genotypes under different clusters

Sl. No.	Cluster	Number of genotypes	Name of the genotypes
1.	I	8	California Wonder, California Wonder-Sel-2, Arka Basant, Belgaum Local, Arka Mohini, Arka Gaurav, Yolo Wonder, 4080-4/2
2.	II	9	Thiawan Local, VN ₂ , Tiptur Local, Guntur Local, 40-86-57, PMR-57, Chilli Yellow, 4080-62, 4/6-1/3
3.	III	1	Paprika (KTPI-19)
4.	IV	3	Ranebennur Local, 42-80-5, Tarihal Local,
5.	V	2	4080-15, 4080-25
6.	VI	1	4080-51
7.	VII	1	Goa Local

Table 7. Intra and inter cluster distance of seven cluster in 25 genotypes of pepper over seasons (*rabi* and *kharif*)

Cluster	I	II	III	IV	V	VI	VII
I	52.28	99.09	103.73	120.19	107.94	170.62	145.18
II		58.73	74.98	157.69	143.88	218.93	95.25
III			0.00	133.55	131.92	187.35	131.24
IV				61.04	85.51	92.00	205.59
V					62.23	151.16	165.68
VI						0.00	279.88
VII							0.00



- | | | | |
|----|---------------------|----|---------------|
| 1 | Arka Mohini | 13 | 4080-15 |
| 2 | Arka Gaurav | 14 | 42-80-5 |
| 3 | Arka Basanth | 15 | 4080-4/2 |
| 4 | California Wonder | 16 | 4/6-1/3 |
| 5 | Yolo Wonder | 17 | 4080-62 |
| 6 | Belgaum Local | 18 | Guntur Local |
| 7 | California Wonder-2 | 19 | Thaiwan Local |
| 8 | Tarihal Local | 20 | Chilli Yellow |
| 9 | Ranebennur Local | 21 | VN-2 |
| 10 | KTP-19 | 22 | 40-86-57 |
| 11 | 4080-25 | 23 | Tiptur Local |
| 12 | 4080-51 | 24 | Goa Local |
| | | 25 | PMR-57/88/K |

Fig. 1. Dendrogram based on morphometric grouping of 25 pepper genotypes

The intra cluster distance was observed highest in the cluster V ($D^2=62.23$) followed by Cluster IV ($D^2=61.04$), Cluster II ($D^2=58.73$) and Cluster I ($D^2=52.28$). Whereas, minimum intra cluster divergence was reported for solitary clusters III, IV and VIII.

4.1.3.3 Cluster means

The cluster means in respect of 19 characters are presented in Table 8. The results indicated that considerable differences were noticed between the clusters for all the characters. The genotype KTPI-19 (Cluster III) was recorded for maximum plant height (85.04 cm) and plant spread (58.72 cm). Whereas, number of primary and secondary branches were maximum in Cluster IV. Goa Local a solitary genotype of Cluster VII (33.83 days) took minimum days to 50 per cent flowering when compared to other clusters. The number of fruits per plant (111.55) and fruit yield per plant (1.60 kg) was highest in Cluster III. While minimum number of fruits per plant (24.10) and fruit yield per plant (0.30 kg/plant) was observed in Cluster I and Cluster VI, respectively.

The average fruit weight (37.78 gm), fruit width (4.73 gm) and locules per plant (3.60) were maximum in Cluster I. The number of seeds varied between 323.28 (Cluster IV) to 45.33 in Cluster VII. Maximum amount of ascorbic acid content (209.75 mg/100 g) and total soluble solids (7.43°brix) was found in Cluster VI (4080.51).

The incidence of powdery mildew during *rabi* season was maximum in Cluster III (71.90%). While minimum incidence was recorded in Cluster VII (18.70%) followed by Cluster VI (25.20%) and Cluster IV (26.00%).

4.2 RANDOM AMPLIFIED POLYMORPHIC DNA (RAPD) PROFILES

The randomly amplified polymorphic DNA data were used to construct a binary matrix based on presence or absence of the amplified

Table 8. Cluster means for various characters of pepper genotypes over seasons (*rabi* and *kharif*)

Characters	I	II	III	IV	V	VI	VII
Plant height (cm)	31.40	67.31	85.04	67.99	55.92	64.82	38.32
Plant spread (cm)	35.97	55.06	58.72	36.89	41.38	44.67	39.98
Number of primary branches	3.22	3.15	2.17	4.25	2.65	2.13	3.10
Number of secondary branches	6.01	6.14	4.70	8.91	5.44	4.30	5.97
Days to 50 per cent flowering	35.58	35.68	40.67	45.39	33.91	37.00	33.83
Average fruit weight (g)	37.78	6.89	23.59	11.35	9.58	12.87	5.94
Fruit length (cm)	6.21	7.65	7.39	4.07	3.79	2.64	5.22
Fruit width (cm)	4.73	2.10	3.86	2.94	2.45	2.47	3.17
Fruit shape index	1.41	4.77	2.23	1.52	2.28	1.07	1.66
Locules/fruit	3.60	2.32	2.00	0.17	3.32	3.07	3.10
Pericarp thickness (cm)	0.40	0.19	0.46	0.18	0.16	0.23	0.12
Pedicle length (cm)	2.33	2.37	1.40	2.45	3.82	1.95	3.16
Seed weight/fruit (g)	4.05	1.36	4.14	1.58	1.24	4.61	0.47
Number of seed/fruit	154.52	97.25	147.65	237.12	163.77	323.28	45.33
Ascorbic acid content (mg/100 g)	191.39	185.10	186.92	162.20	148.74	209.75	123.50
Total soluble solids (°brix)	4.85	5.99	6.95	6.67	7.10	7.43	5.00
Number of fruits/plant	24.10	79.31	111.55	42.05	41.04	36.98	83.83
Fruit yield/plant (kg)	0.81	0.48	1.60	0.35	0.31	0.30	0.57
Per cent powdery mildew disease index	68.90 (56.12)	41.60 (40.17)	71.00 (58.00)	26.00 (30.67)	49.20 (44.54)	25.20 (30.10)	18.70 (25.63)

fragment after separation of PCR products in electrophoresis gels. A genetic similarity analysis among the genotypes was performed using the Jaccard coefficient. The resultant similarity matrix was used to group genotypes through UPGMA analysis. Dendrogram was produced using the NTSYS-pc 2.0 package for numerical taxonomy by pooling data of all the four primers used in the study.

Table 9 reveals that the average number of bands per primer was 9.75. Out of 39 bands, 32 bands were polymorphic (82.05%). The average number of polymorphic bands were 8.00 per primer (Plate 1). Primer OPD-7 produced 100 per cent polymorphism followed by OPC-6 (90.90%), OPD-11 (80.00%) and OPC-8 (42.36%).

4.2.1 Genetic similarity between the genotypes

The maximum genetic similarity was recorded between Tarihal Local and Ranebennur Local (0.93); Guntur Local and 4080-15 (0.89) and KTPI-19 and Ranebennur Local (0.89). The coefficient of genetic similarity between popularly grown commercial varieties of bell peppers *viz.*, California Wonder and Arka Gaurav was 0.86. Whereas, moderate similarity was noticed between California Wonder and Yolo Wonder (0.56).

The least genetic similarity was recorded between Yolo Wonder and Tarihal Local (0.42) followed by PMR-57/88/R and Tarihal Local (0.43) PMR-57/88/K and Goa Local (0.44), PMR-57/88/K and Ranebennur Local (0.47) and PMR-57/88/K and KTPI-19 (0.47). PMR 57/88/K was genetically divergent with most of the genotypes (Table 10).

The first group was further subdivided into two subgroups. The first subgroup comprised most of the large fruited bell peppers. The popular varieties, California Wonder, Arka Gaurav and Belgaum Local were congregated in one cluster. While, Ranebennur Local, Tarihal Local, Paprika (KTPI-19) and Goa Local were in another cluster (Fig. 2).

Table 9. Polymorphism of DNA fragments in 13 pepper cultivars amplified with four random decamer primers

Random primers	Total number of bands	Number of polymorhpic bands	Per cent polymorphism
OPC-6	11	10	90.90
OPC-8	7	3	42.86
OPD-7	11	11	100.00
OPD-11	10	8	80.00
Average	9.75	8.00	78.44
Pooled	39	32	82.05

Table 10. Coefficient of similarity between 13 pepper genotypes using RAPD markers

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.56	1.00											
3	0.73	0.50	1.00										
4	0.86	0.61	0.67	1.00									
5	0.71	0.42	0.74	0.71	1.00								
6	0.78	0.51	0.76	0.79	0.93	1.00							
7	0.80	0.62	0.73	0.81	0.76	0.83	1.00						
8	0.49	0.50	0.67	0.47	0.45	0.48	0.49	1.00					
9	0.80	0.51	0.73	0.76	0.82	0.89	0.80	0.54	1.00				
10	0.63	0.54	0.65	0.69	0.81	0.82	0.74	0.46	0.79	1.00			
11	0.63	0.52	0.80	0.62	0.62	0.71	0.69	0.48	0.69	0.73	1.00		
12	0.71	0.55	0.89	0.71	0.71	0.80	0.76	0.58	0.76	0.69	0.85	1.00	
13	0.53	0.48	0.67	0.52	0.43	0.47	0.59	0.58	0.47	0.44	0.54	0.57	1.00

1. California Wonder
2. Yolo Wonder
3. 4080-15
4. Arka Gaurav
5. Tarihal Local
6. Ranebennur Local
7. Belgaum Local

8. Chilli Yellow
9. Paprika (KTPI-19)
10. Goa Local
11. 4080-25
12. Guntur Local
13. PMR-57/88/K

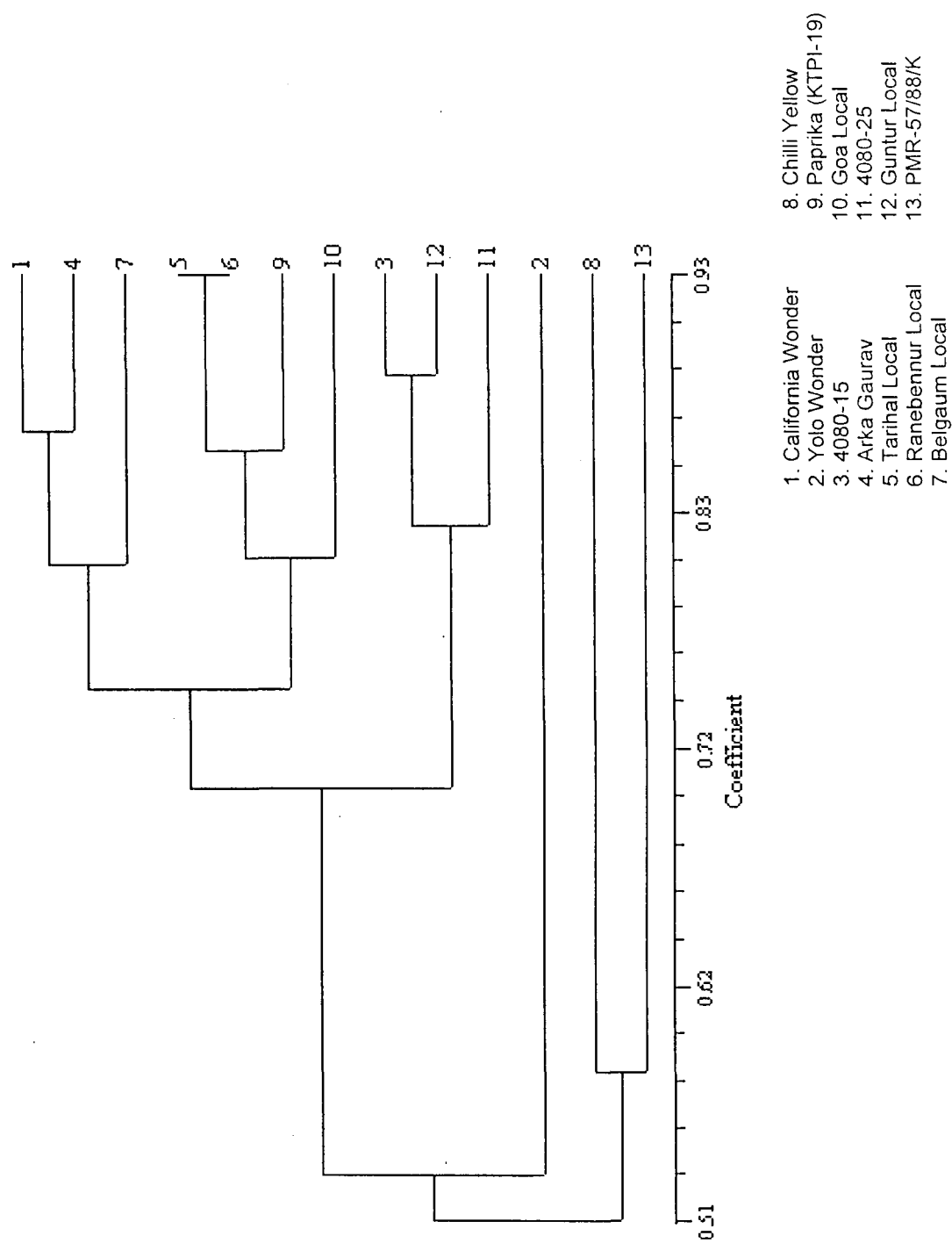
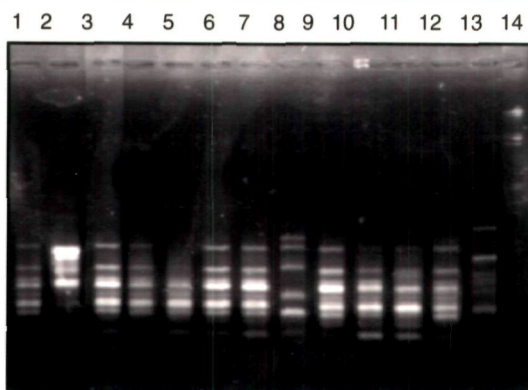
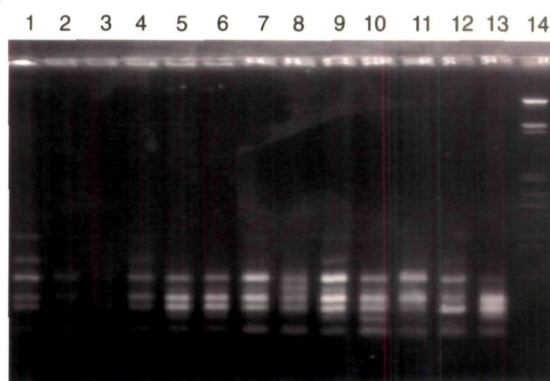


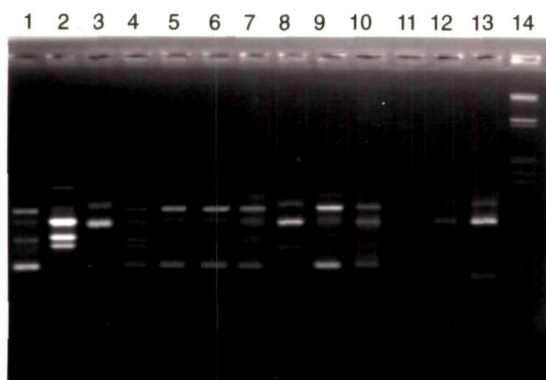
Fig. 2. A dendrogram of 13 pepper genotypes based on average linkage cluster analysis using RAPD markers



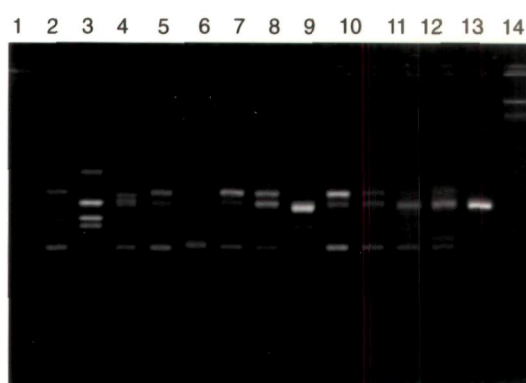
OPC-6



OPC-8



OPD-7



OPD-11

- | | | | |
|-----------------------|----------------------|-------------------|-------------------|
| 1. California Wonder, | 2. Yolo Wonder, | 3. 4080-15, | 4. Arka Gaurav, |
| 5. Tarihal Local, | 6. Ranebennur Local, | 7. Belgaum Local, | 8. Chilli Yellow, |
| 9. Paprika (KTPI-19), | 10. Goa Local, | 11. 4080-25, | 12. Guntur Local, |
| 13. PMR-57/88/K, | 14. Molecular marker | | |

Plate 1. RAPD profiles of 13 pepper genotypes generated by decamer primers

The second subgroup comprised of 4080-25, Guntur Local and Chilli Yellow in one cluster while, Yolo Wonder forms a separate cluster.

Whereas, the second group contained PMR-57/88/K (powdery mildew resistant line developed at IIHR Bangalore using *Capsicum baccatum* var. *pendulum*) and Chilli Yellow.

4.3 EFFECT OF POWDERY MILDEW DISEASE ON POLLEN VIABILITY

The data (Table 11) revealed that high per cent of pollen sterility over the control (uninfected) was noticed in the flowers of infected genotypes of pepper (Plates 2a, 2b, 3a and 3b).

The genotype Yolo Wonder was recorded for higher per cent (158.14%) of pollen sterility followed by California Wonder (130.92%) Guntur Local (118.15%) and Arka Gaurav (116.68) over their respective control.

Whereas, lower per cent of pollen sterility over the respective control was noticed in the genotypes Chilli Yellow (28.54%), PMR-57/88/K (36.34%), Tarihal Local (40.33) and Ranebennur Local (42.05%).

However a range from 8.24 to 14.63 per cent of pollen sterility was noticed in healthy plants of the genotypes.

4.4 EVALUATION OF F₁ HYBRIDS

4.4.1 Analysis of variance

The analysis of variance for 21 characters are presented in Table 12. The results revealed that wide and significant variation was noticed for all the characters in parents and hybrids.

Among the parents, lines (females) exhibited significant difference for most of the traits except for days to 50 per cent flowering, fruit shape

Table 11. Effect of Powdery mildew incidence on pollen fertility in pepper genotypes

Genotypes		Number of pollen grains per microscopic field (10x)			Per cent sterility	Per cent sterility over control
		Fertile	Sterile	Total		
California Wonder	H	43.54	4.96	48.50	10.22	
	I	44.94	13.86	58.80	23.58	130.72
Yolo Wonder	H	57.08	5.12	62.20	8.24	
	I	46.94	12.46	57.40	24.84	158.14
Belgaum Local	H	88.13	12.43	100.56	12.36	
	I	47.20	15.60	62.80	21.66	100.97
Arka Gaurav	H	63.31	9.67	72.98	13.25	
	I	64.73	26.07	90.80	28.71	116.68
Tarihal Local	H	4.54	5.80	51.20	11.33	
	I	47.21	11.39	56.60	15.90	40.33
Ranebennur Local	H	96.26	14.24	110.50	12.89	
	I	77.15	17.30	94.45	18.31	42.05
4080-25	H	29.36	3.09	32.45	9.54	
	I	40.02	9.50	49.62	19.15	100.73
4080-15	H	39.64	6.61	46.25	14.30	
	I	41.25	13.85	55.10	25.15	75.87
KTPI-19	H	73.04	12.51	85.55	14.63	
	I	68.42	23.98	92.40	25.75	77.37
Goa Local	H	91.23	9.33	100.56	9.28	
	I	64.01	15.06	75.31	20.00	115.52
Chilli Yellow	H	112.20	17.60	129.80	13.56	
	I	87.77	18.53	106.30	17.43	28.54
Guntur Local	H	80.25	9.05	89.30	10.14	
	I	83.66	27.34	101.00	22.12	118.15
PMR-57/88/K	H	84.17	12.93	97.10	13.32	
	I	70.18	15.15	85.33	18.16	36.34

H - Healthy plants (control), I - Infected plants



**Plate 2a. Healthy plant
(free from powdery
mildew incidence)**



**Plate 3a. Powdery mildew
affected plant**

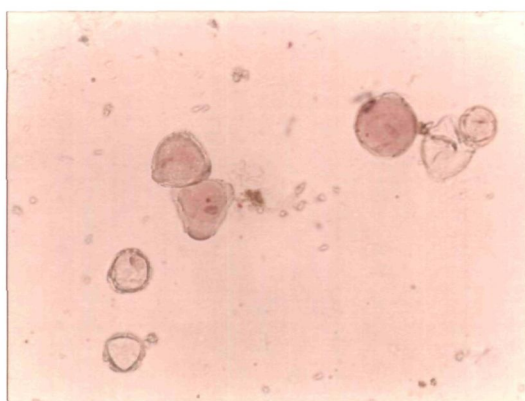


**Plate 2b. Pollens from
aforementioned
(healthy) plant**



**Plate 3b. Pollens from
aforementioned
(diseased) plant**

Table 12. Analysis of variance in respect of 21 traits in pepper (L x T) hybrids

Sl. No.	Characters	Source	Mean sum of square								Parent vs hybrids	Error
			Replication	Parents	Females	Males	Females vs males	Hybrids				
			2	8	2	5	1	17	1			
1.	Seedling height		7.105	32.612**	22.690**	25.007**	90.480**	26.859**	10.862	2.720		
2.	Root length		0.148	3.697**	4.074**	3.517**	3.840**	1.679**	8.359**	0.158		
3.	Plant height		109.173	1025.287**	647.901**	510.512**	4353.939**	2191.151**	56510.950**	35.338		
4.	Plant spread		84.472	302.999**	63.269**	254.100**	1026.953**	349.514**	523.094**	9.413		
5.	Number of primary branches		0.032	0.853**	1.560**	0.633**	0.540**	0.742**	0.425**	0.041		
6.	Number of secondary branches		0.223	2.336**	2.354**	2.813**	0.156	3.053**	0.200	0.111		
7.	Days to 50 per cent flowering		1.054	239.633**	18.132**	341.017**	175.713**	126.662**	20.973**	1.834		
8.	Fruit length		0.431	16.859**	0.468	21.882**	24.523**	21.984**	7.688**	0.221		
9.	Fruit width		0.112	8.589**	0.345**	1.874**	58.656**	4.718**	19.323**	0.0560		
10.	Fruit shape index		0.177	4.585**	0.0265	5.856**	7.348**	1.269**	5.049**	0.0296		
11.	Locules per fruit		0.083	1.840**	1.000**	0.942**	8.012**	1.723**	0.253**	0.0485		
12.	Pericarp thickness		0.0005	0.0078**	0.0036**	0.0570**	0.3313**	0.0896**	0.7482**	0.0006		
13.	Pedicel length		0.135	1.396**	0.641**	1.685**	1.464**	1.609**	0.937**	0.033		
14.	Seed weight per fruit		0.057	8.796**	1.141**	6.425**	35.966**	0.313**	25.752**	0.012		
15.	Number of seeds per fruit		89.605	6836.545**	273.625**	8257.973**	12855.31**	1771.981**	46737.380**	16.641		
16.	Average fruit weight		1.782	1305.786**	42.220**	248.520**	9119.248**	590.766**	1.834	3.963		
17.	Ascorbic acid content		30.815	3106.943**	5231.016**	2801.496**	385.968	7238.140**	1306.500**	102.638		
18.	Total soluble solids		0.099	3.231**	0.074	3.433**	8.536	2.140**	0.326*	0.046		
19.	Number of fruits per plant		274.481	7063.103	3.425	4149.642**	35749.77**	791.104**	5196.781**	35.249		
20.	Fruit yield per plant		0.034	0.524	0.129**	0.765**	0.110*	0.995**	1.248**	0.0192		
21.	Per cent powdery mildew index		3.038	522.681	59.960**	491.520**	1603.938**	130.956**	183.855**	2.832		

* Significant at 5 per cent probability

** Significant at 1 per cent probability

index, total soluble solids and number of fruits per plant. While, testers (males) differed significantly for all the characters. The contribution of line vs testers were significant for 19 characters and non-significant for number of branches and ascorbic acid content. Variance for parents vs hybrids revealed significant difference for most of the characters except seedling height, number of branches and average fruit weight.

4.4.2 *Per se* performance and magnitude of heterosis

The pertinent data of *per se* performance of 28 entries [9 parents + 18 F₁'s and a standard check (Indira)] and magnitude of heterosis are detailed in Tables 13-23.

4.4.2.1 Seedling height (cf. Table 13)

The maximum seedling height was recorded by 4080-15 (22.57 cm) while, higher values were registered in cross combination Yolo Wonder x Chilli Yellow (22.43 cm).

The range of heterosis over mid parent was from -46.42 (California Wonder x 4080-15) to 32.16 (Arka Gaurav x Goa Local) per cent. Out of 18 hybrids, eight showed significant positive heterosis over mid parent. Heterosis over better parent was maximum in the cross combination Arka Gaurav x Tarihal Local (26.23%). None of the crosses showed positive heterosis over best parent. All the hybrids exhibited significant positive heterosis over check except California Wonder x 4080-15 (-10-59%).

4.4.2.2 Root length (cf. Table 13)

The highest root length among the parents was observed in KTPI-19 (5.17 cm). Among the hybrids Yolo Wonder x 4080-15 exhibited 3.83 centimeters of root length.

