"STUDIES ON GENETIC DIVERSITY FOR YIELD AND QUALITY TRAITS IN CHILLI (*Capsicum annuum* L.)"

BY

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DECLARATION

I, Ms. M. JANAKI, hereby declare that the thesis entitled **"STUDIES ON GENETIC DIVERSITY FOR YIELD AND QUALITY TRAITS IN CHILLI (*Capsicum annuum* L.)"** submitted to the Dr. Y.S.R. Horticultural University, Venkataramannagudem, for the degree of Master of Science in Horticulture (Vegetable Science) is the result of original research work done by me. I declare that no material contained in the thesis has been published earlier in any manner.

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CERTIFICATE

Ms. M. JANAKI has satisfactorily prosecuted the course of research and that the thesis entitled **"STUDIES ON GENETIC DIVERSITY FOR YIELD AND QUALITY TRAITS IN CHILLLI (*Capsicum annuum* L.)"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination.

I certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

Place: Venkataramannagudem **(L. NARAM NAIDU)**

Date: **Chairman**

CERTIFICATE

This is to certify that the thesis entitled "**STUDIES ON GENETIC DIVERSITY FOR YIELD AND QUALITY TRAITS IN CHILLLI (*Capsicum annuum* L.)**" submitted in partial fulfillment of the requirements for the degree of Master of Science in Horticulture (Vegetable Science) of Dr.Y.S.R. Horticultural University, Venkataramannagudem, is a record of the bonafide research work carried out by Ms**.** M. JANAKI under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of investigation have been duly acknowledged by the author of the thesis.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	per cent
@	:	at the rate of
&	:	and
^0C	:	Degree Celsius
AA	:	Ascorbic Acid
A	:	Absorbance
ADFW	:	Average Dry Fruit Weight
ANOVA	:	Analysis of variance
AP	:	Andhra Pradesh
ASTA	:	American Spice Trade Association
CD	:	Critical Difference
cm	:	centimetre
COV	:	Co-Variance
C	:	Capsaicin
CV	:	Coefficient of variation
df	:	Degrees of freedom
DFF	:	Days to Fifty per cent Flowering
Dr.YSRHU	:	Dr Y S Rajasekhar Reddy Horticultural University
EC	:	Electrical Conductivity
ESS	:	Error sum of squares
EMSS	:	Error Mean sum of squares
etc.	:	and so on; and other people/things
et al.	:	and others
Fig.	:	Figure
F. test	:	Fishers test
FD	:	Fruit Diameter
FL	:	Fruit Length
FSP	:	Fruit Set Per cent
FYM	:	Farm Yard Manure

g	:	gram
G	:	Genotype
GA	:	Genetic Advance
GAM	:	Genetic Advance as per cent of Mean
GCV	:	Genotypic Coefficient of Variation
HC & RI	:	Horticulture College and Research Institute
HRS	:	Horticultural Research Station
h^2 (b)	:	Heritability in broad sense
i.e.	:	that is
k	:	Selection differential
kg	:	kilogram
kg ha^{-1}	:	kilogram per hectare
l	:	litre
LCA	:	Lam Capsicum Annuum
Ml	:	millilitre
min	:	minutes
mm	:	millimetre
m	:	meter
mg	:	milligram
m.mhos/cm	:	millimhos per centimeter
MAS	:	Marker Assisted Selection
msl	:	mean sea level
MSS	:	Mean Sum of Squares
nm	:	nanometre
no.	:	Number
NaOH	:	Sodium Hydroxide
NPBP	:	Number of Primary Branches per Plant
NFP	:	Number of Fruits per Plant
NSF	:	Number of seeds per fruit
O	:	Oleoresin
P	:	Phenotype

PCV	:	Phenotypic Coefficient of Variation
PH	:	Plant height
pH	:	puissance de hydrogen
RBD	:	Randomised Block Design
RH	:	Relative humidity
r	:	Correlation coefficient
rpm	:	Rotations per minute
RC	:	Red Carotenoids
RSS	:	Replication Sum of Squares
RMSS	:	Replication Mean Sum of Squares
SE(d)	:	Standard error difference
S.Em	:	Standard error mean
SS	:	Sum of Squares
t	:	Treatments
TCV	:	Total Colour Value
T_rSS	:	Treatment Sum of Squares
TSS	:	Total Sum of Squares
T_rMSS	:	Treatment Mean Sum of Squares
t / ha	:	tonne per hectare
ug / ml	:	Microgram per millilitre
viz.	:	namely
V_g	:	Genotypic variance
V_p	:	Phenotypic variance
W.G.Dist.	:	West Godavari District
$\overline{X}$	:	General mean
YC	:	Yellow Carotenoids
YP	:	Yield per Plant

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ABSTRACT

An investigation was carried out during *kharif* 2012-13 at Horticultural Research Station, Lam, Guntur with 63 genotypes of chilli (*Capsicum annuum* L.) in a randomized block design with two replications to study variability, heritability, genetic advance as per cent of mean, genetic divergence, character association and the magnitude of direct and indirect effects of 15 different quantitative and qualitative traits with yield per plant.

