STUDIES ON GENETIC VARIABILITY IN BELL PEPPER (*Capsicum annuum* L.)

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled **"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)",** submitted in partial fulfilment of the requirements for the award of degree of **MASTER SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 India is a bonafide research work carried out by **Ms Radhika Negi (H-2016-102-M)** daughter of Shri Ashok Negi under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

Place : Nauni -Solan
Dated :

(Dr Seema Thakur)
Major Advisor

CERTIFICATE-II

This is to certify that the thesis titled, **"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)",** submitted by **Ms Radhika Negi (H-2016-102-M)** daughter of Shri Ashok Negi to the Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173230 India in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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"Jai Maa Bhimakali"

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Needless to say Errors and Omissions are mine.

Place: Nauni, Solan
Date: **(Radhika Negi)**

CONTENTS

ABBREVIATIONS USED

%	Per cent
/	Per
=	Equal to
×	Multiplication
ANOVA	Analysis of Variance
CD	Critical Difference
cm	Centimeter
et al.	Co-workers
etc	Et cetera
g	Gram
HP	Himachal Pradesh
ha	Hectare (10,000 m^2)
i.e.	Id Est (That is)
kg	Kilogram
kg/ha	Kilogram per hectare
m	Meter
m^2	Meter square
mg	Miligram
mm	Millimeter
MSS	Mean Sum of Square
pH	*Puissance de Hydrogen*
pp	Particular page
RCBD	Randomized Complete Block Design
RH	Relative Humidity
RHS	Royal Horticultural Chart
SS	Sum of Square
TSS	Total Soluble Solids
var.	Variety
viz.,	vi delicet (namely)
@	At the rate of
$^{\circ}$C	Degree Celcius
$^{\circ}$B	Degree Brix
q	Quintal

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Chapter-1

INTRODUCTION

Bell Pepper (*Capsicum annuum* L.) popularly known as sweet pepper, capsicum or Shimla Mirch is a member of family Solanaceae with chromosome number 2n=24. It is a high value vegetable and an important cash crop for temperate regions. It is an important vegetable crop grown worldwide for its delicate taste, pleasant flavour and colour. It is native to Mexico with secondary centre of origin in Guatemala (Bukasov, 1930).

Fruits of bell pepper are generally blocky, square or triangular in shape, thick fleshed, three to four lobed having low to mild pungency. It is mostly consumed raw in green mature forms, cooked as vegetable or widely used in stuffings, bakings, pizza making, preparation of soups and stews for imparting flavour, aroma and colour. Besides, bell pepper is also rich in certain nutrients, by virtue of which it possesses medicinal properties, hence recommended for the treatment of dropsy, colic, toothache and cholera (Peirce, 1987). Nutritionally, it is a rich source of vitamin C ranging from 150-180 mg per 100 g and vitamin A, constituting up to 12 per cent of total pigment content. It is also rich in ascorbic acid content which has an antioxidant property and aids in prevention of certain types of cancer, cardiovascular diseases, stroke, atherosclerosis and cataracts (Maldonado *et al.*, 2002).

Bell peppers are available in different colours *viz.*, yellow, red, green, purple and orange. These plump, bell shaped vegetables were cultivated more than 900 years ago in South and Central America and were given the name 'pepper' by the European colonizers of North America. These can easily grow in different types of climate. Sweet peppers are a great combination of tangy taste and crunchy texture. In India, it was first introduced by the Britishers in Nineteenth century in Shimla hills (Singh *et al*., 1993) therefore, known as 'Shimla Mirch'. It is an important remunerative crop of temperate and sub-temperate regions, growing best at a temperature ranging between 20–30°C in Summers.

It is now widely cultivated in Himachal Pradesh, Jammu and Kashmir, hills of Uttar Pradesh, Andhra Pradesh and Nilgiris during summer and as an autumn crop in Karnataka, Tamil Nadu, Maharashtra, Bihar, West Bengal and Madhya Pradesh. In India, bell pepper is cultivated over an area of about 46,000 ha with a production of 288,000 MT (NHB, 2016). In

Himachal Pradesh, bell pepper is grown as an off season crop during the summer and rainy seasons and is economically important to small and marginal farmers (Sood *et al*., 2009).

Recently, bell pepper has attained a status of high value vegetable in India due to its high nutritional value and export potential. Despite of its economic importance, growers are not in a position to produce good quality capsicum with high productivity due to various biotic (diseases and pest), abiotic (rainfall, temperature, relative humidity and light intensity) and crop factors (flower and fruit drop).

There are a very few varieties available for cultivation in bell pepper in the public sector which has led to near genetic uniformity among these cultivars. Few old introductions like California Wonder are still recommended for commercial cultivation. Now a day's farmers are largely dependent on the private sector for the supply of seed. Genetic restructuring of the bell pepper germplasm in public sector is the need of the hour. In this direction, the first and foremost step is the evaluation of the available germplasm so as to identify the potential genotype for their use either directly as varieties or as parents in future breeding programme.

Existence of sufficient variability in the genetic stock is a pre-requisite for initiation of any breeding programme. The correlation coefficient being the result of cause and effect relationship between different characters may not always provide complete information. Thus, a better understanding of association between the characters is provided by path coefficient analysis. Knowledge of relationship between the characters is important for indirect improvement of characters which are difficult to quantify and having low heritability. Similarly, genetic divergence is another important approach to assess the variability patterns of specific characters in whole germplasm and is suitable to select the parents for crossing and improvement of a specific trait through hybridization, where selection is not responsive.

Keeping in view the importance of crop, present investigations were conducted on twenty-five diverse genotypes of bell pepper with the following objectives:

OBJECTIVES:

i) To assess the genetic variability in different genotypes of bell pepper for important horticultural and yield traits.

ii) To study the association among yield and other important horticultural traits.

iii) To assess the extent of genetic diversity in different genotypes of capsicum.

Chapter-2

REVIEW OF LITERATURE

An attempt has been made to review the relevant literature pertaining to the present studies and presented here under the following heads:

2.1 Genetic variability studies
2.2 Correlation studies
2.3 Path coefficient analysis
2.4 Genetic divergence

2.1 GENETIC VARIABILITY STUDIES

The determination of genetic variability and its partitioning into various components like genotypic, phenotypic and environmental variability is necessary to have an insight into the genetic nature of yield and its components which enable the breeders to adopt a suitable strategy and formulate a comprehensive breeding program, required for the necessary crop improvement.

Chatterjee and Kohli (2004) observed moderate to high heritability estimates for all the traits in twenty-five genotypes of bell pepper. High genotypic coefficients of variation (GCV), high heritability and genetic advance (GA) were found for number of lobes per fruit, fruit width at blossom end and fruit weight at marketable stage. Moderate GCV, GA and moderate to high heritability were recorded for plant height, number of fruits per plant, fruit length, fruit width (middle/centre and stem end) and fruit yield per plant.

Mishra *et al.* (2005) conducted an experiment with twenty-two genotypes of capsicum and observed high phenotypic and genotypic coefficients of variation, heritability and genetic gain for ascorbic acid content, number of fruits per plant, fruit yield per plant, seed yield per fruit and fruit length.

Nazir *et al*. (2005) observed highest phenotypic and genotypic coefficients of variability for average fruit weight. High heritability coupled with high genetic gain was recorded for plant height, plant spread, flesh thickness, number of fruits per plant, weight per fruit and seed yield per plant.

Sood *et al*. (2006) conducted an experiment on twenty-five genotypes of bell pepper and concluded that Phenotypic Coefficients of Variation were high for fruit yield, fruits per plant and marketable fruits per plant. High heritability along with high genetic advance was recorded for fruit yield per plant. High to moderate heritability with low genetic advance was recorded for days to 50 per cent flowering, days to first picking, branches per plant and harvest duration.

Sood *et al.* (2007) concluded that the phenotypic coefficients of variation (PCV) were slightly higher than their corresponding genotypic coefficients of variation (GCV) due to the influence of environment. Higher PCV and GCV were observed for capsaicin content and marketable fruit yield and moderate to low for TSS, ascorbic acid and pericarp thickness. The highest genetic advance was predicted for capsaicin content followed by marketable fruit yield.

Ukkund *et al.* (2007) studied about eighty chilli accessions. High degree of variation was observed for all characters. The difference between phenotypic coefficient of variation and genotypic coefficient of variation was found to be narrow for most of the traits except primary and secondary branches, tertiary branches, 50 per cent flowering and fruit yield per plant. High estimates of heritability were found for plant height (93.40%), days to first flowering (83.50%), per cent fruit set (70.70%), number of fruits per plant (81.10%), fruit length (92.40%), average fruit weight (92.40%) and total green fruits per plant (88.40%). Most of these characters also showed moderate to high estimates of genetic advances as a per cent over mean except days to first flowering.

Dandunayaka (2008) evaluated chilli for twelve horticultural and six quality traits. Considerable variability for most of the characters was indicated by analysis of variance. High phenotypic and genotypic coefficient of variation was observed in yield related traits *viz.*, fruits per plant and fruit weight. These characters are of economic importance and there is scope for improvement through selection. High heritability coupled with high genetic advance as per cent mean was recorded for biochemical parameters, fruits per plant, dry fruit weight, fruit length, fruit diameter and secondary branches, suggesting the involvement of genetic factors.

Sood *et al.* (2009) studied genetic variation for marketable fruit yield, fruits per plant, average fruit weight, pericarp thickness, number of lobes per fruit, TSS, ascorbic acid, capsaicin content and quantified the relationship among these traits. Difference among bell pepper genotypes indicated the presence of significant variation for all the traits. The phenotypic coefficient of variation (PCV) indicated higher values than genotypic coefficient of variation (GCV) for all traits, indicating close association between phenotype and genotype. High heritability estimates along with high genetic advance was recorded for marketable fruits per plant, pericarp thickness, and lobes per fruit thereby, indicating the role of additive gene action for their inheritance. Days to 50 per cent flowering, harvest duration and ascorbic acid had high heritability estimates along with low genetic advance indicating non-additive gene action.

Sharma *et al.* (2010) worked out genetic variability including mean, genotypic and phenotypic variances, coefficient of variation, heritability, and genetic advance on twenty-three genotypes of bell pepper. Significant differences were observed among the genotypes for all the traits under study. The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were high for fruit yield per plant. High heritability along with high genetic advance was recorded for average fruit weight, fruit yield per plant, fruit diameter, number of lobes per fruit, days to first harvest, leaf area and ascorbic acid content, indicating the role of additive gene action for the inheritance of these traits.

Jyothi *et al.* (2011) conducted field experiments on ten chilli genotypes to study genetic variability, heritability and genetic advance as per cent mean for several economic characters. Data were collected on eight characters. Significant differences were observed among genotypes in respect of all the characters studied. Phenotypic Coefficient of Variation (PCV) was slightly higher than Genotypic Coefficient of Variation (GCV) for all the traits, indicating a low environmental influence on expression of these traits.

Luitel (2011) evaluated sweet pepper germplasm for various fruit yield and fruit quality characters and found the presence of appreciable variability in fruit yield and quality traits. Thus these genotypes can be utilized to develop high yielding sweet pepper varieties with better quality traits.

Sood *et al.* (2011) studied nineteen diverse genotypes to assess genetic variation for yield, days to first picking, days to harvest, fruits per plant, fruit length, fruit girth, pericarp thickness, average fruit weight and lobes per fruit. Significant differences were observed for all the traits except days to first picking and lobes per fruit, which revealed the presence of sufficient variability for these traits. The Phenotypic Coefficient of Variation (PCV) exhibited higher values than Genotypic Coefficient of Variation (GCV) for all the traits, indicating close association between phenotype and genotype. High estimates of PCV for fruit yield and fruits per plant indicated the importance of additive genes. High heritability coupled with high to moderate genetic advance was observed for fruit yield per plant, fruits per plant, fruit length, fruit girth, pericarp thickness and average weight, indicating role of additive gene action for its inheritance.

Ahmed *et al.* (2012) studied thirty-four genotypes of bell pepper for nine quantitative characters. The results revealed that PCV was greater than corresponding GCV for all traits. High GCV and heritability accompanied by moderate to high genetic gain was observed for number of fruits and fruit weight. Fruit length and fruit diameter exhibited high heritability coupled with moderate GCV and low genetic gain.

Afroza *et al*. (2013) assessed the genetic variability in ten diverse lines of sweet pepper. Analysis of variance revealed significant differences among the parents and crosses indicating diversity in the germplasm. The magnitudes of phenotypic and genotypic coefficients of variation were moderate to high depicting the ample scope for improvement through selection. The heritability (broad sense) was high for all the traits, except number of locules.

Datta and Chakraborty (2013) conducted an experiment to study the growth, yield and quality characters in fifty-one genotypes of chilli. Significantly highest number of fruits per plant was recorded in genotype CA-29 Ascorbic acid content in red ripe fruit varied from 75.89 to 167.21 mg/ 100g fresh.

Datta and Das (2013) collected fifty-three genotypes of *Capsicum annuum* L. from different parts of India. Variability studies revealed a wide range of variability for all the characters under study. High heritability along with high genetic advance was found for capsaicin content, number of fruits per plant, yield per plant and primary branches per plant. These characters may be considered as reliable selection indices as governed by additive gene action.

Kumari (2013) studied genetic variability in bell pepper and recorded higher genotypic and phenotypic coefficients of variation for number of fruits per plant (30.49 %

and 30.63%), average fruit weight (30.85% and 30.03%) and fruit per plant (32.12% and 32.26%) in bell pepper indicating wide genetic variability for these traits. High heritability coupled with high genetic gain was observed for number of fruits per plant (57.85% and 57.85%), average fruit weight (60.62% and 60.62%) and fruit yield per plant (65.80% and 65.80%), suggesting the role of additive gene action for the inheritance of these traits.

Pandey *et al.* (2013) observed significant variation among all the genotypes for quantitative and qualitative traits in sweet pepper. They observed high heritability along with high GCV and high genetic gain was observed for fruit weight, fruit yield per plant, number of fruits per plant, total chlorophyll and fruit width.

Kumari and Sharma (2014) screened fifteen genotypes of bell pepper for resistance against Phytopthora leaf blight and fruit rot disease. Analysis of variance indicated significant differences among genotypes for the disease under study. Genotypes *viz.*, Feroz and LC-1 were found to be moderately resistant to both disease with lowest apparent infection rate.

Pandit and Adhikary (2014) estimated variability and heritability for important yield and yield contributing traits in fourty one chilli genotypes and recorded very high genetic advance as percent of mean in fruit yield per plant and moderately high genetic advance as percent of mean in days to fifty percent flowering, placenta length, fruit length, number of fruits per plant and number of seeds per plant.

Naik *et al.* (2014) evaluated two F_2 populations of the commercial hybrids. F_2 populations of the commercial hybrids *viz*., Bombay and Atlas were evaluated to study the extent of variability. Considerable variation was observed between and within the populations which was also confirmed by high mean and wider range as evidenced by high PCV and GCV values. The studies concluded that selection strategy for yield improvement should rely on characters *viz.*, fruit weight, fruits per plant, fruit length, fruit surface area, seeds per fruits and pericarp thickness during selection, since these characters exhibited highest direct effect on the yield.

Patel *et al.* (2015) studied genetic variability in fourty diverse genotypes of chilli. The analysis of variance revealed the significant differences among the genotypes for all the character studied which indicated the presence of genetic variability for different traits. The high estimates of GCV and PCV were obtained for number of primary branches per plant, number of secondary branches per plant, number of fruits per plant, average fruit length (cm). High heritability was observed for secondary branches per plant, number of fruits per plant, fruit length, fruit weight, green fruit yield per plant, chlorophyll content, ascorbic acid content and capsaicin content. High heritability coupled with high genetic advance indicated better scope for improvement.