Table 13. *Per se* performance and magnitude of heterosis for seedling height and root length

Sl. No.	Crosses (P ₁ x P ₂)	Seedling height						Root length									
		Per se value (cm)				Per cent heterosis over		Per se value (cm)				Per cent heterosis over					
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC
1.	California Wonder x Tarihal Local	11.77	17.17	18.03	14.47	24.60*	5.01	-20.12*	75.22**	2.20	3.80	2.90	3.00	-3.33	-23.68	-43.91**	3.57
2.	California Wonder x 4080-15	11.77	22.57	9.20	17.17	-46.42**	-59.24**	-59.24**	-10.59	2.20	4.77	1.53	3.49	-56.16**	-67.92**	-70.41**	-45.36**
3.	California Wonder x KTPI-19	11.77	20.43	19.43	16.10	20.70**	-4.89	-13.91	88.82**	2.20	5.17	2.33	3.69	-36.86**	-54.93**	-54.93*	-16.79
4.	California Wonder x Chilli yellow	11.77	19.47	15.23	15.62	-2.50	-21.78*	-32.52**	48.01*	2.20	2.97	2.47	2.59	-4.63	-16.84	-52.22**	-11.79
5.	California Wonder x Goa Local	11.77	15.07	17.53	13.42	30.66*	16.32	-22.33*	70.35**	2.20	3.30	2.60	2.75	-5.45	-21.21	-49.71**	-7.14
6.	California Wonder x Guntur Local	11.77	15.87	15.30	13.82	10.71	-3.57	-32.21**	48.69*	2.20	2.33	3.37	2.27	48.46**	44.64*	-34.82**	20.36
7.	Arka Gaurav x Tarihal Local	17.27	17.17	21.80	17.22	26.60**	26.23*	-3.41	111.86**	4.27	3.80	3.67	4.04	-9.16	-14.05	-29.01**	31.07
8.	Arka Gaurav x 4080-15	17.27	22.57	18.00	19.92	-9.64	-20.25*	-20.25*	74.93**	4.27	4.77	3.20	4.52	-29.20**	-32.91**	-38.10**	14.29
9.	Arka Gaurav x KTPI-19	17.27	20.43	15.57	18.85	-17.40	-23.79*	-31.01**	51.31**	4.27	5.17	2.83	4.72	-40.04**	-45.26**	-45.26**	1.07
10.	Arka Gaurav x Chilli yellow	17.27	19.47	17.97	18.37	-2.18	-7.70	-20.38*	42.74**	4.27	2.97	3.23	3.62	-10.77	-24.36**	-37.52*	15.36
11.	Arka Gaurav x Goa Local	17.27	15.07	21.37	16.17	32.16**	23.74**	-5.32	07.68**	4.27	3.30	3.63	3.79	-4.42	-14.99	-29.79**	29.64
12.	Arka Gaurav x Guntur Local	17.27	15.87	16.90	16.57	1.99	-2.14	-25.12**	64.24**	4.27	2.33	2.67	3.30	-19.09	-37.47**	-48.36**	-4.64
13.	Yolo Wonder x Tarihal Local	14.60	17.17	19.67	15.89	23.79*	14.56	-12.85	91.16**	2.30	3.80	1.73	3.05	-43.28**	-54.49**	-66.54**	-38.21*
14.	Yolo Wonder x 4080-15	14.60	22.57	17.50	18.59	-5.86	-22.46*	-22.46*	170.68**	2.30	4.77	3.93	3.54	11.02	-17.61	-23.98**	40.36*
15.	Yolo Wonder x KTPI-19	14.60	20.43	18.98	17.52	8.33	-7.10	-15.91	84.45**	2.30	5.17	1.50	3.74	-59.89*	-70.99**	-70.99**	-46.43*
16.	Yolo Wonder x Chilli yellow	14.60	19.47	22.43	17.04	31.63**	15.20	-0.62	54.13**	2.30	2.97	2.03	2.64	-23.11	-31.65*	-29.79**	-27.50
17.	Yolo Wonder x Goa Local	14.60	15.07	18.90	14.84	27.36*	25.41*	-16.26	83.67**	2.30	3.30	3.63	2.80	29.64*	10.00	-29.79**	29.64
18.	Yolo Wonder x Guntur Local	14.60	15.87	18.57	15.24	21.85*	17.01	-17.72**	80.47**	2.30	2.33	2.67	2.32	15.09	13.17	-48.36**	-4.64
	Check (Indira)				10.29								2.80				
	S Em±		1.32			1.17	1.35	1.35	1.35			0.42		0.28	0.32	0.32	0.32
	CD 5%		3.94			3.32	3.83	3.83	3.83			1.25		0.79	0.91	0.91	0.91
	CD 1%		5.41			4.42	5.11	5.11	5.11			1.72		1.06	1.21	1.21	1.21

* Significant at 5 per cent probability. ** Significant at 1 per cent probability

The range of heterosis over mid parent varied from -59.89 (Yolo Wonder x KTPI-19) to 48.46 (California Wonder x Guntur Local). Heterosis in F_1 's over their better parent ranged from -70.99 (Yolo Wonder x KTPI-19) to 44.64 (California Wonder x Guntur Local). All the crosses exhibited significant negative heterosis over best parent. Among 18 F_1 's only one cross (Yolo Wonder x 4080-15) exhibited significant positive (40.36%) heterosis over check (Indira).

4.4.2.3 Plant height (cf. Table 14)

The *per se* value for plant height was ranged from 147.43 centimeters (Chilli Yellow) to 42.08 centimeters (California Wonder) for the parents. Whereas, in hybrids the range was from 79.17 centimeters (Arka Gaurav x Chilli Yellow) to 169.33 centimeters (California Wonder x Chilli Yellow). The top cross combination Arka Gaurav x Tarihal Local had a plant height of 114.43 centimeters (Plate 4).

There were 15 crosses which showed significant positive heterosis over mid parent. While seven and four crosses revealed significant positive and negative heterosis over better parent respectively. Two crosses *viz.*, California Wonder x Chilli Yellow (14.85%) and California Wonder x Goa Local (12.58%) were significantly heterotic over best parent. All the crosses were significantly heterotic over check in positive direction.

4.4.2.4 Plant spread (cf. Table 14)

The highest plant spread was noticed in Guntur Local (75.76 cm). Among the hybrids the highest and lowest values were recorded in the cross combination Arka Gaurav x Tarihal Local (76.00 cm) and California Wonder x Tarihal Local (49.39 cm) respectively.

The heterosis over mid parent was as high as 67.59 per cent in Arka Gaurav x Chilli Yellow. The significant positive and negative



Plate 4: F_1 hybrid (Arka Gaurav x Tarihal Local)

heterosis over better parent were revealed by six and three crosses respectively. While, Arka Gaurav x Tarihal Local was the only cross exhibited positive heterosis (0.32%) over best parent. Nine crosses exhibited significant positive heterosis over check, the highest magnitude was noticed in the cross combination Arka Gaurav x Tarihal Local (49.55%).

4.4.2.5 Number of primary branches (cf. Table 15)

The highest (3.40) *per se* value for number of primary branches was revealed by the female parent Arka Gaurav. Among the F₁'s highest number of primary branches was observed in Yolo Wonder x 4080-15 (3.07).

The extent of heterosis over mid parent ranged from -37.50 to 43.50 per cent; over better parent the range was -41.18 to 43.50 per cent and over best parent it was -30.31 to 4.53 per cent. None of the crosses exhibited heterosis over check in desirable direction.

4.4.2.6 Number of secondary branches (cf. Table 15)

The number of secondary branches were high (6.00) in Chilli Yellow. Whereas in F₁'s the cross combination of California Wonder x Chilli Yellow (7.33) revealed higher number of secondary branches.

The extent of heterosis over mid parent was -32.09 to 48.30 while, heterosis over better parent and best parent was ranged from -33.33 to 48.30 and -33.33 to 0.00 per cent respectively. Only one cross combination California Wonder x Chilli Yellow exhibited significant positive heterosis (30.89%) over check.

4.4.2.7 Days to 50 per cent flowering (cf. Table 16)

The male parent Chilli Yellow took minimum number (27.33) of days for 50 per cent flowering compared to other parents. However,

Table 15. *Per se* performance and magnitude of heterosis for number of primary and secondary branches

Sl. No.	Crosses (P ₁ x P ₂)	Number of primary branches						Number of secondary branches					
		Per se value			Per cent heterosis over			Per se value			Per cent heterosis over		
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value
1.	California Wonder x Tarihal Local	2.00	2.67	3.00	2.34	28.21**	12.35	4.53	-11.76	4.00	5.80	6.00	4.90
2.	California Wonder x 4080-15	2.00	2.00	2.00	2.00	0.00	0.00	-30.31**	-41.18**	4.00	4.00	4.50	4.00
3.	California Wonder x KTPI-19	2.00	2.00	2.87	2.00	43.50**	43.50**	0.00	-15.59*	4.00	4.00	5.93	4.00
4.	California Wonder x Chilli yellow	2.00	3.00	2.93	2.50	17.20*	-2.33	2.09	-13.82	4.00	6.00	7.33	5.00
5.	California Wonder x Goa Local	2.00	3.00	2.00	2.50	-20.00**	-33.33**	-30.31**	-41.18**	4.00	6.00	4.00	5.00
6.	California Wonder x Guntur Local	2.00	2.33	3.00	2.17	38.25**	28.75**	4.53	-11.76	4.00	4.70	5.77	4.35
7.	Arka Gaurav x Tarihal Local	3.40	2.67	2.00	3.04	-34.21**	-41.18**	-30.31**	-41.18**	5.00	5.80	5.00	5.40
8.	Arka Gaurav x 4080-15	3.40	2.00	2.00	2.70	-25.93**	-41.18**	-30.31**	-41.18**	5.00	4.00	5.13	4.50
9.	Arka Gaurav x KTPI-19	3.40	2.00	2.00	2.70	-25.93**	-41.18**	-30.31**	-41.18**	5.00	4.00	3.90	4.50
10.	Arka Gaurav x Chilli yellow	3.40	3.00	2.00	3.20	-37.50**	-41.18**	-30.31**	-41.18**	5.00	6.00	4.00	5.50
11.	Arka Gaurav x Goa Local	3.40	3.00	2.00	3.20	-37.50**	-41.18**	-30.31**	-41.18**	5.00	6.00	4.47	5.89
12.	Arka Gaurav x Guntur Local	3.40	2.33	3.00	2.87	4.52	-11.76	4.53	-11.76	5.00	4.70	6.0	5.24
13.	Yolo Wonder x Tarihal Local	3.00	2.67	3.00	2.84	5.63	0.00	4.53	-11.76	5.77	5.80	6.00	5.79
14.	Yolo Wonder x 4080-15	3.00	2.00	3.07	2.50	22.80**	2.33	6.97	-9.70	5.77	4.00	5.87	4.89
15.	Yolo Wonder x KTPI-19	3.00	2.00	2.17	2.50	-13.20	-27.66**	-24.39**	-36.18**	5.77	4.00	4.53	4.89
16.	Yolo Wonder x Chilli yellow	3.00	3.00	2.00	3.00	-33.33**	-33.33**	-30.31**	-41.18**	5.77	6.0	4.00	5.89
17.	Yolo Wonder x Goa Local	3.00	3.00	2.00	3.00	-33.33*	-33.33**	-30.31**	-41.18**	5.77	6.00	4.00	5.89
18.	Yolo Wonder x Guntur Local	3.00	2.33	3.00	3.00	0.00	0.00	4.53	-11.76	5.77	4.70	6.00	5.24
	Check (Indira)				2.87								5.60
	S.E.m±			0.24		0.14	0.17	0.17	0.17			0.54	
	CD 5%			0.72		0.40	0.48	0.48	0.48			1.61	
	CD 1%			0.98		0.52	0.64	0.64	0.64			2.21	

* Significant at 5 per cent probability, ** Significant at 1 per cent probability

Table 16. Per se performance and magnitude of heterosis for days to 50 per cent flowering and average fruit weight

Sl. No.	Crosses (P ₁ x P ₂)	Days to 50 per cent flowering					Average fruit weight										
		Per se value (days)				Per cent heterosis over				Per se value (g)				Per cent heterosis over			
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC
1.	California Wonder x Tarihal Local	34.20	55.13	46.33	44.67	3.72	35.47**	69.52**	32.37**	52.33	19.34	26.28	35.84	-26.67**	-49.78**	-58.57**	-58.57**
2.	California Wonder x 4080-15	34.20	44.37	44.00	39.29	11.99**	28.65*	60.99**	25.71**	52.33	7.75	13.98	30.04	-53.46**	-73.28**	-77.96**	-77.96**
3.	California Wonder x KTPI-19	34.20	42.57	42.30	38.39	10.18**	23.68**	54.77**	20.86*	52.33	28.88	32.43	40.61	-20.14**	-38.03**	-42.13**	-48.87**
4.	California Wonder x Chilli yellow	34.20	27.33	44.70	30.77	45.27**	63.56**	63.56**	27.71**	52.33	5.78	24.80	29.06	-14.66*	-52.61**	-55.75**	-60.90**
5.	California Wonder x Goa Local	34.20	33.85	38.44	34.03	12.96**	13.56**	40.65**	9.83*	52.33	6.61	16.18	29.47	-45.10**	-69.08**	-71.13**	-74.49**
6.	California Wonder x Guntur Local	34.20	28.77	30.00	31.49	-4.73	4.28	9.77	-14.29**	52.33	11.57	11.70	31.95	-63.38**	-77.64**	-79.12**	-81.55**
7.	Arka Gaurav x Tarihal Local	30.47	55.13	32.70	42.80	-23.60**	7.32	19.65*	-6.57	48.54	19.34	55.00	33.94	62.05**	13.31**	-1.86	-13.29**
8.	Arka Gaurav x 4080-15	30.47	44.37	34.20	37.42	-8.61*	12.24**	25.14**	-2.29	48.54	7.75	53.07	28.15	88.52**	9.33	-5.30	-16.33**
9.	Arka Gaurav x KTPI-19	30.47	42.57	31.60	36.52	-13.47**	3.71	15.62**	-9.71*	48.54	28.88	16.21	38.71	-58.12**	-66.60**	-71.07**	-74.44**
10.	Arka Gaurav x Chilli yellow	30.47	27.33	28.67	28.90	-0.80	4.90	4.90	-18.09**	48.54	5.78	18.06	27.16	-33.51**	-62.80**	-67.77**	-71.53**
11.	Arka Gaurav x Goa Local	30.47	33.85	38.00	32.16	18.16**	24.71**	39.04*	8.57	48.54	6.61	34.78	27.58	26.12**	-28.35**	-37.94**	-45.17**
12.	Arka Gaurav x Guntur Local	30.47	28.77	3.00	29.62	8.04	11.23*	17.09**	-8.57	48.54	11.57	15.14	30.06	-49.63**	-68.80**	-72.98**	-76.13**
13.	Yolo Wonder x Tarihal Local	35.11	55.13	44.00	45.12	-2.49	25.32**	60.99**	25.71**	56.04	19.34	33.18	37.69	-11.97*	-40.79**	-40.79	-47.69**
14.	Yolo Wonder x 4080-15	35.11	44.37	25.53	39.74	-35.75**	-27.29*	-6.59	-27.06**	56.04	7.75	20.93	31.90	-34.39**	-62.65**	-62.65**	-67.00**
15.	Yolo Wonder x KTPI-19	35.11	42.57	33.0	38.84	-15.04**	-6.01	20.75**	-5.71	56.04	28.88	45.95	42.46	8.22	-18.00**	-18.00**	-27.56**
16.	Yolo Wonder x Chilli yellow	35.11	27.33	26.04	31.22	-16.59**	-4.72	-4.72	-25.6**	56.04	5.78	28.25	30.91	-8.61	-49.59**	-49.59**	-55.46**
17.	Yolo Wonder x Goa Local	35.11	33.85	35.53	34.48	3.05	4.96	30.00**	1.51	56.04	6.61	10.47	31.35	-66.58**	-81.32**	-81.32**	-83.49**
18.	Yolo Wonder x Guntur Local	35.11	28.77	37.10	31.94	16.16**	28.95**	35.75**	6.00	56.04	11.57	11.51	33.81	-65.96**	-79.46**	-79.46**	-81.85**
	Check (Indira)				35.00								63.43				
	S.Em±			3.33		0.96	1.12	1.12	1.12			7.66		1.41	1.63	1.63	1.63
	CD 5%			9.94		2.72	3.17	3.17	3.17			22.86		4.00	4.62	4.62	4.62
	CD 1%			13.65		3.63	4.24	4.24	4.24			31.39		5.33	5.33	5.33	5.33

* Significant at 5 per cent probability, ** Significant at 1 per cent probability

among the hybrids the cross combination of Yolo Wonder x Chilli Yellow was early flowering (26.04 days) hybrid. The check (Indira) took 35 days to 50 per cent flowering.

The heterosis over mid parent ranged from 45.77 (California Wonder x Chilli Yellow) to -35.75 (Yolo Wonder x 4080-15) per cent. While, heterosis over better parent and best parent ranged from -27.29 (Yolo Wonder x 4080-15) to 63.56 (California Wonder x Chilli Yellow) per cent and from -4.72 (Yolo Wonder x Chilli Yellow) to 69.52 (California Wonder x Tarihal Local) respectively. Six and one hybrids exhibited significant negative heterosis in required direction over mid parent and best parent respectively. While only four crosses showed significant negative heterosis over check.

4.4.2.8 Average fruit weight (cf. Table 16)

The magnitude of variation among the parents for average fruit weight was 5.78 grams (Chilli Yellow) to 56.04 grams (Yolo Wonder).

The cross combination of Arka Gaurav x Tarihal Local (55.00 g) exhibited highest fruit weight among the hybrids. While check (Indira) weighed 63.43 gram.

Three and thirteen crosses exhibited significant positive and negative heterosis over mid parent respectively. The highest positive heterosis over mid parent (88.52%) was noticed in the cross Arka Gaurav x 4080-15. The only cross Arka Gaurav x Tarihal Local (13.13%) recorded significant positive heterosis over better parent. All the crosses showed negative heterosis over best parent and check.

4.4.2.9 Fruit length (cf. Table 17)

The *per se* performance of parents varied from 4.75 centimeters (Tarihal Local) to 10.99 centimeters (Guntur Local) for fruit and length.

While, among the hybrids, fruit length was ranged from 3.82 centimeters (California Wonder x Tarihal Local) to 13.08 centimeters (California Wonder x Chilli Yellow).

Out of 18 crosses five, four, two and three crosses exhibited significant and positive heterosis over mid parent, better parent, best parent and check respectively.

Heterosis over check ranged from -58.70 (California Wonder x Tarihal Local) to 41.41 (California Wonder x Chilli Yellow) per cent for fruit length.

4.4.2.10 Fruit width (cf. Table 17)

The maximum and minimum magnitude of fruit width was noticed by Yolo Wonder (6.16) and Chilli Yellow (1.44) respectively. Among the hybrids Arka Gaurav x Tarihal Local (7.35 cm) exhibited highest *per se* value for fruit width.

There were ten and three crosses with significant positive and negative heterosis respectively over mid parent. None of the crosses were significantly and positively heterotic over better parent and best parent except Arka Gaurav x Tarihal Local (34.12%; 19.32%) and Arka Gaurav x 4080-15 (19.89%; 6.66%). No cross combination showed significant positive heterosis over check.

4.4.2.11 Fruit shape index (cf. Table 18)

The mean *per se* values for fruit shape index was ranged from 1.01 (Tarihal Local) to 4.72 (Guntur Local) for the parents. Among F₁ hybrids this trait was ranged from 0.73 (California Wonder x Tarihal Local) to 2.96 (California Wonder x KTPI-19).

Out of 18 crosses nine showed significant and negative heterosis over mid parent. The highest significant negative heterosis over mid

Table 18. *Per se* performance and magnitude of heterosis for fruit shape index and locules per fruit

Sl. No.	Crosses (P ₁ x P ₂)	Fruit shape index						Locules per fruit									
		Per cent heterosis over						Per cent heterosis over									
		Per se value			Mean parental value	Per se value			Per se value			Mean parental value	Per se value				
P ₁	P ₂	F ₁	MP	BP		BSP	SC	P ₁	P ₂	F ₁	MP		BP	BSP	SC		
1.	California Wonder x Tarihal Local	1.33	1.01	0.73	1.17	-37.61**	-27.72	-27.72	-45.93**	4.00	3.00	4.67	3.50	33.43**	55.67**	133.50**	29.72**
2.	California Wonder x 4080-15	1.33	2.06	1.01	1.70	-40.59**	-24.06	0.00	-25.19	4.00	3.00	3.73	3.50	6.57	24.33**	86.50**	3.61
3.	California Wonder x KTPI-19	1.33	2.10	1.67	1.72	-2.91	25.56	65.35**	23.70	4.00	2.00	3.67	3.00	22.33**	83.50**	83.33**	1.94
4.	California Wonder x Chilli yellow	1.33	3.63	2.96	2.48	19.35**	122.56**	193.07**	119.26**	4.00	2.00	3.00	3.00	0.00	50.00**	50.00**	-16.67*
5.	California Wonder x Goa Local	1.33	1.51	1.05	1.42	-26.06*	-21.05	3.96	-22.22	4.00	3.20	4.00	3.60	11.11	25.00**	100.00**	11.11
6.	California Wonder x Guntur Local	1.33	4.72	2.50	3.03	-17.49**	87.96**	147.52**	85.19**	4.00	2.00	2.00	3.00	-33.33**	0.00	0.00	-44.44**
7.	Arka Gaurav x Tarihal Local	1.51	1.01	1.45	1.26	15.08	43.56*	43.56*	7.41	3.00	3.00	3.87	3.00	29.00**	29.00**	93.50**	7.50
8.	Arka Gaurav x 4080-15	1.51	2.06	1.38	1.79	-22.91*	-8.61	36.63*	2.22	3.00	3.00	3.00	3.00	0.00	0.00	50.00**	-16.67*
9.	Arka Gaurav x KTPI-19	1.51	2.10	1.48	1.81	-18.23*	-1.99	46.53*	9.63	3.00	2.00	3.00	2.50	20.00*	50.00**	50.00**	-16.67*
10.	Arka Gaurav x Chilli yellow	1.51	3.63	1.03	2.57	-59.92**	-31.79*	1.98	-23.70	3.00	2.00	3.00	2.50	20.00*	50.00**	50.00**	-16.67*
11.	Arka Gaurav x Goa Local	1.51	1.51	0.89	1.51	-41.06**	-41.06**	-11.88	-34.07*	3.00	3.00	3.00	3.00	0.00	0.00	50.00**	-16.67*
12.	Arka Gaurav x Guntur Local	1.51	4.72	1.81	3.12	-41.99**	19.86	79.21**	34.07*	3.00	2.00	2.53	2.50	1.20	26.50*	26.50*	-29.72**
13.	Yolo Wonder x Tarihal Local	1.36	1.01	0.93	1.19	-21.85	-7.92	-7.92	-31.11*	4.00	3.00	3.00	3.50	-14.29**	0.00	50.00**	-16.67*
14.	Yolo Wonder x 4080-15	1.36	2.06	1.48	1.71	-13.45	8.82	46.53*	9.63	4.00	3.00	2.80	3.50	-20.00*	-6.67	40.00**	-22.22**
15.	Yolo Wonder x KTPI-19	1.36	2.10	2.23	1.73	28.90**	63.97**	120.79**	65.19**	4.00	2.00	2.00	3.00	-33.33**	0.00	0.00	-44.44**
16.	Yolo Wonder x Chilli yellow	1.36	3.63	2.42	2.50	-3.20	77.94**	139.60**	79.26**	4.00	2.00	3.00	3.00	0.00	50.00**	50.00**	-16.67*
17.	Yolo Wonder x Goa Local	1.36	1.51	1.52	1.44	5.56	11.76	50.50*	12.59	4.00	3.20	2.00	3.60	-44.44**	-37.50**	0.00	-44.44**
18.	Yolo Wonder x Guntur Local	1.36	4.72	2.30	3.04	-24.34**	69.12**	127.72**	70.37**	4.00	2.00	2.00	3.00	-33.33**	0.00	0.00	-44.44**
	Check (Indira)				3.6								1.35				
	S.E.m±			0.25		0.16	0.18	0.18	0.18			0.28		0.122	0.141	0.141	0.141
	CD 5%			0.75		0.45	0.51	0.51	0.51			0.84		0.35	0.40	0.40	0.40
	CD 1%			1.02		0.61	0.68	0.68	0.68			1.15		0.46	0.53	0.53	0.53

* Significant at 5 per cent probability, ** Significant at 1 per cent probability

parent was observed in Arka Gaurav x Chilli Yellow (-59.92%) over better parent (-41.06%) and standard check (-34.07). Whereas, Arka Gaurav x Goa Local showed highest negative heterosis over better parent (-41.06%) and standard check (-34.07).

4.4.2.12 Locules per fruit (cf. Table 18)

The locules number influences the shelf life of bell pepper and those with less number of locules per fruit keeps better.

Among the parents the locule number was ranged from 2.00 (KTPI-19, Chilli Yellow and Guntur Local) to 4.00 (California Wonder and Yolo Wonder) and among the hybrids the range was between 2.00 (California Wonder x Guntur Local; Yolo Wonder x KTPI-19, Yolo Wonder x Goa Local and Yolo Wonder x Guntur Local) to 4.67 (California Wonder x Tarihah Local).