The study revealed significant differences among genotypes for different characters studied. The genotypic coefficients of variation for all the characters studied were lesser than the phenotypic coefficients of variation indicating the masking effect of the environment. High heritability coupled with high genetic advance as per cent of mean was observed for all the characters except days to 50 per cent flowering indicating the predominance of additive gene action suggesting, direct phenotypic selection may be useful with respect to these traits.

Correlation and path analysis revealed that plant height, fruit set per cent, number of fruits per plant, number of seeds per fruit and ascorbic acid had positive significant association and positive direct effects on yield per plant indicating the use of these attributes in selection to evolve high yielding varieties of chilli.

The results of multivariate analysis indicated the presence of considerable genetic divergence among the 63 genotypes studied. The 63 genotypes were grouped into 8 clusters in both D^2 analysis and Ward's minimum variance method. This

analysis clearly indicated that the genetic diversity and geographical diversity were not related.

By Mahalanobis' D^2 statistic, it could be inferred that fruit diameter followed by yellow carotenoids, red carotenoids, ascorbic acid and capsaicin contributed maximum towards genetic divergence.

Principal component analysis identified six principal components (PCs), which contributed 76.83 per cent of cumulative variance. The significant factors loaded in PC_1 towards maximum genetic divergence were number of seeds per fruit, total color value, ascorbic acid, number of fruits per plant, average dry fruit weight and fruit diameter. 2D and 3D graphs showed wide divergence between Warangal chapatta and LCA-724, LCA-756, LCA-353, LCA-716, Aparna which are also distantly placed with LCA-702 signifying their usefulness in chilli breeding to develop high heterotic hybrids.

Agglomerative cluster analysis revealed wide genetic distance between the genotypes of cluster VII (LCA-707, HC-28, LCA-720, KT-1 and LCA-702), cluster IV (LCA-353, LCA-716, LCA-756, LCA-724, LCA-703, Punjab Gucchedar, Pusa Sadabahar, LCA-714, Pant C-1 and LCA-710) and the cluster VIII (Warangal chapatta).

The genotypes Warangal chapatta, LCA-702, LCA-724, LCA-756, LCA-353 and LCA-716 showed maximum inter-cluster distance in Mahalanobis' D^2 analysis, principal component analysis and cluster analysis and can be exploited for the development of heterotic hybrids in future breeding programmes.

Chapter-I

Introduction

CHAPTER I

INTRODUCTION

Chilli (*Capsicum annuum* L.) is one of the most important commercial crops of India. It belongs to the genus *Capsicum* under the family Solanaceae. In India, only two species *viz*., *Capsicum annuum* L. and *Capsicum frutescence* L. are well known and most of the cultivated varieties belong to *Capsicum annuum*. This cultivated species has its unique place in the diet as a vegetable cum spice crop (Gadaginmath, 1992).

The primary centre of origin of chilli is said to be Mexico with secondary centre in Guatemala and Bulgaria (Salvador, 2002). It was introduced in Europe by Columbus in 15^{th} century and spread to rest of the globe along the spice trading routes to Africa, India, China and Japan. Chilli was introduced in India by the Portuguese from Brazil in the middle of 17^{th} century.

Chilli has diverse uses as spice, condiment, culinary supplement, medicine, vegetable and ornamental plant. Chilli is an indispensable spice, due to its pungency, taste, appealing colour and flavour. It is the second largest commodity after black pepper (*Piper nigrum* L.) in the international spice trade. In India, it is an important ingredient in daily cuisine and is also used in the preparation of pickles, chutneys, sauces etc.

The fruit is a rich source of vitamin A, E, C and P (Hosmani, 1993). The pungency in chilli is due to a crystalline, acrid, volatile alkaloid, capsaicin present in placenta and pericarp of the fruit which has high diverse prophylactic and therapeutic uses in Allopathic and Ayurvedic medicine value (Sumathy and Mathew, 1984). It is also a good source of oleoresin which has varied uses in processed food and beverage industries and got high export potential. The natural color extracts of chilli are also finding increased value in place of artificial colours in the food items especially in developed countries.