Swamy *et al*. (2015) evaluated varieties and hybrids of capsicum for different quality attributes under 50 per cent shade net house. The hybrid, Angel recorded significantly high ascorbic acid content closely followed by the variety, Arka Gaurav. The capsaicin content was found meagre in all the varieties and hybrids. Whereas, high Total Soluble Solids was recorded in the variety, Arka Gaurav followed by the hybrid, Angel.

Rekha *et al.* (2016) assessed forty three genotypes of chilli (*Capsicum annuum* L.) and recorded high coefficient of variation both at phenotypic and genotypic level for the traits like fruit set per cent, number of fruits per plant, dry fruit yield per plant, number of seeds per fruit and average dry fruit weight.

Murmu *et al*. (2017) studied genetic variability in twenty-four genotypes of chilli and revealed the significant differences among the genotypes for almost all the characters. The results revealed the presence of a good amount of genetic variability for different traits.

Thakur *et al.* (2017) observed high heritability coupled with high genetic gain for average fruit weight, fruit yield per plant and fruit length which indicated the presence of additive gene action and thus, offered more scope for reliable and effective selection.

2.2 CORRELATRION STUDIES:

The correlation between different quantitative characters provides an idea of association that could be effectively exploited to formulate selection strategies for improving yield components. For any effective selection programme, it would be desirable to consider the relative magnitude of association of various characters with yield.

Aliyu et al. (2000) studied correlation in bell pepper and observed a positive and highly significant association among fruit yield, fruit number, fruit diameter, number of seeds per plant and seed yield.

Chatterjee and Kohli (2001) studied correlation in bell pepper and observed significant differences for all the traits under study. Yield was found to be significantly and positively correlated with fruit weight, fruit width, pericarp thickness, number of seeds per fruit and 1000-seed weight.

Feipeng and Huang (2004) conducted an experiment to study correlation for major horticultural traits in sweet pepper and reported that number of fruits per plant and fruit weight were closely related to total yield.

Bindal *et al.* (2005) studied twenty-two genotypes of bell pepper and observed significant and positive correlation between fruit yield and number of marketable fruits per plant, harvesting duration, fruit length and fruit width. The number of days to 50 per cent flowering showed a negative and significant correlation with fruit yield.

Bharadwaj *et al*. (2007) conducted an experiment on twenty seven diverse genotypes of chilli to work out character association between fruit yield and nine other characters. Results showed that fruit yield was positively associated with number of branches per plant and number of fruits per plant. Number of branches per plant was also found positively correlated with fruit width, number of fruits per plant and fruit yield.

Gazala *et al.* (2007) concluded that seed yield was significantly and positively correlated with days taken to first flower appearance, days to first picking and pedicel length in bell pepper. However, seed yield was found significantly and negatively correlated with fruit yield.

Ukkund *et al.* (2007) studied eighty genotypically diverse indigenous and exotic genotypes of chilli for thirteen important horticultural traits. The phenotypic and genotypic association of fruit yield was significantly positive with all the characters except days to first flowering and average fruit weight.

Narciso (2009) in his studies reported strong and negative correlation between fruit length and fruit diameter in sweet pepper .

Sood *et al.* (2009) found higher genotypic correlations than the corresponding phenotypic correlations, revealing inherent association among traits. Character association analysis revealed that fruit yield per plant was strongly associated with number of fruits per plant, hence it could be considered as one of the important selection criteria in the improvement of fruit yield.

Sharma *et al.* (2010) studied twenty-three genotypes of bell pepper and revealed significant positive correlation of the traits *viz.*, fruit length, fruit diameter and number of fruits per plant with fruit yield per plant.

Afroza *et al*. (2013) studied the correlation in bell pepper and observed that fruit yield per plant exhibited significant positive correlation with days to first flowering, days to first fruit set, number of branches per plant, fruit length, fruit diameter, flesh thickness, average fruit weight, number of fruits per plant and average seed weight per fruit both at genotypic and phenotypic levels.

Kumari (2013) studied nineteen genotypes of bell pepper and observed that fruit yield per plant had positive and significant correlation with number of fruits per plant and average fruit weight.

Singh *et al.* (2014) conducted an experiment on twenty-three genotypes of chilli to study the correlation. The number of fruits per plant was significantly and positively correlated with fruit weight per plant and red ripened fruit yield. Green fruit yield per plant and dry yield per plant were positively and significantly correlated with number of fruits per plant and fruit weight.

Patel *et al.* (2015) studied fourty diverse genotypes of chilli and concluded that genotypic correlation coefficients were higher in magnitude than their corresponding phenotypic correlation coefficients for all the traits. Green fruit yield per plant had significant and positive association with number of fruits per plant, average fruit weight, moisture content and chlorophyll content at both genotypic and phenotypic levels which concluded that these traits were major yield attributing traits.

2.3 PATH ANALYSIS:

The path coefficient technique developed by Wright in 1921 helps in estimating direct and indirect contribution of various components in building up the total correlation towards yield. On the basis of these studies the quantum importance of individual characters is marked to facilitate the selection programme for better gains.

Aliyu *et al*. (2000) conducted an experiment to study path analysis in sweet pepper and showed that characters like total dry weight, leaf area index, fruit diameter and number of seeds per plant had a positive and large direct effect on yield.

Mishra *et al*. (2002) conducted an experiment to study path coefficient analysis studies in sweet pepper and observed that highest positive direct effect on fruit yield per plant was exhibited by number of fruits per plant both at phenotypic and genetic levels. Days to 50 per cent flowering, leaf area, number of pickings, and 1000 seed weight registered high negative direct effect on fruit yield per plant. Ascorbic acid content also revealed negative direct effect on fruit yield per plant.

Bindal *et al.* (2005) studied twenty-two genotypes of capsicum and the path coefficient analysis revealed that the number of marketable fruits per plant had the greatest direct effect on fruit yield per plant.

Ukkund *et al.* (2007) studied path analysis in chilli. The genotypic and phenotypic path coefficient revealed that total green yield had high direct positive effect from early and late fruit yield. So selection based on early and late fruit yield would be rewarding.

Madosa *et al.* (2008) evaluated 24 landraces of sweet pepper and observed that fruit diameter had a significant and major contribution on fruit weight in comparison to fruit length, diameter and pulp thickness. The results concluded that fruit weight is influenced by fruit diameter and pulp thickness and yield per plant depends on number of fruits per plant and fruit diameter.

Sood *et al.* (2009) concluded that maximum direct effect on fruit yield per plant was exhibited by number of fruits per plant followed by harvest duration, average fruit weight, and pericarp thickness whereas marketable fruits per plant and days to 50 per cent flowering had negative direct effects in bell pepper.

Sharma *et al.* (2010) studied twenty-three diverse genotypes of bell pepper and highest positive direct effect was exhibited by number of fruits per plant followed by average fruit weight, number of branches per plant, pedicel length and harvest duration at genotypic level.

Kumari (2013) observed maximum positive direct effect towards yield per plant by number of fruits per plant and average fruit weight in bell pepper.

Sasu *et al.* (2013) conducted path coefficient analysis studies in bell pepper and observed that fruit weight per plant was mainly influenced by the number of fruits and fruit weight. Number of fruits per plant showed a negative influence on production per plant by fruit diameter, and fruit weight. Fruit weight exhibited an indirect and positive effect on production per plant, through fruit length and diameter.

Singh *et al.* (2014) studied the path coefficient analysis in chilli and indicated that number of fruits per plant, fruit width and average fruit weight were major yield components which could be considered as selection indices for improvement. The results suggested that due emphasis should be given to the genotypes which have maximum number of fruits per plant, fruit length, fruit girth and fruit weight because of their high positive direct effect on dry fruit yield.

Patel *et al.* (2015) studied fourty diverse genotypes of chilli for different traits. Number of secondary branches per plant, number of fruits per plant and average fruit weight had high and positive direct effects on green fruit yield per plant. For maximizing the green fruit yield, weightage should be given to the genotypes having early flowering, more number of fruits per plant, high average fruit weight, more number of secondary branches per plant and high moisture content.

2.3 GENETIC DIVERGENCE

In genetic studies the study of genetic divergence is used to differentiate well defined population and to choose suitable parents for obtaining heterotic hybrids and cross combinations that are likely to provide better recombinants with desired agronomic values in later generations. The theoretical background of Mahalanobis D^2 statistics or generalized distance among group constellation has been critically discussed in a series of communications (Rao, 1952 and Anderson, 1958). The D^2 statistics was found to be an effective tool among the various techniques available for genetics differentiation among population (Rao, 1960; Cassie, 1963 and Sabal, 1965).

Sudre *et al.* (2005) studied genetic divergence in fifty-six accessions of chilli and sweet pepper for the traits like fruit length, fruit diameter, number of seeds per fruit, average fruit weight, plant height, plant canopy width, thousand seed weight, days to flowering, days to fruiting, fruit number per plant and fruit weight per plant and reported significant difference for all descriptors evaluated.

Sudre *et al.* (2006) studied genetic divergence in *Capsicum species* accessions and observed that qualitative traits analysed by Tocher's method were competent to differentiate among the species *C. annuum* var. *annuum*, *C. annuum* var. *glabriusculum*, *C. chinense*, and *C. pubescens.*

Bozokalfa *et al.* (2009) characterized pepper genotypes for sixty-seven agromorphological traits from seedling emergence to crop maturity. The morphological data were analyzed by cluster and principal component analysis. The findings showed that eleven components accounted for 77.50% in the first and ten component for 71.52% of variability in the second growing season, respectively. Three groups in first and seven groups in the second year clustered as a result of cluster analysis based on morphoagronomic properties were recorded. The greater part of variation was accounted for characters *viz*., fruit diameter, fruit weight, fruit wall thickness, fruit productivity, soluble solids and dry matter content.

Buttow *et al.* (2010) carried a study to evaluate and characterize genetic diversity among *C. annuum* accessions which belongs to Capsicum Embrapa Clima Temperado genebank and characterized twenty accessions through thirty-six multicategorical morphologic descriptors. Genetic diversity was assessed using Tocher's grouping method and UPGMA. Three groups of accessions were formed by Tocher method. Moderate genetic variability among twenty accessions of *C. annuum* was recorded.

Farhad *et al.* (2010) grouped fourty-five capsicum genotypes into six clusters by using cluster analysis technique to study genetic diversity in capsicum and observed that the characters like plant height and number of secondary branches per plant contributed maximum towards divergence among capsicum genotypes. Cluster I and cluster III had maximum (11) and cluster II had the minimum number (3) genotypes. The highest inter cluster distance was observed between cluster II and IV and lowest between I and IV.

Monteiro *et al.* (2010) studied genetic divergence in twenty-three accessions of the *Capsicum*, for seven quantitative and nineteen qualitative multicategorical traits by using multivariate technique and reported significant differences among the accessions of peppers for all quantitative characters. Eight clusters for both quantitative descriptors and qualitative multicategoric descriptors from Tocher's optimization method were identified. The UPGMA method detected three clusters for quantitative descriptors and four clusters within qualitative multicategoric descriptors.

Zadeh *et al.* (2010) studied genetic diversity in pepper on important traits like fruit length, fruit width, fruit dry weight and thousand seed weight. The observations recorded considerable genetic variation in the evaluated genotypes and indicated that morphological traits can be significant tools for classification and separation of pepper genotypes.

Misra *et al.* (2011) studied genetic divergence among thirty-eight accessions of *Capsicum annuum* for fifteen morphological, growth and chemotypic characters including days to first flowering, fruit set, plant height, primary, secondary and tertiary branches, leaf surface area, fruit length and diameter, fruit surface area, fresh and dry fruit weight, capsaicin and capsanthin content and revealed that genotypes were grouped into seven clusters. The studies also indicated wide range of D^2 values contributing substantial diversity among accessions.

Maga *et al.* (2012) assessed the genetic diversity among yellow pepper genotypes using agro morphological traits. The cluster analysis grouped the genotypes into three clusters. Cluster I consisted of six genotypes that were characterized with short and early flowering habit. Cluster II comprised three genotypes, which were characterized by moderate to low performance in almost all the traits examined. Cluster III comprised eight genotypes with the lowest values for plant height, number of primary branches per plant, number of nodes per plant and pedicel length except fruit width. These genotypes however had fruits of moderate girth and weight, and also demonstrated high fruit setting capacity. It indicated that, there was considerable variability in the population which allowed the genotypes to be separated into distinct groups. Clustering of genotypes into groups was based on genetic similarity information and genotypes that clustered in similar groups possess common genetic relationships as opposed to those that clustered in different groups.

Occhiuto *et al.* (2014) assessed the genetic diversity among thirty three accessions of capsicum using thirty five qualitative and nineteen quantitative traits. The study was mainly directed towards the characterization of *Capsicum* germplasm suitable for paprika production. On the basis of cluster analysis all the accessions were grouped into three groups *viz.*, Group I; included five entries, with triangular fruits of greater pulp thickness, wider and smaller length, Group II; included twenty five entries with elongated fruits and Group III; included three accessions of spicy peppers, corresponding to *Capsicum baccatum*, characterized by the largest number of fruits per plant, less fruit weight and pungent fruits. As a result of pepper germplasm evaluation, fourteen promising accessions were selected, which could be incorporated in future breeding program for quality fruit production in paprika.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled **"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)"** was carried out at the Experimental Farm of Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan HP during Kharif, 2017. The details of materials used and methods adopted to carry out the present studies are given in this chapter.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experimental site of the Department of Vegetable Science is located at Nauni, about 13 km from Solan, at an altitude of 1276 m above mean sea level lying between latitude 30°52′ 30″ North and longitude 77° 11′ 30″ East. It falls in sub-humid, sub temperate and mid- hill zone of Himachal Pradesh.

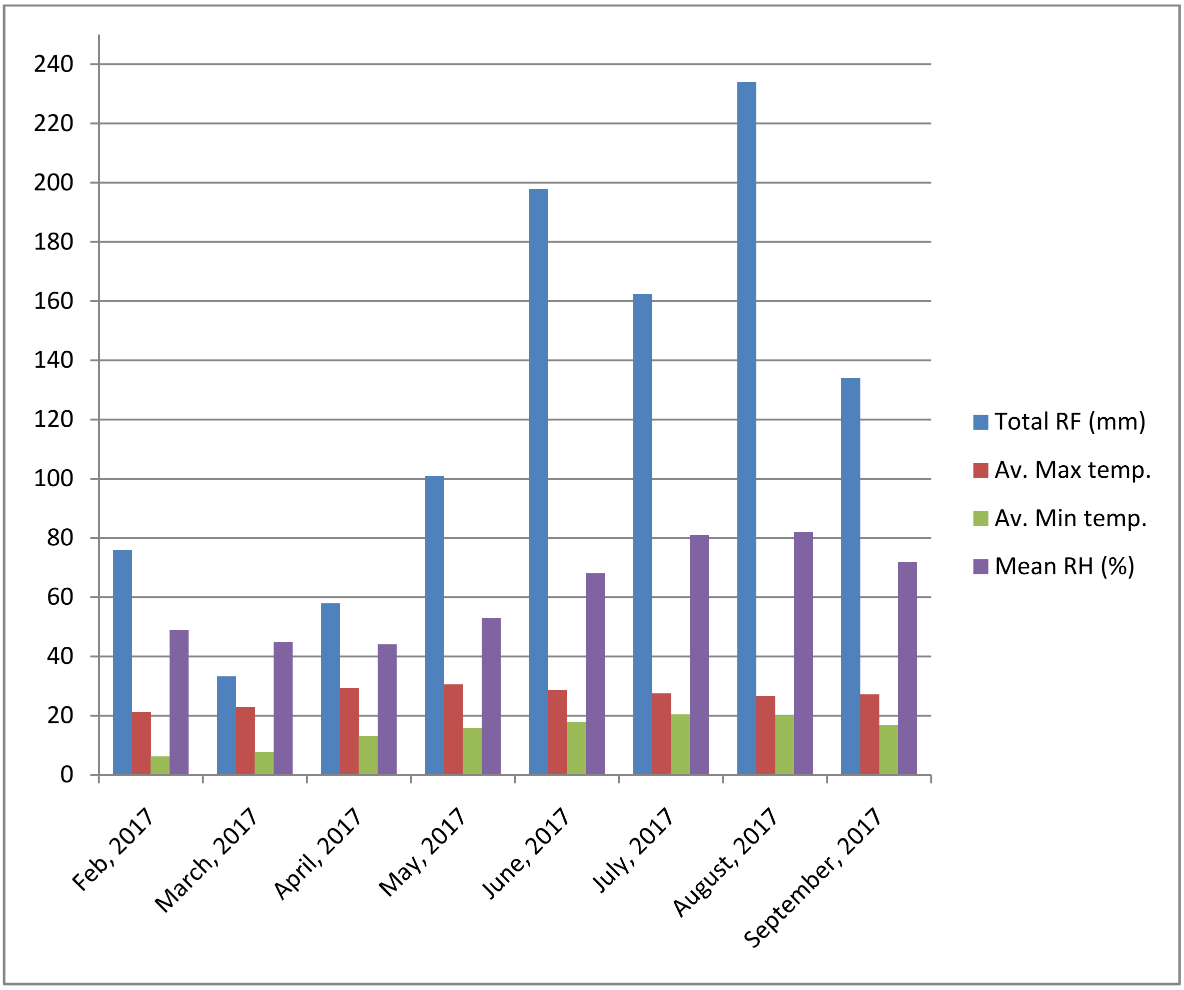
3.1.2 Climate and weather conditions

The climate of Experimental Site is generally characterized as sub-temperate with mild summers and cool winters. Weather conditions which prevailed during growing period were recorded and have been presented in Appendix-I. Generally, May and June are the hottest months and December and January are the coldest ones. Mean temperature during the cropping season varied from 13.7 to 24^{0}C while the relative humidity varied from 44% to 82%. The total rainfall during growing season varied from 33.2 mm to 233.8 mm most of which was received in month of August. Graphical representation of monthly data pertaining to the temperature, rainfall and relative humidity during the growing season is given in Figure 1.