Out of 18 F₁'s, three, one and twelve crosses showed significant negative heterosis in desired direction over mid parent better parent and check respectively. None of the crosses showed significant heterosis in required direction over best parent. There were four, six and four crosses revealed zero per cent heterosis over mid, better and best parents respectively.

4.4.2.13 Pericarp thickness (cf. Table 19)

The *per se* values for pericarp thickness ranged from 0.05 centimeters (Chilli Yellow) to 0.42 centimeters (California Wonder, Yolo Wonder and KTPI-19) for the parents. While, for F₁'s it varied from 0.11 centimeters (Yolo Wonder x Goa Local) to 0.61 (California Wonder x KTPI-19).

The heterosis over mid parent ranged from -59.26 (Yolo Wonder x Goa Local) to 134.15 (Arka Gaurav x Chilli Yellow) per cent. While,

Table 19. Per se performance and magnitude of heterosis for pericarp thickness and pedicel length

Sl. No.	Crosses (P ₁ x P ₂)	Pericarp thickness								Pedicel length							
		Per se value (cm)				Per cent heterosis over				Per se value (cm)				Per cent heterosis over			
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC
1.	California Wonder x Tarihal Local	0.42	0.21	0.43	0.315	36.51**	140.76**	760.00**	7.50	2.42	3.95	3.42	3.185	7.38	-13.42*	-21.92**	11.40
2.	California Wonder x 4080-15	0.42	0.10	0.55	0.260	111.54**	450.00**	1000.00**	37.5**	2.42	3.48	3.69	2.950	25.08**	6.03	-15.75**	20.20**
3.	California Wonder x KTPI-19	0.42	0.42	0.61	0.420	45.24**	45.24**	1120.00**	52.5**	2.42	2.16	3.52	2.290	53.71**	45.45**	-19.63**	14.66*
4.	California Wonder x Chilli yellow	0.42	0.05	0.54	0.235	129.79**	980.00**	980.00**	35.0**	2.42	3.41	3.56	2.915	22.52**	4.40	-18.72**	15.96*
5.	California Wonder x Goa Local	0.42	0.12	0.41	0.270	51.85**	241.67**	720.00**	2.50	2.42	3.29	2.50	2.855	-12.43	-24.01**	-42.92**	-18.57**
6.	California Wonder x Guntur Local	0.42	0.07	0.44	0.245	79.52**	527.57**	780.00**	10.00	2.42	4.38	2.41	3.400	-29.12**	-44.98**	-44.98**	-21.50**
7.	Arka Gaurav x Tarihal Local	0.36	0.21	0.30	0.285	5.26**	42.86**	500.00**	-25.00**	3.25	3.95	5.30	3.600	47.22**	34.18**	21.00**	72.64**
8.	Arka Gaurav x 4080-15	0.36	0.10	0.38	0.230	65.22**	280.00**	660.00**	-5.00	3.25	3.48	2.37	3.365	-29.57**	-31.90**	-45.89**	-22.80**
9.	Arka Gaurav x KTPI-19	0.36	0.42	0.30	0.390	-23.08**	-16.67**	500.00**	-25.0**	3.25	2.16	2.49	2.705	-7.95	-23.38**	-43.15**	-18.89**
10.	Arka Gaurav x Chilli yellow	0.36	0.05	0.48	0.205	134.15**	860.00*	860.00**	20.00**	3.25	3.41	2.47	3.330	-25.88**	-27.57**	-43.61**	-18.89**
11.	Arka Gaurav x Goa Local	0.36	0.12	0.15	0.240	-37.50**	25.00**	200.00**	-62.50**	3.25	3.29	3.11	3.270	-4.89	-5.47	-28.99**	1.30
12.	Arka Gaurav x Guntur Local	0.36	0.07	0.27	0.215	25.58**	74.00**	440.00**	-32.50**	3.25	4.38	3.14	3.815	-17.69**	-28.31**	-28.31**	2.28
13.	Yolo Wonder x Tarihal Local	0.42	0.21	0.41	0.315	30.16**	95.23**	720.00**	2.50	3.18	3.95	2.45	3.565	-31.28**	-37.97**	-44.06**	-20.20**
14.	Yolo Wonder x 4080-15	0.42	0.10	0.52	0.260	102.58**	420.00**	740.00**	30.00**	3.18	3.48	3.08	3.330	-7.51	-11.49	-29.68**	0.33
15.	Yolo Wonder x KTPI-19	0.42	0.42	0.54	0.420	28.57**	28.57**	980.00**	35.00**	3.18	2.16	3.32	2.670	24.34**	4.40	-24.20**	8.14
16.	Yolo Wonder x Chilli yellow	0.42	0.05	0.53	0.235	125.53**	960.00**	960.00**	32.50**	3.18	3.41	2.67	3.295	-18.97**	-21.70**	-39.04**	-13.03
17.	Yolo Wonder x Goa Local	0.42	0.12	0.11	0.270	-59.26**	-8.33	120.00**	-72.50**	3.18	3.29	2.28	3.235	-29.52**	-30.70**	-47.95**	-25.73**
18.	Yolo Wonder x Guntur Local	0.42	0.07	0.21	0.245	-14.28	200.00**	320.00**	-47.50**	3.18	4.38	3.19	2.780	-15.61**	-27.12**	-27.17**	3.91
	Check (Indira)				0.40								3.07				
	S.E.m±			0.082		0.018	0.021	0.021	0.021			0.47		0.13	0.15	0.15	0.15
	CD 5%			0.24		0.051	0.060	0.060	0.060			1.40		0.37	0.43	0.43	0.43
	CD 1%			0.34		0.068	0.079	0.079	0.079			1.93		0.49	0.57	0.57	0.57

* Significant at 5 per cent probability, ** Significant at 1 per cent probability

heterosis over better parent and best parent ranged from -16.67 (Arka Gaurav x KTPI-19) to 980.00 (California Wonder x Chilli Yellow) per cent and 120.00 (Yolo Wonder x Goa Local) to 1120.00 (California Wonder x KTPI-19) per cent respectively. Out of 18 crosses, seven revealed negative heterosis over check.

4.4.2.14 Pedicel length (cf. Table 19)

The maximum and minimum pedicel length was noticed in Guntur Local (4.38 cm) and KTPI-19 (2.16 cm) respectively. Whereas in the hybrids pedicel length varied between 2.28 centimeters (Yolo Wonder x Goa Local) to 3.69 centimeters (California Wonder x 4080-15).

The highest mid parent (53.71%) and better parent heterosis (45.45%) was noticed in California Wonder x KTPI-19. While best parent (21.00%) heterosis was recorded in the cross combination of Arka Gaurav x Tarihal Local.

The Arka Gaurav x Tarihal Local (72.64%) and California Wonder x 4080-15 (20.20%) showed highly significant heterosis over check.

4.4.2.15 Seed weight per fruit (cf. Table 20)

Among the female parents the minimum seed weight per fruit was recorded by Arka Gaurav (3.09 g), whereas, the male parent Goa Local (0.35 g) was recorded minimum seed weight per fruit.

The *per se* performance ranged from 0.62 (Arka Gaurav x Guntur Local) to 1.62 (Yolo Wonder x KTPI-19) grams.

The mid parent heterosis was ranged from -75.09 to -41.39 per cent while, heterosis over better parent and best parent ranged from -73.20 to 123.81 per cent and -65.71 and 362.86 per cent respectively. All the 18

crosses showed negative significant heterosis over check in desired direction.

4.4.2.16 Number of seeds per fruit (cf. Table 20)

A greater range of variation was observed for number of seeds among testers which ranged from 46.28 (Goa Local) to 182.52 (Tarihal Local). Among lines the range was from 143.96 (Arka Gaurav) to 160.45 (Yolo Wonder). However, in F_1 's minimum number of seeds were found in the cross combination of Yolo Wonder x Guntur Local (21.83) and maximum seeds were in the cross Arka Gaurav x Tarihal Local (126.93).

The magnitude of heterosis over mid parental value varied between -81.32 (Yolo Wonder x Guntur Local) to -21.10 (California Wonder x 4080-15) per cent in desirable direction. The significant negative heterosis over better parent and best parent was observed in 12 and 17 crosses respectively. Highest magnitude of negative heterosis was revealed in the cross combination Yolo Wonder x Guntur Local (-88.44%) over check in desirable direction.

4.4.2.17 Ascorbic acid content (cf. Table 21)

Among the lines ascorbic acid ranged from 145.25 mg/100 g (Yolo Wonder) to 223.13 mg/100 g (California Wonder). Whereas, among testers the range was from 155.72 mg/100 g (Tarihal Local) to 242.71 (Goa Local). The maximum ascorbic acid content was noticed in California Wonder x Goa Local (232.92 mg/100 g) for the hybrids.

The magnitude of heterosis over mid parent extended from -61.59 (California Wonder x Goa Local) per cent to 30.22 (California Wonder x Tarihal Local) per cent. There were a total of six hybrids exhibited significant positive heterosis while, none of the cross showed significant heterosis over best parent. However, the cross combination California

Table 21. Per se performance and magnitude of heterosis for ascorbic acid content and total soluble solids

Sl. No.	Crosses (P ₁ x P ₂)	Ascorbic acid content						Total soluble solids									
		Per se value (mg/100 g)				Per cent heterosis over		Per se value (°brix)				Per cent heterosis over					
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC
1.	California Wonder x Tarihal Local	223.13	155.72	246.67	189.43	30.22**	10.55*	1.63	17.18**	4.93	7.58	6.13	6.26	-2.08	-19.13**	-19.17**	0.49
2.	California Wonder x 4080-15	223.13	177.97	207.00	200.55	3.22	-7.23	-14.71**	-1.66	4.93	7.13	6.16	6.03	2.16	-13.60**	-18.73**	0.98
3.	California Wonder x KTPI-19	223.13	202.16	233.00	212.65	9.57*	4.42	-4.00	10.69	4.93	7.01	6.27	5.97	5.02	-10.56**	-17.28**	2.79
4.	California Wonder x Chilli yellow	223.13	216.78	234.67	219.96	6.69	5.17	-3.31	11.48	4.93	5.34	6.21	5.14	20.82**	16.29**	-18.07**	1.80
5.	California Wonder x Goa Local	223.13	242.71	89.47	232.92	-61.59**	-63.14**	-63.14**	-57.5**	4.93	5.00	6.05	4.97	21.73**	21.00**	-20.18**	-0.82
6.	California Wonder x Guntur Local	223.13	210.25	204.67	216.69	-5.55	-8.27	-15.67**	-2.77	4.93	5.77	6.15	5.35	14.95**	6.59	-18.87**	0.82
7.	Arka Gaurav x Tarihal Local	210.30	155.72	184.53	183.01	0.83	-12.25*	-23.97**	-12.34*	5.23	7.58	5.00	6.41	-22.00**	-34.04**	-33.91**	-18.03**
8.	Arka Gaurav x 4080-15	210.30	177.97	215.06	194.14	10.78*	2.26	-11.39*	2.17	5.23	7.13	7.18	6.18	16.18**	0.70	-5.28	17.70**
9.	Arka Gaurav x KTPI-19	210.30	202.16	226.33	206.23	9.75*	7.62	-6.75	7.52	5.23	7.01	7.15	6.12	16.83**	2.00	-5.67	17.21**
10.	Arka Gaurav x Chilli yellow	210.30	216.78	232.67	213.54	8.96	7.33	-4.14	10.53	5.23	5.34	5.05	5.29	-4.54	-5.43	-33.38**	-17.21**
11.	Arka Gaurav x Goa Local	210.30	242.71	131.22	226.51	-42.07**	-45.93**	-45.83*	-37.66**	5.23	5.00	6.31	5.12	23.24**	21.60**	-16.75**	3.44
12.	Arka Gaurav x Guntur Local	210.30	210.25	224.67	210.28	6.84	6.83	-7.43	6.73	5.23	5.77	6.01	5.50	9.27*	4.16	-20.71**	-1.48
13.	Yolo Wonder x Tarihal Local	145.25	155.72	173.15	150.49	15.06*	11.19	-28.66**	-17.74**	5.17	7.58	4.67	6.38	-26.80**	-38.39**	-38.39**	-23.44**
14.	Yolo Wonder x 4080-15	145.25	177.97	144.28	161.61	-10.10	-18.37**	-40.14**	-30.98**	5.17	7.13	4.97	6.15	-19.19**	-30.29**	-34.43**	-18.52**
15.	Yolo Wonder x KTPI-19	145.25	202.16	171.53	173.71	-1.25	-15.15*	-29.33**	-18.51**	5.17	7.01	4.72	6.09	-22.50**	-32.67**	-37.73**	-22.62**
16.	Yolo Wonder x Chilli yellow	145.25	216.78	211.00	181.02	16.56**	-2.67	-13.06**	0.24	5.17	5.34	5.91	5.26	12.36**	10.67*	-22.03**	-3.11
17.	Yolo Wonder x Goa Local	145.25	242.71	81.77	193.98	-57.85**	-66.31**	-66.31**	-61.15**	5.17	5.00	4.07	5.09	-20.34**	-21.28**	-46.31**	-33.28**
18.	Yolo Wonder x Guntur Local	145.25	210.25	201.85	177.75	13.56*	-4.00	-16.83**	-4.11	5.17	5.77	5.87	5.47	7.31	1.73	-22.56**	-3.77
	Check (Indira)			210.50									6.10				
	S.E.m±			12.01		7.16	8.27	8.27	8.27			0.42		0.15	0.18	0.18	0.18
	CD 5%			35.83		20.31	23.46	23.46	23.46			1.25		0.43	0.51	0.51	0.51
	CD 1%			49.22		27.08	31.28	31.28	31.28			1.72		0.57	0.68	0.68	0.68

* Significant at 5 per cent probability. ** Significant at 1 per cent probability

Wonder x Tarihal Local showed significant positive heterosis over better parent (10.55%) and check (17.18%).

4.4.2.18 Total soluble solids (cf. Table 21)

The parents recorded wider variation of total soluble solids which ranged from 5.00° to 7.58° brix for testers and 4.93° to 5.17° brix for lines. Among F₁'s the range was from 7.18° brix in Arka Gaurav x 4080-15 to 4.07° brix in Yolo Wonder x Goa Local.

Out of 18 F₁'s eight and five crosses showed positive and negative heterosis over mid parent respectively. The better parent heterosis ranged from -32.67 (Yolo Wonder x KTPI-19) to 21.60 (Arka Gaurav x Goa Local) per cent. All the crosses showed negative heterosis over best parent while, only two crosses *viz.*, Arka Gaurav x 4080-15 (17.70%) and Arka Gaurav x KTPI-19 (17.21%) recorded positive heterosis over check.

4.4.2.19 Number of fruits per plant (cf. Table 22)

Among the parents maximum number of fruits (135.34) per plant was registered in male parent Chilli Yellow. While, minimum number of fruits in female parent Yolo Wonder (21.45). The cross combination California Wonder x Chilli Yellow recorded highest number of fruits (96.57) per plant.

There were three, one and zero number of hybrids significantly heterotic over mid parent, better parent and best parent respectively in positive direction. The highest mid parent (106.39%) and better parent (55.42%) heterosis was noticed in cross combination Yolo Wonder x Tarihal Local. All the crosses except California Wonder x 4080-15 (17.05%) and Yolo Wonder x Guntur Local (8.92%) had significant positive heterosis over check.

Table 22. *Per se* performance and magnitude of heterosis for number of fruits per plant and fruit yield per plant

Sl. No.	Crosses (P ₁ x P ₂)	Number of fruits per plant						Fruit yield per plant													
		Per se value						Per cent heterosis over				Per se value (kg)						Per cent heterosis over			
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC	P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP	SC				
1.	California Wonder x Tarihal Local	19.36	42.39	51.21	30.88	65.84**	20.81	-62.16**	85.75**	0.78	0.40	1.03	0.59	74.58**	32.05	-42.13**	-36.42**				
2.	California Wonder x 4080-15	19.36	61.61	32.27	40.49	-20.30	-47.62**	-76.16**	17.05	0.78	0.54	0.36	0.66	-45.45**	-53.85**	-79.77**	-77.78**				
3.	California Wonder x KTPI-19	19.36	125.51	51.69	72.44	-28.64**	-58.82**	-61.81**	87.49**	0.78	1.78	1.53	1.28	19.53	-14.06	-14.06	-5.56				
4.	California Wonder x Chilli yellow	19.36	135.34	96.57	77.35	24.85**	-28.65**	-28.65**	250.27**	0.78	0.58	1.24	0.68	82.35**	58.97**	-30.34**	-23.46*				
5.	California Wonder x Goa Local	19.36	104.35	42.87	61.86	-30.70**	-58.92**	-68.32**	55.50*	0.78	0.72	0.46	0.75	-38.67*	-41.03*	-74.16**	-71.60**				
6.	California Wonder x Guntur Local	19.36	115.58	45.52	67.47	-32.53**	-60.62**	-66.37**	65.12*	0.78	0.61	0.58	0.70	17.14	-25.64	-67.42**	-64.20**				
7.	Arka Gaurav x Tarihal Local	20.01	42.39	46.79	31.20	49.97*	-10.38	-65.43**	69.71**	0.40	0.40	1.98	0.40	395.00**	395.00**	11.24	22.22*				
8.	Arka Gaurav x 4080-15	20.01	61.61	49.29	40.81	20.78	-20.01	-63.58**	78.78**	0.40	0.54	1.88	0.47	300.00**	248.15**	5.62	16.05				
9.	Arka Gaurav x KTPI-19	20.01	125.51	55.67	72.76	-23.49**	-55.65**	-58.87**	101.92**	0.40	1.78	0.99	1.09	-9.17	-44.38**	44.38**	-38.89**				
10.	Arka Gaurav x Chilli yellow	20.01	135.34	67.29	77.68	-13.38	-50.28**	-50.28**	144.07**	0.40	0.58	0.67	0.49	36.73	15.52	-62.36**	-58.64**				
11.	Arka Gaurav x Goa Local	20.01	104.35	46.03	62.18	-25.97**	-55.89**	-65.99**	66.96**	0.40	0.72	0.43	0.56	-23.21	-40.28	-75.84**	-73.46**				
12.	Arka Gaurav x Guntur Local	20.01	115.58	51.75	67.80	-23.67**	-55.23**	-61.76**	87.70**	0.40	0.61	0.44	0.51	-13.72	-27.87	-75.28**	-72.84**				
13.	Yolo Wonder x Tarihal Local	21.45	42.39	65.88	31.72	106.39**	55.42**	-51.32**	138.96**	0.73	0.40	0.97	0.57	70.18**	32.88	-45.50**	-40.12**				
14.	Yolo Wonder x 4080-15	21.45	61.61	75.48	41.53	81.75**	22.51*	-44.23**	173.78**	0.73	0.54	1.63	0.64	154.69**	123.29**	-8.43	0.62				
15.	Yolo Wonder x KTPI-19	21.45	125.51	62.05	73.48	-15.56	-50.56**	-54.15**	124.99**	0.73	1.78	1.91	1.26	51.59**	7.30	7.30	17.90*				
16.	Yolo Wonder x Chilli yellow	21.45	135.34	43.15	78.40	-44.96**	-68.12**	-68.12**	56.51*	0.73	0.58	0.91	0.66	37.88	24.66	-48.88**	-43.83**				
17.	Yolo Wonder x Goa Local	21.45	104.35	71.84	62.90	14.21	-31.15**	-46.92**	160.57**	0.73	0.72	0.50	0.73	-31.51	-31.5	-71.91**	-69.13**				
18.	Yolo Wonder x Guntur Local	21.45	115.58	30.03	68.52	-56.17**	-74.02*	-77.81**	8.92	0.73	0.61	0.31	0.67	-53.73*	-57.53**	-82.58**	-80.86**				
	Check (Indira)				27.57																
	S.E.m±			10.36		4.20	4.85	4.85	4.85			0.28	1.62	0.10	0.11	0.11	0.11				
	CD 5%			30.91		11.94	13.76	13.76	13.76			0.84		0.28	0.31	0.31	0.31				
	CD 1%			42.46		15.88	18.34	18.34	18.34			1.15		0.38	0.42	0.42	0.42				

* Significant at 5 per cent probability. ** Significant at 1 per cent probability

4.4.2.20 Fruit yield per plant (cf. Table 22)

The male parent KTPI-19 (1.78 kg) registered highest yield per plant followed by female parent California Wonder (0.78 kg). Among the hybrids the maximum yield was obtained in cross combination of Arka Gaurav x Tarihal Local (1.98 kg) followed by Yolo Wonder x KTPI-19 (1.91 kg) and Arka Gaurav x 4080-15 (1.88 kg).

Heterosis over mid, better and best parent for yield ranged from -53.73 (Yolo Wonder x Guntur Local) to 395.00 (Arka Gaurav x Tarihal Local) per cent; -57.53 (Yolo Wonder x Guntur Local) to 395.00 (Arka Gaurav x Tarihal Local) and -82.58 (Yolo Wonder x Guntur Local) to 11.24 (Arka Gaurav x Tarihal Local) per cent respectively. Among 18 hybrids the number of positive and significant heterosis were seven, four and two over mid parent, better parent and check. While none of the crosses revealed significant positive heterosis over best parent.

4.4.2.21 Per cent powdery mildew disease index (cf. Table 23)

The disease incidence was maximum in California Wonder (76.00%) and minimum in Tarihal Local (21.20%). The hybrids showed wide range of disease reaction from 19.90 (California Wonder x Tarihal Local) to 58.50 (Arka Gaurav x Chilli Yellow) per cent.

Among 18 crosses eleven, four and eight crosses revealed significant negative heterosis over mid parent, better parent and check in desirable direction. All the crosses showed significant positive heterosis over best parent. The highest magnitude of heterosis over mid, better and check was seen in California Wonder x Tarihal Local (-39.91%), California Wonder x KTPI-19 (-21.37%) and California Wonder x Tarihal Local (-53.40) in desirable direction respectively.

Table 23. *Per se* performance and magnitude of heterosis for incidence of powdery mildew

Sl. No.	Crosses (P ₁ x P ₂)	Per cent powdery mildew index						
		Per se value (%)			Per cent heterosis over			
		P ₁	P ₂	F ₁	Mean parental value	MP	BP	BSP
1.	California Wonder x Tarihal Local	60.64 (76.00)	27.42 (21.20)	26.46 (19.90)	44.03	-39.91**	-3.50	-3.50
2.	California Wonder x 4080-15	60.64 (76.00)	63.80 (52.98)	42.84 (46.20)	56.81	-24.59**	-19.14**	56.24**
3.	California Wonder x KTPI-19	60.64 (76.00)	71.70 (57.23)	45.00 (50.00)	58.94	-23.65**	-21.37**	64.11**
4.	California Wonder x Chilli yellow	60.64 (76.00)	32.34 (28.60)	42.93 (46.40)	46.49	-7.66*	32.74**	56.56**
5.	California Wonder x Goa Local	60.24 (76.00)	36.31 (35.10)	42.21 (45.10)	48.28	-12.57**	16.25**	53.94**
6.	California Wonder x Guntur Local	60.24 (76.00)	28.72 (23.10)	46.08 (51.40)	44.48	3.60	60.45**	58.05**
7.	Arka Gaurav x Tarihal Local	52.38 (62.70)	27.42 (21.20)	32.29 (28.58)	39.90	-19.07**	17.76*	17.76*
8.	Arka Gaurav x 4080-15	52.38 (62.70)	63.80 (52.98)	41.51 (43.90)	52.68	-21.20**	-20.75**	51.39**
9.	Arka Gaurav x KTPI-19	52.38 (62.70)	71.70 (57.23)	48.18 (55.10)	54.81	-12.10**	-8.02**	75.71**
10.	Arka Gaurav x Chilli yellow	52.38 (62.70)	32.34 (28.60)	43.18 (46.80)	42.36	1.94	33.52**	57.48**
11.	Arka Gaurav x Goa Local	52.38 (62.70)	36.31 (35.10)	49.89 (58.50)	44.35	12.49**	37.40	81.95**
12.	Arka Gaurav x Guntur Local	52.38 (62.70)	28.72 (23.10)	38.50 (38.80)	40.55	-5.06	34.05**	40.41**
13.	Yolo Wonder x Tarihal Local	53.53 (64.55)	27.42 (21.20)	32.52 (28.90)	40.48	-19.65**	18.61*	18.61*
14.	Yolo Wonder x 4080-15	53.53 (64.55)	63.80 (52.98)	44.87 (49.80)	53.26	-15.75**	-15.31**	63.64**
15.	Yolo Wonder x KTPI-19	53.53 (64.55)	71.70 (57.23)	49.72 (58.20)	55.38	-10.22**	-7.12*	81.33**
16.	Yolo Wonder x Chilli yellow	53.53 (64.55)	32.34 (28.60)	44.68 (47.70)	42.94	4.05	38.16**	62.95**
17.	Yolo Wonder x Goa Local	53.53 (64.55)	36.31 (35.10)	42.97 (46.50)	44.92	4.34	18.34**	56.71**
18.	Yolo Wonder x Guntur Local	53.53 (64.55)	28.72 (23.10)	31.76 (27.70)	41.13	-22.78**	10.58	15.83*
	Check (Indira)				70.79			
	S.E.m±			2.34		1.19	1.37	1.37
	CD 5%			6.98		3.38	3.89	3.89
	CD 1%			9.59		4.50	5.18	5.18

* Significant at 5 per cent probability, ** Significant at 1 per cent probability
Figures in parenthesis indicate transformed values

4.4.3 Analysis of variance for combining ability

The analysis of variance for combining ability with respect to 21 characters is presented in Table 24. The differences among lines (females) were significant for 20 characters except for fruit length. Variation among testers (males) was significant for all the traits studied except for seed weight per fruit.