India is the largest producer, consumer and exporter of chilli with an annual production of 1.22 million tonnes from 0.79 million ha (National Horticulture Board, 2010-11). However, almost 85-90 per cent of what is being produced is utilized for domestic consumption leaving only 10-15 per cent for export. Andhra Pradesh (53%), Karnataka (13%), Maharashtra (9%), Orissa (7%), Tamil Nadu (7%) and Madhya Pradesh (2%) are the important states producing the crop. The productivity of chilli in India is 1.50 tonnes ha^{-1}, which is far below its potential.

Andhra Pradesh is the leading producer of the crop in the country with an annual production of 0.63 million tonnes from 0.19 million ha while the productivity is 3.30 tonnes ha^{-1} (Spice Board of India, 2011). The state shares major portion of the exports from our country. Guntur, Warangal, Khammam, Prakasam, Kurnool and Krishna districts contribute nearly 80 per cent of chilli production in the state.

India has greater potential to increase the chilli production in order to promote exports which may help in price stabilization of the commodity within the country, particularly during the peak periods of production. Despite continuous efforts by the researchers and other stake holders of the crop at various levels, the productivity of the crop has not gained momentum, considering its potential. The low productivity is often attributed to many limiting factors such as lack of superior genotypes / improved cultivars for use in breeding programme to develop potential hybrids, severe incidence of insect pests (thrips, mites and borers) and diseases (anthracnose, leaf spots and viral diseases) resulting in tremendous reduction in yield and quality. Further, the high variability present in the crop has so far not been fully exploited in the crop improvement programme.

Adequate knowledge on variability, genetic divergence, character association and the extent of contribution of each character to fruit yield is a prerequisite to plan appropriate breeding programme and evolve high yielding cultivars or hybrids with suitable traits. To develop such breeding programmes, the breeders need to evaluate the available germplasm for variability and divergence and to understand the performance of genotypes in terms of yield and yield attributing characters. This facilitates identification of promising genotypes and the stable ones can either be released as a variety or used in further breeding programmes.

The genus *Capsicum* is often cross pollinated one and the natural cross pollination may go upto 70 per cent depending on the extent of style exsertion, time of dehiscence of anthers, wind direction and insect population (Murthy and Murthy, 1962 and Hosmani, 1993). Hence, breeding methods of both self and cross pollinated crops could be employed for crop improvement. A comprehensive knowledge of available variability within the breeding material of a crop species for desired characters enables the breeders to identify most potential genotypes. The phenotypic variation arises as a result of genotypic and interaction between genotypic and environmental variation. But for making effective selection, the heritable component *i.e.,* the genetic variation is more important. The genetic variability along with heritability should be considered for assessing the maximum and accurate effect of selection (Burton, 1952). Thus, success in a crop improvement programme depends, chiefly on the availability of genetic variability in the crop.

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 methods. Therefore, heritability studies are of foremost important to judge whether the observed variation for a particular character is due to genotype or environment.

Correlation and path coefficient analysis furnishes information regarding the nature and magnitude of various associations and help in the measurement of direct influence of one variable on other. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection can be based for improvement in yield. Mahalanobis'D^2 technique appears to be a fruitful approach which is based on multivariate analysis and serves to be a good index of estimating genetic diversity (Gadekar *et al.,* 1992).

Genetic improvement mainly depends upon the amount of genetic variability in the population. Crop improvement in chilli has so far been achieved by exploiting the available sources of variability. Naturally, the genetic variation or diversity for most of the yield attributes is considerably high in chilli. There is a need to seek improvement in complex quantitative trait such as yield. As a result of free exchange of chilli germplasm, lot of introgression of characters has taken place in many local chilli cultivars resulting in enhancement of variability and new genetic combinations.

Keeping this in view, the present investigation was undertaken with the following objectives.

1. To study the genetic variability in chilli germplasm for quantitative and qualitative traits.
2. To estimate phenotypic and genotypic correlations among yield and it's component characters and quality traits.
3. To estimate direct and indirect effects of different component characters on yield.
4. To assess the magnitude of genetic divergence and to classify the genotypes into different groups.

Chapter-II

Review of Literature

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CHAPTER II

REVIEW OF LITERATURE

The plant breeder is primarily concerned with the improvement of both quantitative and qualitative characters. It is necessary to understand the genetic architecture of the various characters of importance and interrelationship among them. In the present investigation, an attempt has been made to study genetic variability, heritability, genetic advance, character association, path coefficient analysis and genetic divergence in chilli. A brief review of available literature pertaining to the investigation is presented in this chapter under the following heads.