3.1.3 Soil.

The soil structure of experimental site is gravelly loam to gravelly clay loam with pH ranging from 6.85 - 7.04.

Fig 1 Graphical representation of monthly data pertaining to the temperature, relative humidity and rainfall during the growing season, 2017



Source: Meteorological Observatory, Department of Environmental Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173 230

3.2 EXPERIMENTAL MATERIAL

The experimental material for the present investigation comprised of twenty five diverse genotypes of bell pepper (*Capsicum annuum* L.) including a check variety Solan Bharpur. The genotypes along with their sources of collection have been presented in Table 3.1.

3.3 EXPERIMENTAL LAYOUT

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Sixteen seedlings of each entry were transplanted on April 21, 2017 at a spacing of 60 × 45 cm in a plot size of 2.40 m × 1.80 m in each replication. The genotypes along with their sources have been presented in table 3.1.

Table 3.1: Bell pepper genotypes along with sources of collection used in the present study

S.NO.	GENOTYPE	PLACE OF COLLECTION
1.	Palam Bell	IARI Regional Station, Katrain (Kullu Valley)
2.	Yolo Wonder	IARI Regional Station, Katrain (Kullu Valley)
3.	Arka Basant	IARI Regional Station, Katrain (Kullu Valley)
4.	Nishat	IARI Regional Station, Katrain (Kullu Valley)
5.	Harit Red Fruit	IARI Regional Station, Katrain (Kullu Valley)
6.	HC-201 PL-3	IARI Regional Station, Katrain (Kullu Valley)
7.	CW-308	IARI Regional Station, Katrain (Kullu Valley)
8.	RY.PL-1	IARI Regional Station, Katrain (Kullu Valley)
9.	PT.12.3	IARI Regional Station, Katrain (Kullu Valley)
10.	KC-10	IARI Regional Station, Katrain (Kullu Valley)
11.	KC-11	IARI Regional Station, Katrain (Kullu Valley)
12..	KC-12	IARI Regional Station, Katrain (Kullu Valley)
13..	IIVR CW	IIVR, Varanasi, UP
14.	Nirmal Karol	Village Karol, P.O – Kandaghat
15.	Dyarag Selection	Village Dyarag, P.O – Juanji, Solan
16.	Deothi Selection	Village Deothi, P.O – Solan
17.	Kadar Selection	Village Kadar, P.O – Kandaghat
18.	Ghalai Selection	Village Ghalai, P.O – Kandaghat
19.	Tikker Selection	Village Tikker, P.O – Solan
20.	YW.PL-4	Department of Vegetable Science, UHF, Nauni
21.	UHFBP-3	Department of Vegetable Science, UHF, Nauni
22.	UHFBP-5	Department of Vegetable Science, UHF, Nauni
23.	UHFBP-6	Department of Vegetable Science, UHF, Nauni
24.	CW.PL-2	Department of Vegetable Science, UHF, Nauni
25.	Solan Bharpur*	Department of Vegetable Science, UHF, Nauni

Solan Bharpur* = check variety

The standard cultural practices for raising healthy crop of bell pepper were followed as per the Package of Practices for Vegetable Crops, published by Directorate of Extension Education, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP (Anonymous, 2014) (Plate-1).

3.4 OBSERVATIONS RECORDED

Data were recorded on five randomly taken plants from each plot/treatment and the average was worked out to record the mean value in each replication for all the characters under study. Observations were recorded on following characters:

3.4.1 Days to first picking

Days taken from transplanting to the first harvest were counted for each genotype.

3.4.2 Number of primary branches per plant

Number of primary branches emerging directly from the main stem was counted at the time of last picking and mean was worked out.

3.4.3 Plant height (cm)

Plant height of five randomly selected plants was measured from the ground level to the highest tip of the plant at the end of the crop season and average was worked out and expressed in centimeters.

3.4.4 Fruit shape (cm)

Fruit shape of each genotype was observed and recorded on point score as described by Shrivastava *et al*. (2001) in the Minimal Descriptors of Agri-Horticultural crops: part II: Vegetable Crops. National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi, (India).

1. Elongate
2. Almost round
3. Triangular
4. Companulate
5. Blocky
6. Others (Specify)

Plate 1: View of experimental field showing different genotypes of bell pepper

3.4.5 Fruit colour

The colour of the fruits at fresh marketable stage was compared with the Royal Horticultural Society (RHS) colour chart and fruits were classified into different colour groups accordingly.

3.4.6 Number of lobes per fruit

Number of lobes per fruit of five randomly selected fruits was counted at the blossom end of the fruits and average was worked out. Pointed fruits/ conical fruits were considered as single lobed.

3.4.7 Fruit length (cm)

Polar distance of five random fruits at second harvesting was measured by using digital Vernier Calliper from the stem end to the blossom end of the fruit and average was worked out.

3.4.8 Fruit breadth (cm)

The fruits used for recording the length were also used to measure the fruit breadth. The measurements were taken from peduncle end, middle and near apex with a digital Vernier Calliper. The average of these three values was taken as fruit breadth.

3.4.9 Fruit weight (g)

Weight of five randomly taken fruits was summed and averaged to workout fruit weight.

3.4.10 Pericarp thickness (mm)

Pericarp thickness of five randomly harvested fruits of second harvest was measured after cutting the fruits transversely. Measurements were done with digital Vernier Calliper in millimeters and mean value was worked out.

3.4.11 Number of fruits per plant

Total number of marketable fruits from all the harvest on each of five randomly taken plants were summed and averaged to workout number of fruits per plant.

3.4.12 Fruit yield per plant (g)

The total fruit yield obtained from five tagged plants in each genotype was divided by five to get an average fruit yield per plant.

3.4.13 Number of seeds per fruit

Five healthy fruits in each treatment were allowed to ripe on the plant. Their seeds were extracted and dried in shade to workout seed number per fruit in each genotype.

3.4.14 Thousand seed weight (g)

Weight of thousand seeds was measured for each genotype by using electronic balance.

3.4.15 Total soluble solids (°B)

The fruits which were used for recording length and breadth were also used to estimate Total Soluble Solids (TSS) with the help of hand refractrometer. The fruits were cut at middle and the extract was dropped on the measuring surface of hand refractrometer and TSS was recorded as degree Brix value.

3.4.16 Ascorbic acid content (mg/100g)

Ascorbic acid content of fruits was determined as per 2,6-dichlorophenol-indophenol visual titration method as described by Ranganna (1986). The samples extracted in 3% metaphosphoric acid solution were titrated with 2,6-dichlorophenol-indophe dye to a pink end point persisting for 15 seconds. The ascorbic acid content was calculated by means of the following formula:

$$\text{mg of ascorbic acid per 100 g or 100 ml} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquot of extract taken for estimation} \times \text{Weight of sample taken for estimation}}$$

3.4.17 Incidence/Severity of diseases:

***Phytophthora* fruit rot incidence (%)**

The fruit rot incidence was recorded at regular intervals by adopting following method:

$$\text{Incidence (\%)} = \frac{\text{Number of diseased fruits}}{\text{Total number of fruits}} \times 100$$

***Phytophthora* leaf blight severity (%)**

Leaf blight severity was recorded by using the following scale adopted by James (1974).

Disease Ratings	Percent Disease on leaves (%)	Description of Symptoms
1.	0.0	Plants completely healthy with no blight symptoms
2.	25.0	Plants show slight infection roughly one in every four leaves infected ; disease mainly on lower leaves
3.	50.0	Nearly 50% leaves including upper ones infected, the plants appear to be blighted
4.	75.0	Nearly 75% of the foliage infected, the plants appear to be Blighted
5.	100.0	Almost all the leaves are infected, plants completely defoliated, leaving behind the main stem.

The percent leaf blight severity was calculated according to McKinney (1923).

$$\text{Leaf blight severity (\%)} = \frac{\text{Sum of all disease ratings}}{\text{Total number of ratings x maximum disease grade}} \times 100$$

3.5 STATISTICAL ANALYSIS

The data recorded was analysed by using MS-Excel, OPSTAT and SPAR 2.0. The mean values of each genotype in each replication for all the traits were subjected to statistical analysis as per Randomized Complete Block Design.

3.5.1 Analysis of Variance

For working out the analysis of variance, the data was subjected to analysis as per design suggested by Panse and Sukhatme (2000).

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

Where,

Yij = Phenotypic observation of i^{th} genotype grown in j^{th} replication

μ = General population mean

g_i = Effect of i^{th} genotype

r_j = Effect of j^{th} replication

e_{ij} = Error component

Source of variation	**Degree of freedom**	**Sum of Square**	**Mean Sum of Square**	**Expected Mean Sum of Squares**
Replication (r)	r-1	Sr	Sr/(r-1)=Mr	$\sigma^2 e+g\sigma^2 r$
Genotypes (g)	g-1	Sg	Sg/(g-1)=Mg	$\sigma^2 e+r\sigma^2 g$
Error (e)	(r-1) (g-1)	Se	Se/(r-1) (g-1)=Me	$\sigma^2 e$

Where,

r = Number of replications

g = Number of genotypes

Sr = Sum of squares due to replications

Sg = Sum of squares due to genotypes

Se = Sum of squares due to error

Mr = Mean sum of squares due to replications

Mg = Mean sum of squares due to genotypes

Me = Mean sum of squares due to error

$\sigma^2 r$ = Variance due to replications

$\sigma^2 g$ = Variance due to genotypes

$\sigma^2 e$ = Error variance

The replication and entries mean sum of square were tested against error mean squares by 'F' test for (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom at P = 0.05. The calculated F-value will be compared with tabulated F-value. When F-test will be found significant, critical difference will be calculated to find out the superiority of one genotype over the others.

The standard error and critical differences will be calculated as follows:

SE (m) ± = $\sqrt{Me/r}$

SE (d) ± = $\sqrt{2\,Me/r}$

CD $_{(0.05)}$ = S.E. (d) x t $_{(0.05)}$ (r-1) (g-1) df

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference

CD $_{(0.05)}$ = Critical difference at 5 per cent level of significance

3.5.2 Mean performance and genetic variability

The Genotypic and Phenotypic Coefficients of variability were calculated as per formulae given by Burton and De-Vane (1953).

A) Genotypic Coefficient of Variability (GCV)

$$\text{GCV (\%)} = \frac{\sqrt{\text{Genotypic variance (Vg)}}}{\text{General mean of population } (\bar{x})} \times 100$$

B) Phenotypic Coefficient of Variability (PCV)

$$\text{PCV (\%)} = \frac{\sqrt{\text{Phenotypic variance (Vp)}}}{\text{General mean of population } (\bar{x})} \times 100$$

3.5.3 Heritability (in broad sense)

Heritability in broad sense was calculated by the formula as suggested by Burton and De vane (1953) and Allard (1960).

$$\text{Heritability } (h^2\%) = \frac{Vg}{Vp} \times 100$$

Where,

Vg = Genotypic variance [Vg = (Mg - Me) / r]

Vp = Phenotypic variance [Vg + Ve]

3.5.4 Genetic advance (GA)

The expected genetic advance (GA) resulting from selection of five per cent superior individuals was worked out as suggested by Allard (1960).

$$GA = H \times \sigma p \times K$$

Where,

H = Heritability in broad sense

σp = Phenotypic standard deviation

K = 2.06 (Selection differential at 5 per cent selection index)

3.5.4.1 Genetic gain

Genetic gain expressed as per cent of population mean, was calculated by the method given by Johnson *et al.* (1955).

$$\text{Genetic gain} = \frac{\text{Genetic advance}}{\text{General popuation mean}} \quad x \quad 100$$

For categorizing the magnitude of different parameters, Sharma (1994) suggested the following limits:

PCV and GCV

> 30% - High
15-30% - Moderate
<15% - Low

Heritability (H)

>80% - High
50-80% - Moderate
<50% - Low

Genetic gain (GG)

>50% - High
25-50% - Moderate
<25% - Low

3.5.5 Correlations

The genotypic and phenotypic correlations were calculated as per Al-Jibouri *et al.* (1958) by using analysis of variance and covariance matrix in which total variability split into replications, genotypes and errors. All the components of variance were estimated from the analysis of covariance as given below:

3.5.5.1 Analysis of Variance and Covariance

Source of variance	**Degree of freedom**	**Mean sum of squares**		**Mean sum of products**	**Variance**
		X	**Y**		
Replications (r)	r-1				
Genotypes (g)	g-1	Mg X	Mg Y	Mg XY = MP_1	MP_1/MP_2
Error (e)	(r-1) (g-1)	Me X	Me Y	Me XY = MP_2	

Genotypic, phenotypic and environmental covariances between X and Y characters were worked out as under:

Ve XY	=	MP_2
Vg XY	=	$(MP_1 - MP_2) / r$
Vp XY	=	Vg XY + Ve XY

Where,

Ve XY	=	Environmental covariance between X and Y
Vg XY	=	Genetic covariance between X and Y
Vp XY	=	Phenotypic covariance between X and Y

3.5.5.2 Coefficients of correlation

a) Genotypic correlation coefficient between X and Y

$$r_g = \frac{Vg\,XY}{\sqrt{Vg\,X \times Vg\,Y}}$$

Where,

Vg XY	=	Genotypic covariance between X and Y
Vg X	=	Genotypic variance of X
Vg Y	=	Genotypic variance of Y

b) Phenotypic correlation coefficient between X and Y

$$r_p = \frac{Vp\,XY}{\sqrt{Vp\,X \times Vp\,Y}}$$

Where,

Vp XY	=	Phenotypic covariance between X and Y
Vp X	=	Phenotypic variance of X
Vp Y	=	Phenotypic variance of Y
Genotypic variance (Vg)	=	(Mg - Me) / r
Phenotypic variance (Vp)	=	(Vg + Ve)

The calculated correlation coefficients (r) values were compared with ‘r’ tabulated values as given by Fisher and Yates (1963) at (n-2) degrees of freedom to test their significance, where ‘n’ denotes number of genotypes. If calculated ‘r’ value at 5 per cent level of significance was greater than tabulated value of ‘r’, the correlation was said to be significant.