Among hybrids significant variation was noticed for all the characters excluding number of primary branches and seed weight per fruit which showed insignificant magnitude of variation.

From the Table 24 it was evident that variance due to dominance effect (σ^2D) was higher than variance due to additivity (σ^2A) in all the cases except for plant height, fruit width, locules per fruit, pericarp thickness, ascorbic acid content and powdery mildew disease incidence. These aforesaid six traits showed high additive variance.

4.4.4 General combining ability (*gca*) effects and specific combining ability (*sca*) effects

The results pertaining to general combining ability effects of nine parents and specific combining ability effects of 18 hybrids in relation to all the characters are presented in Table 25 and 26 respectively.

4.4.4.1 Seedling height

Among the lines and the testers Yolo Wonder (1.43) and Tarihal Local (1.92) respectively showed highly significant and positive *gca* effects. Out of 18 crosses three crosses [California Wonder x KTPI-19 (3.56); Arka Gaurav x KTPI-19 (2.41) and Yolo Wonder x Chilli Yellow (2.46)] were recorded significant positive *sca* effects.

Table 24. Analysis of variance for combining ability in respect of 21 traits in pepper (L x T) hybrids

Sl. No.	Source Characters	Mean sum of square					σ^2A	σ^2D	σ^2A/σ^2D
		Replication	Females	Males	Female x male	Error			
		2	2	5	10	34			
1.	Seedling height	8.559	63.227**	28.774**	18.627**	2.833	4.06	5.20	0.780
2.	Root length	0.257	2.524**	1.147**	1.777**	0.157	0.01	0.05	0.200
3.	Plant height	96.796	7903.753**	2056.502**	1115.955**	48.556	572.47	355.80	1.609
4.	Plant spread	52.738	198.912**	573.370**	267.708**	10.754	17.55	85.60	0.205
5.	Number of primary branches	0.0035	1.096**	1.064**	0.509**	0.0094	0.08	0.10	0.800
6.	Number of secondary branches	0.128	3.230**	3.357**	00.104	0.104	0.09	0.80	0.112
7.	Days to 50 per cent flowering	2.456	363.812**	82.364**	101.381**	1.637	18.03	33.20	0.543
8.	Fruit length	0.818	6.125	14.008**	29.144**	28.794	-2.83	9.60	-0.295
9.	Fruit width	0.051	3.067**	11.742**	1.536**	0.0725	0.87	0.49	1.775
10.	Fruit shape index	0.107	1.104**	2.400**	0.736**	0.026	0.15	0.20	0.750
11.	Locules per fruit	0.091	4.945**	2.577**	0.652**	0.073	0.46	0.19	2.421
12.	Pericarp thickness	0.0004	0.040**	0.183**	0.053**	0.0009	0.01	0.001	10.00
13.	Pedicle length	0.051	0.685**	1.213**	1.992**	0.033	0.15	0.60	0.250
14.	Seed weight per fruit	0.038	0.305**	0.528	0.207	0.688	0.03	0.07	0.429
15.	Number of seeds per fruit	127.768	980.449**	2245.08**	1693.738**	13.707	-12.00	560.00	-0.021
16.	Average fruit weight	3.984	571.533**	719.731**	530.129**	2.553	17.11	175.80	0.973
17.	Ascorbic acid content	86.888	8865.32**	18362.57**	1350.485**	51.771	1816.81	432.90	4.197
18.	Total soluble solids	0.027	7.324**	1.048**	1.649**	0.053	0.38	0.53	0.717
19.	Number of fruits per plant	212.606	151.073**	646.846**	986.239**	19.173	86.26	322.30	0.268
20.	Fruit yield per plant	0.066	0.208*	1.824**	0.738**	0.024	0.04	0.20	0.20
21.	Per cent powdery mildew index	3.932	9.607*	336.596**	52.405**	3.082	17.88	16.40	1.090

* Significant at 5 per cent probability

** Significant at 1 per cent probability

Table 25. Estimates of general combining ability (gca) effects for 21 characters in pepper (L x T) hybrids

Sl. No.	Characters	Parents	Seedling height	Root length	Plant height	Plant spread	No. of primary branches	No. of secondary branches	Days to 50% flowering	Average fruit weight	Fruit length	Fruit width
Lines												
1.	California Wonder		-2.12**	-0.24	18.00**	0.72	0.19**	0.45**	5.18**	-5.10**	-0.59**	-0.31**
2.	Arka Gourav		0.69	0.43*	-23.00**	2.91**	-0.28**	-0.39**	-2.92**	6.05**	-0.02	0.47**
3.	Yolo Wonder		1.43**	-0.19	5.00**	-3.62**	0.09**	-0.07	-2.25**	-0.95**	0.59**	-0.16**
	S.E.m±		0.26	0.14	1.09	0.52	0.02	0.05	0.20	0.25	0.08	0.04
	CD at 5%		0.747	0.402	3.133	1.494	0.057	0.144	0.575	0.718	0.223	0.15
	CD at 1%		1.003	0.540	4.206	2.002	0.077	0.193	0.770	0.810	0.309	0.154
Testers												
1.	Tarihal Local		1.92**	-0.01	-12.95**	4.70**	0.22**	0.53**	5.23**	12.16**	-0.68**	1.34**
2.	4080-15		-3.01**	0.11	-14.68**	-5.69**	-0.09**	0.03	-1.21*	3.33**	0.51**	1.07**
3.	KTP1-19		0.08	0.55**	-3.66	4.77**	-0.10**	-0.35**	-0.15	5.54**	1.53**	0.02
4.	Chilli Yellow		0.63	0.20	22.64**	-13.75**	-0.14**	-0.02	-2.65**	-2.29**	1.07**	-0.87**
5.	Goa Local		1.36*	0.51**	-5.58*	3.84**	-0.45**	-0.98**	1.54**	-5.52**	-1.77**	0.12
6.	Guntur Local		-0.99	0.13	14.22**	6.13**	0.55**	0.79**	-2.75**	-13.21**	-0.69**	-1.68**
	S.E.m±		0.42	0.10	1.73	0.81	0.02	0.08	0.32	0.40	0.13	0.07
	CD at 5%		1.207	0.287	4.972	2.328	0.057	0.233	0.919	1.149	0.374	0.201
	CD at 1%		1.621	0.386	6.676	3.126	0.077	0.309	1.235	1.544	0.502	0.270

Contd.....

Sl. No.	Characters	Parents	Fruit shape index	Locules/ fruit	Pericarp thickness	Pedicle length	Seed weight/fruit	Number of seeds/ fruit	Ascorbic acid content	Total soluble solid	Number of fruits/plant	Fruit yield per plant	Per cent powdery mildew index
Lines													
1.	California Wonder		0.05	0.50**	0.05**	0.13*	-0.13**	2.40**	12.91**	0.39**	-1.39	-0.12**	-0.50
2.	Arka Gourav		-0.27**	0.50**	-0.01**	0.07	0.001	5.88**	12.72**	0.35**	-1.94	0.07*	0.84*
3.	Yolo Wonder		0.22**	-0.55**	-0.04**	-0.22**	0.13**	-8.28**	-25.63**	-0.74**	3.33**	0.05	-0.34
	S.E.m±		0.03	0.04	0.001	0.03	0.01	0.58	1.13	0.04	0.69	0.02	0.28
	CD at 5%		0.086	0.115	0.003	0.086	0.029	1.667	3.248	0.115	1.983	0.057	0.805
	CD at 1%		0.116	0.154	0.004	0.116	0.038	2.238	4.361	0.154	2.663	0.077	1.080
Testers													
1.	Tarihal Local		-0.57**	0.83**	0.06**	0.67**	0.23**	25.04**	11.77**	-0.50**	-0.12	0.34**	-11.00**
2.	4080-15		-0.32**	0.16	0.09**	-0.01	0.14**	9.66**	-0.61	0.33**	-2.40	0.30**	1.65*
3.	KTP1-19		0.19**	-0.13	0.07**	0.05	0.20*	1.26	20.65**	0.28**	1.73	0.48**	6.21**
4.	Chilli Yellow		0.53**	-0.01	0.13*	-0.16*	-0.14**	-6.71**	36.33**	-0.04	14.26**	-0.05	2.18**
5.	Goa Local		-0.45**	-0.01	-0.22**	-0.42**	-0.03	-9.51**	88.82**	-0.29**	-1.16	-0.52**	3.60**
6.	Guntur Local		0.62**	-0.84**	-0.13**	-0.14	-0.40**	-19.75**	20.68**	0.23*	-12.31**	-0.55**	-2.64**
	S.E.m±		0.04	0.07	0.01	0.05	0.02	0.92	1.79	0.06	1.09	0.04	0.44
	CD at 5%		0.115	0.200	0.029	0.144	0.057	2.644	5.144	0.172	3.133	0.115	1.264
	CD at 1%		0.154	0.270	0.038	0.193	0.077	3.550	6.908	0.231	4.206	0.154	1.698

* Significant at 5 per cent probability

** Significant at 1 per cent probability

Table 26. Estimates of specific combining ability (sca) effects for 21 characters in pepper (L x T) hybrids

Sl. No.	Hybrids	Seedling height	Root length	Plant height	Plant spread	No. of primary branches	No. of secondary branches	Days to 50% flowering	Average fruit weight	Fruit length	Fruit width	Fruit shape index
1.	California Wonder x Tarihal Local	0.32	0.37	-19.65**	-9.97**	0.15**	-0.12	0.15	-6.77**	-2.31**	-0.58**	-0.35**
2.	California Wonder x 4080-15	-3.58**	-1.11**	-1.01	5.68**	-0.54**	-1.12**	4.25**	-10.25**	-2.07**	-0.33**	-0.33**
3.	California Wonder x KTPI-19	3.56**	0.35	-3.04	3.30	0.34**	0.69**	1.49*	6.00**	-1.18**	-0.19	-0.17
4.	California Wonder x Chilli Yellow	-1.19	0.13	3.90	-3.42*	0.44**	1.77**	6.39**	6.20**	5.20**	0.84**	0.78**
5.	California Wonder x Goa Local	0.39	-0.45*	28.75**	-2.48	-0.19**	-0.61**	-4.06**	0.81	0.38	0.57**	-0.15
6.	California Wonder x Guntur Local	0.50	0.71**	-8.95*	6.90**	-0.19**	-0.61**	-8.21**	4.02**	-0.02	-0.32*	0.22*
7.	Arka Gaurav x Tarihal Local	1.28	0.47*	25.59**	9.00**	-0.38**	-0.28	-5.39**	10.80**	4.25**	0.78**	0.68**
8.	Arka Gaurav x 4080-15	2.41**	-0.12	15.46**	-5.78**	-0.08	0.35*	2.55**	17.70**	2.16**	0.27*	0.36**
9.	Arka Gaurav x KTPI-19	-3.12	0.18	-5.83	-2.26	-0.06	-0.50**	-1.11	-21.37**	-2.18**	-0.71**	-0.05
10.	Arka Gaurav x Chilli Yellow	-1.27	0.22	-20.16**	3.88*	-0.03	-0.73**	-1.54*	-11.69**	-2.73**	0.17	-0.84**
11.	Arka Gaurav x Goa Local	1.41	-0.09	-17.04**	-11.41**	0.28**	0.70**	3.60**	8.25**	-1.34**	-0.58**	0.00
12.	Arka Gaurav x Guntur Local	-0.71	-0.66**	1.99	6.57**	0.28**	0.46**	1.89**	-3.69**	-0.16	0.07	-0.15
13.	Yolo Wonder x Tarihal Local	-1.60	-0.84**	-5.94	0.97	0.24**	0.40*	5.24**	-4.03**	-1.94**	-0.20	-0.33**
14.	Yolo Wonder x 4080-15	1.17	1.24**	-14.44**	0.09	0.62**	0.77**	-6.79**	-7.45**	-0.09	0.05	-0.03
15.	Yolo Wonder x KTPI-19	-0.44	-0.53*	8.87*	-1.03	-0.27**	-0.19	0.38	15.37**	3.36**	0.90**	0.22*
16.	Yolo Wonder x Chilli yellow	2.46**	-0.35	16.27**	-0.45	-0.40**	-1.04**	-4.84**	5.49**	-2.47**	-1.01**	0.07
17.	Yolo Wonder x Goa Local	-1.80*	0.54**	-11.71**	13.89**	-0.09*	-0.09	0.46	-9.06**	0.97**	0.01	0.15
18.	Yolo Wonder x Guntur Local	0.21	-0.04	6.96	-13.47**	-0.09*	0.15	6.32**	-0.33	0.18	0.25	-0.07
	S.Em±	0.59	0.14	2.45	1.15	0.03	0.11	0.45	0.56	0.19	0.09	0.06
	CD 5%	1.695	0.402	7.041	3.305	0.086	0.316	1.293	1.609	0.546	0.259	0.172
	CD 1%	2.280	0.540	9.454	4.439	0.118	0.424	1.737	2.161	0.733	0.347	0.231

* Significant at 5 per cent probability

** Significant at 1 per cent probability

Table 26. Contd.....

Sl. No.	Hybrids	Locules/ fruit	Pericarp thickness	Pedicel length	Seed weight / fruit	Number of seeds	Ascorbic acid content	Total soluble solids	Number of fruits/ plant	Fruit yield/ plant	Per cent powdery mildew index
1.	California Wonder x Tarihal Local	0.33*	-0.13**	-0.44**	0.12**	-21.37**	0.47**	32.27**	-2.03	-0.17*	-3.46**
2.	California Wonder x 4080-15	0.06	-0.04**	0.51**	-0.06	18.48**	-0.34**	4.98	-18.69**	-0.81**	0.27
3.	California Wonder x KTPI-19	0.28	0.04**	0.28**	0.05	-6.85**	-0.16	9.72*	-3.39	0.18*	-2.13*
4.	California Wonder x Chilli Yellow	-0.50**	-0.09**	0.53**	0.12**	-2.75	0.10	-3.97	28.95**	0.42**	-0.16
5.	California Wonder x Goa Local	0.50**	0.13**	-0.26**	0.09*	-0.97	0.19	-24.35**	-9.32**	0.12	-2.31*
6.	California Wonder x Guntur Local	-0.67**	0.08**	-0.63**	-0.31**	13.47**	-0.25*	-18.65**	4.47*	0.26**	7.80**
7.	Arka Gaurav x Tarihal Local	-0.03	0.08**	1.49**	0.10*	25.23**	-0.60**	-29.55**	-5.89*	0.58**	1.03
8.	Arka Gaurav x 4080-15	-0.23	0.007	-0.77**	0.03	-3.34	0.73**	13.23**	-1.12	0.51**	-2.40**
9.	Arka Gaurav x KTPI-19	0.06	-0.20**	-0.71**	-0.38**	-36.10**	0.75**	3.50	1.14	-0.56**	-0.29
10.	Arka Gaurav x Chilli Yellow	-0.05	0.06**	-0.53**	0.23**	7.35**	-1.02**	-6.61	0.23	-0.35**	-1.25
11.	Arka Gaurav x Goa Local	-0.05	-0.06**	0.39**	-0.04	-0.57	0.48**	17.86**	-5.61*	0.11	4.03**
12.	Arka Gaurav x Guntur Local	0.30*	-0.02	0.13	0.06	7.44**	-0.35**	1.57	11.26**	-0.07	-1.12
13.	Yolo Wonder x Tarihal Local	0.30*	-0.06**	-1.05**	-0.22**	-3.87**	0.13	-2.72	7.92**	-0.40**	2.43**
14.	Yolo Wonder x 4080-15	0.17	0.03*	0.26**	0.03	-15.13**	-0.39**	-18.21**	19.80**	0.29**	2.13**
15.	Yolo Wonder x KTPI-19	-0.34*	0.16**	0.43**	0.33**	42.96**	-0.59**	-13.22**	2.25	0.38**	2.42**
16.	Yolo Wonder x Chilli yellow	-0.55**	0.00	-0.01	-0.35**	-4.60*	0.92**	10.58**	-29.18**	-0.08	1.41
17.	Yolo Wonder x Goa Local	-0.45**	-0.07**	0.13	-0.05	1.55	-0.67**	6.49	14.93**	-0.01	-1.72
18.	Yolo Wonder x Guntur Local	0.37*	-0.06**	0.50**	0.25**	-20.91**	0.60**	17.07**	-15.73**	-0.18*	-6.68**
	S.Em±	0.10	0.01	0.06	0.03	1.30	0.08	2.53	1.54	0.05	0.62
	CD 5%	0.287	0.029	0.172	0.086	3.736	0.230	7.271	4.426	0.144	1.782
	CD 1%	0.386	0.039	0.231	0.116	5.017	0.309	9.763	5.943	0.193	2.392

* Significant at 5 per cent probability

** Significant at 1 per cent probability

4.4.4.2 Root length

The female parent Arka Gaurav (0.43) and male parents KTPI-19 (0.55) and Goa Local (0.51) showed significant *gca* effects for root length.

Among 18 crosses California Wonder x Guntur Local (0.71), Yolo Wonder x 4080-15 (1.24) and Yolo Wonder x Goa Local (0.54) were recorded highly significant positive *sca* effects.

4.4.4.3 Plant height

The data on *gca* effects on plant height revealed that among female parents California Wonder (18.00) and Yolo Wonder (5.00) showed significant positive *gca* effects while, none of the testers were good combiners in required direction.

Out of 18 hybrids five crosses were positively significant for *sca* effect. California Wonder x Goa Local was the best combiner with *sca* effect of 28.75 for plant height.

4.4.4.4 Plant spread

The *gca* effect for plant spread indicated that the best combiners were Arka Gaurav (2.91), KTPI-19 (4.77) and Tarihal Local (4.70).

There were six crosses with significant positive *sca* effect. Yolo Wonder x Guntur Local (13.89) and Arka Gaurav x Tarihal Local (9.00) being best combiners in positive direction.

4.4.4.5 Number of primary branches

The data on *gca* and *sca* effects on number of primary branches revealed that among nine parents only four parents *viz.*, California Wonder (0.19) and Yolo Wonder (0.09) among the lines; Tarihal Local (0.22) and Guntur Local (0.55) among the testers were best general combiners.

Among 18 hybrids seven and eight hybrids showed significant positive and negative *sca* effects respectively. The cross combination of Yolo Wonder x 4080-15 (0.62) was recorded for highest positive *sca* effects.

4.4.4.6 Number of secondary branches

The *gca* and *sca* effects for this character showed that California Wonder (0.45) and Tarihal Local (0.53) were good general combiners in desired direction.

The estimates of *sca* effect was highly significant in positive direction for five hybrids. Whereas, six hybrids showed significant negative *sca* effects. Highest positive *sca* effect was recorded in cross combination California Wonder x Chilli Yellow (1.77).

4.4.4.7 Days to 50 per cent flowering

The female parents, Arka Gaurav (-2.92) and Yolo Wonder (-2.25) and male parents Chilli Yellow (-2.65) and Guntur Local (-2.75) were noticed as good combiners.

Out of 18 hybrids six and eight crosses were noticed significant negative and positive *sca* effects respectively. California Wonder x Guntur Local (-8.21) was best specific combiner in negative direction (desirable direction).

4.4.4.8 Average fruit weight

All the nine parents revealed highly significant *gca* effect for average fruit weight. Tarihal Local a male parent (12.16) showed highest magnitude of *gca* effect followed by the female parent Arka Gaurav (6.05) for average fruit weight.

Among 18 hybrids eight crosses were good specific combiners. Arka Gaurav x 4080-15 (17.70) followed by Yolo Wonder x KTPI-19 (15.37) and Arka Gaurav x Tarihal Local (10.80) showed highest magnitude of *sca* effect.

4.4.4.9 Fruit length

The data on *gca* and *sca* effects pertaining to fruit length indicated that among lines, Yolo Wonder (0.59) and among testers 4080-15 (0.51), KTPI-19 (1.53) and Chilli Yellow (1.07) recorded highly significant positive *gca* effects.

Five hybrids showed good specific combining ability effect for fruit length. The highest magnitude of *sca* effect was seen in the cross combination of California Wonder x Chilli Yellow (5.20) followed by Arka Gaurav x Tarihal Local (4.25) for fruit length.

4.4.4.10 Fruit width

Among female parents Arka Gaurav (0.47) was found to be the best combiner. While, among males Tarihal Local and 4080-15 were having high *gca* effects for fruit width.

Five crosses exhibited significant positive *sca* effects whereas, six had significant negative *sca* effects. The *sca* effect was highest in the hybrid California Wonder x Chilli Yellow (0.84) followed by Arka Gaurav x Tarihal Local (0.78) for fruit width.

4.4.4.11 Fruit shape index

The results on fruit shape index indicated that the female parent Arka Gaurav (-0.27) and male parent Tarihal Local (-0.57), 4080-15 (-0.32) and Goa Local (-0.45) recorded highly significant *gca* effect in desirable (negative) direction.

Four crosses each showed significant positive and negative *sca* effects for fruit shape index. The highest positive and negative *sca* effect was recorded by Arka Gaurav x Chilli Yellow (0.84) and California Wonder x Tarihal Local (-0.35) respectively.

4.4.4.12 Locules per fruit

The *gca* effects for locules per fruit indicated that Yolo Wonder (-0.22), Chilli Yellow (-0.16) and Goa Local (-0.42) showed significant negative effect in desirable direction.

Among 18 crosses five and four crosses showed significant negative and positive *sca* effects respectively. The cross combination California Wonder x Guntur Local (-0.67) was recorded for high negative *sca* effect followed by Yolo Wonder x Chilli Yellow (-0.55) for locules per fruit.

4.4.4.13 Pericarp thickness

Significant negative general combiners were Arka Gaurav (-0.01), Yolo Wonder (-0.04), Goa Local (-0.22) and Guntur Local (-0.13) in desired direction for pericarp thickness.

Out of 18 crosses, eight and seven crosses recorded significant negative and positive *sca* effects respectively for pericarp thickness. The highest magnitude of negative (-0.20) and positive (0.16) *sca* effects were observed in the cross combination of California Wonder x Tarihal Local (-0.13) and Arka Gaurav x KTPI-19 (-0.20) respectively for pericarp thickness.

4.4.4.14 Pedicel length

The *gca* effects for pedicel length was significant in desired positive direction by California Wonder (0.13) and Tarihal Local (0.67) among lines and testers respectively.

The number of crosses showing positive and negative *sca* effects were ten and eight respectively for pedicel length. The highest significant positive *sca* effect was obtained in the cross combination of California Wonder x 4080-15 (0.51) followed by California Wonder x KTPI-19 (0.28) and California Wonder x Chilli Yellow (0.53) for the trait.

4.4.4.15 Seed weight per fruit

Among the lines California Wonder (-0.13) and among testers Chilli Yellow (-0.14), and Guntur Local (-0.40) were good general combiners for seed weight per fruit.

Estimates of *sca* effects were significant for eleven crosses. Out of which four were in desired (negative) direction. The cross combination of Yolo Wonder x Chilli Yellow (-0.35) was the best combiner for lesser seed weight per fruit.

4.4.4.16 Number of seeds per fruit

The female parent Yolo Wonder (-8.28) and the male parents Chilli Yellow (-6.71), Goa Local (-9.51) and Guntur Local (-19.75) were best general combiners for number of seeds per fruit.

Out of 18 crosses, seven and six hybrids showed significant negative and positive *sca* effects respectively for number of seeds per fruit. The highest negative *sca* effect was observed in the cross combination of California Wonder x Tarihal Local (-21.37) for number of seeds per fruit.

4.4.4.17 Ascorbic acid content

Among parents, California Wonder (12.91) Arka Gaurav (12.72), Tarihal Local (11.77) KTPI-19 (20.65), Chilli Yellow (36.33) and Guntur Local (20.68) were the good general combiners for ascorbic acid content.

The estimates of *sca* effects revealed that five crosses exhibited positive significant effect. The cross Yolo Wonder x Chilli Yellow (0.92) and Arka Gaurav x KTPI-19 (0.75) manifested highest specific combining ability effect for ascorbic acid content.

4.4.4.18 Total soluble solids

California Wonder (0.39), Arka Gaurav (0.35), Tarihal Local (11.77), KTPI-19 (20.65), Chilli Yellow (36.33) and Guntur Local (20.68) were the good general combiners for total soluble solids.

Out of 18 cross combinations, five crosses were good general combiners. The highest *sca* effect was recorded in California Wonder x Tarihal Local (32.27) for total soluble solids.

4.4.4.19 Number of fruits per plant

The female parent Yolo Wonder (3.33) and male parent Chilli Yellow (14.26) were the good general combiners for number of fruits per plant.

There were equal number of cross combinations (six each) which recorded significant positive and negative *sca* effects. The highest significant desirable specific combiner for number of fruits per plant was California Wonder x Chilli Yellow (28.95) followed by Yolo Wonder x 4080-15 (19.80).

4.4.4.20 Fruit yield per plant

Among three lines only Arka Gaurav (0.07) recorded significant *gca* effect for fruit yield per plant. While, among testers highly significant positive *gca* effect was noticed in Tarihal Local (0.34), 4080-15 (0.30) and KTPI-19 (0.48) for fruit yield per plant.