- Genetic Variability, Heritability and Genetic advance
- Character association
- Path coefficient analysis
- Genetic divergence

2.1 GENETIC VARIABILITY

A critical estimate and study of genetic variability is a pre-requisite for initiating appropriate breeding procedures in crop improvement programmes which demands wide range of variability in a population. The improvement in any crop is proportional to the magnitude of its genetic variability present in the germplasm. Greater the variability in a population, greater is the chance for effective selection for desirable types (Vavilov, 1951).

The variability observed in any population could be due to two factors, the genetic and environmental, which further decide the genetic gain possible through selection in the given population. The genetic and environmental components of variation were discussed in the early part of last century by Johannsen (1909), who attributed the variation in a segregating population to both heritable and non-heritable factors and variation within pure line to only environmental factors. Nelson-Ehle (1909) and East (1916) later confirmed Johannsen’s work and showed that, continuous variation also confirms to Mendelian genetics.

The phenotypic variability is a measure of variability due to genotype, environment, and their interaction. The genetic variability is the real measure of variability concealed in a population. It indicates the relative magnitude of genetic diversity existing in the breeding population and helps to compare the genetic variability present for different characters.

The success of breeding programme for high yield and quality depends on the nature and magnitude of variation available in the genotypes. Selection from quantitative characters is less efficient, if it is based on phenotypic expression. Hence, it is necessary to assess the relative extent of genetic and non-genetic variability exhibited by individual characters. So, partitioning of overall variability into heritable and non-heritable components by calculating genetic parameters such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) is necessary (Chadha and Sindhu, 1983 and Singh and Singh, 1994).

HERITABILITY AND GENETIC ADVANCE

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 methods. Therefore, heritability studies are of foremost importance to judge whether the observed variation for a particular character is due to genotype or due to environment. The ratio of genotypic variance to total variance in non segregating population is known as heritability in broad sense (Hanson *et al.*,1956) whereas, the ratio of additive variance to the total or phenotypic variance is referred to as narrow sense heritability (Lush, 1949). Thus, heritability denotes the proportion of phenotypic variance that is due to genotype which is heritable.

Genetic advance is the measure of improvement that can be achieved by practicing selection in a population. Genetic advance under selection is the improvement in the mean genotypic value of selected plants over parental population which further depends upon the genetic variability present in the population, heritability of the characters and the intensity of selection. Heritability estimates may not provide clear predictability of the breeding value. Therefore, estimation of heritability accompanied with genetic advance is generally more useful than heritability alone in prediction of the resultant effect for selecting the best individuals (Johnson *et al.*, 1955). This is due to the fact that, a character having high heritability may have very less phenotypic variation thus leading to low genetic advances. But, in the presence of additive gene effects high genetic advances can be expected (Panse, 1957).

Hence, study on components of variance and heritable components with suitable genetic parameters such as genotypic and phenotypic coefficients of variation, heritability and genetic advance are important tools for the breeders in selection of elite genotypes from diverse population.

A brief review of the nature of Genetic variability, Heritability and Genetic advance in chilli investigated by several workers is presented in Table 2.1.

2.2 CHARACTER ASSOCIATION

The correlation coefficient analysis measures the mutual relationship between various characters and it determines the component traits on which selection can be made upon to improve the yield. There are three types of correlations viz., phenotypic, genotypic and environmental correlations.

Phenotypic correlation is the observable correlation between two variables and includes both genotypic and environmental effects. Genotypic correlation on the other hand, is the inherent association between two variables which may be either due to pleiotropic action of genes or linkage or more likely both are developmentally induced relationships (Harland 1939). Genotypic correlation measures the magnitude of relationship between various characters that determines the component characters on which selection can be made for improvement in yield (Johnson *et al.*, 1955).

A brief review of the nature of correlation of different characters on yield in chilli investigated by several workers is presented in Table 2.2.

2.3 PATH COEFFICIENT ANALYSIS

The path analysis is a standardized partial regression coefficient as it measures the direct influence of one variable upon other and permits the separation of correlation coefficient into components of direct and indirect effects of a set of independent variables on a dependent variable.

The concept of path analysis was originally developed by Wright (1921), but the technique was first used for plant selection by Dewey and Lu (1959) as a means of separating direct and indirect contribution of various characters, which is not possible through correlation coefficient. Basically the technique aims to improve a dependent character like yield when the independent characters have a significant relation in desirable direction and positive direct effect or indirect effect through other traits on the dependent characters. The use of this technique requires cause and effect situation among the variables (Singh and Choudhary, 1979).