3.5.6 Path coefficient analysis

Path coefficient was obtained according to the procedure as suggested by Wright (1921) and as elaborated by Dewey and Lu (1959).

The following equation wa used for estimating direct and indirect effects

$$r_{iy} = r_{in}P_{iy} + \ldots\ldots\ldots + P_{iy} \ldots\ldots\ldots + r_{in}P_{ny}$$

Where

r_{iy} = denote coefficient of correlation between causal factor X_i and dependent character Y.

r_{in} = denote coefficient of correlation among all possible combinations of causal factors.

P_{iy} = denote direct effect of character X_i upon the character Y.

Residual factor was obtained as follows

$$P_zY_n = \sqrt{1-R^2}$$

Where $R^2 = \sum_{t=1}^{n} P^2_{iy} + 2\sum_{i<j}^{n} P_{iy}P_{jy}r_{ij}$

Which is the square of the multiple correlation coefficient (R) and is known as coefficient of determination.

3.5.7 Genetic divergence

The genetic divergence was estimated by Mahalanobis ‘D^2’ statistics (generalized distance as suggested by (Rao, 1952) and canonical variate analysis. The calculation of D^2 values involved following steps (Murty and Arunachalam, 1967).

i. A set of uncorrelated linear combinations (Y's) was obtained by pivotal condensation of the common dispersion matrix (Rao, 1952) of a set of correlated variable (X's) and this matrix was arranged with the help of error mean sum of square and sum of products.

ii. Using the relationship between Y's and X's the mean value of different genotypes for different characters (X_1 to X_{13}) were transformed into the mean values of asset of uncorrelated linear combinations (Y_1- Y_{13}).

iii. The D^2 values between i^{th} and j^{th} genotypes for P^{th} characters was calculated as under:

$$D^2_{ij}= \sum_{t=1}^{P}(Yit - Yjt)^2$$

Where

Yit is uncorrelated mean value of i^{th} genotype for't' characters

Yjt is uncorrelated mean value of j^{th} genotype for't' characters

D^2ij is D^2 between i^{th} and j^{th} accessions.

In all combinations each character was ranked based on their contribution towards divergence between two entries (di= Yit- Yjt). Rank 1 is given to the highest mean difference and rank P to the lowest difference, where, P is the total number of characters.

i. The 'P' component and D^2 for each combination were ranked in descending order of magnitude.

ii. The ranks were added up for each component D^2 over all combination and the rank totals were obtained.

3.5.7.1 Group constellation

Varieties were grouped into a number of clusters. D^2 being treated as the square of generalized distance, according to the method described by Tocher (Rao, 1952). The criterion used in clustering by this method is that any two genotypes belonging to the same cluster should, at least on an average, show a smaller D^2 value than those belonging to two different clusters. In other words, if variety V_1 and V_2 are close together and variety V_3 is distinct from both shown by this generalized distance, V_1 and V_2 from one cluster.

The average D^2 values of all possible genotypes combinations in one cluster with those in the other were computed and its square root was used to represent the 'statistical distance' between two clusters.

3.5.7.2 Intra-and cluster genetic distances

For the measure of intra cluster D^2 values, the following formula was used

Intra-and inter cluster $D^2 = \frac{\sum Di^2}{N}$

$$N = n (n-1) /2$$

Where,

$\sum D_i^2$ is the sum of D^2 values between all possible combinations (N) within and between clusters, respectively.

n = number of populations included in a cluster

Intra-and inter cluster genetic distances (d) where computed square root of average intra-and inter cluster D^2 values *i.e.*, $d = \sqrt{D^2}$

Chapter-4

RESULTS AND DISCUSSION

The present investigation entitled, **"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)"** was carried out with twenty five diverse genotypes of capsicum collected from different sources, for yield and yield contributing traits, including one standard check variety (Solan Bharpur) at Experimental Farm, Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during Kharif season of 2017. It was done with the objectives to ascertain mean performance of different genotypes over check and to generate information on the extent of genetic diversity, association among different traits and direct and indirect effects of component traits on fruit yield per plant. The experimental results obtained are presented under the following subheads:

4.1 Variability Studies

4.1.1 Mean performance of the genotypes

4.1.2 Parameters of variability

4.2 Correlation Studies

4.2.1 Phenotypic correlations

4.2.2 Genotypic correlations

4.3 Path Coefficient Analysis

4.3.1 Direct and indirect effects

4.4 Genetic Divergence Studies

4.1 VARIABILITY STUDIES

4.1.1 Mean performance of genotypes

The analysis of variance indicated highly significant differences among the genotypes for all the traits studied, which revealed the existence of good deal of variability in the germplasm. The results on the mean performance of all the genotypes for various traits under study has been described as below:

4.1.1.1 Days to first picking

Earliness is one of the major objectives in breeding early cultivars and for early supply of the produce without much competition and consequently making the crop more profitable. The data presented in Table 4.1 on the mean performance of different genotypes for days to first picking depicted that genotypes ranged from 62.00 to 78.67 for days to first picking with the grand mean of 71.33 days. KC-12 was earliest and took minimum days to first picking (62 days) in comparison to the check variety, Solan Bharpur (68.33 days). Whereas maximum days to first picking were recorded in variety Tikker Selection (78.67 days). Early genotypes can be incorporated in breeding programmes to develop early cultivars in Bell pepper. Wide variation for this character was also reported by Kurubetta and Patil (2009), Sharma *et al*. (2010), Sood *et al*. (2011), Sood and Kumar (2011), Halim and Islam (2013), Kanwar *et al.* (2014) and Sharma *et al*. (2018).

4.1.1.2 Number of primary branches per plant

Number of primary branches per plant is an important yield contributing trait, having a direct effect on yield. The plant having more number of branches results in increased productivity. Number of primary branches per plant ranged between 2.27 to 3.80 (Table 4.1). Comparison of data recorded on number of primary branches per plant showed that the genotype IIVR CW (3.80) had maximum number of primary branches, which was found statistically at par with three genotypes YW.PL-4 (3.47), KC-11 (3.33) and CW.PL-2 (3.27) in comparison to check variety, Solan Bharpur (2.60). Whereas minimum number of primary branches was observed in Kadar Selection (2.27) which was found statistically at par with ten genotypes *viz*., Arka Basant (2.40), Deothi Selection (2.53), UHFBP-6 (2.53), Harit Red Fruit (2.60), RY.PL-1 (2.60), Nishat (2.67), HC-201-PL-3 (2.73), UHFBP-3 (2.73), Yolo Wonder (2.80) and Ghalai Selection (2.80). Similar variations for number of branches per plant had also been reported by Sharma *et al*. (2010), Misra *et al.* (2011), Datta and Chakraborty (2013), Datta and Das (2013).

4.1.1.3 Plant height (cm)

Plant height is considered as an important yield contributing trait, because it leads to more number of branches and prolonged harvest duration, ultimately resulting in increased productivity. Plant height also determines the harvest duration of the crop. In the midhills of Himachal Pradesh, tall varieties/hybrids are preferred over dwarf. All the genotypes showed significant variations for plant height. It ranged from 58.33-107.20 cm (Table 4.1). General mean for the character was 74.22 cm. Eight genotypes recorded higher plant height than population mean. The comparison of the genotypes revealed maximum plant height in recorded in Nishat (107.20 cm) which was significantly higher than the check variety, *viz.*, Solan Bharpur (61.97 cm), whereas minimum plant height was observed in YW.PL-4 (58.33 cm). The results are in line with the earlier findings of Ben-Chaim and Paran (2000), Bozokalfa *et al.* (2009), Misra *et al.* (2011), Datta and Chakraborty (2013), Datta and Das (2013), Vikram *et al.* (2014) and Murmu *et al*. (2017).

Table 4.1 Mean performance of bell pepper genotypes for days to first picking, number of primary branches per plant and plant height (cm)

Genotype	Days to first picking	Number of primary branches per plant	Plant height (cm)
Palam Bell	73.33	2.87	93.73
Yolo Wonder	70.67	2.80	68.20
Arka Basant	70.00	2.40	76.73
Nishat	74.00	2.67	107.20
Harit Red Fruit	71.00	2.60	67.67
HC-201-PL-3	66.00	2.73	72.40
CW-308	69.00	3.07	70.53
RY.PL-1	75.00	2.60	68.07
PT.12.3	72.67	2.87	62.80
KC-10	71.33	3.20	70.80
KC-11	69.33	3.33	70.80
KC-12	62.00	3.13	72.07
IIVR CW	71.33	3.80	85.00
Nirmal Karol	73.33	3.00	67.93
Dyarag Selection	72.67	2.87	86.80
Deothi Selection	70.00	2.53	72.47
Kadar Selection	78.00	2.27	81.10
Ghalai Selection	70.67	2.80	81.73
Tikker Selection	78.67	3.13	73.87
YW.PL-4	71.67	3.47	58.33
UHFBP-3	70.00	2.73	75.00
UHFBP-5	71.33	3.67	72.73
UHFBP-6	70.67	2.53	69.27
CW.PL-2	72.33	3.27	68.33
Solan Bharpur	68.33	2.60	61.97
Mean	71.33	2.90	74.22
SE (±m)	0.94	0.19	0.56
CD (0.05)	2.67	0.53	1.59

4.1.1.4 Fruit Shape

Fruit shape is an important character which determines the acceptability in the market. The standard shape for bell peppers is blocky, which is mostly preferred by the consumers. The shape of fruit presented in Table 4.2 revealed that fruit shape was blocky in all genotypes except Palam Bell which was cheese shaped. The results were in conformity with those reported by Pradheep and Veeraragavathatham (2006) and Datta and Das (2013).

Table 4.2 Fruit shape and fruit colour observed in different genotypes of bell pepper (*Capsicum annuum* L.)

Genotype	Fruit shape	Fruit colour
Palam Bell	Cheese	Yellow Green Group 145 A
Yolo Wonder	Blocky	Green Group 137 A
Arka Basant	Blocky	Yellow Group D
Nishat	Blocky	Yellow Green Group 146 A
Harit Red Fruit	Blocky	Green Group 137 A
HC-201-PL-3	Blocky	Yellow Green Group 147 A
CW-308	Blocky	Green Group 137 B
RY.PL-1	Blocky	Yellow Green Group 144 A
PT.12.3	Blocky	Yellow Green Group 147 A
KC-10	Blocky	Yellow Green Group 146 A
KC-11	Blocky	Yellow Green Group 146 A
KC-12	Blocky	Green Group 137 A
IIVR CW	Blocky	Green Group 137 C
Nirmal Karol	Blocky	Green Group 137 C
Dyarag Selection	Blocky	Yellow Green Group 146 A
Deothi Selection	Blocky	Yellow Green Group 146 B
Kadar Selection	Blocky	Green Group 137 A
Ghalai Selection	Blocky	Yellow Green Group 146 A
Tikker Selection	Blocky	Green Group 137 A
YW.PL-4	Blocky	Green Group 137 A
UHFBP-3	Blocky	Yellow Green Group 146 B
UHFBP-5	Blocky	Yellow Green Group 146 B
UHFBP-6	Blocky	Yellow Green Group 146 B
CW.PL-2	Blocky	Green Group 137 B
Solan Bharpur	Blocky	Green Group 137 B

4.1.1.5 Fruit colour

The colour of the fruit determines the marketable acceptability of bell pepper. Generally uniform, non blotchy fruits are desirable in the market. It is evident from the table 4.2 that three colour intensities *viz*., yellow green group, green group and yellow group were observed. Out of twenty-five genotypes, thirteen had yellow green group, eleven had green group and only one had yellow group. The green colour of the fruit is principally due to the presence of chlorophyll and to the carotenoids, typical of the chloroplast, such as oxygenated carotenoids or xanthophylls, violaxanthin, neoxanthin, and lutein, as well as β-carotene (Minguez-Mosquera and Hornero-Mendez, 1993). These results were in conformity with those reported by Pradheep and Veeraragavathatham (2006), Nkansah *et al*. (2011), Choudhary *et al.* (2011) and Datta and Das (2013).

4.1.1.6 Number of lobes per fruit

Number of lobes per fruit affects the shape of fruit in bell pepper. Generally a medium sized, blocky and four lobed fruit is acceptable in the market. Maximum number of lobes per fruit was recorded in IIVR CW (3.80) which was statistically at par with Yolo Wonder (3.53), YW.PL-4 (3.60) and CW.PL-2 (3.60) whereas, the number of lobes recorded for check variety was 3.27. Minimum number of lobes per fruit was noticed in UHFBP-3 (2.53) which was statistically at par with seven genotypes. Variability in number of lobes per fruit has also been obtained by Chatterjee and Kohli (2004), Sood *et al*. (2009), Sharma *et al*. (2010) and Sood *et al*. (2011).

4.1.1.7 Fruit length (cm)

The perusal of data presented in table 4.3 revealed significant variations for fruit length. Eleven genotypes including check cultivar produced longer fruits than population mean (7.33 cm). Maximum fruit length was recorded in the genotype Arka Basant (9.12 cm) which was in statistically proximity with Harit Red Fruit (8.99 cm). It was statistically and significantly higher than the check variety Solan Bharpur (7.34 cm) and minimum fruit length was observed in Palam Bell (3.93 cm). Ten genotypes were found superior over check variety. Variability in fruit length has also been observed by Ben-Chaim and Paran (2000), Chatterjee and Kohli (2004), Mishra *et al*. (2005), Nazir *et al.* (2005), Nkansah *et al*. (2011), Sood *et al*. (2011), Ahmed *et al*. (2012), Afroza *et al*. (2013), Naik *et al*. (2014), Thakur *et al*. (2017), Yadahalli *et al*. (2017). The results were comparable to the findings of the present investigation.

Table 4.3 Mean performance of bell pepper genotypes for number of lobes per fruit, fruit length (cm), fruit breadth (cm) and fruit weight (g)

Genotype	Number of lobes per fruit	Fruit length (cm)	Fruit breadth (cm)	Fruit weight (g)
Palam Bell	2.67	3.93	5.76	55.70
Yolo Wonder	3.53	7.40	4.58	88.33
Arka Basant	3.40	9.12	5.39	51.33
Nishat	3.40	6.63	5.85	75.00
Harit Red Fruit	3.20	8.99	5.43	57.67
HC-201-PL-3	2.73	6.47	4.56	55.60
CW-308	3.73	8.05	5.69	85.81
RY.PL-1	3.33	7.68	4.96	67.43
PT.12.3	3.20	7.17	5.23	49.67
KC-10	3.27	7.35	5.81	39.33
KC-11	3.13	6.75	5.77	37.00
KC-12	2.87	6.91	5.71	64.00
IIVR CW	3.80	8.49	6.15	79.76
Nirmal Karol	2.80	7.13	5.34	58.19
Dyarag Selection	3.33	6.42	5.95	58.28
Deothi Selection	3.40	7.05	5.54	56.19
Kadar Selection	2.80	7.06	5.53	55.67
Ghalai Selection	2.73	7.27	5.61	62.17
Tikker Selection	2.67	6.91	5.98	59.67
YW.PL-4	3.60	8.59	4.77	76.00
UHFBP-3	2.53	7.69	4.95	67.00
UHFBP-5	2.93	7.31	5.22	52.67
UHFBP-6	2.80	7.19	5.35	55.33
CW.PL-2	3.60	8.43	6.06	77.67
Solan Bharpur	3.27	7.34	5.10	46.67
Mean	3.15	7.33	5.45	61.29
SE (±m)	0.10	0.15	0.17	1.77
CD (0.05)	0.29	0.43	0.48	5.05

4.1.1.8 Fruit breadth (cm)

Comparison of the mean values of different genotypes depicted that thirteen genotypes had higher fruit breadth than population mean (5.45 cm). Maximum fruit breadth was observed in the genotype IIVR CW (6.15 cm), which was found statistically at par with nine genotypes, UHFBP-6 (6.06 cm), Tikker Selection (5.98 cm), Dyarag Selection (5.95 cm), Nishat (5.85 cm), KC-10 (5.81 cm), KC-11 (5.77 cm), Palam Bell (5.76 cm), KC-12 (5.71 cm) and CW-308 (5.69 cm), whereas the fruit breadth recorded for the check variety Solan Bharpur was (5.10 cm). Significantly, minimum fruit breadth was recorded in HC-201-PL-3 (4.56 cm) which was significantly at par with four genotypes, Yolo Wonder (4.58 cm), YW.PL-4 (4.77 cm), UHFBP-3 (4.95 cm) and RY.PL-1 (4.96 cm). Similar variations for fruit breadth had also been reported by Ben-Chaim *et al.* (2000), Chatterjee and Kohli (2004), Nazir *et al.* (2005), Sharma *et al.* (2010), Ahmed *et al.* (2012) and Pandey *et al.* (2013), Yadahalli *et al*. (2017).