Thirteen crosses manifested significant *sca* effects, out of which six crosses were in positive direction. The highest positive *sca* effect was

noticed in Arka Gaurav x Tarihal Local (0.58) followed by Arka Gaurav x 4080-15 (0.51), California Wonder x Chilli Yellow (0.42) and Yolo Wonder x KTPI-19 (0.38) for fruit yield per plant.

4.4.4.21 Per cent powdery mildew disease index

The female parent, California Wonder and Yolo Wonder were recorded for negative *gca* effects for powdery mildew resistance. While, the male parents Tarihal Local (-11.00) and Guntur Local (-2.64) were good general combiners for powdery mildew resistance.

Out of 18 crosses only California Wonder x Tarihal Local (-3.46), Arka Gaurav x 4080-15 (-2.40) and Yolo Wonder x Guntur Local (-6.68) recorded highly significant negative *sca* effect in desirable direction for the disease resistance.

4.5 INHERITANCE PATTERN OF FRUIT SHAPE IN BELL PEPPER

The distribution of fruit shape for the F_1 and F_2 populations from the crosses Arka Gaurav x Tarihal Local, Arka Gaurav x 4080-15 and Yolo Wonder x KTPI-19 are presented in Table 27.

4.5.1 Shape of fruits

Blocky and Round shaped fruits were noted in segregating population of Arka Gaurav x Tarihal Local and Arka Gaurav x 4080-15 while, Triangular and Blocky shaped fruits were obtained in F_2 population of Yolo Wonder x KTPI-19.

The shape of the fruits were recorded as per the descriptors for vegetable crops by NBPGR, New Delhi.

Two phenotypic classes with parental dominance were observed in respective F_2 population. The F_1 population of Arka Gaurav x Tarihal

Table 27. Segregation in F₂ population for fruit shape in bell peppers

Sl. No.	Crosses		Total number of plants	Observed			Ratio	Expected			χ^2	Table z at 5% probability
				Blocky	Triangular	Round		Blocky	Triangular	Round		
1.	Arka Gaurav x Tarihal Local	F ₁ F ₂	15 250	15 176.00	- -	- 74.00	3:1	187.50	-	62.50	2.82	3.84
2.	Arka Gaurav x 4080-15	F ₁ F ₂	15 256	15 195.00	- -	- 61.00	3:1	192.00	-	64.00	0.18	3.84
3.	Yalo Wonder x KTPI-19	F ₁ F ₂	15 256	- 72.00	15 184.00	- -	3:1	64.00	192.00	-	0.33	3.84

Local and Arka Gaurav x 4080-15 exhibited Blocky shaped fruits. Whereas, Yolo Wonder x KTPI-19 exhibited Triangular shaped fruits.

Chi square analysis (Table 27) of F_2 data showed a good fit to 3:1 ratio of (Blocky : Round) and (Triangular : Round) with round shaped being recessive.

4.6 ISOLATION OF TRANSGRESSIVE SEGREGANTS

Analysis of segregants in three different F_2 population for important economic characters revealed that higher frequency of transgressive segregants for fruit shape index with respect to better parent (21.20%) and standard check (28.00%) (Table 28) was observed in the segregating population of Arka Gaurav x Tarihal Local.

The F_2 population of Arka Gaurav x 4080-15 (8.98%) and Arka Gaurav x Tarihal Local (0.80%) recorded higher frequency of transgressive segregants for average fruit weight over better parents and standard check respectively.

The per cent transgressive segregants for fruit yield per plant was of higher magnitude in the F_2 population of Arka Gaurav x Tarihal Local over better parent (24.40%) and standard check (1.60%) followed by Arka Gaurav x 4080-15 over better parent (11.72%) and standard check (1.56%) (Plates 5, 6 and 7).

4.7 CHLOROPHYLL AND VIABLE MUTANTS OF TARIHAL LOCAL

The seeds of Tarihal Local were subjected to acute irradiation with gamma rays at 10 KR, 15 KR and 20 KR. The M_2 populations were studied for chlorophyll and viable mutants.

Table 28. Per cent transgressive segregants of three different F₂ population for three characters with respect to better parent (BP) and standard check (SC)

Sl. No.	Cross	Fruit shape index (blocky)		Fruit weight (g/fruit)		Fruit yield/plant (kg/plant)	
		BP	SC	BP	SC	BP	SC
1.	Arka Gaurav x Tarihal Local (250 plants)	21.20	28.00	8.00	0.80	24.00	1.60
2.	Arka Gaurav x 4080-15 (256 plants)	7.03	21.48	8.98	0.00	11.72	1.56
3.	Yolo Wonder x KTPI-19 (256 plants)	1.17	1.17	8.59	0.00	2.34	0.39

Fruit shape index : Higher values than the better parent/standard check with blocky shaped large fruits were considered to calculate per cent transgressive segregants

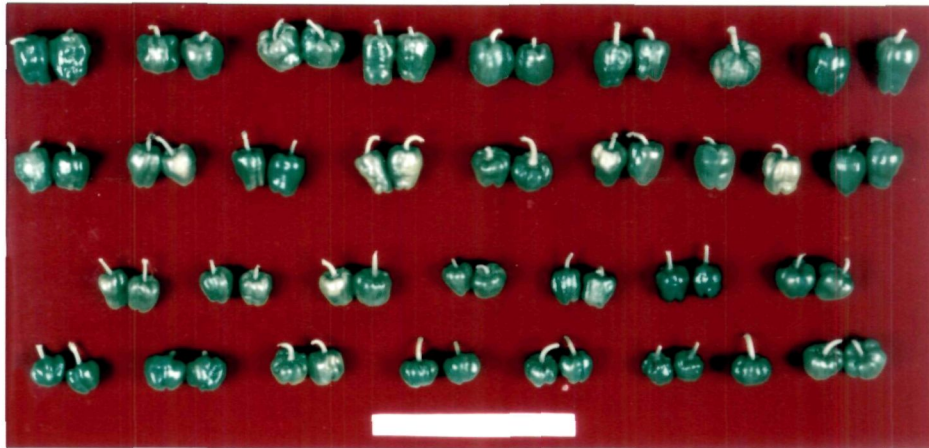


Plate 5: Fruits of F_2 population (Arka Gaurav x Tarihal Local)

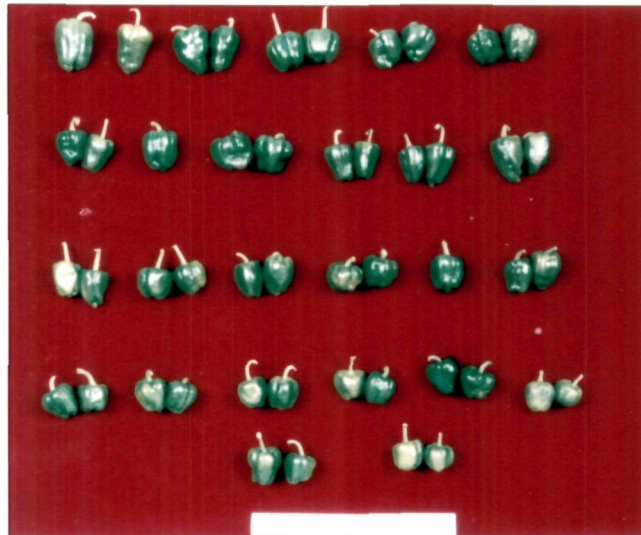


Plate 6: Fruits of F_2 population (Arka Gaurav x 4080-15)



Plate 7: Fruits of F_2 population (Yolo Wonder x KTPI-19)

4.7.1 Chlorophyll mutants

Among different chlorophyll mutant types as classified by Gustaffson (1947). "Xantha" (these mutants were distinguished by their uniform yellow colour with total absence of chlorophyll. They emerged one or two days later than green seedling and survived for about a week) type of mutants were observed in higher frequency in the present investigation (Table 29).

None of the seedlings were devoid of chlorophyll in control population. The M₂ population of Tarihal Local (20 KR) showed 1.42 per cent of chlorophyll mutant. While, the M₂ population treated with 10 KR and 15 KR recorded 1.33 per cent and 0.97 per cent seedlings with xanth type of chlorophyll mutants respectively.

4.7.2 Viable mutants

The changes were noticed in M₂ population with respect to leaf shape, days taken to first flowering (>40 DAT as late and <40 DAT as early flowering) and fruit shape (complanate and round shaped fruits) as given in Table 30.

The control population had all the plants with lanceolate (narrow) type of leaf shape, late flowering (>40 DAT) and round shaped fruits.

The M₂ population of Tarihal Local treatment with 10 KR possessed 3.24 per cent. While 15 KR had 8.44 per cent and 20 KR recorded for 5.71 per cent of the plants with broader leaves or deltate shaped leafy mutants.

Early flowering (<40 DAT) was noticed in all the M₂ population of Tarihal Local. The frequency of mutants ranged from 4.24 per cent (10 KR) to 10.62 per cent (15 KR) in the M₂ population for different treatments.

Table 29. Chlorophyll mutant of observed in M₂ population of Tarihal Local

Population	Number of seedlings	Chlorophyll mutants
Control	100	-
10 KR	600	8 (1.33)
15 KR	620	6 (0.97)
20 KR	700	10 (1.42)

Table 30. Viable mutants observed in M₂ population of Tarihal Local

Population	Total number of plants	Leaf shape		Days to I flowering		Fruit shape	
		Lanceolate	Ovate	Early (<40)	Late (>40)	Companulate	Round
Control	70	70	-	-	70	-	70
10 KR	401		13 (3.24)	17 (4.24)		2 (0.50)	
15 KR	320		27 (8.44)	34 (10.62)		1 (0.31)	
20 KR	350		20 (5.71)	30 (8.57)		4 (1.14)	

These mutants took less than 40 days to flower after transplanting. The M₂ population treated with gamma rays at 20 KR exhibited 8.57 per cent of plants in the population flowered earlier (<40 DAT) compared to control which took more than 40 days to flower.

Fruit shape is an important criteria in selection based on consumer preference. In the experiment almost all the plants in M₂ population for fruit shape resembled the control population. However, few plants in each treatment of M₂ population exhibited companulate type of fruit shape.

The highest frequency of companulate type of fruit shape mutants (1.14%) were observed in M₂ population treated with 20 KR of gamma rays followed by 10 KR (0.50%) and 15 KR (0.31).

4.7.3 Quantitative characters (cf. Table 31)

4.7.3.1 Number of fruits per plant

The number of fruits per plant ranged from 1.00 to 11.00, 2.00 to 17.00 and 1.00 to 22.00 with mean values of 5.645, 7.226 and 6.323 in M₂ population of Tarihal Local treated with 10 KR, 15 KR and 20 KR respectively.

The treatment 20 KR revealed maximum variance (28.426) and co-efficient of variability (84.320%) for number of fruits per plant.

The control showed maximum number of fruits per plant (29.903). The range was from 25.00 to 36.00. The variance of 8.290 and coefficient of variability of 9.63 per cent was noticed for the trait in the control population.

4.7.3.2 Fruit yield per plant (cf. Table 31)

The mean fruit yield was maximum in control (0.273 kg/plant) followed by the treatments 15 KR (0.265 kg/plant), 10 KR (0.055 kg/plant) and 20 KR (0.047 kg/plant).

Table 31. Range, mean, variance and coefficient of variability for number of fruits per plant and yield per plant in M₂ generation different doses of Gamma rays

Treatment M ₂ generation	Range	Mean	SE±	Variance	CV %
Control					
Number of fruits/plant	25.00-36.00	29.903	0.517	8.290	9.63
Yield per plant (kg)	0.18-0.36	0.273	0.008	0.002	16.85
10 KR					
Number of fruits/plant	1.00-11.00	5.645	0.536	8.903	52.86
Yield per plant (kg)	0.01-0.12	0.055	0.006	0.001	56.36
15 KR					
Number of fruits/plant	2.00-17.00	7.226	0.719	16.047	55.43
Yield per plant (kg)	0.05-0.80	0.265	0.035	0.039	74.34
20 KR					
Number of fruits/plant	1.00-22.00	6.323	0.958	28.426	84.32
Yield per plant (kg)	0.01-0.16	0.047	0.007	0.001	78.72

Among the treatments wider range of fruit yield per plant was noticed in 15 KR (0.05-0.80 kg). While the range was from 0.18 to 0.36 kilograms per plant in the control (untreated) population.

Higher magnitude of variance and coefficient of variability was noticed in the M₂ population of Tarihal Local treated with 15 KR (0.039) and 20 KR (78.72%) respectively. The coefficient of variability was recorded 16.85 per cent in control population of Tarihal Local for fruit yield per plant.

Discussion

V. DISCUSSION

The bell pepper is highly remunerative vegetable crop as it fetches higher prices in the cosmopolitan cities. The cultivation of the crop in tropical regions is mainly confined to cooler seasons. It lacks adaptability to varied environmental conditions. Therefore, genotypic responses to changing adaphic conditions becomes necessity. This gives an understanding of genotype x environment (G x E) responses for developing suitable varieties or hybrids.

Several studies suggest that in India variability in large fruited bell peppers is low with lesser number of varieties. However, there are local types well adopted to tropical conditions with more number of fruits but smaller in size having variable degree of pungency and tolerant to powdery mildew disease which have not been exploited.

In northern transitional tract of Karnataka, farmers prefer some of the local cultivars which bear small fruits with more number of ridges. Under such situation, breeder have to aim at evolving genotypes that are more preferred for respective regions and yet be productive and show substantial increase over existing commercial varieties with respect to yield and other economic traits (medium pungency, larger fruit size and lesser ridges). This would be possible through hybridization of local types with large fruited bell peppers which in turn would depend upon nature, magnitude and inter-relationship of heritable variation and diversity between the parents. Further, mutation breeding and isolation of transgressive segregants from the F₂ population aims at germplasm innovation.

Based on these aspects evaluation of genotypes, identification of pepper germplasm based on RAPD markers, hybridization, isolation of transgressive segregants and mutation studies on 'Tarihal Local' was undertaken. The results obtained are discussed in this chapter.

5.1 EVALUATION OF GENOTYPES

5.1.1 Genetic variability, environmental influence on genotypes

The successful vegetable improvement for higher yield and its contributing characters and quality attributes needs sound knowledge of genetic architecture of the crop and inheritance of important character of interest to the breeder. Bell pepper improvement programme depends on the nature and magnitude of genetic variability and the degree of transmission of the traits. But to achieve an accurate estimate of genetic parameters the estimate of genetic variability devoid of genotype x environment (G x E) component is necessary. As the evaluation of the genotypes in one season or location are always confound with G x E interaction component. Thus, the values are inflated and higher in magnitude than the usual values.

At present there is no commercial variety or hybrid in sweet pepper resistant or tolerant to powdery mildew disease. This necessitates the search for genotypes resistant to the disease in popularly grown local cultivars of the bell pepper. In view of this attempt was made to evaluate 25 genotypes which included large fruited bell peppers, paprika type, pungent peppers and local cultivars over two seasons. This provided an opportunity to look into the influence of environment on the expression of different characters in terms of magnitude of various genetic parameter and search for genes resistance to powdery mildew among the existing germplasm.

The results indicated significant variation among all the genotypes for all the characters in *rabi* season, *kharif* season and over two seasons. The component of genotype x environment (G x E) interaction was also significant for most of the characters except for locules per fruit, pericarp thickness and number of seeds per fruit indicated differential response

among the genotypes studied. These findings were in accordance with Wani *et al.* (2003).

The plant yield, a complex trait is known to be influenced by the environment and other component characters *viz.*, number of fruits per plant and average fruit weight.

The genotypic (*rabi* = 54.52%; *kharif* = 54.64% and pooled environment = 46.97%) and phenotypic (*rabi* = 57.69%; *kharif* = 58.48% and pooled environment = 46.75%) coefficient of variability recorded in individual seasons were of higher magnitude for fruit yield per plant when compared over two seasons. This was because of the separation of variance due to G x E interaction (V_{gxe}) from environmental variance (V_e). Thereby, getting more precise estimates of genotypic variance. Though there was high heritability (102.00%), lower estimates of genetic advance as per cent mean (31.72%) was recorded over two seasons when compared to that of individual seasons. Thus, indicating unfavourable influence of environment on fruit yield per plant. Hence, selection of yield based on the performance in one season may not be effective. The non-additive gene effect for yield per plant was confirmed by high heritability with lower genetic advance over mean. Similar results were observed by Mulge (1992) in bell pepper and Jagdeesha (2000) in chilli.

It was evident from the results that there was lesser influence of environment on yield components like number of fruits, average fruit weight and fruit related traits (fruit length, fruit width, pericarp thickness, seed weight per fruit, fruit shape index). These characters showed lesser magnitude of environmental variance and variance due to G x E interaction. The other genetic parameters *viz.*, GCV, PCV, heritability and genetic advance as per cent mean did not differ much during individual seasons and over two seasons. Higher magnitude of the genetic parameter

in *rabi*, *kharif* and over two seasons indicated the presence of additive gene effects for aforesaid yield components and fruit related traits.

The quality parameters *viz.*, total soluble solids showed higher magnitude of variance due to genotype x environment (G x E) interaction (2.667) when compared to variance due to genotype ($V_g = 1.069$) suggesting environmental influence for the expression of total soluble solids. Hence, total soluble solids varies with the environment. Further, total soluble solids and ascorbic acid content showed moderate variability with high heritability and lower magnitude of genetic advance in *rabi*, *kharif* and over two seasons indicating non-additive gene effect for these two traits. Therefore heterosis breeding should be suggested for these characters. The results were in accordance with the findings of Nair and George (1973) and Thakur and Brar (1975) in chilli.

The occurrence of powdery mildew disease was noticed during *rabi* season since, the cool dry weather condition is congenial for the disease incidence in *Capsicum*.

The high genotypic coefficient of variability (GCV=26.80%), heritability (98.50) and genetic advance as per cent mean (54.80%) was noticed in the germplasm screened for the disease resistance. Thus, there was ample scope for selection against disease susceptibility among the germplasm studied. Daubeze *et al.* (1995) reported high heritability for the disease resistance while, Hiremath (1997) reported low GCV with moderate heritability and genetic advance in chilli for powdery mildew resistance. However, the local cultivars Tarihal Local and Ranebennur Local were more acclimatized to local conditions and are tolerant to powdery mildew disease incidence. Hence, these local types could be included in the breeding programme.

5.1.2 Genetic divergence

The variability among different genotypes of crop species is known as genetic diversity. Genetic diversity arises due to geographical separation or due to genetic barriers to crossability. This plays an important role in plant breeding because, it is a belief that hybrids between lines of diverse origin generally display a greater heterosis than between closely related strains. Twenty five genotypes used in the present study exhibited wide range of variability for different characters. These genotypes included, large fruited bell peppers, hot peppers, paprika type and local cultivars. The genotypes were grouped under seven divergent clusters.

The maximum intra cluster distance was recorded for V ($D^2=62.23$) followed by IV ($D^2=61.04$), II ($D^2=58.73$) and I ($D^2=52.25$) indicated the genotypes existing in these clusters were more heterogeneous. Senapati *et al.* (2003) opined similar results in chilli. Whereas, higher inter cluster distance was observed between cluster VI and VII ($D^2=279.88$) followed by II and VI ($D^2=218.93$) suggested high divergence between the two clusters for various characters.

All the bell shaped large fruited genotypes (California Wonder, CW-2, Arka Basant, Arka Mohini, Arka Gaurav, Belgaum Local and Yolo Wonder) were congregated in cluster I. Whereas, most of the pungent long types were grouped under cluster II. The powdery mildew tolerant genotypes *viz.*, Tarihal Local, Ranebennur Local, Chilli Yellow and PMR-57/88/k were clustered under IV and II cluster.

Based on the cluster means for each character it was possible to group the cluster according to their average performance for a particular character.

The clusters III (1.60 kg/plant), I (0.81 kg/plant) and VII (0.57 kg/plant) could be categorised under high fruit yielding groups. While, VI (0.30), V (0.31 kg/plant) and IV (0.35 kg/plant) under low yielding clusters. Cluster III (KTPI-19) had higher number of fruits per plant (111.55) and average fruit weight (23.59 g). Whereas, cluster I comprised of bell peppers had higher magnitude of average fruit weight (37.78 g) which contributed to the total yield potential in bell peppers.

An assessment of contribution of different character towards total genetic divergence revealed that number of seeds (55.00%), number of fruits per plant (21.67%), ascorbic acid content (15.33%) and average fruit weight (3.67%) were the major contributors to the total divergence. The contribution to the total divergence by these attributes indicate their role in maintaining variability in natural population. These results are in accordance with the findings of Shirsat (1994) and Shaik (2002) in chilli.

5.2 MOLECULAR POLYMORPHISM AND POLLEN VIABILITY STUDIES

5.2.1 Molecular polymorphism

Genetic variation is a prerequisite for any crop improvement programme. DNA markers represent genetic variation permitting one to estimate relatedness between different genotypes and consequently to predict which mating system might produce new and superior gene combination. These markers are also used to portray diversity within cultivated germplasm (Smith *et al.*, 1990) and to identify groupings of cultivars which are adapted to particular regions.

Several kinds of DNA based molecular markers such as RFLP, RAPD, AFLP's *etc.*, are available which detect polymorphism at the DNA level. These markers have been used for assessing genetic diversity as well as DNA finger printing in *Capsicum* (Wang *et al.*, 1996 and Rodriguez *et al.*, 1999).

In this investigation, informative RAPD primers selected in earlier experiments were used in the evaluation of 13 genotypes. These 13 genotypes were chosen since, each of the 13 genotypes represent different fruit shape, level of pungency, reaction towards powdery mildew disease incidence. Thus the genotypes included large fruited bell peppers, pungent peppers, local cultivars and powdery mildew tolerant lines. Moreover, nine of these 13 genotypes were included in the hybridization programme of the investigation. Hence, this would help to detect molecular polymorphism of intraspecific varieties of *Capsicum annuum* L.

It was evident from the results that there was 82.05 per cent polymorphism existing among the pepper genotypes revealed by the four primers. Out of 39 amplification product detected by the germplasm, 32 were polymorphic. Thus, the chosen primers were able to recognize the genetic differences among the genotypes.

The primers OPD-7 (100.00%) and OPC-6 (99.99%) had the highest discriminating power. Therefore these primers could be used to identify all the 13 genotypes.

Considering the dendrogram constructed from the pooled data of all the primers (Fig. 2) did not follow definite trend in relation to the character of interest such as susceptibility or resistance to powdery mildew disease. However, the pattern of variation in genotypes was similar to that of Lefebvre *et al.* (1993) and Paran *et al.* (1998) in pepper. The long fruited pungent cultivar formed more divergent group as evident from the lesser magnitude of coefficient of similarity (0.57 to 0.58) than the less pungent large fruited cultivars (California Wonder, Belgaum Local and Arka Gaurav) with higher magnitude of coefficient of similarity ranged (0.81 to 0.83). These large fruited genotypes were also highly susceptible to powdery mildew disease. Within the group of large fruited cultivars, limited variation was detected except for Yolo Wonder which formed a

separate cluster. While, the local cultivars Tarihal Local and Ranebennur Local were closely related to bell peppers than to the long fruited (chilli) types.

The genotype PMR-57/88/k a powdery mildew resistant line was developed at IIHR, Bangalore using *Capsicum baccatum* var. *pendulum* as a source of resistance. The genotype formed a separate group along with Chilli Yellow a tolerant variety to the disease, probably both the genotypes possessed common pedigree. These lines showed minimum coefficient of similarity with all other genotypes.

The information obtained in the present study could be of practical use for actual breeding programme by crossing diverse genotype to get a heterotic hybrids. Secondly, genome mapping for powdery mildew disease resistance or susceptibility one can use nearby DNA marker to diagnose the presence of the gene, without having to wait for the gene effect to be seen. Use of RAPD markers for identifying linked loci and development of SCAR markers to isolate the gene responsible for powdery mildew resistance needs to be explored by developing recombinant inbred lines (RILs) by crossing susceptible and resistant plants.

5.2.2 Effect of powdery mildew disease on pollen viability

The powdery mildew disease is caused by the air borne fungus *Leveillula taurica* in *Capsicum*. The experiments on the effect of powdery mildew disease on pollen viability were very meager. The pollen sterility might be one of the reasons to decrease the yield and the quality of fruits in the affected plants. Hence, the study was conducted to test the pollen viability due to powdery mildew disease on the selected 13 genotypes used in RAPD analysis.

It was evident from the results that per cent pollen sterility was maximum over the control in infected plants of Yolo Wonder (158.14%)

followed by California Wonder (130.72%) and Guntur local (118.15%). These genotypes were highly susceptible to the disease under field conditions. The least per cent pollen sterility was noticed in Chilli Yellow (28.54%), PMR-57/88/k (36.34%), Tarihal Local (40.33%) and Ranebennur Local (42.05%) over their respective control. The local cultivars *viz.*, Tarihal Local and Ranebennur Local were tolerant to powdery mildew disease under local environmental conditions and are further well adopted to northern transitional tract of Karnataka.

There are hardly any reports on air borne fungal spores that cause any damage to reproductive biology. However, Nair (1979) hypothesised that the loss of viability might be due to consumption of protoplasm by the fungi or due to hyphal penetration into the pollen grain. This might draw nutrients from protoplasm by means of haustoria at severe incidence of powdery mildew.