If the correlation coefficient between a causal factor and the effect is almost equal to its direct effects, then correlation explains the true relationship through this trait will be effective. If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects seem to be cause of positive correlation. In such situations, the indirect causal factors are to be considered simultaneously for selection. If the Correlation coefficient may be negative but the direct effect is positive and high. Under these circumstances, a restricted simultaneous selection model is to be followed i.e. restrictions to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect. If the correlation coefficient is negative and direct effect is also negative, then we have to drop the selection based on that character. The residual effect determines how best the causal factors account for the variability of the dependent factor. If residual effect is high, some other factors, which have not been considered here, need to be included in this analysis to account fully for the variation in yield.

Brief review of direct effects of component characters on yield is presented in Table: 2.3.

2.4 GENETIC DIVERGENCE:

The magnitude of divergence between two groups under consideration is provided by D^2 statistic developed by Mahalanobis (1936). For the first time D^2 statistic was applied for biological population by Nair and Mukherji (1960) to classify the natural and plantation teak tree types. Its application was extended later to taxonomic studies. Murthy and Pavate (1962) observed that D^2 analysis can be extended to the situations where overlapping species need to be discriminated and also when the discrimination at subspecies level is needed. This technique was subsequently used in different vegetable crops.

Thirty three chilli genotypes studied were grouped into 11 clusters by Varalaxmi and Babu (1991). Out of 10 characters studied, fruits per plant, leaf area index, fruit weight and total yield were reported to be the chief contributors towards genetic divergence. They did not observe firm relationship between genetic divergence and geographical distances.

Karad *et al.* (2002) grouped 40 chilli genotypes into eight clusters and the D^2 values ranged between 0.1032 and 8.7702. Cluster I was the largest containing 23 genotypes, followed by cluster II (4 genotypes). Inter-cluster distance (D^2) ranged between 7.45 (clusters II and V) and 1.15 (clusters III and VII).

Begam (2002) grouped 46 chilli genotypes into 13 clusters which showed inter cluster D^2 values ranging between 18.91 and 87.12. Seed number per fruit, dry fruit yield per plant and number of fruits per plant were the chief contributors towards diversity. Maximum diversity as revealed by inter cluster distance was observed between cluster VI and XIII with D^2 value of 82.21.

Prabhudeva (2003) grouped 36 genotypes into 11 clusters with D^2 values ranging from 34.02 to 102.13. According to him genetic diversity was not an index of geographical diversity. Fruits per plant, fruit weight and plant height were the characters which contribute maximum towards diversity. He observed maximum inter cluster distance between cluster I and II, suggesting that the genotypes belonging to these clusters form ideal pairs for developing hybrids.

Twenty diverse chilli genotypes studied for 11 characters were grouped into 6 clusters by Senapati *et al.* (2003). Cluster I was the largest with 13 genotypes followed by cluster III and IV with 2 genotypes each. They observed maximum genetic distance between cluster II and cluster VI, suggesting wide diversity between these groups and four characters viz., fresh fruit weight, fruit girth, fruit length and fruit number per plant were the chief contributors towards genetic divergence.

Gogate *et al.* (2006) grouped the genotypes into 11 clusters based on D^2 values. The genotypes were distributed randomly irrespective of geographic origin. The intra cluster distances ranged from 0.00 to 875.95. Number of fruits per plant, chlorophyll content, green fruit yield and ascorbic content largely influenced genetic discrimination of genotypes. Genotypes Jwala, RHRC 16-5, ACG 349, ACS 98-8, ACS 92-4, S 49 and ACS 2000-02 were identified as promising parents for breeding programme.

Vani *et al*. (2007b) evaluated fifty-five accessions of chilli (*C. annuum*) for 15 quantitative characters, including yield. Plant height, yield per plant, contributed maximum towards diversity. D^2 analysis grouped all the genotypes into XIV clusters with 10 solitary clusters, and the D^2 values varied between 14.38 and 85.01. Cluster I was the largest containing 32 genotypes, followed by clusters II and IV with five genotypes each. The maximum intra-cluster distance was reported in cluster I, where as inter-cluster distance was maximum between clusters VII and XI. Cluster mean analysis showed that solitary clusters, i.e. cluster XI (IC-32), cluster XII (Pusa Jwala) and cluster XIV (IC-16), were having high mean values for yield per plant, average fruit weight, seeds per fruit and fruit length.

Forty accessions were grouped into 7 clusters by Dutonde *et al.* (2008) with Cluster I comprising 17 genotypes, followed by Cluster IV (11) and Cluster III (8). The maximum inter cluster distance (D=104.98) was observed between Cluster IV and Cluster VII. Intercrossing among the genotypes belonging to Cluster-II, IV and VII was suggested to develop high yielding varieties with other desirable characters.