4.1.1.9 Fruit weight (g)

Fruit weight is one of the most important character which has a direct effect on yield per plant. Under Indian marketing system, medium sized fruits (50-80 g) are generally preferred. It is evident from Table 4.3 that significant differences were observed among all the genotypes for fruit weight. It ranged from 37.00 to 88.33 g. General mean for the character was 61.29 g. Ten genotypes had higher average fruit weight than population mean. Maximum average fruit weight was recorded in Yolo Wonder (88.33 g) and it was found statistically at par with CW-308 (85.81 g), as compared to check variety, Solan Bharpur (46.67 g). Minimum fruit weight was observed in KC-11 (37.00 g) and it was statistically at par with genotype KC-10 (39.33 g). Similar variations for fruit weight had also been reported by Ben-Chaim and Paran (2000), Sood *et al.* (2009), Nkansah *et al*. (2011), Sharma *et al*. (2010), Ahmed *et al*. (2012), Kumari (2013), Thakur *et al*. (2017).

4.1.1.10 Pericarp thickness (mm)

Pericarp thickness is a very important character which decides the firmness of fruit. Thick fleshed bell pepper can withstand long shipping distance. The observation recorded on pericarp thickness (Table 4.4) revealed that maximum pericarp thickness (6.41 mm) was obtained in RY.PL-1, which was followed close to the heels by Harit Red Fruit (6.21 mm). The recorded pericarp thickness of check variety, Solan Bharpur was 4.66 mm. Minimum pericarp thickness was recorded in Kadar Selection (3.87 mm). Variability in pericarp thickness has also been obtained by Ben-Chaim and Paran (2000), Sood *et al.* (2009), Sharma *et al*. (2010), Nkanshah *et al*. (2011), Sood *et al*. (2011), Yadahalli *et al*. (2017).

4.1.1.11 Number of fruits per plant

Number of fruits per plant is the most important component trait, which is directly related with increased fruit yield per plant. The perusal of the data revealed that fourteen genotypes including check cultivar recorded higher number of fruits per plant than the population mean (12.54). For number of fruits per plant check variety, Solan Bharpur (18.20) maintained its superiority over all other genotypes. Minimum number of fruits per plant were observed in genotype RY.PL-1 (6.73). The results were in line with the findings of Mishra *et al*. (2005), Sood *et al*. (2009), Nkansah *et al*. (2011), Sood *et al*. (2011), Ahmed *et al*. (2012), Kumari (2013), Naik *et al*. (2014).

4.1.1.12 Fruit yield per plant (g)

The main focus of cultivating a crop is to have the maximum yield per unit area for better returns. Moreover, high fruit yield is the ultimate goal of any breeding program; hence, it requires the highest consideration. It is the key factor in adaptation of variety by farmers. The observation recorded for fruit yield per plant showed significant variation among various genotypes under study. Thirteen genotypes including check cultivar recorded higher fruit yield per plant than the population mean. Maximum fruit yield per plant was recorded in the genotype CW-308 (1015.03 g) and it was found statistically at par with genotype IIVR CW (978.77 g), whereas the recorded fruit yield per plant for check variety, Solan Bharpur was (852.40 g). Minimum fruit yield per plant was observed in RY.PL-1 (455.18 g) and it was found statistically at par with two genotypes *viz*., UHFBP-3 (544 g) and KC-11 (545 g). Amongst all the genotypes under study, five genotypes *viz*.., Tikker Selection (854.80 g), Harit Red Fruit (878.27 g), Dyarag Selection (880.56 g), IIVR CW (978.77 g) and CW-308 (1015.03 g) were found superior over check cultivar Solan Bharpur (852.40) for marketable fruit yield per plant. Similar variations for fruit yield per plant (g) in different genotypes of capsicum had also been reported by earlier workers like Chatterjee and Kohli (2004), Mishra *et al*. (2005), Nazir *et al*. (2005), Sood *et al*. (2009), Sharma *et al*. (2010), Afroza *et al*. (2013), Kumari (2013), Pandey *et al*. (2013) and Thakur *et al*. (2017).

4.1.1.13 Number of seeds per fruit

Perusal of table 4.5 revealed that number of seeds per fruit ranged from 126.53 to 302.60. The mean performance depicted maximum number of seeds per fruit in KC-11 (302.60). The minimum value for number of seeds per fruit was recorded in RY.PL-1

(126.53), which was statistically at par with two genotypes Kadar Selection (126.93) and PT.12.3 (133.47). The check variety, Solan Bharpur, recorded 191.27 seeds. The grand mean of the population was 202.27 seeds. Similar variations for number of seeds per fruit had also been reported by Nkansah *et al*. (2011) and Naik *et al*. (2014).

Table 4.4 Mean performance of bell pepper genotypes for pericarp thickness (mm), number of fruits per plant, fruit yield per plant (g)

Genotype	Pericarp thickness (mm)	Number of fruits per plant	Fruit yield per plant (g)
Palam Bell	5.81	13.27	744.12
Yolo Wonder	5.69	8.60	760.60
Arka Basant	5.16	12.47	643.07
Nishat	4.62	8.73	659.00
Harit Red Fruit	6.21	15.13	878.27
HC-201-PL-3	4.20	13.13	734.56
CW-308	4.38	11.80	1,015.03
RY.PL-1	6.41	6.73	455.18
PT.12.3	4.60	14.80	737.87
KC-10	4.23	14.93	588.00
KC-11	5.05	14.67	545.00
KC-12	5.21	11.47	731.27
IIVR CW	5.67	12.27	978.77
Nirmal Karol	4.77	13.87	811.69
Dyarag Selection	4.40	15.40	880.56
Deothi Selection	4.56	14.27	803.31
Kadar Selection	3.87	13.67	761.00
Ghalai Selection	5.21	13.20	821.22
Tikker Selection	4.62	14.27	854.80
YW.PL-4	5.31	10.27	781.20
UHFBP-3	4.44	8.13	544.00
UHFBP-5	4.68	10.87	574.13
UHFBP-6	4.76	14.00	774.67
CW.PL-2	4.80	9.40	732.60
Solan Bharpur	4.66	18.20	852.40
Mean	4.93	12.54	746.49
SE (±m)	0.18	0.46	40.57
CD (0.05)	0.51	1.32	115.71

Table 4.5 Mean performance of bell pepper genotypes for number of seeds per fruit and thousand seed weight (g)

Genotype	Number of seeds per fruit	Thousand seed weight (g)
Palam Bell	154.93	9.65
Yolo Wonder	246.40	7.62
Arka Basant	188.73	7.93
Nishat	240.93	6.53
Harit Red Fruit	246.33	7.26
HC-201-PL-3	203.60	6.50
CW-308	191.73	7.79
RY.PL-1	126.53	9.29
PT.12.3	133.47	7.20
KC-10	204.13	8.16
KC-11	302.60	7.58
KC-12	174.13	5.70
IIVR CW	190.87	5.37
Nirmal Karol	246.67	7.58
Dyarag Selection	216.20	6.50
Deothi Selection	227.07	6.49
Kadar Selection	126.93	6.87
Ghalai Selection	193.60	6.04
Tikker Selection	172.33	6.66
YW.PL-4	260.80	5.71
UHFBP-3	194.20	4.79
UHFBP-5	179.93	6.26
UHFBP-6	186.60	7.13
CW.PL-2	256.73	7.74
Solan Bharpur	191.27	5.74
Mean	202.27	6.96
SE (±m)	9.66	0.18
CD (0.05)	27.54	0.52

4.1.1.14 Thousand seed weight (g)

The data obtained on thousand seed weight (g) showed significant variation among the divergent genotypes. It ranged from 4.79 to 9.65 g. The mean performance depicted maximum thousand seed weight in genotype Palam Bell (9.65 g) which maintained its superiority over all other genotypes including check variety, Solan Bharpur (5.74 g). The minimum value for thousand seed weight was recorded in UHFBP-3 (4.79 g). Similar variations for thousand seed weight had also been reported by Chatterjee and Kohli (2001), Mishra *et al.* (2002) and Ghazizadeh *et al.* (2010).

4.1.1.15 Total Soluble Solids (^{o}B)

Total Soluble Solids content is also one of the most important quality parameters in the processing industry. The observation recorded on this trait showed significant variations among all the genotypes for total soluble solids content (4.20-8.20 ^{o}B). Significantly higher total soluble solids were observed in the genotype CW.PL-2 (8.20 ^{o}B) while minimum total soluble solids were observed in PT.12.3 (4.20 ^{o}B), whereas total soluble solids observed for check cultivar Solan Bharpur were (5.63). In overall, fifteen genotypes were found superior over check cultivar Solan Bharpur (5.63 ^{o}B) for the trait under study. Naik *et al.* (2010) and Swamy *et al.* (2015) had also similar results for total soluble solids content in capsicum.

4.1.1.16 Ascorbic acid content (mg/100g)

Ascorbic acid is the major component of the nutritional quality in capsicum. In the present studies, ascorbic acid content ranged from 104.00 to 171.38 mg/ 100g. Maximum ascorbic acid was observed in the genotype IIVR CW (171.38 mg/ 100g), which was significantly higher than all other genotypes under study. Minimum ascorbic acid was observed in HC-201-PL-3 (104 mg/ 100 g) which was statistically at par with Harit Red Fruit (104.50 mg/ 100g). In the present studies, seven genotypes *viz.,* CW.PL-2 (145.26 mg/ 100g), KC- 11 (145.26 mg/ 100g), KC-10 (146.30 mg/ 100g), Arka Basant (146.30 mg/ 100g), Palam Bell (147.35 mg/ 100g), CW-308 (149.44 mg/ 100g) and IIVR CW (171.38 mg/ 100g) were found better than check cultivar Solan Bharpur (141.08 mg/ 100g) for ascorbic acid content in the fruits. The results of present findings for ascorbic acid content in capsicum fruits are in line with Choudhary *et al.* (2011), Datta and Chakraborty (2013), Datta and Das (2013), Vikram *et al.* (2014) and Swamy *et al.* (2015).

4.1.1.17 *Phytopthora* fruit rot incidence (%)

Phytopthora fruit rot is one of the most destructive diseases causing huge losses to capsicum crop particularly during rainy season. Due to growing environmental concerns breeding for resistance varieties is an approach for the effective management of the disease. There is need to screen different genotypes of capsicum having resistance to *Phytophthora* fruit rot disease. In the present studies, perusal of data in table 4.7 revealed that *Phytopthora* fruit rot incidence among different capsicum genotypes ranged from 10.09-29.65%. Minimum *Phytopthora* fruit rot incidence was recorded in the genotype Dyarag Selection (10.09%). These findings are in agreement with Kumari and Sharma (2014) for *Phytopthora* fruit rot in different capsicum genotypes.

Table 4.6 Mean performance of bell pepper genotypes for total soluble solids (^{0}B) and ascorbic acid content (mg/100g)

Genotype	Total soluble solids (^{0}B)	Ascorbic acid (mg/ 100g)
Palam Bell	6.00	147.35
Yolo Wonder	6.03	131.67
Arka Basant	5.07	146.30
Nishat	6.00	123.31
Harit Red Fruit	6.00	104.50
HC-201-PL-3	6.10	104.00
CW-308	6.00	149.44
RY.PL-1	5.00	126.45
PT.12.3	4.20	141.08
KC-10	6.10	146.30
KC-11	6.00	145.26
KC-12	5.90	127.49
IIVR CW	5.13	171.38
Nirmal Karol	5.00	130.63
Dyarag Selection	6.07	140.03
Deothi Selection	5.93	113.91
Kadar Selection	6.00	112.86
Ghalai Selection	5.13	137.94
Tikker Selection	5.03	131.67
YW.PL-4	5.23	134.81
UHFBP-3	6.07	138.99
UHFBP-5	5.37	112.86
UHFBP-6	5.80	129.58
CW.PL-2	8.20	145.26
Solan Bharpur	5.63	141.08
Mean	5.72	133.37
SE (±m)	0.13	3.74
CD (0.05)	0.36	10.65

CW-308

IIVR CW

Dyarag Selection

Harit Red Fruit

Tikker Selection

Solan Bharpur (Check variety)

Plate 2: Top six promising genotypes of bell pepper

4.1.1.16 *Phytophthora* leaf blight severity

The data recorded on *Phytophthora* leaf blight severity has been presented in (Table 4.7), which revealed that *Phytopthora* leaf blight severity among different capsicum genotypes under study ranged from 21.33 to 39.33%. Minimum leaf blight severity in genotype; PT.12.3 (21.33%) and was statistically at par with nine genotypes, Tikker Selection (21.78%), check variety Solan Bharpur (22.22%), Nirmal Karol (22.22%), HC-201-PL-3 (22.67%), Ghalai Selection (23.11%), Dyarag Selection (24.44%), UHFBP-5 (25.33%), Yolo Wonder(25.78%), Deothi Selection (26.67%).

Table 4.7 Mean performance of bell pepper genotypes for *Phytophthora* fruit rot incidence (%) and *Phytophthora* leaf blight severity (%)

Genotypes	*Phytophthora* fruit rot incidence (%)*	*Phytophthora* leaf blight severity (%)*
Palam Bell	16.88 (4.23)	28.89 (5.47)
Yolo Wonder	18.01 (4.35)	25.78 (5.17)
Arka Basant	20.10 (4.59)	29.78 (5.55)
Nishat	19.84 (4.56)	37.33 (6.16)
Harit Red Fruit	21.50 (4.74)	26.67 5.25)
HC-201-PL-3	23.37 (4.94)	22.67 (4.86)
CW-308	14.52 (3.94)	28.45 (5.42)
RY.PL-1	12.65 (3.69)	28.00 (5.38)
PT.12.3	26.36 (5.22)	21.33 (4.72)
KC-10	29.65 (5.52)	30.95 (5.64)
KC-11	25.96 (5.19)	32.00 (5.75)
KC-12	17.20 (4.26)	27.56 (5.34)
IIVR CW	15.78 (4.08)	28.00 (5.38)
Nirmal Karol	13.80 (3.84)	22.22 (4.82)
Dyarag Selection	10.09 (3.32)	24.44 (5.03)
Deothi Selection	16.59 (4.18)	26.67 (5.24)
Kadar Selection	17.56 (4.30)	39.33 (6.33)
Ghalai Selection	15.35 (4.03)	23.11 (4.91)
Tikker Selection	10.86 (3.44)	21.78 (4.77)
YW.PL-4	14.85 (3.96)	27.11 (5.30)
UHFBP-3	20.75 (4.65)	28.00 (5.37)
UHFBP-5	21.52 (4.74)	25.33 (5.13)
UHFBP-6	18.93 (4.43)	24.00 (5.00)
CW.PL-2	17.37 (4.28)	27.11 (5.30)
Solan Bharpur	13.29 (3.77)	22.22 (4.81)
Mean	4.33	5.28
SE (±m)	0.19	0.18
CD (0.05)	0.54	0.52

*Figures in the parenthesis are square root transformed values.