Further, powdery mildew causes yield loss upto 20 per cent and deterioration in quality of fruit in pepper (Gohokar and Peshney, 1981).

It was noticed that a range of 8.24 to 14.63 per cent sterility was observed in all the uninfected plants of the respective genotypes. This might be due to abiotic stress or inherent characteristic of the genotype. Similar findings were reported by Raghavendra (2002) in tomato.

Hence, from the investigation on effect of powdery mildew disease on pollen viability it could be inferred that the effect on reproductive organ by the powdery mildew disease might be one of the reasons for deterioration in fruit quality and yield loss in pepper.

5.3.1 Heterosis and combining ability effects

Heterosis for marketable yield is more important in vegetable crops and is determined by total productivity and quality of the produce (Riggs, 1988).

Based on *per se* performance Arka Gaurav x Tarihal Local (1.98 kg/plant) had highest yielding potential followed by Yolo Wonder x KTPI-19 (1.91 kg/plant) and Arka Gaurav x 4080-15 (1.88 kg/plant). The magnitude of standard heterosis revealed that these hybrids were positively and significantly heterotic for yield per plant. Out of which Arka Gaurav x Tarihal Local (395.00%) and Arka Gaurav x 4080-15 (248.15%) were heterotic over better parent.

Yield is a composite character influenced and regulated by component characters (Sinha and Khanna, 1975). This is evidenced by significant positive heterosis over better parent for fruit width, fruit length and average fruit weight in top two heterotic crosses.

The top crosses (Table 32) were considered best not only for their yielding potential but also for blocky/bell shaped fruits with fruit shape index of 1.79 (Arka Gaurav x Tarihal Local) and 1.81 (Arka Gaurav x 4080-15) (Plate 8a, 8b, 9a, 9b and 10).

When the quality parameters, *viz.*, ascorbic acid content and total soluble solids were taken into consideration along with yield, the hybrid Arka Gaurav x 4080-15 could be exploited for higher ascorbic acid content (215.06 mg/100 g) and total soluble solids (7.18° brix). This cross showed significant positive heterosis over mid parent for these two traits.

Organoleptic test for pungency revealed that most of the cross combination (mildly pungent x pungent) were pungent (Table 32), indicating dominance of pungency over non-pungent type. Ohta (1962) studied that inheritance of pungency was dominant and polygenic in nature.

With regard to powdery mildew disease incidence though the cross combination Arka Gaurav x Tarihal Local (32.29%), California Wonder x Tarihal Local (26.46%) and Yolo Wonder x Tarihal Local (32.52%) showed



**Plate 8a. F_1 hybrid
(Arka Gaurav x Tarihal Local)**



**Plate 9a. F_1 hybrid
(Arka Gaurav x 4080-15)**



**Plate 8b. Cross section of
 F_1 hybrid fruits
(Arka Gaurav x Tarihal Local)**



**Plate 9b. Cross section of
 F_1 hybrid fruits
(Arka Gaurav x 4080-15)**



**Plate 10: F_1 hybrid
(Yolo Wonder x KTPI-19)**

Table 32. Organoleptic grading of pungency and qualitative description of fruit shape of bell pepper hybrid

Sl. No.	Crosses	Pungency			Fruit shape		
		P ₁	P ₂	F ₁	P ₁	P ₂	F ₁
1.	California Wonder x Tarihal Local	1	4	2	Blocky	Round	Blocky
2.	California Wonder x 4080-15	1	2	2	Blocky	Triangular	Companulate
3.	California Wonder x KTPI-19	1	1	1	Blocky	Companulate	Triangular
4.	California Wonder x Chilli Yellow	1	3	3	Blocky	Elongate	Elongate
5.	California Wonder x Goa Local	1	3	2	Blocky	Companulate	Companulate
6.	California Wonder x Guntur Local	1	3	2	Blocky	Elongate	Elongate
7.	Arka Gaurav x Tarihal Local	1	4	3	Blocky	Round	Blocky
8.	Arka Gaurav x 4080-15	1	2	3	Blocky	Companulate	Blocky
9.	Arka Gaurav x KTPI-19	1	1	1	Blocky	Triangular	Companulate
10.	Arka Gaurav x Chilli Yellow	1	3	2	Blocky	Elongate	Companulate
11.	Arka Gaurav x Goa Local	1	3	3	Blocky	Companulate	Companulate
12.	Arka Gaurav x Guntur Local	1	3	3	Blocky	Elongate	Elongate
13.	Yolo Wonder x Tarihal Local	1	4	2	Blocky	Round	Blocky
14.	Yolo Wonder x 4080-15	1	2	2	Blocky	Companulate	Companulate
15.	Yolo Wonder x KTPI-19	1	1	1	Blocky	Triangular	Triangular
16.	Yolo Wonder x Chilli Yellow	1	3	2	Blocky	Elongate	Elongate
17.	Yolo Wonder x Goa Local	1	3	2	Blocky	Companulate	Triangular
18.	Yolo Wonder x Guntur Local	1	3	2	Blocky	Elongate	Elongate

1: Mildly pungent

3: Pungent

2: Moderately Pungent

4: Highly pungent

least per cent of disease incidence. The heterotic effect over better parent was in opposite direction. This might be due to wide variation existing in the parents of the crosses for the disease reaction (Ram *et al.*, 1997 and Lohithaswa *et al.*, 2001b). Hence, selection for powdery mildew disease incidence in bell pepper could be simplified by selecting the parents based on *per se* performance. However, all the 18 crosses were significantly heterotic over standard check in desirable direction. The best cross Arka Gaurav x 4080-15 was significantly heterotic over better parent (-20.75).

Further, a persual of top heterotic crosses were not consistent for all the traits (Patel *et al.*, 1997). Hence, specific hybrids with significant heterosis for individual character were obtained which could be commercially exploited for specific purpose.

Overall, it could be inferred the best crosses *viz.*, Arka Gaurav x Tarihal Local and Arka Gaurav x 4080-15 were heterotic for most of the economic characters.

The heterotic effect of these crosses would be further confirmed by their significant positive *sca* [Arka Gaurav x Tarihal Local (0.58) and Arka Gaurav x 4080-15 (0.51)] effect for yield as depicted in ven diagram (Fig.3). The top crosses were also best specific combiners for component character like fruit width, fruit length and average fruit weight. Similar result were observed by Naik (1999) and Ahmed *et al.* (2003) in bell pepper.

The parents involved in Arka Gaurav (0.07) x Tarihal Local (0.34) and Arka Gaurav (0.07) x 4080-15 (0.30) had significant positive *x* positive *gca* effect for yield. The parents involved in these crosses also showed significant positive general combining ability effect for fruit width and average fruit weight. Thus, genetic interaction might be of additive x additive gene effect in their heterotic crosses. That is, there was equal

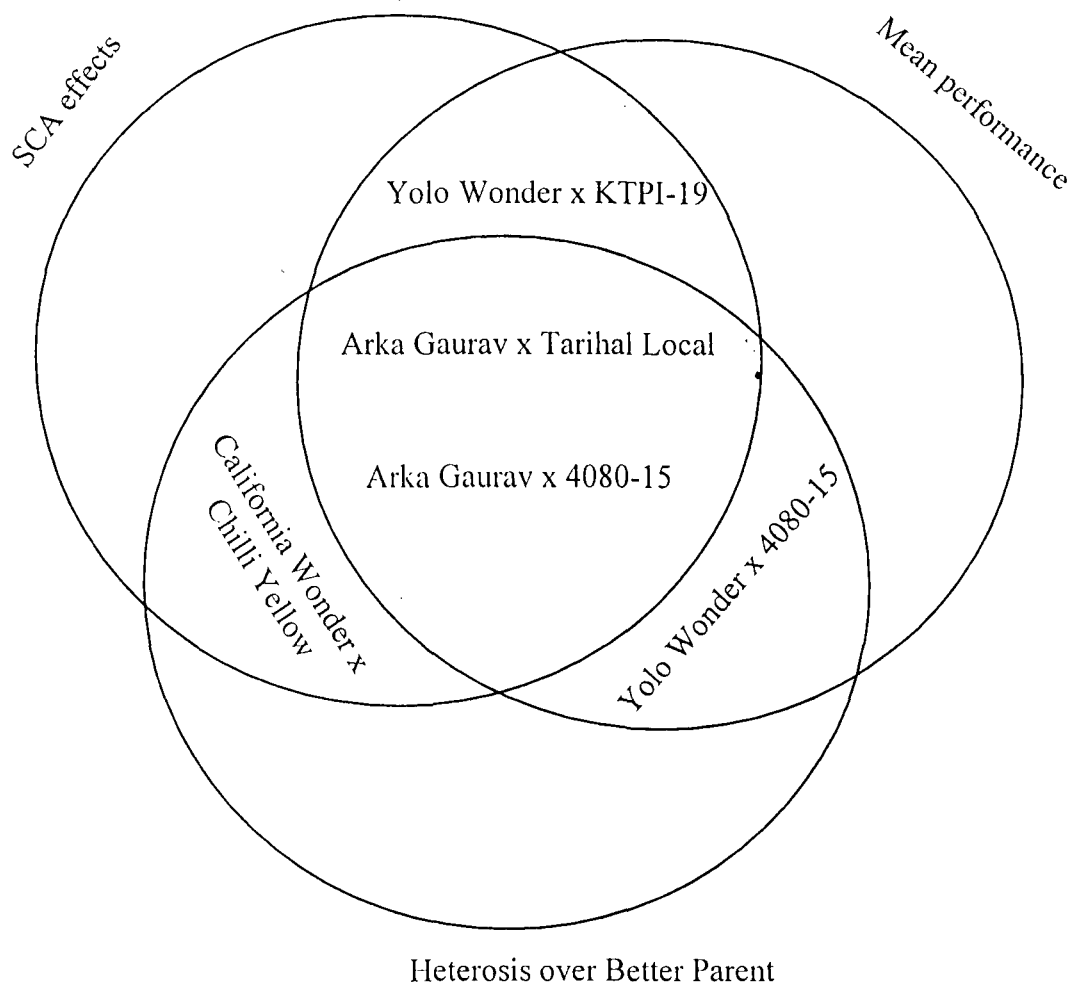


Fig. 3. Ven diagram for mean performance, heterosis and *sca* effect with respect to yield plant

contribution for the characters from both the parents in these crosses. Ahmed *et al.* (2003) in bell pepper and Kulkarni (2003) in tomato reported similar results in their respective studies.

Combining ability analysis revealed that the importance of both additive and non additive gene effect for yield, average fruit weight fruit width and number of fruits per plant with predominance of non additive gene effect. The results were in confirmation with the findings of Basavaraj (1997) and Verma and Sharma (1998) in chilli.

Thus, the foregoing discussion reveals that the hybridization followed by recurrent selection for yield and its component characters should be adopted to bring the desirable changes.

With respect to quality parameters among the top crosses Arka Gaurav x 4080-15 was the good combiner for ascorbic acid (0.73) and total soluble solids (13.23). Whereas, Yolo Wonder x Chilli Yellow (0.92) and California Wonder x Tarihal Local (32.27) were the best combiner for ascorbic acid content and total soluble solids, respectively. One of the parents involved in all the aforesaid crosses is good general combiner for the respective trait. Hence, the high *sca* effect observed might be due to compliment type of gene effects. Basavaraj (1997) opined similar results in chilli for ascorbic acid content.

Thus, choice of parent based on combining ability effect is a sound preposition (Sharma, 1994).

Regarding powdery mildew resistance the cross Arka Gaurav x 4080-15 (-2.40) along with good yield and quality attributes showed significant desirable (negative) *sca* effect. Both the parents involved in the cross were poor combiners for powdery mildew resistance. Whereas, the other best specific combiners *viz.*, Yolo Wonder x Guntur local (-6.68) and California Wonder x Tarihal Local (-3.46) included the male parents with

good general combining ability effects [Guntur local (-2.64) and Tarihal Local (-11.00)].

Therefore, the *sca* effects were mainly due to dominance x dominance and dominance x additive type. Krishna Murthy and Deshpande (1997a) reported dominant and polygenic inheritance for the trait. However, most of the crosses were poor combiners for disease resistance, hence, simple selection would suffice for improvement against powdery mildew disease.

In the study, on the basis of morphometric divergence, the significant heterosis (over better parent) for yield and related character was observed in the cross combination of Arka Gaurav x Tarihal Local, Arka Gaurav x 4080-15 and Yolo wonder x KTPI-19. However based on the divergent studies it was evident that the top heterotic crosses did not possess parents with more genetic distance. It was in accordance with the findings of Arunachalum (2001) who reported that F_1 heterosis enhanced when parents were selected from the intermediate crosses similar results were reported by Shifriss and Sacks (1980) in cross between sweet peppers and hot peppers.

5.4 INHERITANCE OF FRUIT SHAPE AND ISOLATION OF TRANSGRESSIVE SEGREGANTS

The fruit shape forms the basis of consumer preference Kambanonda (1950) reported that fruit shapes and sizes are quantitatively inherited. However, in the investigation based on qualitative description of fruit shape (Srivastava *et al.*, 2001), they were broadly classified into blocky shaped, companulate shaped, triangular shaped and round shaped fruits.

The F_1 's of the cross combination Arka Gaurav (Blocky) x Tarihal Local (Round) and Arka Gaurav x 4080-15 (companulate) were all blocky

and large shaped fruits. While the F_1 's of Yolo Wonder (Blocky) x KTPI-19 (Triangular) were all large and triangular shaped fruits.

These F_1 's were advanced to F_2 by selfing, to study the inheritance of fruit shape in bell pepper. The segregation pattern in F_2 's of the three crosses based on chi-square test fitted 3:1 ratio of fitness which revealed that blocky shaped fruits were dominant to round types in earlier two crosses. Whereas, in the cross Yolo Wonder x KTPI-19 triangular shaped fruits were predominant than blocky types.

Further, these three F_2 populations of Arka Gaurav x Tarinhal local (250 plants), Arka Gaurav x 4080-15 (256 plants) and Yolo Wonder x KTPI-19 (256 plants) were investigated to isolate transgressive segregants with respect to fruit shape index, average fruit weight and fruit yield per plant (Fig. 4, 5 and 6).

The F_2 population of Arka Gaurav x Tarihal Local possessed high frequency of transgressive segregants for fruit yield per plant (24% plants > 0.5 kg/plant) and fruit shape index (21.50% plants > 1.5) over their better parent performance. Arka Gaurav x 4080-15 could produce high frequency (8.98%) of transgressive segregants over its better parent (>51 g) for average fruit weight (Fig. 5).

Economic segregants based on *per se* performance of check revealed that the segregants of the cross combination of Arka Gaurav x Tarihal Local was highly preferable and could be commercially exploited. Since the F_2 population of this cross showed highest frequency of segregants for yield (1.60%), average fruit weight (0.80%) and fruit shape index (28.00%) (blocky and larger fruits). Thus by recombination of genes from different elite cultivars, a few progeny may receive a more complete repertoire of "favorable" genes than either parent.

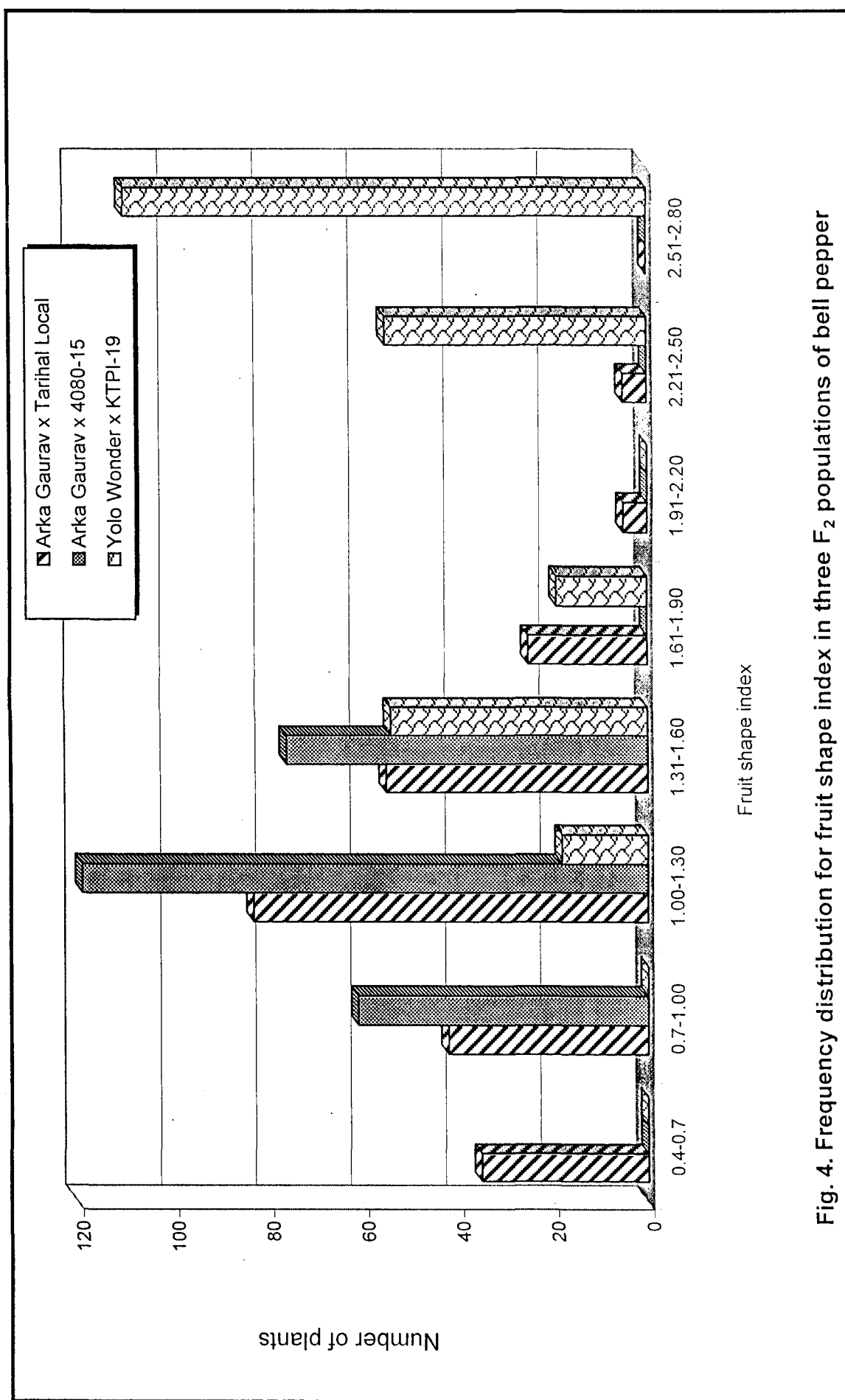


Fig. 4. Frequency distribution for fruit shape index in three F_2 populations of bell pepper

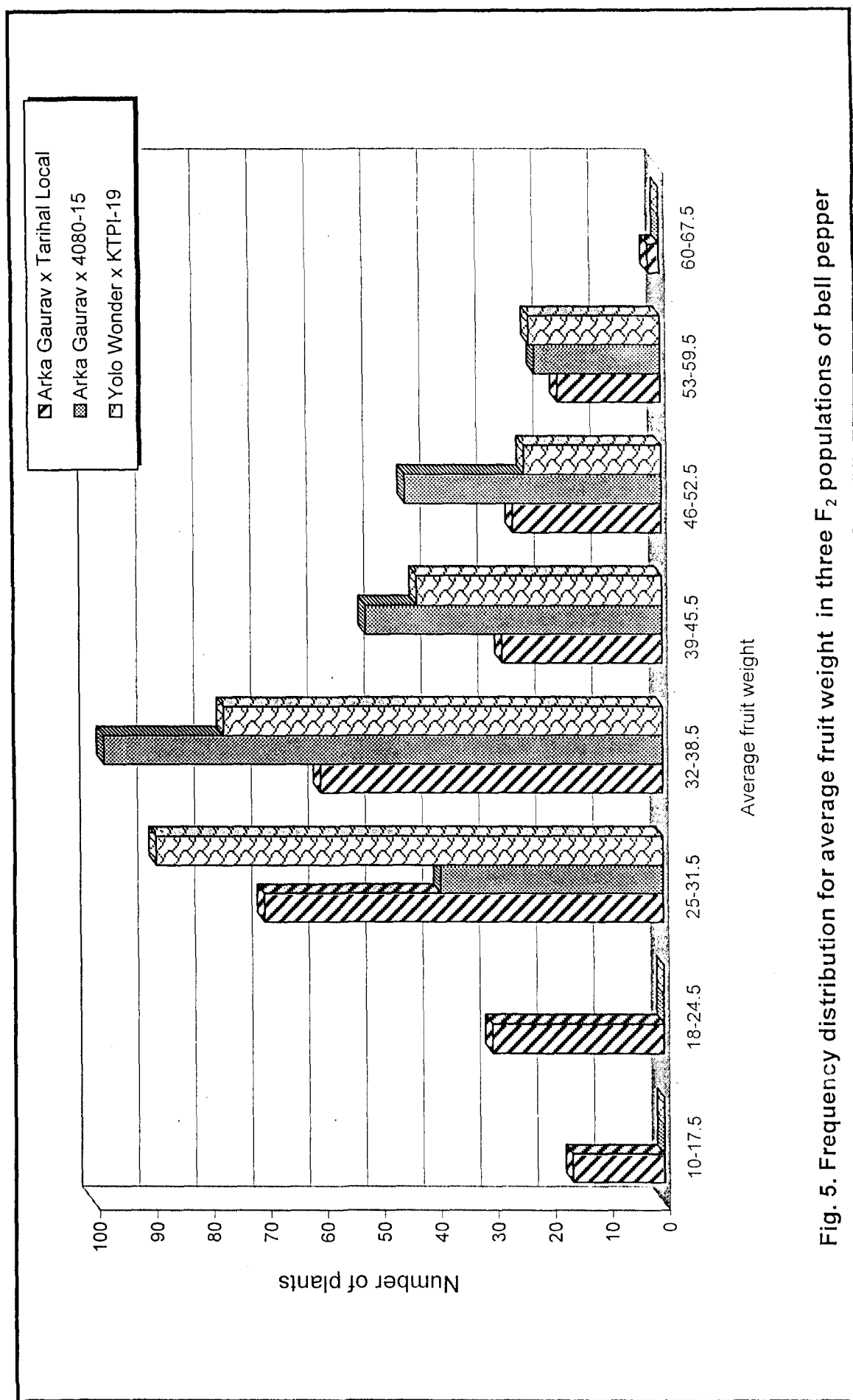


Fig. 5. Frequency distribution for average fruit weight in three F_2 populations of bell pepper

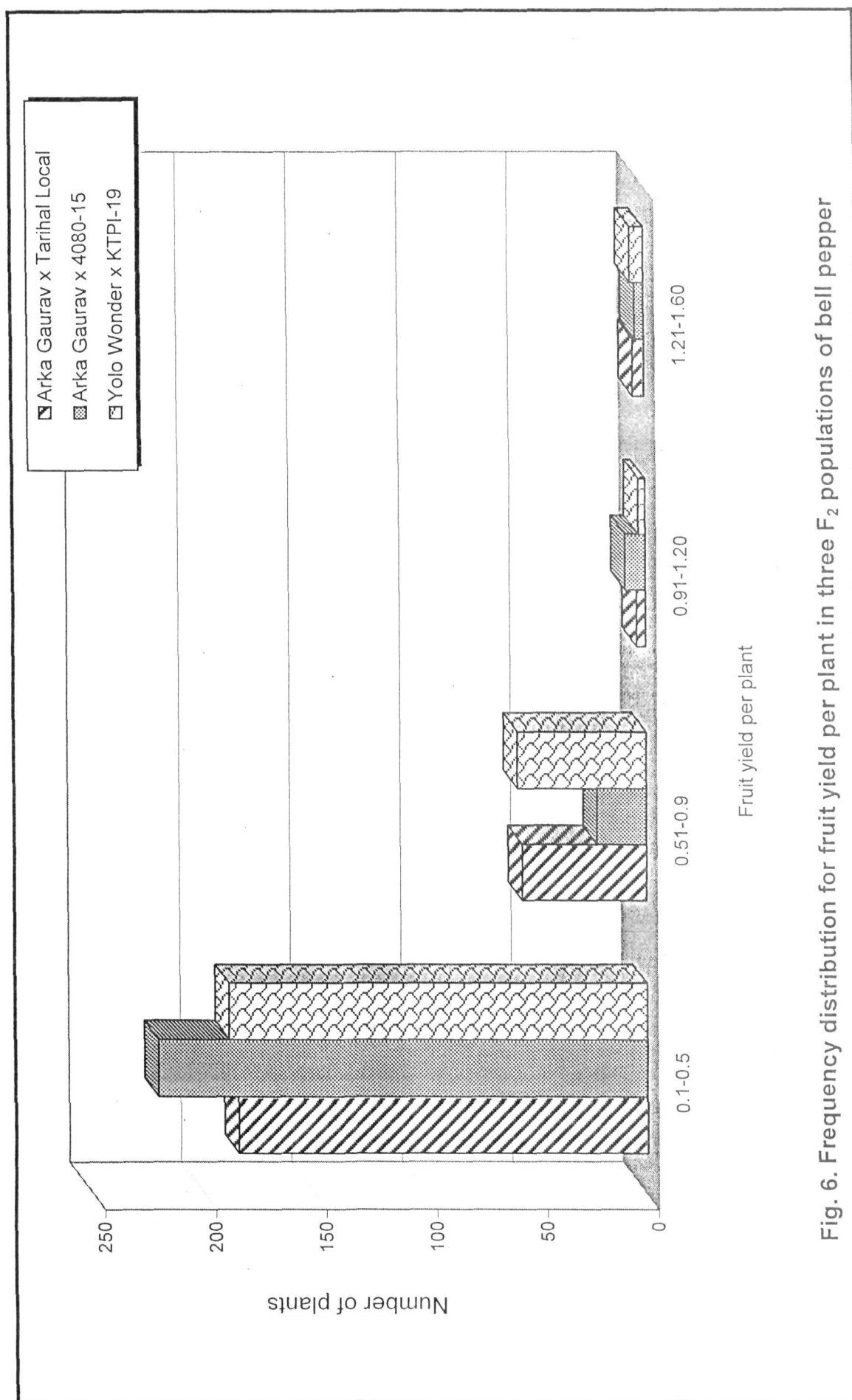


Fig. 6. Frequency distribution for fruit yield per plant in three F_2 populations of bell pepper

This kind of useful segregants being isolated and their utility has been reported by Wang *et al.* (2003) in chilli and Kulkarni (2003) in tomato. Ahmed *et al.* (2003) reported that combining parents with high *gca* effects tends to ensure transgressive segregants. This was evident from the fact that the aforesaid cross combination possessed parents with high *gca* status.