Pandey *et al.* (2008) divided the twenty-one genotypes into 2 clusters which were further *sub* divided into 2 groups using Ward's method.

Ajjapplavara (2009) grouped 36 chilli genotypes into 11 clusters on the basis of genetic distance. Cluster-II was the largest, consisting of 16 genotypes, while cluster, IV, V, VI, VII, VIII, IX and XI contained single genotype each and the maximum inter cluster distance was 125.45 (between the II and X). Among the different characters studied, fruits per plant, fruit yield per plant, plant height and green fruit weight contributed significantly for the genetic diversity. The genotypes Phule Sai, LCA-206, Pant C-1, KDC-1 and AD-5 from these clusters were suggested as parental donors for future hybridization programme to improve fruit yield.

Based on morphological and agronomic properties Kadri *et al.* (2009) grouped 48 genotypes into seven groups. The first six principal components axes accounted for

54.29% of the variance among the 48 accessions and their lines. The largest group contained 29 genotypes while the smallest had only 6 genotypes.

Thul *et al*. (2009) evaluated 24 accessions for 12 quantitative and qualitative traits and grouped all 24 accessions into six clusters. Cluster I consisted of 33.3% of accessions (8) and cluster II of 29.17% of accessions (7), while clusters V and VI consisted of single genotypes. The three characteristics that played the greatest role in differentiation were fruit diameter, number of fruits per plant, and leaf diameter.

Farhad *et al.* (2010) grouped 45 chilli genotypes into six clusters. Cluster I and cluster III had maximum number (11) and cluster II had the minimum number (3) of genotypes. The highest inter-cluster distance was observed between cluster II and IV and the lowest between cluster I and IV. Cluster II (D=4.91) recorded the highest intra-cluster distance and the lowest was observed in cluster I(D=3.41).

Kumar et al. (2010) evaluated 25 chilli genotypes and clustered them into eight constellations. Cluster I contained nine genotypes followed by cluster-II (four) cluster IV and V (two each). The maximum inter cluster distance (D=12.75) was observed between cluster VI and cluster VIII. The cluster IV recorded maximum intracluster distance (D=5.91). Intercrossing among the genotypes belonging to cluster III, IV and I was suggested to develop high yielding varieties with desirable characters.

Kumari *et al*. (2010) evaluated ninety four paprika (*Capsicum annuum*) accessions for 17 characters and grouped them into 10 clusters through Mahalanobis D^2 analysis. The largest group was cluster I which comprised of 24 genotypes. The cluster distances ranged from 15789.6 (between cluster II and cluster X) to 856.7 (between cluster 1 and cluster II).

Forty nine diverse materials of chilli were studied by Pandit *et al.* (2010) for estimation of genetic divergence through multivariate analyses using D^2 statistic. Based on the divergence (D^2 values) between any two genotypes, a logical grouping of the genotypes with low D^2 value could be arrived at by Tocher's method. The genotypes were grouped into 17 clusters. Cluster 1 having the maximum number of genotypes (nine genotypes). The intra and inter cluster distance represented the index of genetic diversity in clusters. The intra cluster distance was low, revealing homogeneity in the genotypes in a particular cluster for expression of the 12 characters under consideration. The inter cluster divergence was maximum between cluster 11 and 16 (32.40), suggesting wide diversity between them.

Fifty chilli germplasm lines were grouped into four and three clusters in first year and second year, respectively by Singh and Singh (2010). Highest intra-cluster D^2 values (468.96) and genetic distance (21.85) in first year was estimated for cluster III and maximum inter-cluster D^2 values (984.71) and genetic distance (31.38) were recorded between cluster II and III followed by cluster I and III (816.43 and 28.57). In second year, cluster I had maximum intra-cluster D^2 values and distance of 121.00 and 11.00, respectively. Maximum inter-cluster D^2 values (824.91) and genetic distance (28.72) were recorded between cluster II and III followed by cluster I and II (747.37 and 27.34).

Sudre *et al.* (2010) grouped 55 *Capsicum* spp accessions into five groups (G1, G2, G3, G4, G5) using Ward-MLM procedure. Group G1 was formed by 12 accessions of *C. annuum* var. *annuum* and only one accession of *C. baccatum* var. *pendulum*. Group G2 was represented by six accessions, five of *C. frutescens* and one of *C. chinense*. Group G3 consisted of 13 accessions of *C. baccatum*, of which 11 belonged to *C. baccatum* var. *pendulum* and two to *C. baccatum* var. *baccatum*.