Whereas, maximum Phytophthora leaf blight severity was recorded in Kadar Selection (39.33%), which was statistically at par with KC-11 (32%). These findings are in agreement with Kumari and Sharma (2014) for *Phytopthora* leaf blight severity in different capsicum genotypes.

4.1.2 Parameters of variability

The analysis of variance (ANNOVA) and the computation of genotypic coefficient of variance (GCV), phenotypic coefficient of variance (PCV), heritability (in broad sense), genetic advance and genetic gain was statistically worked out to facilitate selection for various traits, have been represented in Table 4.8.

4.1.2.1 Coefficients of variability

To initiate any breeding programme, information about the genetic variability in the population is a pre requisite. Measure of genotypic and phenotypic coefficients of variation is useful in detecting the amount of variability present in the germplasm. Presence of high variability offers much scope for improvement and enables the breeders to identify the most potential genotype. As the phenotypic variation is the outcome of genotypic, environmental and interaction between genotypic and environmental variation, so it is not useful in effective selection. For making effective selections, the heritable unit *i.e.*, the genetic variation specifically additive genetic variability present in population is adopted by breeders for improvement of different economic traits. In the present investigation, phenotypic coefficients of variability were higher in magnitude than the corresponding genotypic coefficients of variability, though the difference was less in majority of cases thus, indicating that environmental factors have played less influence on the expression of these characters. Coefficients of variation varied in magnitude indicating that there was a great diversity in the experimental material under study. Similar results were also reported by Sharma and Sharma (2006).

Perusal of Table 4.8 revealed that moderate phenotypic and genotypic coefficients of variation were observed for number of seeds (22.70% and 21.14%) followed by number of fruits per plant (22.31% and 21.37%), fruit weight (22.00% and 21.42%), fruit yield per plant (19.70% and 17.31%) and thousand seed weight (16.95% and 16.32%). These results are also in confirmation with earlier workers like Chatterjee and Kohli (2004), Islam and Singh (2006), Johri and Kumar (2007) and Sharma *et al.* (2010).

Table :4.8 Estimation of parameters of variability in bell pepper (*Capsicum annuum* L.) for various traits

Characters	Range	Mean	Coefficients of variability (%)		Heritability (%)	Genetic advance	Genetic gain (%)
			Phenotypic	Genotypic			
Days to first picking	62.00 - 78.67	71.33	5.07	4.54	79.94	5.96	8.35
Number of primary branches	2.27 - 3.80	2.90	15.11	10.77	50.87	0.46	15.83
Plant height (cm)	58.33 - 107.20	74.22	14.20	14.15	99.16	21.54	29.02
Number of lobes per fruit	2.53 - 3.80	3.15	12.61	11.31	80.49	0.66	20.90
Fruit length (cm)	3.93 - 9.12	7.33	14.33	13.87	93.72	2.03	27.66
Fruit breadth (cm)	4.56 - 6.15	5.45	9.30	7.59	66.52	0.70	12.75
Fruit weight (g)	37.00 - 88.33	61.29	22.00	21.42	94.82	26.33	42.96
Pericarp thickness (mm)	3.87 - 6.41	4.93	13.86	12.37	79.71	1.12	22.75
Number of fruits per plant	6.73 - 18.20	12.54	22.31	21.37	91.74	5.29	42.16
Number of seeds per fruits	126.53-302.60	202.27	22.70	21.14	86.73	82.05	40.56
Thousand seed weight (g)	4.79-9.65	6.96	16.95	16.32	92.80	2.26	32.39
Total soluble solids (^{0}B)	4.20 - 8.20	5.72	13.07	12.49	91.25	1.41	24.57
Ascorbic acid (mg/ 100g)	104.00 - 171.38	133.37	12.37	11.38	84.62	28.75	21.56
Yield per plant (g)	455.18 -1015.03	746.49	19.70	17.31	77.18	233.82	31.32

Moderate phenotypic coefficient of variation and low genotypic coefficient of variation were recorded for number of primary branches (15.11% and 10.77%). Low phenotypic and genotypic coefficients of variations were observed for most of the characters *viz.*, days to first picking (5.07% and 4.54%), fruit breadth (9.30% and 7.59%), ascorbic acid content (12.37% and 11.38%), number of lobes per fruit (12.61% and 11.31%), total soluble solids (13.07% and 12.49%), pericarp thickness (13.86% and 12.37%), plant height (14.20% and 14.15%) and fruit length (14.33% and 13.87%). Some of these results were in confirmation with Sood *et al.* (2011), Ahmed *et al.* (2012), Afroza *et al.* (2013) and Pandey *et al.* (2013).

4.1.2.2 Heritability

Heritability is the portion of phenotypic variation which is transmitted from parent to progeny. Higher the heritable variation, greater will be the possibility of fixing the characters by selection. Hence, heritable studies are of foremost importance to judge whether the observed variation for a particular character is due to genotype or due to environment. Johnson *et al*. (1995) stated that heritability estimates together with the genetic advance provides better response during selection than either of the parameters alone.

Estimates of heritability (broad sense) were also worked out in the present studies and have been presented in table 4.8. The range of heritability was observed from 50.87 to 99.16 per cent. In the present study, high heritability was exhibited by all characters. Highest heritability was recorded for plant height (99.16%) followed by fruit weight (94.82%), fruit length (93.72%), thousand seed weight (92.80%), number of fruits per plant (91.74%), total soluble solids (91.25%), number of seeds per fruit (86.73%), ascorbic acid (84.62%) and number of lobes per fruit (80.49%). However, characters *viz.*, days to first picking (79.94%), pericarp thickness (79.71%), yield per plant (77.18%), fruit breadth (66.52%) and number of primary branches (50.87%), showed moderate heritability. The results are in consonance with the findings of Chatterjee and Kohli (2004), Mishra *et al.* (2005), Nazir *et al.* (2005), Islam and Singh (2006), Sharma and Sharma (2006), Sharma *et al.* (2010), Sood *et al.* (2011), Ahmed *et al.* (2012), Afroza *et al.* (2013) and Pandey *et al.* (2013).

4.1.2.3 Genetic gain

Genetic advance expressed as per cent of population mean (genetic gain) was low to high for various characters studied. It ranged from 8.35% to 42.96 % (Table 4.8). It was found moderate for the characters *viz*., fruit weight (42.96%) followed by number of fruits per plant

(42.16), number of seeds per fruits (40.56%), thousand seed weight (32.39%), yield per plant (31.32%), plant height (29.02%)and fruit length (27.66%).

Lowest genetic gain of 8.35 per cent was observed in days to first picking followed by fruit breadth (12.75%), number of lobes per fruit (20.90%), ascorbic acid content (21.56%), pericarp thickness (22.75%) and total soluble solids (24.57%). Similar results were also reported by Mishra *et al.* (2005), Islam and Singh (2006) and Ahmed *et al.* (2012). for some of the traits.

High heritability coupled with moderate genetic gain was found for the traits like plant height (99.16% and 29.02%), fruit weight (94.82% and 42.96%), fruit length (93.72% and 27.66%), thousand seed weight (92.80% and 32.39%), number of fruits per plant (91.74% and 42.16%) and number of seeds per fruit (86.73% and 40.56%), which indicates that these characters were under the strong influence of additive gene action and hence simple selection based on phenotypic performance of these traits would be more effective. High heritability along with low genetic gain was recorded for the characters like number of lobes per fruit (80.49% and 20.90%), ascorbic acid content (84.62% and 21.56%) and total soluble solids (91.25% and 24.57%) whereas moderate heritability along with low genetic gain was recorded for the characters like number of primary branches (50.87% and 15.83%), fruit breadth (66.52% and 12.75%), fruit yield per plant (77.18% and 31.32%), pericarp thickness (79.71% and 22.75%) and days to first picking (79.94% and 8.35%), which indicated that these traits are strongly governed by non additive gene effects. The improvement in these traits can be achieved by partitioning the genetic variance further and making selection for suitable types in segregating generations. Islam and Singh (2006), Sood *et al.* (2009) and Sharma *et al.* (2010) also reported similar results for some of the traits.

4.2. CORRELATION STUDIES

Knowledge of degree of association of yield with its components is of great importance, because yield is not an independent character, but it is the resultant of the interactions of a number of component characters among themselves as well as with the environment in which the plant grow. Further, each character is likely to be modified by action of genes present in the genotypes of plant and also by the environment and it becomes difficult to evaluate this complex character directly. Therefore, correlation study of yield with its component traits has been executed, to find out the yield contributing traits.

The correlation coefficients among the different characters were worked out at phenotypic and genotypic levels. In general, the genotypic correlation coefficients were higher in magnitude than phenotypic correlation coefficients.

The correlation coefficients among fourteen characters showed that fruit yield per plant had positive and significant association with number of fruits per plant (0.421 and 0.459), fruit weight (0.370 and 0.342), fruit breadth (0.339 and 0.211), number of lobes per fruit (0.273 and 0.244) and number of primary branches (0.229 and 0.133), whereas it was negative and significantly correlated with thousand seed weight (-0.254 and -0.226).

Besides this, significant positive correlation of fruit weight was observed with number of primary branches (0.283 and 0.198), number of lobes per fruit (0.482 and 0.431) and fruit length (0.292 and 0.281). Significant positive correlation of plant height was observed with days to first picking (0.256 and 0.232). Number of lobes per fruit were significantly and positively correlated with number of primary branches (0.364 and 0.235). Fruit length was significantly and positively correlated with number of lobes per fruits (0.545 and 0.488) whereas, it had significant negative correlation with plant height (-0.468 and -0.450). Fruit breadth was significantly and positively correlated with days to first picking (0.267 and 0.169), number of primary branches (0.457 and 0.233), and plant height (0.536 and 0.430). Pericarp thickness was significantly and positively correlated with number of lobes per plant (0.248 and 0.175) and fruit weight (0.275 and 0.245).

Number of fruits per plants were significantly and positively correlated with fruit breadth (0.288 and 0.203) whereas it had significant negative correlation with fruit weight (-0.696 and -0.639) and pericarp thickness (-0.323 and -0.277). Number of seeds per fruit were significantly and positively correlated with number of primary branches (0.432 and 0.219), number of lobes per fruit (0.329 and 0.314) and fruit length (0.229 and 0.207) whereas it had significant negative correlation with days to first picking (-0.258 and -0.189). Thousand seed weight was significantly and positively correlated with days to first picking (0.327 and 0.257) and pericarp thickness (0.334 and 0.319) whereas it had significant negative correlation with number of primary branches (-0.274 and -0.100) and fruit length (-0.261 and -0.256). Total

Table 4.9 Genotypic and Phenotypic coefficients of correlation among different characters in bell pepper (*Capsicum annuum* L.)

Characters		DTFP	NPB	PH	NLPF	FL	FB	FW	PT	NFPP	NSPF	TSW	TSS	AA
NPB	G	-0.103												
	P	-0.146												
PH	G	0.256*	-0.101											
	P	0.232*	-0.079											
NLPF	G	-0.068	0.364*	-0.114										
	P	-0.040	0.235*	-0.094										
FL	G	-0.104	0.157	-0.468*	0.545*									
	P	-0.069	0.064	-0.450*	0.488*									
FB	G	0.267*	0.457*	0.536*	0.151	-0.119								
	P	0.169*	0.233*	0.430*	0.118	-0.110								
FW	G	0.043	0.283*	0.119	0.482*	0.292*	-0.063							
	P	0.011	0.198*	0.121	0.431*	0.281*	-0.057							
PT	G	-0.016	0.147	-0.064	0.248*	0.175	-0.115	0.275*						
	P	-0.049	0.132	-0.046	0.175*	0.130	-0.088	0.245*						
NFPP	G	-0.058	-0.100	-0.143	-0.185	-0.196	0.288*	-0.696*	-0.323*					
	P	-0.060	-0.072	-0.132	-0.153	-0.183	0.203*	-0.639*	-0.277*					
NSPF	G	-0.258*	0.432*	-0.104	0.329*	0.229*	0.027	0.119	0.064	-0.001				
	P	-0.189*	0.219*	-0.089	0.314*	0.207*	0.051	0.103	0.041	-0.011				
TSW	G	0.327*	-0.274*	0.026	0.096	-0.261*	0.097	-0.130	0.334*	-0.056	-0.126			
	P	0.257*	-0.100*	0.027	0.074	-0.256*	0.045	-0.121	0.319*	-0.061	-0.131			
TSS	G	-0.179	0.037	0.116	0.138	-0.037	0.246*	0.208	-0.200	-0.169	0.424*	0.101		
	P	-0.143	-0.017	0.117	0.134	-0.030	0.224*	0.197	-0.138	-0.165	0.388*	0.079		
AA	G	0.009	0.638*	0.090	0.412*	0.080	0.503*	0.163	0.100	0.028	0.010	0.075	-0.064	
	P	-0.034	0.466*	0.090	0.329*	0.085	0.332*	0.157	0.128	0.021	0.036	0.056	-0.035	
FYPP	G	-0.003	0.229*	0.011	0.273*	0.103	0.339*	0.370*	-0.080	0.421*	0.067	-0.254*	-0.022	0.190
	P	-0.053	0.133*	0.024	0.244*	0.103	0.211*	0.342*	-0.047	0.459*	0.038	-0.226*	-0.018	0.169

*** Significance at 5% level of significance**

Where,

DTFP- days to first picking, NPB- number of primary branches, PH- plant height (cm), NLPF- number of lobes per fruit FL- fruit length (cm), FB- fruit breadth (cm), FW- fruit weight (g), PT-pericarp thickness (mm), NFPP- number of fruits per plant, NSPF- number of seeds per fruit, TSW- thousand seed weight (g), TSS- total soluble solids (^{0}B), AA- ascorbic acid content (mg/100 g) and FYPP- fruit yield per plant (g) soluble solids were significantly and positively correlated with fruit breadth (0.246 and 0.224) and number of seeds per fruit (0.424 and 0.388). Ascorbic acid content was significantly and positively correlated with number of primary branches (0.638 and 0.466), number of lobes per fruit (0.412and 0.329) and fruit breadth (0.503 and 0.332). Rest of trait combinations had non-significant genotypic and phenotypic correlation coefficient. The present investigation is in the confirmation with Aliyu *et al.* (2000), Kohli and Chatterjee (2000), Ibrahim *et al*. (2001), Mishra *et al*. (2002), Sreelathakumary and Rajamony (2002), Bindal *et al.* (2005), Smitha and Basavaraja (2006), Bharadwaj *et al*. (2007), Sood *et al.* (2007), Madosa *et al.* (2008), Madosa *et al.* (2010), Sharma *et al.* (2010), Sood *et al.* (2011), Lahbib *et al.* (2012), Afroza *et al.* (2013) and Kumari (2013).

Based on correlation coefficients, it may be concluded that number of fruits per plant, fruit length, fruit breadth, number of primary branches and number of lobes were main fruit yield contributing characters which should be considered during selection for improving fruit yield per plant.

4.3. PATH COEFFICIENT ANALYSIS

Although correlation studies are helpful in determining the components of yield, but it does not provide a clear picture of nature and extent of contributions made by number of independent traits. Path coefficient analysis devised by Dewey and Lu (1959), however, provides a realistic basis for allocation of appropriate weightage to various attributes while designing a pragmatic programme for the improvement of yield. Path coefficient analysis depicts the effects of different independent characters individually and in combination with other characters on the expression of different characters on yield. The observed correlation coefficients of yield with its contributing traits were partitioned into direct and indirect effects. Path coefficient analysis provides an effective means of a critical examination of specific force action to produce a given correlation and measure the relative importance of each factor. In this analysis, green fruit yield per plant was taken as dependant variable and rest of the characters were considered as independent variables. The results obtained have been presented in Table 4.10.