5.5 IMPROVEMENT OF 'TARIHAL LOCAL' THROUGH MUTATION

Tarihal Local is a popular bell pepper cultivar widely adapted in northern Karnataka. Tarihal Local is a late bearer with smaller fruit size and higher pungency. This necessitates for the improvement of the local cultivars through mutation breeding. The seeds were treated with three different doses of gamma rays at BARC, Mumbai.

The frequency of mutants were very low in M_1 population since only dominant mutations are detectable in M_1 population. Therefore, selection was carried out in M_2 population. The studies in M_2 population included frequency and spectrum of chlorophyll mutations and economically viable mutations along with quantitative characters on M_2 population.

The chlorophyll mutations are most conspicuous and are easily detectable. In the investigation "Xantha" type of chlorophyll mutants were more frequent than albino or striata type.

Among the treatments seeds treated with 20 KR gamma rays was showing (1.42) per cent chlorophyll mutants in comparison with other treatments. Gustaffson (1947) was of opinion that meiotically abnormal M_1 plants produce chlorophyll mutants in M_2 population. The chlorophyll mutation frequency expressed on M_2 seedling basis was better index and is a more reliable measure (Mohanrao, 1972) as it is proportional to changes that are induced. Similar results of chlorophyll mutants was observed by Ramalingam (1977) and Kamannavar (1981) in chilli.

A wide range of viable mutants have been reported by Ramalingam (1977); Indira and Abraham (1977); Kamannavar (1981) and Mehta *et al.* (1999).

The leaf modification with respect to shape and size was observed in all the M₂ populations. Tarihal Local (untreated) has got lanceolate leaf type while, deltoid type leaves were observed in the mutants (3.24% in 10 KR; 8.44% in 15 KR and 5.71% in 20 KR gamma irradiation). Such mutations are genetically unstable (Prina, 1996). If the changes in leaf shape is genetically stable they could be utilized as marker in development of hybrids.

Early flowering was noticed in M₂ population for all the treatments. The flowering was advanced by 10-15 days when compared with control which took more than 40 days to flower after transplanting. Early flowering mutants were observed by Mehta *et al.* (1999) in chilli.

The important criteria for improvement in Tarihal Local is fruit size and shape with less wrinkles. Few of the mutants with slight elongation of fruits (complanate type) were noticed in all the treatments at a lesser percentage (0.5% in 10 KR; 0.31% in 15 KR; 1.14% in 20 KR). On the contrary, shrivelled and malformed small fruits were observed at higher percentage. This might be due to lethal effect of gamma irradiation on the crop. Similar kind of results were obtained by Kamannavar (1981) and Raghuvanshi and Singh (1982) in *Capsicum* and chilli.

The viable mutants with altered morphology (Fig. 7), obviously resulted from the alteration in the developmental processes. In some cases immediate adaptability into horticultural system with slight modification is suggested. Though, most of the mutants are not directly utilized.

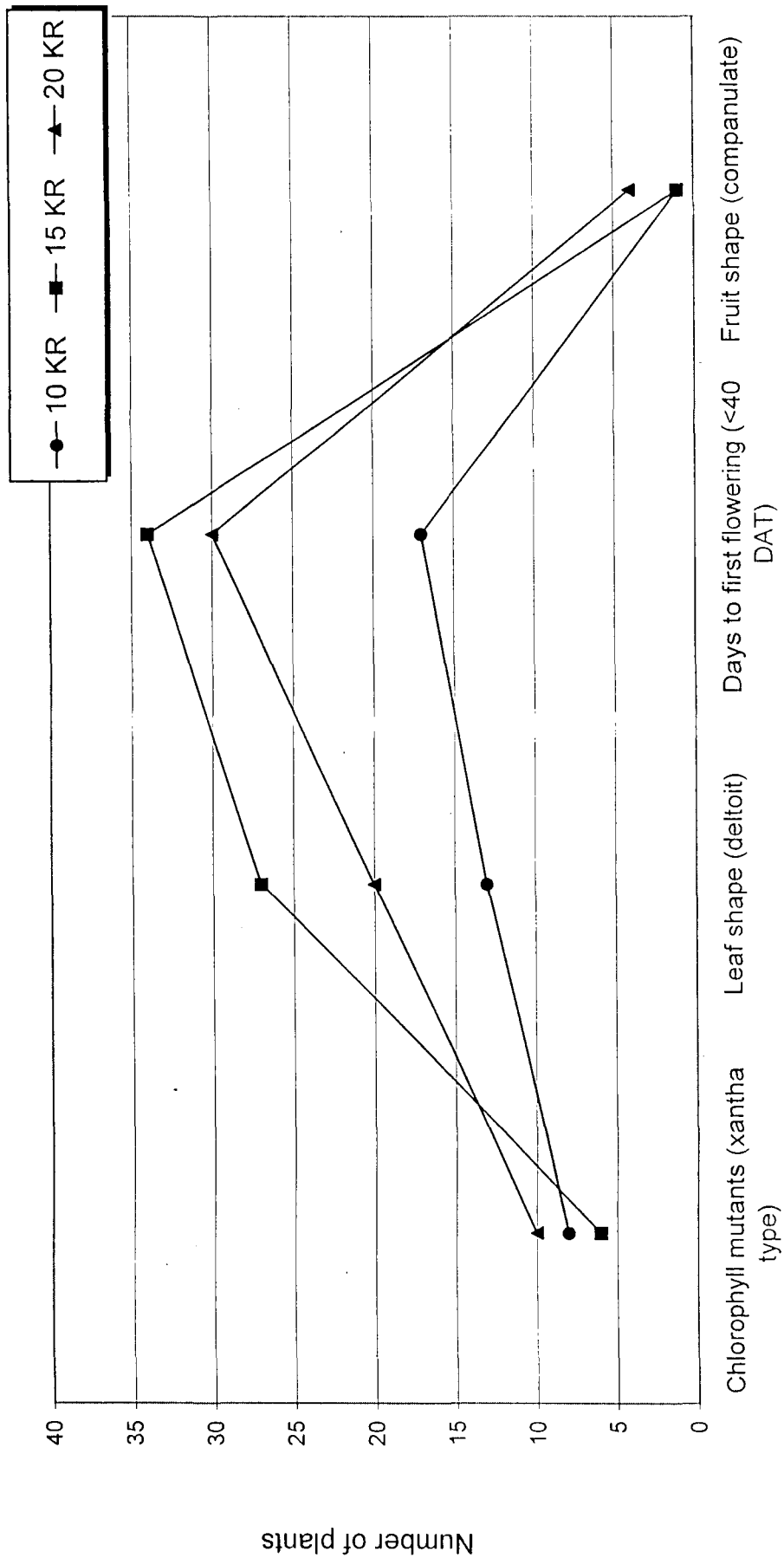


Fig. 7. Frequency distribution for chlorophyll mutants, leaf shape, days to first flowering and fruit shape three M_2 populations of Tarihal Local

The reduction in number of fruits per plant (Fig. 8) was observed at all the doses of gamma rays treated in comparison with the control. While, variance (8.903 to 28.426) and coefficient of variability (56.36% to 78.72%) increased with higher doses.

In case of fruit yield per plant (Fig. 9) there was drastic reduction performance in all the treatments [0.255 kg/plant (10 KR), 0.265 kg/plant (15 KR) and 0.047 kg/plant (20 KR)] when compared with the control (0.273). However high variability was noticed in 20 KR (78.72%) among all the treatments for fruit yield per plant.

The micromutants are the results of changes in polygenes. Hence, they occur in both positive and negative direction. However, in most cases deleterious effect were more than the useful effects resulting in decrease of yield per plant. Similar results were reported in *Capsicum* by Kamannavar (1981).

Thus, it could be concluded that frequency of useful mutants and variability could be further enhanced in M₃ population which would give ample scope for selection of desirable mutants.

5.6 FUTURE LINE OF WORK

1. Top F₁ hybrids viz., Arka Gaurav x 4080-15 and Arka Gaurav x Tarihal Local should be taken for multilocal trials
2. Transgressive segregants noticed in F₂ population must be further selfed and developed into pure lines
3. Detailed studies on local cultivars and their ability to contribute good characters by hybridization should be undertaken

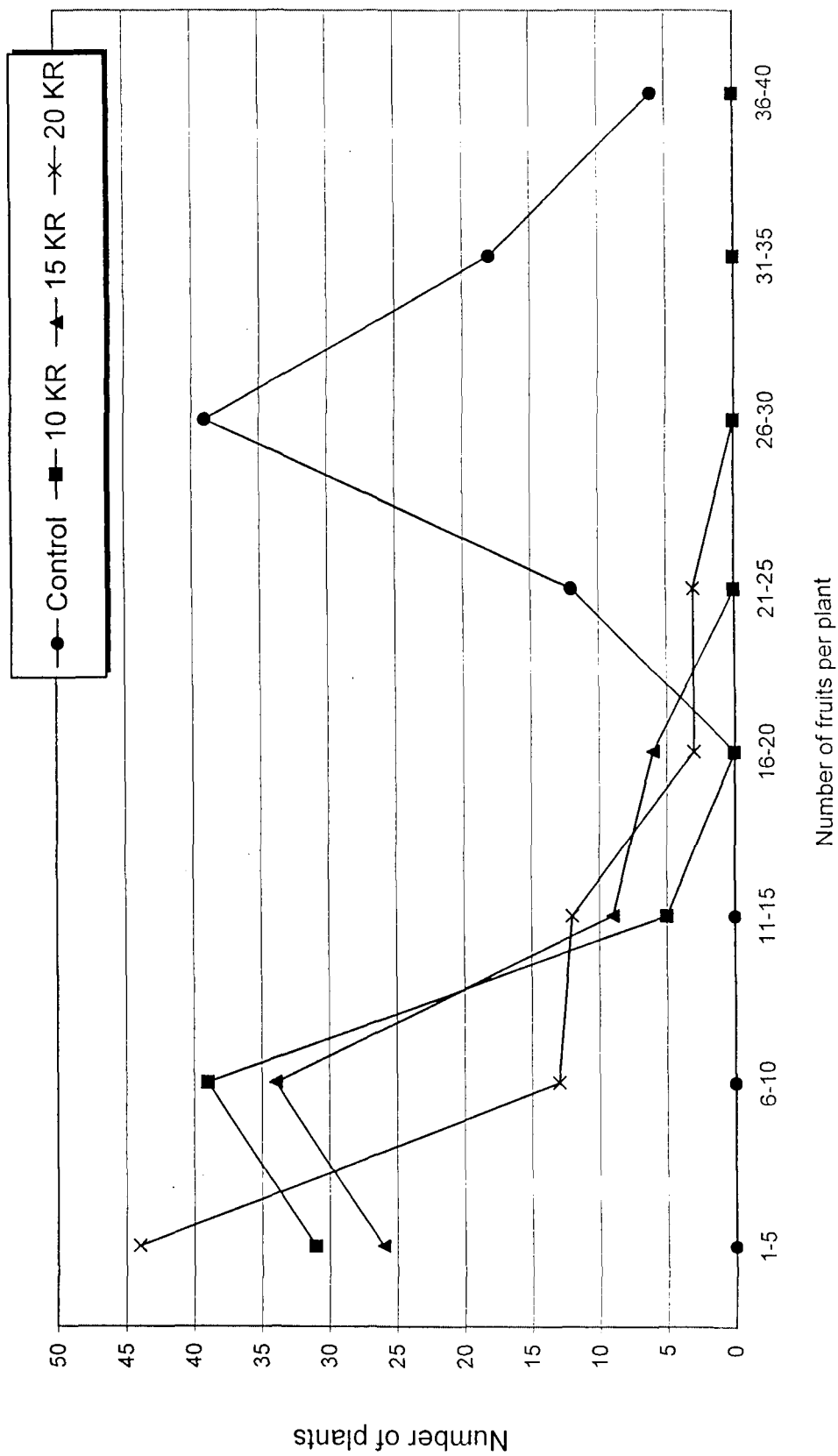


Fig. 8. Frequency distribution for number of fruits per plant in M_2 population of bell pepper along with control

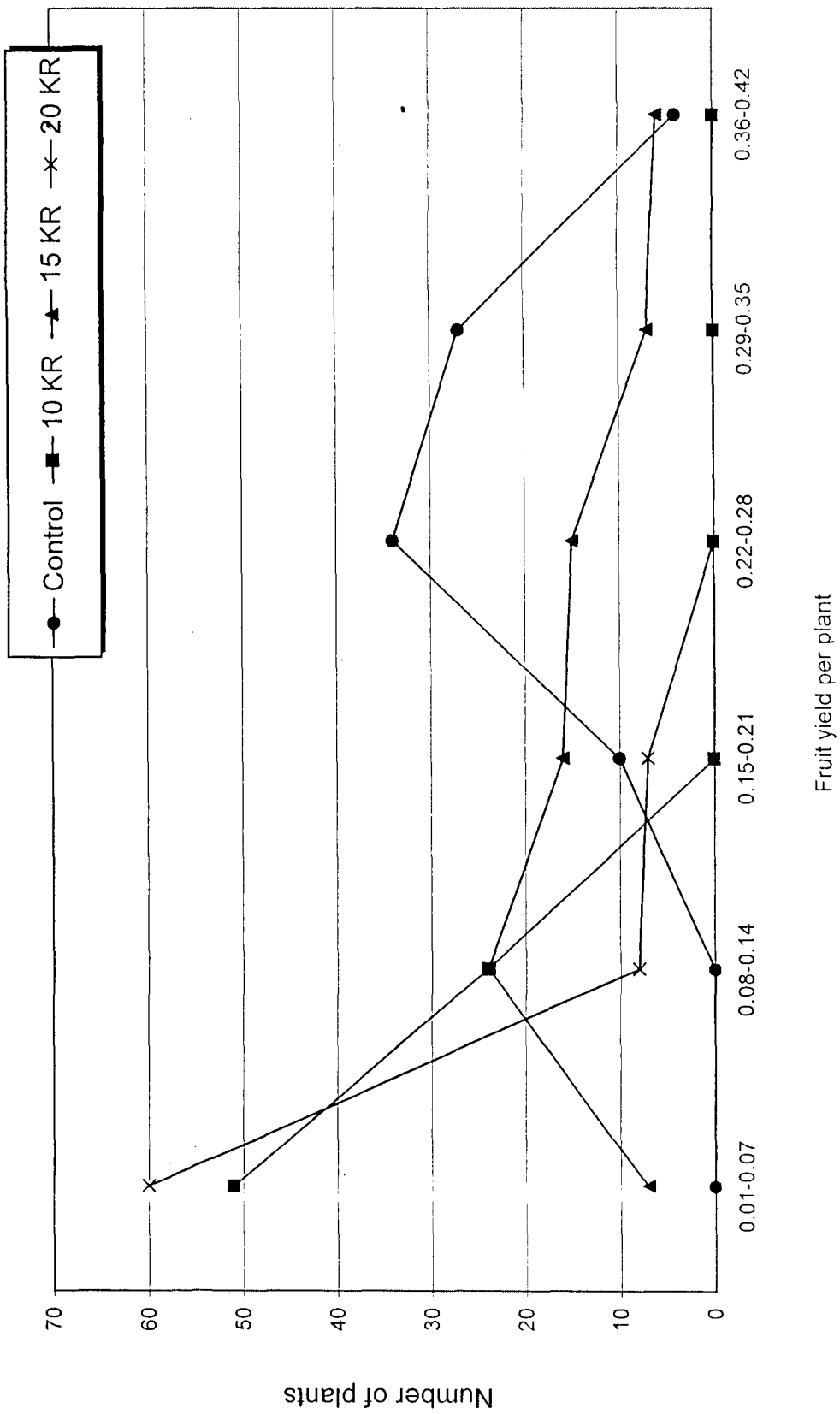


Fig. 9. Frequency distribution for fruit yield per plant in M_2 population of bell pepper along with control

4. Studies on fungal infection on reproductive biology of *Capsicum*, its effect on yield and quality attributes and mapping of powdery mildew resistant loci in pepper germplasm should be conducted
5. Mutation study on local cultivar 'Tarihal Local' should be continued to get desirable mutants in further generations. It might be also suggested that different types of mutagens with different doses could be tried out to increase the frequency of viable mutants of the local cultivar 'Tarihal Local'

Summary

VI. SUMMARY

Investigation on "genetic studies in bell pepper" was undertaken during 2000 to 2003 in the Olericulture Unit, Department of Horticulture, University of Agricultural Sciences, Dharwad, to elicit information on nature of variability with respect to environment in intraspecific varieties of pepper, divergence studies, molecular polymorphism, effect of powdery mildew disease on pollen viability, heterosis, combining ability studies, isolation of transgressive segregants and improvement of Tarihal local through mutation breeding.

Twenty five genotypes (included large fruited bell peppers, hot peppers, paprika type and local cultivars of bell pepper and chilli) were evaluated under field conditions during *rabi* 2000 and *kharif* 2001 for various horticultural traits. These genotypes were also screened for powdery mildew disease resistance during *rabi* 2000. In most of the cases in the past, the nature and quantum of variability were studied by evaluating the genotypes in one season. In such cases the estimation of genotypic variance are biased, as $G \times E$ interaction is involved. Hence, genetic variability was studied in more than one season.

All the growth and fruit related traits had lesser magnitude of V_e and $V_{g \times e}$ components indicating lesser influence of environment on the expression of these characters. This is further, indicated by the narrow difference of coefficient of variability due to genotype and phenotype recorded in individual seasons and over two seasons for the traits. High heritability with high genetic advance suggested presence of additive gene effect for the growth and fruit related characters.

Fruit yield per plant and total soluble solids recorded high $V_{g \times e}$ (i.e., $> V_g$). Higher influence of environment is also indicated by higher magnitude of heritability and lower genetic advance as per cent mean.

Genetic diversity in the available germplasm was assessed by using D^2 statistic. Twenty five genotypes were grouped into seven clusters. Higher inter cluster distance was observed between cluster VI and VII ($D^2=279.88$) followed by II and VI ($D^2=218.93$). All the bell shaped large fruited genotypes (California Wonder, CW-2, Arka Basanth, Belgaum Local, Arka Mohini, Arka Gaurav and Yolo Wonder) were congregated in cluster I. While, most of the pungent long types were grouped under cluster II. The local genotypes *viz.*, Tarihal Local and Ranebennur Local were tolerant to powdery mildew disease were congregated in the cluster IV. The cluster III, I and VII could be categorised under high yielding cluster.

Out of 25 genotypes, 13 genotypes were selected based on morphometric groupings. Each of these genotypes represent different fruit shape, level of pungency and reaction towards powdery mildew disease. Local types were also included to study the RAPD patterns of 13 genotypes with respect to four random decamer primers. The primers OPD-7 (100.00%) and OPC-06 (99.09%) had the highest discriminating power. The pattern of variation in genotype suggested that all the long fruited pungent cultivar formed more divergent group than the less pungent large fruited cultivars (California Wonder, Belgaum Local and Arka Gaurav).

The local cultivars Tarihal Local and Ranebennur Local are closely related to large fruited bell pepper than to the long pungent types. The genotype PMR-57/88/k (a powdery mildew resistant line developed at IIHR, Bangalore using *C. baccatum* var *pendulum* as source of resistance) formed a separate group.

The aforesaid 13 genotypes were subjected to study effect of powdery mildew disease incidence on pollen viability of the genotypes. It was noticed that the infected plants of Yolo Wonder (158.14%) showed

higher per cent sterility over the control followed by California Wonder (130.72). The least per cent sterility over control was noticed in Chilli Yellow (28.54%), PMR-57/88/k (36.34%) and Tarihal Local (40.33). Thus it could be concluded that the effect on reproductive organ by the disease might be one of the reasons for yield loss in pepper.

Nine divergent parents based on the earlier studies of the investigation were used in the hybridization programme. The following three genotypes having large bell shaped fruits with mild pungency and susceptibility to powdery mildew disease were used as female parents (California Wonder, Arka Gaurav and Yolo Wonder). The six genotypes included local large fruited cultivars (Tarihal Local), paprika type (KTPI-19), long pungent types (Chili Yellow and Guntur Local), companulate pungent type (4080-15 and Goa Local) were used as testers. All the 18 F_1 's parents (9) and standard check (Indira) were evaluated in *kharif* 2002.

Among the 18 cross combinations Arka Gaurav x Tarihal Local (1.98 g/plant), Arka Gaurav x 4080-15 (1.88 kg/plant) and Yolo Wonder x KTPI-19 (1.91 kg/plant) were best heterotic crosses with respect to yield, average fruit weight and fruit width. Further, top heterotic crosses were confirmed by their good specific combining ability effects. The parents involved in these crosses were good general combiners for yield per plant, average fruit weight and fruit width per plant. Additive x additive type of gene effects play an important role in producing heterotic hybrids. For fruit yield, quality attributes and tolerance to powdery mildew disease the cross combination of Arka Gaurav x 4080-15 showed significant desirable heterosis over better parent and check. Hence, this cross could be commercially exploited. Wherever Tarihal Local was used as male parent, the cross had shown best performance against powdery mildew disease incidence. This was evident from the *per se* performance of the crosses (California Wonder x Tarihal Local, Arka Gaurav x Tarihal Local and Yolo Wonder x Tarihal Local).

The top crosses (*viz.*, Arka Gaurav x Tarihal Local, Arka Gaurav x 4080-15 and Yolo Wonder x KTPI-19) were selfed to get F₂ population to study the inheritance pattern of fruit shape and isolation of transgressive segregants. Based on qualitative description of fruit shape of large fruited bell peppers 'blocky' type fruit shape were dominant to 'round' shaped fruit in the cross combination of Arka Gaurav x Tarihal Local and Arka Gaurav x 4080-15. While, 'triangular' shaped fruits are dominant to round types in the cross combination Yolo Wonder x KTPI-19. The F₂ population of Arka Gaurav x Tarihal Local showed highest frequency of economic segregants for yield (1.60%) average fruit weight (0.80%) and fruit shape index (28.00) (*i.e.*, blocky and larger fruits). Thus, by recombination of genes from elite cultivars (general combining effect) a progeny was receive repertoire favourable genes than either parent.

'Tarihal Local' a local cultivar of northern transitional tract of Karnataka possess smaller fruit size and it is a late bearing cultivar. One of the ways to improve Tarihal Local is through mutation breeding. The seeds of Tarihal Local were irradiated by gamma rays @ 10 KR, 15 KR and 20 KR at BARC, Mumbai.

The mutants obtained from M₂ population of all the treatments were early flowering (<40 DAT) and broader leaved compared to the control. The frequency of early flowering (10.62%) and broader leaved mutants (8.44%) in M₂ population of Tarihal Local was in higher magnitude when treated @ 15 KR.

Higher coefficient of variability (78.72%) was noticed in M₂ population treated with 20 KR gamma rays when compared to control (16.85%). Thus, from the mutation studies it could be concluded that frequency of useful mutants and variability could be enhanced in M₃ population for further selection of desirable mutants.