Shrilekha *et al.* (2011) grouped thirty eight accessions into 7 clusters, wherein substantial diversity among accessions was indicated by the wide range of D^2 values (752.901 - 1918683.00). Five accessions labeled for high capsaicin content (%) and six for high capsanthin content (%) and two for dual purpose had characteristics desirable.

Lahbib *et al*. (2012) studied eleven populations grouped into three clusters and reported that the accessions FTC-1, FTC-2, FTC-5, FTC-7, FTC-8 and FCT-9 belonged to group 1. The accessions FTC-3, FTC-4, FTC-10 and FTC-11 belonged to group 2 and the accession FTC-6 formed the third group.

2.6 QUALITY STUDIES

2.6.1 Ascorbic acid (mg / 100g)

Chilli is considered to be rich source of ascorbic acid (Vit-C) and minerals. It is the source for commercial preparation of Vit-C.

The ascorbic acid content was highest at ripening stage of chilli (Havaldar and Hossain 1997) while Betlach (1967) found no marked difference between parents and F1 pongency for ascorbic acid content. Alpatiev and Kherenova (1970) reported that the ascorbic acid content in hybrid was close to that of the better parent. Nawalagatti *et al*. (1999) reported that the ascorbic acid content was highest in the hybrids followed by the cultivars and was least in the lines.

Kumar *et al*. (2003) evaluated thirty chilli genotypes and reported that the mean ascorbic acid content was lowest in genotype DCL 344 (78.30 mg/100 g) and highest in genotype ACS 2000-02 (188 mg/100 g). The total mean ascorbic acid content was 130.01 mg/100 g fresh fruit weight. Longer fruits contained higher ascorbic acid content than the shorter fruits.

The highest vitamin C content of 221.5 mg/100g was observed in cv.Phule Jyothi and the lowest (93.00mg/100g) in cv. Achari among the seven genotypes studied (Cheema and Pant, 2011).

2.6.2 Oleoresin (%)

Chilli is a good source of chilli oleoresin, which is the total flavour extract of dried and ground chillies. Nawalagatti *et al*. (1999) reported the highest oleoresin content in the hybrids followed by the cultivars and was the least in the lines.

Among 17 parents and 42 hybrids of chilli the highest oleoresin content was observed in MS 12x2529 (Singh *et al*. 2003).

Pandey *et al.* (2008) evaluating twenty-one genotypes of chilli reported seasonal variation in respect of oleoresin content which varied from 9.0 to 21.8 per cent.

Jyothi *et al.* (2008) studied twenty three cultivars and reported the highest oleoresin content in DCL 352 (13.82%) and the lowest in PC-7 (6.91%).

2.6.3 Capsaicin (%)

Pungency of chilli is due to a crystalline acrid volatile alkaloid called capsaicin.

Boronat *et al*. (1999) reported that the ratio of capsaicin to dihydrocapsaicin to be in the range of 0.64 to 1.94. Mathur *et al.* (2000) reported Tejpur cultivar (*C.frutescence*) containing highest amount of capsaicin and dihydrocapsaicin (4.28 & 1.42%) to be the most pungent.

The capsaicin content varied with the variety (Dabrowska et al. 2000) and has been reported to accumulate uniformly with progressive fruit development (Jha *et al*. (2001).

Kumar *et al*. (2003) evaluated thirty chilli genotypes and reported that capsaicin content showed a narrow range of variation from 0.33 mg/100 mg in genotype Rajasthan local to 0.49 mg/100 mg in genotype KDCS-810, with an overall mean of 0.41 mg/100 mg. Short fruits which were small and thin contained more capsaicin compared to long fruits.

According to Singh *et al*. (2003) 17 parents and 42 hybrids of chilli cv. Punjab Lal recorded the highest capsaicin concentration in powder (0.70%) and capsaicin level in oleoresin (3.05%) among the evaluated.

Prasanth *et al*. (2007) reported six chilli genotypes with high capsaicin content (>1), while 3 genotypes with low capsaicin value (<0.20) while evaluating twenty seven accessions of chilli.

Pandey *et al.* (2008) evaluated twenty-one genotypes of chilli during two seasons and observed the capsaicin content to be in the range of 0.18 to 2.01%.

Jyothi *et al.* (2008) studied twenty three cultivars and reported that the capsaicin content among the entries was in the range of 0.256% (SKAU-C-101) to 0.528% (BC-40-2).