The path coefficient analysis at genotypic level showing the direct and indirect effects of significant characters over marketable fruit yield per plant have been represented in

Table 4.10 Estimates of direct and indirect effects of different traits on yield of bell pepper (*Capsicum annuum* L.)

Characters	DTFP	NPB	PH	NLPF	FL	FB	FW	PT	NFPP	NSPF	TSW	TSS	AA	rg with FYPP
DTFP	**-0.118**	0.005	-0.029	0.009	-0.002	0.089	0.059	0.001	-0.068	-0.004	0.019	0.037	-0.001	-0.003
NPB	0.012	**-0.046**	0.011	-0.050	0.004	0.151	0.386	-0.008	-0.118	0.007	-0.016	-0.008	-0.096	0.229
PH	-0.030	0.005	**-0.105**	0.016	-0.010	0.177	0.162	0.003	-0.169	-0.002	0.001	-0.024	-0.013	0.011
NLPF	0.008	-0.017	0.012	**-0.138**	0.012	0.050	0.657	-0.013	-0.218	0.006	0.005	-0.029	-0.062	-0.273
FL	0.012	-0.007	0.049	-0.075	**0.022**	-0.040	0.398	-0.009	-0.232	0.004	-0.015	0.008	-0.012	0.103
FB	-0.032	-0.021	-0.056	-0.021	-0.003	**0.331**	-0.086	0.007	0.340	0.000	0.006	-0.051	-0.075	0.339
FW	-0.005	-0.013	-0.012	-0.066	0.006	-0.021	**1.362**	-0.015	-0.822	0.002	-0.007	-0.043	-0.024	0.342
PT	0.002	-0.008	0.007	-0.034	0.004	-0.038	0.375	**-0.053**	-0.382	0.001	0.019	0.042	-0.015	-0.080
NFPP	0.007	0.005	0.015	0.025	-0.004	0.095	-0.948	0.017	**1.182**	0.000	-0.003	0.034	-0.004	0.421
NSPF	0.030	-0.020	0.011	-0.045	0.005	0.009	0.162	-0.003	-0.001	**0.016**	-0.007	-0.088	-0.002	0.067
TSW	-0.039	0.013	-0.003	-0.013	-0.006	0.032	-0.177	-0.018	-0.066	-0.002	**0.057**	-0.021	-0.011	-0.254
TSS	0.021	-0.002	-0.012	-0.019	-0.001	0.081	0.283	0.011	-0.199	0.007	0.006	**-0.208**	0.010	-0.022
AA	-0.001	-0.029	-0.009	-0.057	0.002	0.167	0.223	-0.005	0.033	0.000	0.004	0.012	**-0.150**	0.190

rg = genotypic correlation coefficient
Diagonal figures represent the direct effect
Residual effect: = 0.003

*** Significance at 5% level of significance**
Where,
DTFP- days to first picking, NPB- number of primary branches, PH- plant height (cm),NLPF- number of lobes per fruit FL- fruit length (cm), FB- fruit breadth (cm), FW- fruit weight (g), PT-pericarp thickness (mm), NFPP- number of fruits per plant, NSPF- number of seeds per fruit, TSW- thousand seed weight (g), TSS- total soluble solids (^{0}B), AA- ascorbic acid content (mg/100 g) and FYPP- fruit yield per plant (g)

Table 4.10. The data revealed that fruit weight (1.362) had maximum positive direct effect on fruit yield per plant followed by number of fruits per plant (1.182), fruit breadth (0.331), thousand seed weight (0.057), fruit length (0.022) and number of seeds per fruit (0.016). While, the maximum negative direct effect on fruit yield was recorded by total soluble solids (-0.208) followed by ascorbic acid (-0.150), number of lobes per fruit (-0.138), days to first picking (-0.118), plant height (-0.105), pericarp thickness (-0.053) and number of primary branches (-0.046).

Number of lobes per fruit (0.657) followed by fruit length (0.398), number of primary branches (0.386), pericarp thickness (0.375), total soluble solids (0.283), ascorbic acid (0.223), plant height (0.162), number of seeds per fruit (0.162) and days to first picking exerted (0.059) maximum positive indirect effect towards yield *via* fruit weight. Fruit breadth (0.340) followed by ascorbic acid (0.033) exerted maximum positive indirect effect towards yield *via* number of fruits per plant. Plant height (0.177) followed by ascorbic acid (0.167), number of primary branches (0.151), number of fruits per plant (0.095), days to first picking (0.089), total soluble solids (0.081), number of lobes per fruit (0.050), thousand seed weight (0.032) and number of seeds per fruit (0.009) exerted maximum positive indirect effect towards yield *via* fruit breadth. Days to first picking (0.019) and pericarp thickness (0.019) followed by total soluble solids and fruit breadth (0.006), number of lobes per fruit (0.005), ascorbic acid (0.004), and plant height (0.001) exerted maximum positive indirect effects towards yield via thousand seed weight. Number of lobes per fruit (0.012) followed by fruit weight (0.006), number of seeds per fruit (0.005), number of primary branches and pericarp thickness (0.004) and ascorbic acid (0.002) exerted maximum positive indirect effect towards yield *via* fruit length. Number of primary branches and total soluble solids (0.007) followed by number of lobes per fruit (0.006), fruit length (0.004), fruit weight (0.002) and pericarp thickness (0.001) exerted maximum positive indirect effect towards yield *via* number of seeds per fruit.

Number of seeds per fruit (-0.088) followed by fruit breadth (-0.051), fruit weight (-0.043), number of lobes per fruit (-0.029), plant height (-0.024), thousand seed weight (-0.021) and number of primary branches (-0.008) exerted maximum negative indirect effect towards yield *via* total soluble solids. Number of primary branches (-0.096) followed by fruit breadth (-0.075), number of lobes per fruit (-0.062), fruit weight (-0.024), pericarp thickness (-0.015), plant height (-0.013), fruit length (-0.012), thousand seed weight (-0.011), number of fruits per plant (-0.004), number of seeds per plant (-0.002) and days to first picking (-0.001) exerted maximum negative indirect effect towards yield *via* ascorbic acid. Fruit length (-0.075) followed by fruit weight (-0.066), ascorbic acid (-0.057), number of primary branches (-0.050), number of seeds per fruit (-0.045), pericarp thickness (-0.034), fruit breadth (-0.021), total soluble solids (-0.019) and thousand seed weight (-0.013) exerted maximum negative indirect effect towards yield *via* number of lobes per fruit. Thousand seed weight (-0.039) followed by fruit breadth (-0.032), plant height (-0.030), fruit weight (-0.005) and ascorbic acid (-0.001) exerted maximum negative indirect effect towards yield *via* days to first picking. Fruit breadth (-0.056) followed by days to first picking (-0.029), Fruit weight and total soluble solids (-0.0012), ascorbic acid (-0.009) and thousand seed weight (-0.003) exerted maximum negative indirect effect towards yield *via* plant height. Thousand seed weight (-0.018) followed by fruit weight (-0.015), number of lobes per fruit (-0.013), fruit length (-0.009), number of primary branches (-0. 008), ascorbic acid (-0.005) and number of seeds per fruit (-0.003) exerted maximum negative indirect effect towards yield *via* pericarp thickness. Ascorbic acid (-0.029) followed by fruit breadth (-0.021), number of seeds per fruit (-0.020), number of lobes per fruit (-0.017), fruit weight (-0.013), pericarp thickness (-0.008), fruit length (-0.007) and total soluble solids (-0.002) exerted maximum negative indirect effect towards yield via number of primary branches.

In view of the direct and indirect contributions of component traits towards fruit yield, selection on the basis of horticultural traits *viz*., average fruit weight and number of fruits per plant would be a paying preposition in the genotypes included in the study. Similar results were reported by Deka and Shadeque (1997), Kohli and Chatterjee (2000), Mishra *et al.* (2002), Nazir *et al.* (2005), Sood *et al.* (2009), Johri and Kumar (2007), Naik *et al.* (2010), Sharma *et al.* (2010), Kumari (2013) and Sasu *et al.* (2013).

Low magnitude of residual effect at genotypic level indicated that the traits included in the present investigation accounted for most of the variation present in the dependent variable *i.e*. fruit yield per plant. The studies on path coefficient analysis suggested that selection for fruit weight, number of fruits per plant, fruit breadth, thousand seed weight, fruit length and number of seeds per fruit would be effective for improving yield in bell pepper.

4.4 GENETIC DIVERGENCE

Estimating genetic diversity and determining the relationships between germplasm collections helps to ensure that germplasm is efficiently collected and managed. The analysis of variance revealed highly significant differences among the genotypes for all the characters studied, indicating the existence of wide genetic divergence among them. On the basis of performance of various traits, all the genotypes were grouped into different clusters. Information on genetic diversity was also used to identify the promising diverse genotypes, which may be used in further breeding programmes.

Genetic divergence plays a key role in analyzing the general distance among the genotypes selected as parents. Within a certain limit, hybridization of more divergent parents is expected to enhance the level of heterosis and generate wide range of variability in segregating generations.

In the present investigation twenty five genotypes were grouped in to three clusters based on Mahalanobis D^2 values. The cluster I contained thirteen genotypes, cluster II contained five genotypes and cluster III contained seven genotypes.

Table 4.11: Clustering pattern of twenty-five genotypes on the basis of genetic divergence

Cluster	Number of genotypes	Genotypes
I	13	Harit Red Fruit, HC-201-PL-3, PT.12.3, KC-12, Nirmal Karol, Dyarag Selection, Deothi Selection, Ghalai Selection, Tikker Selection, UHFBP-3, UHFBP-5, UHFBP-6, Solan Bharpur
II	5	Yolo Wonder, CW-308, IIVR CW, YW.PL-4, CW.PL-2
III	7	Palam Bell, Arka Basant, Nishat PL-2, RY.PL-1, KC-10, KC-11, Kadar Selection

Group constellation of bell pepper genotypes through genetic divergence has also been reported by earlier workers like Sudre *et al.* (2006), Buttow *et al.* (2010), Farhad *et al.* (2010), Ghazizadeh *et al.* (2010), Monteiro *et al.* (2010), Zadeh *et al.* (2010), Misra *et al.* (2011), Maga *et al.* (2012) and Occhiuto *et al.* (2014).

Average inter-cluster and intra-cluster distance (D^2) values are presented in Table 11. The diagonal figures in the table represent the intra-cluster distance. The intra-cluster distance varied from 2.895 (cluster I) to 3.961 (cluster III). Since crossing of genotypes belonging to same cluster do not expect to yield superior hybrids or segregants, inter cluster distances were also worked out. The inter cluster distance was maximum to the tune of 4.351 between cluster II and III followed by cluster I and II (3.840) and cluster I and III (3.008).

The minimum inter cluster distance was observed for cluster I and III (3.008). The cluster with higher inter cluster distances indicated that the genotypes included in those clusters had high genetic variation and hybridization between genotypes of these cluster may result heterotic progenies because of convergence of diverse genes scattered in parents .

Table 4.12 Average intra (Diagonal) and inter- cluster (Lower half diagonal) distance (D^2)

Clusters	**I**	**II**	**III**
I	**2.895**		
II	3.840	**3.147**	
III	3.008	4.351	**3.961**

A wide range of inter cluster genetic distance among the different cluster of bell pepper genotypes have also been reported by Sudre *et al.* (2006), Buttow *et al.* (2010), Farhad *et al.* (2010), Ghazizadeh *et al.* (2010), Monteiro *et al.* (2010), Zadeh *et al.* (2010), Misra *et al.* (2011), Maga *et al.* (2012) and Occhiuto *et al.* (2014).

Furthermore, for getting the reliable conformity on the basis of cluster means, it was calculated for various horticulture traits and had been represented in Table 12. Minimum days to first picking were observed in cluster I (70.62) followed by cluster II (71.00) and cluster III (73.00). Cluster II exhibited maximum mean value for number of primary branches (3.28) followed by cluster I (2.86) and cluster III (2.76). Cluster III recorded maximum plant height (81.20 cm) followed by cluster I (72.05 cm) and cluster II (70.08 cm). Number of lobes per fruit were maximum in cluster II (3.65) followed by cluster III (3.14) and cluster I (2.96). Maximum fruit length was exhibited by cluster II (8.19 cm) followed by cluster I (7.22 cm) and cluster III (6.93 cm), while maximum fruit breadth was recorded in cluster III (5.58 cm) followed by cluster II (5.45 cm) and cluster I (5.38 cm). Fruit weight was maximum in cluster II (81.51 g) followed by cluster I (57.16 g) and cluster III (54.49 g). For pericarp thickness, cluster II (5.17 mm) exhibited maximum value followed by cluster III (5.01 mm) and cluster I (4.79 mm).

Maximum number of fruits per plant was observed in cluster I (13.60) followed by cluster III (12.07) and cluster II (10.47). Fruit yield per plant was recorded maximum in the cluster II (853.64 g) followed by cluster I (769.13 g) and cluster III (627.91 g). Cluster II exhibited maximum number of seeds per fruit (229.31) followed by cluster I (197.34) and cluster III (192.11).

Table: 4.13 Cluster means for different trait in twenty-five genotypes of bell pepper

Characters	I	II	III
Days to first picking	70.62	71.00	73.00
Number of branches per plant	2.86	3.28	2.76
Plant height (cm)	72.05	70.08	81.20
Number of lobes per fruit	2.96	3.65	3.14
Fruit length (cm)	7.22	8.19	6.93
Fruit breadth (cm)	5.38	5.45	5.58
Fruit weight (g)	57.16	81.51	54.49
Pericarp thickness (mm)	4.79	5.17	5.01
Number of fruits per plant	13.60	10.47	12.07
Fruit yield per plant (g)	769.13	853.64	627.91
Number of seeds per fruit	197.34	229.31	192.11
Thousand seed weight (g)	6.45	6.85	8.00
Total soluble solids (^{0}B)	5.56	6.12	5.74
Ascorbic acid (mg/ 100g)	127.21	146.51	135.40

Whereas maximum thousand seed weight was observed in cluster III (8.00 g) followed by cluster II (6.85 g) and cluster I (6.45 g). Highest total soluble solid was recorded in cluster II (6.12 ^{0}B) followed by cluster III (5.74 ^{0}B) and cluster I (5.56 ^{0}B). The highest ascorbic acid content was recorded in cluster II (146.51 mg/ 100g) followed by cluster III (135.40 mg/ 100g) and cluster I (127.21 mg/ 100g). Similar results were also recorded by earlier workers like Sudre *et al.* (2006), Buttow *et al.* (2010), Farhad *et al.* (2010), Ghazizadeh *et al.* (2010), Monteiro *et al.* (2010), Zadeh *et al.* (2010), Misra *et al.* (2011), Maga *et al.* (2012) and Occhiuto *et al.* (2014).

Chapter-5

SUMMARY AND CONCLUSION

Bell pepper, commonly known as 'Shimla Mirch' is one of the most popular and highly remunerative fresh vegetable grown worldwide due to its combination of colour, flavour, and nutritional value. It occupies a pride place among the vegetables in Indian cuisine due to its delicate taste and pleasant flavour coupled with high ascorbic acid, minerals and vitamins. It is an important off season vegetable crop of hilly regions, grown during the summer and rainy months and is economically important to small and marginal farmers, fetching good prices to the growers. Due to scanty genetic diversity and rigorous horticultural standards within bell pepper group, only a few varieties/hybrids have been developed. Considering its economic importance and demand as a high value crop and an off- season crop, there is a continuing need to develop and identify varieties with improved production potential and nutritional quality. The selection and success of crop improvement programme lies on the availability of germplasm, extent of variability and the association of quantitative characters with yield and amongst themselves. Collection and maintenance of the genetic diversity is also important to avoid the genetic erosion in bell pepper.