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Appendices

APPENDIX I

Meteorological data for the cropping season (2001-03) and average of 51 years (1950-2000) as recorded at
Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad

		Rainfall (mm)					Relative humidity (%)					Temperature (°C)									
Sl. No.	Month	1950-1999	2000	2001	2002	2003	1950-1999	2000	2001	2002	2003	Minimum			Maximum						
												1950-1999	2000	2001	2002	2003	1950-1999	2000	2001	2002	2003
1.	January	0.11	0.00	0.00	0.00	0.00	66.37	48.00	55.00	70.16	61.06	14.61	15.10	15.00	14.50	16.17	30.45	30.00	29.90	30.10	30.27
2.	February	0.00	0.00	0.00	62.70	0.00	56.71	52.00	50.00	60.08	61.50	15.68	15.70	16.80	17.90	17.41	32.26	32.20	34.00	32.05	33.84
3.	March	7.45	0.00	0.00	0.00	0.70	56.62	47.00	45.00	68.34	65.96	18.80	18.50	18.50	20.00	20.22	35.80	35.20	35.30	36.02	36.50
4.	April	42.90	44.10	52.10	67.00	-	60.46	57.00	55.00	71.73	-	21.40	21.50	22.00	21.70	-	38.23	37.30	35.70	37.20	-
5.	May	85.92	45.40	23.10	57.90	-	81.32	67.00	59.00	78.60	-	21.47	21.10	21.50	23.62	-	36.64	33.90	34.80	34.90	-
6.	June	110.50	50.70	32.50	60.50	-	88.39	79.00	75.00	87.60	-	21.21	21.30	21.30	21.90	-	29.76	29.00	30.30	29.60	-
7.	July	156.09	125.20	33.10	15.00	-	88.39	81.00	81.00	86.22	-	21.40	20.40	21.10	21.30	-	27.05	26.80	26.80	28.40	-
8.	August	103.31	50.40	58.10	48.10	-	86.84	81.00	81.00	88.38	-	20.66	20.20	20.90	20.50	-	27.08	27.20	27.20	26.60	-
9.	September	99.47	132.10	53.60	6.60	-	83.15	76.00	72.00	82.70	-	20.15	20.10	20.20	20.63	-	29.39	29.00	30.10	29.86	-
10.	October	135.79	88.30	17.00	103.66	-	76.23	77.00	65.00	77.70	-	19.76	20.20	19.90	20.40	-	30.84	29.50	30.10	30.70	-
11.	November	34.38	0.00	0.00	7.00	-	68.39	68.39	55.00	71.26	-	16.35	16.90	17.90	21.70	-	29.50	30.40	31.00	30.46	-
12.	December	6.35	3.00	0.00	-	-	64.21	64.41	55.00	57.60	-	13.48	13.40	13.70	14.37	-	29.65	28.30	29.60	30.17	-
	Total	783.29	539.20	269.60	429.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX II

Physical and chemical properties of soil from experimental site

Particular	Value obtained	Method adopted
A. Physical properties		
Particle size analysis		International pipette method (Piper, 1966)
Clay (%)	32.70	
Silt (%)	9.50	
Fine sand (%)	31.24	
Coarse sand (%)	26.56	
Textural class	Sandy clay	
B. Chemical properties		
Soil pH (soil water ratio 1: 2.5)	6.70	pH meter (Jackson, 1967)
EC (soil water ratio, 1:2.5 dS/m)	0.75	EC bridge (Jackson, 1967)
CEC (cmole (p+)/kg)	25.40	Sodium saturation method (Black, 1965)
Available N (kg/ha)	264.52	Alkaline permanganate method (Subbaiah and Asija, 1956)
Available P ₂ O ₅ (kg/ha)	16.50	Olsen's method (Jackson, 1967)
Available K ₂ O (kg/ha)	245.35	Flame photometer (Jackson, 1967)

APPENDIX III

Characteristics of 25 pepper genotypes

Genotypes	Fruit shape	Level of pungency	Powdery mildew disease reaction
Arka Mohini	Blocky	Mild pungent	Susceptible
Arka Gaurav	Blocky	Mild pungent	Susceptible
Arka Basanth	Blocky	Mild pungent	Susceptible
California Wonder	Blocky	Mild pungent	Susceptible
Yolo Wonder	Blocky	Mild pungent	Susceptible
Belgaum Local	Blocky	Mild pungent	Susceptible
California Wonder-2	Blocky	Mild pungent	Susceptible
Tarihal Local	Round	High pungent	Tolerant
Ranebennur Local	Round	High pungent	Tolerant
KTPI-19	Triangular	Mild pungent	Susceptible
4080-25	Companulate	Pungent	Moderately susceptible
4080-51	Round	Pungent	Tolerant
4080-15	Companulate	Pungent	Susceptible
42-80-5	Triangular	Pungent	Tolerant
4080-4/2	Companulate	Pungent	Tolerant
4/6-1/3	Companulate	Pungent	Tolerant
4080-62	Companulate	Pungent	Tolerant
Guntur Local	Elongate	Pungent	Susceptible
Thaiwan Local	Elongate	High pungent	Tolerant
Chilli Yellow	Elongate	Pungent	Tolerant
VN-2	Elongate	High pungent	Susceptible
40-86-57	Triangular	Pungent	Susceptible
Tiptur Local	Elongate	High pungent	Tolerant
Goa Local	Companulate	Pungent	Moderately susceptible
PMR-57/88/K	Elongate	Pungent	Tolerant

APPENDIX IV

Stock solutions for DNA extraction

1. Extraction buffer : 100 mM Tris-HCl, pH 8.0
50 mM EDTA, pH 8.0
500 mM NaCl
2. SDS (20%)
3. Potassium acetate (5 M)
4. Isopropanol
5. Ammonium acetate (10 M)
6. Ethyl alcohol (70%)
7. TE Bufer : Tris (10 mM) containign EDTA (1mM)

APPENDIX V

Stock solutions for RAPD-PCR

A. Working solutions

- a. Random primers (15 η g per μ l)
- b. Template DNA (10 η g per μ l)
- c. dNTPs mix (10 mM)
- d. Taq DNA polymerase (2 units per μ l)

B. Amplification mix for PCR

	Ingredient	Quantity (μ l)
a.	Sterile distilled water	16.5
b.	10 X taq assay buffer with $MgCl_2$	02.5
c.	dNTPs mix (10 mM)	01.0
d.	Primer (15 η g/ μ l)	02.0
e.	Taq DNA polymerase (2 U/ μ l)	01.0
f.	Template DNA (10 η g/ μ l)	02.0
	Total	25.0 per reaction

APPENDIX VI

Agarose gel electrophoresis for separation of RAPD

A. Requirements

➤ Submarine electrophoresis unit, Gel casting trough, gel combs, power pack, UV transilluminator, orange filter, camera, *etc.*,

➤ Agarose, Bromohenol blue, Ethidium bromide

➤ 10 x TBE (stock) (pH 8.3) - Tris 108 g

Boric acid 55 g

EDTA 9.3 g

Volume made up to 1 litre

➤ 1 x TBE (pH 8.3) (working solution) 10 ml of 10 x TBE was made upto 100 ml, using distilled H₂O.

➤ λ DNA/*Hind*III and ϕ X 174/*Hae*III digest mix.

B. Procedure

➤ 1.1 g of agarose was weighed and added to a conical flask containing 110 ml of 1 x TBE buffer.

➤ The agarose was melted by heating the solution on a gas stove and the solution was stirred to ensure even mixing and complete dissolution of agarose.

➤ The solution was then cooled to about 45-40°C.

➤ 5 μ l of ethidium bromide (0.5 μ g ml⁻¹) was added to the molten agarose and mixed well.

- The solution was poured into the gel casting platform after inserting the comb in the trough. While pouring, sufficient care was taken to avoid trapping of the air bubbles in the gel.
- The gel was allowed to solidify and comb was removed after placing the solidified gel into the electrophoretic apparatus containing sufficient buffer (1 X TBE) so as to cover the wells and entire gel completely.
- The amplified products (25 μ l) were carefully loaded into the sample wells, after mixing it with 4 μ l of 30 per cent glycerol containing bromophenol blue as a tracking dye.
- Molecular weight marker (λ DNA/*Hind*III and OX 174/*Hae*III digest) (10 μ l) was loaded in the first lane of each gel.
- Electrophoresis was carried out at 100 volts, until the tracking dye migrated to the end of the gel.
- The gel was taken out from electrophoretic apparatus and stained by placing it in distilled water containing ethidium bromide (0.5 μ g ml⁻¹) for 10 minutes.
- Ethidium bromide stained DNA bands were viewed under UV transilluminator and photographed for documentation.

APPENDIX VII

Per se performance of 25 genotypes of pepper evaluated during rabi, kharif and over two seasons

	Plant height			Plant spread			Number of primary branches			Number of secondary branches			Days to 50 per cent flowering			Average fruit weight (g)		
	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean
Arka Mohini	25.48	24.66	25.06	28.53	30.00	29.27	3.00	3.00	3.00	6.00	6.00	6.00	33.67	37.00	35.33	27.90	23.02	25.46
Arka Gaurav	42.42	35.25	38.84	40.07	45.70	42.88	2.47	2.67	2.57	5.27	5.33	5.30	35.00	37.67	36.33	22.70	18.98	20.84
Arka Basanth	43.01	33.39	38.20	25.40	23.23	24.32	3.67	3.87	3.77	5.80	5.93	5.87	34.33	39.00	36.67	52.84	43.34	47.99
California Wonder	49.65	40.02	43.83	39.83	38.57	39.20	3.00	3.00	3.00	6.00	6.13	6.07	31.00	33.67	32.33	50.03	46.53	48.28
Yolo Wonder	52.14	46.52	49.34	38.23	44.47	41.32	2.67	2.93	2.80	5.60	5.53	5.50	32.67	35.67	34.17	59.38	47.18	53.03
Belgaum Local	35.69	28.34	32.02	34.97	37.43	36.55	3.00	3.20	3.10	6.23	6.33	6.28	31.33	35.33	33.33	54.92	47.98	51.46
California Wonder-2	49.63	52.52	51.08	33.13	32.10	32.58	4.17	4.80	4.48	6.40	7.20	6.80	33.33	35.00	34.17	55.81	43.20	49.51
Tarihal Local	82.12	79.42	80.77	36.20	42.27	38.90	5.13	6.67	5.60	11.93	12.47	12.20	52.00	48.33	50.17	19.40	13.83	16.62
Ranebennur Local	75.53	77.19	76.36	33.87	37.60	35.57	4.00	5.07	4.63	8.93	10.00	9.30	49.67	45.67	47.67	14.83	7.04	10.94
KTP-19	83.92	86.14	85.04	55.40	62.03	58.72	2.13	2.20	2.17	4.47	4.93	4.70	41.00	38.67	40.67	30.17	20.35	23.59
4080-25	43.92	62.75	55.01	31.80	30.97	31.25	2.87	3.07	2.93	5.87	5.93	5.90	36.00	35.67	35.83	14.20	11.40	12.80
4080-51	65.48	64.15	64.82	46.50	42.80	44.67	2.20	2.07	2.13	4.47	4.13	4.30	36.67	37.33	37.00	11.07	14.67	12.87
4080-15	56.76	56.77	56.84	53.77	49.23	51.50	2.27	2.47	2.37	4.80	5.13	4.97	32.00	32.00	32.00	6.98	6.07	6.36
42-80-5	44.26	50.07	46.83	29.87	22.53	26.20	2.53	2.73	2.63	4.33	6.20	5.22	37.33	39.33	38.33	7.37	5.59	6.48
4080-4/2	68.38	67.32	68.35	42.63	38.90	40.77	3.07	3.07	3.07	6.27	6.20	6.23	41.33	43.67	42.33	8.22	3.14	5.68
4/6-1/3	52.75	54.98	53.87	39.07	32.63	35.85	2.47	2.40	2.43	4.13	4.07	4.10	38.00	40.33	39.17	3.78	3.86	3.83
4080-62	70.61	75.13	63.37	46.97	41.60	44.95	2.73	3.00	2.87	5.20	5.27	5.27	38.00	40.33	39.17	4.17	4.08	3.96
Guntur Local	86.07	88.64	88.36	70.53	80.33	75.43	4.13	5.00	4.07	8.00	8.07	8.03	34.67	33.67	34.17	6.58	8.09	7.34
Thaiwan Local	70.11	74.80	71.63	56.23	58.20	56.55	2.60	2.33	2.46	5.67	5.93	5.77	32.33	29.00	30.67	6.13	6.80	6.46
Chilli Yellow	65.38	69.40	66.89	53.73	54.43	53.98	2.73	2.87	2.80	5.73	5.80	5.77	33.67	30.67	32.17	4.64	5.50	5.07
VN-2	64.45	72.48	68.47	54.70	69.43	62.06	3.00	3.93	3.47	6.67	6.93	6.73	34.00	36.67	35.33	15.17	15.00	15.07
40-86-57	55.79	50.57	53.19	54.13	48.43	51.28	2.00	2.33	2.17	4.00	4.13	4.07	40.67	41.33	41.00	9.71	8.07	8.89
Tiptur Local	86.47	86.58	86.52	63.33	85.27	74.30	3.33	3.00	3.13	6.87	7.07	6.97	35.67	33.33	34.50	8.62	9.00	8.71
Goa Local	38.69	37.96	38.32	48.77	32.90	40.80	3.00	3.20	3.10	6.00	6.13	5.97	32.00	29.00	30.50	6.78	5.09	5.94
PMR-57/88/K	64.17	68.91	66.04	50.43	61.13	55.78	4.20	5.07	4.63	8.53	8.60	8.57	39.00	35.67	37.33	1.85	3.52	2.69
S.Em±	2.24	1.96	3.39	2.17	1.85	3.40	0.21	0.15	0.25	0.209	0.200	0.203	0.715	0.831	0.585	2.87	3.781	2.067

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	Fruit length (cm)			Fruit width (cm)			Fruit shape index			Locules per fruits			Pericarp thickness (cm)			Pedicel length (cm)		
	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean
Arka Mohini	5.36	5.43	5.40	4.39	4.08	4.23	1.22	1.33	1.28	4.00	4.00	4.00	0.31	0.28	0.29	2.14	2.15	2.15
Arka Gaurav	7.63	6.61	7.12	3.59	3.10	3.35	2.13	2.13	2.13	3.00	3.00	3.00	0.42	0.43	0.42	2.08	1.99	2.04
Arka Basanth	8.05	5.55	6.80	5.54	5.27	5.41	1.45	1.05	1.25	3.00	3.00	3.00	0.49	0.34	0.41	2.03	2.06	2.05
California Wonder	7.73	6.01	6.67	6.48	5.59	5.91	1.20	1.69	1.15	4.00	4.00	4.00	0.52	0.38	0.45	1.67	1.87	1.77
Yolo Wonder	8.04	5.66	6.85	6.20	5.12	5.66	1.30	1.11	1.21	4.00	4.00	4.00	0.54	0.43	0.49	1.85	2.02	1.94
Belgaum Local	7.00	6.34	6.67	5.48	5.26	5.37	1.39	1.20	1.29	3.13	3.33	3.23	0.40	0.52	0.46	2.44	2.44	2.44
California Wonder-2	6.55	6.25	6.40	5.58	5.28	5.42	1.18	1.19	1.19	4.00	4.00	4.00	0.62	0.53	0.56	3.19	2.97	3.08
Tarihal Local	3.62	2.81	3.22	3.57	3.51	3.54	1.01	0.80	0.91	3.00	3.0	3.00	0.23	0.19	0.21	2.62	2.35	2.49
Ranebennur Local	6.28	2.80	3.05	3.32	2.65	2.98	1.00	1.06	1.03	4.00	3.87	3.93	0.19	0.19	0.19	2.05	1.98	2.02
KTPIL-19	7.02	7.77	7.39	3.09	3.55	3.86	2.27	2.19	2.23	2.00	2.00	2.00	0.52	0.41	0.46	1.38	1.43	1.40
4080-25	3.09	3.10	3.09	3.84	3.41	3.62	0.81	0.91	0.86	3.27	3.47	3.37	0.16	0.20	0.18	2.40	2.48	2.44
4080-51	2.57	2.71	2.64	2.47	2.47	2.47	1.04	1.10	1.07	3.00	3.13	3.07	0.25	0.21	0.23	1.92	1.97	1.95
4080-15	5.04	4.17	4.49	1.13	1.45	1.29	4.50	2.91	3.71	3.20	3.33	3.27	0.14	0.12	0.13	3.52	3.76	3.64
42-80-5	5.59	6.27	5.93	2.44	2.17	2.30	2.32	2.89	2.61	3.03	3.07	3.05	0.13	0.09	0.11	3.05	2.29	2.85
4080-4/2	3.59	3.57	3.58	3.42	1.50	2.46	1.05	2.46	1.76	3.53	3.67	3.60	0.15	0.13	0.14	3.08	3.30	3.19
4/6-1/3	3.83	3.52	3.68	3.14	3.23	3.19	1.23	1.13	1.18	3.00	3.00	3.00	0.35	0.26	0.31	1.62	1.88	1.75
4080-62	3.49	4.00	3.74	3.20	3.52	3.42	1.09	1.13	1.11	4.00	3.93	3.97	0.26	0.17	0.21	1.54	1.66	1.60
Guntur Local	1.02	12.20	11.11	2.02	1.77	1.90	4.99	7.52	6.26	2.00	2.00	2.00	0.08	0.09	0.09	3.25	3.44	3.35
Thaiwan Local	11.00	12.17	11.58	1.00	1.47	1.24	10.97	8.34	9.66	2.00	2.00	2.00	0.11	0.13	0.12	3.01	3.27	3.10
Chilli Yellow	5.17	6.95	6.06	1.65	1.70	1.68	3.15	4.11	3.63	2.00	2.00	2.00	0.10	0.12	0.11	1.78	1.97	1.88
VN-2	10.09	12.20	11.15	1.79	2.31	1.95	6.41	4.97	5.87	2.00	2.00	2.00	0.18	0.17	0.17	1.48	1.56	1.52
40-86-57	2.98	3.62	3.30	2.92	3.00	2.96	1.05	1.20	1.13	4.00	4.00	4.00	0.43	0.40	0.41	1.52	1.92	1.72
Tiptur Local	11.63	13.01	12.32	1.45	1.64	1.55	8.06	7.92	7.99	2.00	2.00	2.20	0.19	0.19	0.19	3.88	4.18	4.03
Goa Local	4.67	5.77	5.22	3.16	3.17	3.17	1.48	1.83	1.66	3.10	3.10	3.10	0.13	0.12	0.12	2.96	3.36	3.16
PMR-57/88/K	5.33	6.52	5.93	0.75	1.25	1.00	7.10	5.23	6.14	2.00	2.00	2.00	0.14	0.16	0.15	2.37	2.44	2.40
S.Em±	0.270	0.164	0.139	0.222	0.125	0.215	0.310	0.243	0.129	0.101	0.066	0.064	0.038	0.047	0.027	0.109	0.090	0.103

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	Seed weight			Number of seeds			Ascorbic acid			TSS			Number of fruits per plant			Yield per plant		
	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean	Rabi	Kharif	Mean
Arka Mohini	4.96	5.27	5.12	166.27	153.67	159.97	214.47	197.10	205.78	4.27	4.20	4.23	20.43	17.20	18.82	0.31	0.29	0.30
Arka Gaurav	1.89	2.20	2.05	118.10	114.40	116.25	224.67	174.00	199.33	4.00	4.00	4.00	17.30	20.47	18.89	0.36	0.28	0.32
Arka Basanth	3.42	3.17	3.30	146.97	144.00	145.48	229.60	174.33	201.97	5.53	5.47	5.50	20.17	13.40	18.45	0.40	0.35	0.37
California Wonder	4.17	4.93	4.55	146.97	154.40	150.68	218.43	190.33	204.38	5.27	5.13	5.20	21.10	18.53	19.60	0.80	0.61	0.70
Yolo Wonder	4.00	4.25	4.13	179.83	191.03	185.43	150.74	106.60	128.67	5.00	4.87	4.93	22.73	15.30	19.02	0.82	0.62	0.69
Belgaum Local	6.95	7.07	7.01	174.70	171.73	173.21	212.07	179.27	195.67	4.60	4.60	4.60	24.70	13.70	19.20	0.94	0.69	0.85
California Wonder-2	5.50	5.18	5.38	154.03	148.13	151.08	220.40	186.67	203.48	5.40	5.00	5.20	29.30	18.67	23.98	0.75	0.55	0.65
Tarihal Local	1.79	2.17	1.98	212.30	205.10	208.70	180.97	142.10	161.53	7.67	7.53	7.60	29.83	23.37	24.93	0.32	0.28	0.30
Ranebennur Local	1.06	1.50	1.28	265.10	274.47	269.78	163.97	153.63	158.80	7.20	7.07	7.13	39.67	38.97	39.28	0.43	0.33	0.38
KTPI-19	5.14	3.94	4.14	150.53	144.77	147.65	167.73	206.10	186.92	7.03	6.87	6.95	133.07	90.47	111.55	1.71	1.5	1.60
4080-25	1.39	2.43	1.92	230.37	206.07	218.22	103.33	107.87	105.60	7.30	7.27	7.28	40.77	39.63	40.10	0.28	0.28	0.28
4080-51	5.15	4.07	4.61	303.23	343.33	323.28	206.97	212.53	109.75	7.50	7.33	7.43	33.00	32.77	32.88	0.34	0.26	0.30
4080-15	0.61	0.50	0.55	105.63	113.00	109.32	200.43	183.33	191.88	7.00	6.87	6.93	51.17	40.97	46.07	0.36	0.31	0.34
42-80-5	1.19	1.55	1.47	233.90	231.90	232.90	180.33	152.20	166.27	5.33	5.20	5.27	65.57	58.57	61.95	0.45	0.31	0.38
4080-4/2	1.15	0.64	0.83	157.07	151.00	154.03	173.53	210.20	191.86	5.20	5.00	5.10	73.43	36.03	54.83	0.37	0.33	0.35
4/6-1/3	1.75	0.73	1.20	116.13	103.37	109.75	161.90	126.67	144.28	5.27	5.07	5.17	92.93	99.97	96.55	0.50	0.41	0.46
4080-62	1.31	1.17	1.24	129.23	129.17	129.20	215.53	198.53	207.03	6.80	6.53	6.67	92.13	127.87	109.85	0.51	0.46	0.48
Guntur Local	0.34	0.77	0.55	69.13	84.40	76.76	189.43	202.43	195.93	5.17	5.00	5.08	57.87	56.77	57.30	0.33	0.42	0.37
Thaiwan Local	1.14	1.30	1.22	107.97	90.87	99.42	166.67	195.07	180.83	6.50	6.00	6.25	59.13	68.97	64.05	0.30	0.32	0.31
Chilli Yellow	0.57	0.87	0.72	82.43	92.37	87.40	223.53	203.87	213.70	5.60	5.33	5.40	105.97	113.80	109.55	0.53	0.57	0.55
VN-2	3.64	4.27	3.96	80.73	113.07	96.90	202.67	147.83	175.25	6.83	6.60	6.72	51.73	49.87	50.80	0.60	0.80	0.70
40-86-57	1.05	1.27	1.16	88.27	103.10	95.68	180.83	158.47	169.65	6.37	6.07	6.22	53.70	105.77	79.74	0.39	0.43	0.41
Tiptur Local	1.11	1.44	1.28	86.60	110.33	98.46	210.27	210.97	210.62	6.13	6.00	6.07	61.17	52.70	56.93	0.49	0.40	0.44
Goa Local	0.40	0.53	0.47	44.27	46.40	45.33	134.03	112.97	123.50	6.07	4.93	5.00	95.10	72.30	83.70	0.65	0.51	0.57
PMR-57/88/K	0.89	0.94	0.91	81.20	82.23	81.72	197.67	146.23	168.62	6.33	6.27	6.30	82.80	95.13	88.96	0.32	0.47	0.38
S.Em±	0.156	0.156	0.139	12.38	11.57	18.55	10.970	15.271	9.694	0.097	0.085	0.072	7.29	11.44		0.081	0.078	0.068

GENETIC STUDIES IN BELL PEPPER

(*Capsicum annuum* L. var. *grossum* Sendt.)

NANDADEVI

2004

Dr. P. R. DHARMATTI
MAJOR ADVISOR

ABSTRACT

Investigation on genetic studies in bell pepper was undertaken during 2000 to 2003 in the Department of Horticulture and Institute of Agri-Biotechnology, UAS, Dharwad.

Twenty-five genotypes (included large fruited bell peppers, hot peppers, paprika type and local cultivars) were evaluated under field conditions during *rabi* 2000 and *kharif* 2001 for different traits to know GxE interaction and genetic parameters. It was observed that fruit yield per plant and TSS recorded high $V_g \times e$ (i.e. $> V_g$) suggesting influence of environment for these traits. This was further confirmed with higher magnitude of heritability along with lower values of genetic advance over mean.

Genetic divergence studies suggested that all the bell shaped large genotypes were congregated in cluster I, while most of the pungent long types were grouped under cluster II.

Out of 25 genotypes, 13 were selected based on morphometric groupings to study the RAPD patterns. It was observed that the local cultivars Tarihal Local and Ranebennur Local were closely related to large fruited bell peppers while the genotype PMR-57/88/K (powdery mildew resistant genotype) formed a separate group. The said 13 genotypes were subjected to study the effect of powdery mildew incidence on pollen viability. The infected plants of Chilli Yellow, PMR-57/88/k and Tarihal Local showed least per cent sterility over control.

Nine divergent parents were used in L x T mating design. Among the 18 cross combination Arka Gaurav x Tarihal Local and Arka Gaurav x 4080-15 was heterotic for fruit yield, quality attribute and tolerance to powdery mildew incidence.

The study on inheritance of fruit shape revealed that blocky shaped fruits were dominant to round shaped fruits while, triangular shaped are dominant to blocky shaped. The F₂ population of Arka Gaurav x Tarihal Local possessed higher frequency of transgressive segregants while Arka Gaurav x 4080-15 could produce higher magnitude of transgressive segregants for average fruit weight.

The local cultivar 'Tarihal Local' was subject to gamma rays @ 10 KR, 15 KR and 20 KR. Higher frequency of early flowering and broader leaved mutants in M₂ population was noticed when treated @ 15 KR.