The present investigations entitled **"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)"** was therefore carried out on twenty-five genotypes of bell pepper including check variety, Solan Bharpur. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications at the Experiment Farm of Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal during Kharif season 2017 to ascertain the extent of variability, correlation and path coefficient analysis for yield and other horticultural traits along with the estimation of genetic divergence among the genotypes.

The characters selected for the evaluation of the germplasm were days to first picking, number of branches per plant, plant height (cm), fruit shape, fruit colour, number of lobes per fruit, fruit length (cm), fruit breadth (cm), fruit weight (g), pericarp thickness (mm), number of fruits per plant, fruit yield per plant (g), number of seeds per fruit, thousand seed weight (g), total soluble solids (^{o}B), ascorbic acid content (mg/100g), *Phytophthora* fruit rot incidence (%) and *Phythophthora* leaf blight severity (%) under field conditions. The data generated were analysed statistically to work out the coefficient of variation, heritability, genetic advance, genetic gain, correlation and path coefficients.

The results of the experiment are summarized here as under in this chapter:-

Analysis of variance revealed significant differences among the genotypes for all the traits. The minimum days to first picking were recorded in genotype KC-12 (62.00 days) and maximum days to first picking were recorded in Tikker Selection (78.67 days). Number of branches per plant was observed maximum in IIVR CW (3.80) and it was observed minimum in Kadar selection (2.27). For plant height (cm) maximum plant height was observed in Nishat (107.20 cm) and minimum in YW.PL-4 (58.33 cm). For fruit colour three colour intensities *viz.*, yellow green group, green group and yellow group were observed. Out of twenty five genotypes, thirteen had yellow green group, eleven had green group and only one had yellow group. Fruit shape was blocky for all the genotypes except Palam Bell where it was found to be cheese type. Maximum number of lobes per plant were observed in IIVR CW (3.80) and minimum were observed in UHFBP-3 (2.53). Fruit length was found maximum in Arka Basant (9.12 cm) and minimum in Palam Bell (3.93 cm). Similarly, fruit breadth (cm) was recorded maximum in IIVR CW (6.15 cm) and minimum in HC-201-PL-3 (4.56 cm). Further, fruit weight was found maximum in Yolo Wonder (88.33 g) while, KC-10 recorded minimum fruit weight (37.33 g). Maximum pericarp thickness was observed in RY.PL-1 (6.41 mm) and minimum in Kadar Selection (3.87 mm). Maximum number of fruits per plant was observed in check variety, Solan Bharpur (18.20) and minimum in RY.PL-1 (6.73). Fruit yield per plant was found highest in CW-308 (1015.03 g) and RY.PL-1 was lowest in recording fruit yield to the tune of 455.18 g. Maximum number of seeds per fruit was observed in KC-11 (302.60) and minimum in Kadar Selection (126.53). Further, thousand seed weight was maximum in Palam Bell (9.65 g) while UHFBP-3 recorded minimum thousand seed weight (4.79 g). Total Soluble Solids (^{o}B) was found maximum in CW.PL-2 (8.20 ^{o}B) and minimum in PT.12.3 (4.20 ^{o}B). Ascorbic acid content (mg/100g) was found maximum in IIVR CW (171.38 mg/100 g) and minimum in HC-201-PL-3 (104 mg/100 g). Under field conditions, genotypes *viz.*, Dyarag Selection and PT.12.3 (10.09%) showed minimum *Phythophthora* fruit rot incidence of 10.09% and *Phythophthora* leaf blight severity 21.33%, respectively.

Parameters of Variability

The estimates of phenotypic and genotypic coefficients of variations were moderate for number of seeds (22.70% and 21.14%) followed close to the heels by number of fruits per plant (22.31% and 21.37%), fruit weight (22.00% and 21.42%), fruit yield per plant (19.70% and 17.31%) and thousand seed weight (16.95% and 16.32%), indicating the existence of substantial variability, pointing ample scope for their improvement through selection.

High heritability coupled with moderate genetic gain was found for the traits *viz*., plant height (99.16% and 29.02%), fruit weight (94.82% and 42.96%), fruit length (93.72% and 27.66%), thousand seed weight (92.80% and 32.39%), number of fruits per plant (91.74% and 42.16%) and number of seeds per fruit (86.73% and 40.56%), which indicates the predominance of additive variance in expression of these traits.

Correlation Studies

The correlation coefficients among the different characters were worked out at phenotypic and genotypic levels. In general, genotypic correlation coefficients were higher than the phenotypic coefficients. The phenotypic and genotypic correlation coefficients among different characters showed that yield per plant had positive and significant association with number of fruits per plant (0.421 and 0.459), fruit weight (0.370 and 0.342), fruit breadth (0.339 and 0.211), number of lobes per fruit (0.273 and 0.244) and number of primary branches (0.229 and 0.133). Hence, on the basis of correlation studies, it is summarized that the selection for number of fruits per plant, fruit weight, fruit breadth, number of lobes per fruit, number of primary branches will be effective in increasing fruit yield in bell pepper.

Path coefficient analysis

The path coefficient analysis indicated that out of all the characters studied maximum positive direct contribution towards fruit yield per plant was contributed by fruit weight (1.362) followed by number of fruits per plant (1.182), fruit breadth (0.331), thousand seed weight (0.057), fruit length (0.022) and number of seeds per fruit (0.016). These characters should be given due consideration for breeding high yield per plant. Whereas, maximum negative direct effect on fruit yield was recorded by total soluble solids (-0.208) followed by ascorbic acid (-0.150), number of lobes per fruit (-0.138), days to first picking (-0.118), plant height (-0.105), pericarp thickness (-0.053) and number of primary branches (-0.046).

Genetic Divergence

For those traits, where selection is not responsive and non-additive gene action plays a major role in the expression, hybridization between diverse parents on the basis of their cluster mean performance is advocated to get superior hybrids in F_1 or transgressive segregants in subsequent generations. In the present studies, on the basis of genetic divergence, twenty five genotypes were grouped in to three clusters. Maximum number of genotypes were accommodated in cluster I. Average intracluster distance was maximum in cluster III (3.961) and minimum in cluster I (2.895). The inter cluster distance was recorded maximum to the tune of 4.351 between cluster II and III, indicating that hybridization between the genotypes from cluster II and III can be utilized for getting superior recombinants/transgressive segregants in segregating generations of bell pepper. Furthermore, cluster means of the various characters indicated that among the three clusters, cluster II was found superior for important traits *viz*., fruit length (cm), fruit weight (g), pericarp thickness (mm), number of seeds per fruit, number of lobes per fruit, fruit yield per plant (g), number of branches, total soluble solids (^{o}B) and ascorbic acid content (mg/100 g). Cluster III was found superior for the traits like days to first picking, plant height (cm) and thousand seed weight (g). Cluster I was found superior for number of fruits per plant.

CONCLUSION

- In the present investigations, it is concluded that the genotype, CW-308 performed better in terms of yield and other horticultural traits over the check variety, Solan Bharpur. So, this genotype offers an ample scope for the release in the mid hill conditions of Himachal Pradesh after multilocation testing.
- A wide range of variability and heritability was depicted for the characters *viz*., fruit length, fruit breadth, plant height, average fruit weight, number of fruits per plant and fruit yield. High heritability coupled with moderate genetic gain was found for the traits like plant height (99.16% and 29.02%), fruit weight (94.82% and 42.96%),fruit length (93.72% and 27.66%), thousand seed weight (92.80% and 32.39%), number of fruits per plant (91.74% and 42.16%) and number of seeds per fruit (86.73% and 40.56%). Therefore, these characters can be improved by selection. Moderate heritability coupled with low genetic gain was obtained for fruit yield. Hence, the improvement in these traits can be achieved by further partitioning the genetic variance and making selection for suitable types in segregating generations.

Table 4.14 Best three genotypes with respect to different characters in bell pepper

Character	Genotypes	Mean
Days to first picking	KC-12	62
	HC-201-PL-3	66
	CW-308	69
Number of primary branches per plant	IIVR CW	3.80
	UHFBP-5	3.67
	YW.PL-4	3.47
Plant Height (cm)	Nishat	107.20
	Palam Bell	93.73
	Dyarag Selection	86.80
Number of lobes per fruit	IIVR CW	3.80
	CW-308	3.73
	YW.PL-4 and CW.PL-2	3.60
Fruit length (cm)	Arka Basant	9.12
	Harit Red Fruit	8.99
	YW.PL-4	8.59
Fruit breadth (cm)	IIVR CW	6.15
	CW.PL-2	6.06
	Tikker Selection	5.98
Fruit weight (g)	Yolo Wonder	88.33
	CW-308	85.81
	IIVR CW	79.76
Pericarp thickness (mm)	RY.PL-1	6.41
	Harit Red Fruit	6.21
	Palam Bell	5.81
Number of fruits per plant	Solan Bharpur	18.20
	Dyarag Selection	15.40
	Harit Red fruit	15.13
Fruit yield per plant (g)	CW-308	1,015.03
	IIVR CW	978.77
	Dyarag Selection	880.56
Number of seeds per fruit	KC-11	302.60
	YW.PL-4	260.80
	CW.PL-2	256.73
Thousand seed weight (g)	Palam Bell	9.65
	RY.PL-1	9.29
	KC-10	8.16
Total Soluble Solids (^{0}B)	CW-308	8.20
	HC-201-PL-3 and KC-10	6.10
	Dyarag Selection and UHFBP-3	6.07
Ascorbic acid (mg/ 100g)	IIVR CW	171.38
	CW-308	149.44
	Palam Bell	147.35
Phytophthora fruit rot incidence (%)	Dyarag Selection	10.09
	Tikker Selection	10.86
	RY.PL-1	12.65
Phytophthora leaf blight severity (%)	PT.12.3	21.33
	Tikker Selection	21.78
	Solan Bharpur and Nirmal Karol	22.22

- A highly significant and positive genotypic and phenotypic correlation of yield per plant was found with number of fruits per plant, fruit weight, fruit breadth, number of lobes per fruit and number of primary branches. Therefore, main emphasis should be given on these characters, while making the selection in bell pepper genotypes for high yield.
- Maximum positive and direct effect towards yield was contributed by fruit weight followed by number of fruits per plant, fruit breadth, thousand seed weight, fruit length and number of seeds per fruit. The improvement in these characters will lead to higher yield in bell pepper.
- For the traits, where selection is not effective, genetic divergence can play an important role on further partitioning of variability. In the present investigation, genetic divergence studies, grouped twenty five genotypes into three clusters. The hybridization between genotypes of cluster II and cluster III can be utilized for getting superior recombinants or transgressive segregants in segregating population because these clusters were found most divergent.

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Title of Thesis	:	**"Studies on genetic variability in bell pepper (*Capsicum annuum* L.)"**
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Admission Number	:	H-2016-102-M
Major Advisor	:	Dr Seema Thakur
Major Field	:	Vegetable Science
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ABSTRACT

The present investigation entitled "Studies on genetic variability in bell pepper (*Capsicum annum* L)" was carried out at the Experimental Farm of Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during *Kharif* season, 2017. Twenty-five diverse genotypes of bell pepper including check variety, Solan Bharpur were evaluated to ascertain extent of variability, correlation and path coefficient analysis for yield and other horticultural traits along with the estimation of genetic divergence among the genotypes. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Analysis of variance showed significant differences among all the genotypes for all the characters under study. CW-308, IIVR CW, Dyarag Selection, Harit Red Fruit and Tikker Selection performed best in terms of yield and other horticultural traits over the check variety, Solan Bharpur. So, these genotype can offer an ample scope for the release in mid hill conditions of Himachal Pradesh after multilocational testing. High heritability coupled with moderate genetic gain was found for plant height, fruit weight, fruit length, thousand seed weight, number of fruits per plant and number of seeds per fruit which indicated the predominance of additive variance in expression of these traits. Yield was significantly and positively correlated with number of fruits per plant, fruit weight, fruit breadth, number of lobes per fruit and number of primary branches. Therefore, main emphasis should be given on these characters, while making the selection in bell pepper genotypes for high yield. Path analysis revealed that fruit weight had maximum positive direct effect on yield followed by number of fruits per plant, fruit breadth, thousand seed weight, fruit length and number of seeds per fruit. The improvement in these characters will lead to higher yield in bell pepper. Genetic divergence studies revealed that hybridization between genotypes of cluster II and III will be more rewarding for getting superior progeny(s).

Signature of Major Advisor **Signature of the Student**

Countersigned

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APPENDIX I

AGRO-METEOROLOGICAL DATA DURING GROWING PERIOD, 2017

Month	2017			
	T-max. (^0C)	T-min. (^0C)	RH (%)	Rainfall (mm)
February	21.3	6.1	49	7.6
March	22.9	7.8	25	33.2
April	29.3	13.2	44	57.8
May	30.5	15.8	53	110.8
June	28.7	17.9	68	197.8
July	27.6	20.4	81	162.3
August	26.7	20.1	82	233.8
September	27.2	16.8	77	133.8

Source: Meterological Observatory, Department of Environmental Sciences, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP, 173 230

APPENDIX-II

Analysis of variance for various horticultural traits in bell pepper

Characters / Source	df	Days to first picking	Number of primary branches per plant	Plant height (cm)	Number of lobes per fruit	Fruit length (cm)	Fruit breadth (cm)	Fruit weight (g)	Pericarp thickness (mm)
Replication	2	49.974	1.588	1.840	0.068	1.028	2.119	126.92	1.054
Genotypes	24	34.028*	0.380*	331.587*	0.411*	1.212*	0.599*	526.267*	1.122*
Error	48	2.626	0.103	0.927	0.030	0.095	0.086	9.412	0.094
Total	74	86.628	2.071	334.354	0.509	2.335	2.804	662.599	2.270

Characters / Source	df	Number of fruits per plant	Fruit yield per plant (g)	Number of seeds per fruit	Thousand seed weight (g)	Total Soluble Solids (°B)	Ascorbic acid content (mg/ 100g)	*Phytophthora* fruit rot incidence (%)	*Phytophthora* leaf blight severity (%)
Replication	2	42.275	271,865.724	5,640.066	1.392	0.173	1708.102	0.408	0.405
Genotypes	24	22.187*	55,014.005*	5,766.461*	3.982*	1.579*	732.547*	0.891*	0.485*
Error	48	0.646	4,936.825	279.756	0.100	0.049	41.854	0.109	0.101
Total	74	65.108	331,816.554	11,686.283	5.474	1.801	2,482.503	1.408	0.991

BRIEF BIO-DATA

Name	:	**Radhika Negi**
Father's Name	:	Sh Ashok Negi
Mother's Name	:	Smt Bindra Negi
Date of Birth	:	31.01.1994
Sex	:	Female
Marital Status	:	Unmarried
Nationality	:	Indian

Educational Qualifications :

Certificate/ Degree	Month & Year	School/ College	Board/ University	Marks (%)	Division
Matriculation	May, 2009	Kendriya Vidhyalaya ITBP School PO Bonda Sarahan, Distt Shimla (HP)	Central Board of Secondary Education (CBSE)	70.00	First
10+2	March, 2011	Govt Sr Sec School, Sangla Distt Kinnaur (HP)	HP Board of School Education, Dharmshala Distt Kangra (HP)	72.60	First
BSc (Hons) Horticulture	July, 2016	College of Horticulture, Dr YSPUHF, Nauni, Solan (HP)	Dr YS Parmar University of Horticulture and Fty, Nauni, Solan (HP)	81.80	First

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Place: Nauni, Solan (HP)
Date:
(Radhika Negi)