2.6.4 Total colour value (ASTA units)

The intensity of green color at immature stage and that of red colour at ripening in chilli are important quality characters for domestic and export purposes. The red color of chilli fruit is mainly due to capsanthin and capsorubin while chlorophyll pigment is responsible for green color. Extractable pigment expressed in American Spice Trade Association (ASTA) units indicates colour intensity. Extractable color in chilli is measured by measuring the absorbance of an acetone extract by a spectrophotometer capable of accurately measuring absorbency at 460 nm. A number of varieties have been red in chilli for color and quality. The average of 2 years data of extractable colour in ASTA revealed that Buncton 50, has the highest content of pigments 269 ASTA units (Derrera, 2000). Hungary has produced very high quality condiment paprika (*Capsicum annuum Longum* group) unparalled in the world market, its bouquet, taste and color are supreme. It is reported that under Australian environmental conditions, Hungarian cultivars generate considerably higher pigment content. Milled paprika and its extract, oleoresin are used as a natural colouring source in a wide variety of foods, cosmetics and drugs. It has such a large advantage over chilli powder, creating cultivars with high pigment content and the ability to produce high pigment yield per unit area has to be given importance (Reves *et al*., 1987) in breeding programmes.

Singh *et al*. (2003) evaluated 17 parents and 42 hybrids of chilli (*C. annuum*) and reported that S 2529 exhibited the maximum colouring matter in powder (185.18 ASTA units) and colouring matter in oleoresin (883.86 ASTA units).

Prasanth *et al*. (2007) studied twenty-seven accessions of chilli (26 belonging to *Capsicum annuum* and one to *Capsicum baccatum*) and reported the colour value in the range of 32.82 to 208.56 ASTA units, with a mean value of 117.05 ASTA units.

Pandey *et al.* (2008) evaluated twenty-one genotypes of chilli for two seasons and reported that the mean extractable colour of the two seasons ranged from 53.3 to 346.0 ASTA units.

Jyothi *et al.* (2008) studied twenty three cultivars of which PC-7 and PC-6 from Pantnagar recorded the highest colour value of 50782 and 49456 EOA colour value respectively and the lowest colour value was recorded by DCL-352(19932 EOA).

A brief review of literature on variability, heritability and genetic advance, correlation and path analysis related to ascorbic acid content, oleoresin content, color value and capsaicin content are presented in table 2.1, 2.2 & 2.3.

Chapter- III

Materials and Methods

CHAPTER - III

MATERIALS AND METHODS

The present investigation on "**Studies on genetic diversity for yield and quality traits in chilli (*Capsicum annuum* L.)**" was undertaken to study the genetic variability, heritability, genetic advance, character association, path coefficient analysis and genetic divergence. Details pertaining to materials used and methodology employed in the investigation are presented in this chapter.

3.1 LOCATION AND CLIMATE

The experiment was conducted at Horticultural Research Station (HRS) Lam, Guntur. The site of the experiment is situated on 16^0 2’ North latitude and $80^0$3’ East longitude at an altitude of 31.5m above mean sea level. The meteorological data for the period of experimentation was recorded at the meteorological observatory of RARS Lam are presented in the Annexure I.

3.2 EXPERIMENTAL DETAILS

3.2.1 Layout of experiment

The entire germplasm of chilli was laid out in a Randomized Block Design with two replications (Fig 3). Twelve plants of each genotype were transplanted in each replication in one row.

Design	:	Randomized Block Design (RBD)
Number of treatments	:	63
Replications	:	2
Plot size	:	One row of 4 m length
Spacing	:	75 cm x 30 cm
Number plants per row	:	12
Date of transplanting	:	9th September, 2012
Season	:	*Kharif* , 2012-13
Location	:	Horticultural Research Station, Lam farm, Guntur

3.2.2 Experimental material

The experimental material consisted of sixty three genotypes with one check variety LCA-334 obtained from germplasm collection of Horticultural Research Station, Lam farm, Guntur (Table 3)

Table 3: source of the chilli genotypes *(Capsicum annuum* L.*)*

Treatment	Accession Number	Source
$T_{1.}$	G-3	HRS, Lam farm, Guntur
T_2.	G-4	HRS, Lam farm, Guntur
T_3.	G-5	HRS, Lam farm, Guntur
T_4.	LCA-206	HRS, Lam farm, Guntur
$T_{5.}$	LCA-235	HRS, Lam farm, Guntur
T_6.	LCA-305	HRS, Lam farm, Guntur
T_7.	LCA-315	HRS, Lam farm, Guntur
T_8.	LCA-353	HRS, Lam farm, Guntur
$T_{9.}$	LCA-357	HRS, Lam farm, Guntur
T_{10}.	LCA-424	HRS, Lam farm, Guntur
T_{11}.	LCA-436	HRS, Lam farm, Guntur
$T_{12.}$	LCA-620	HRS, Lam farm, Guntur
$T_{13.}$	LCA-625	HRS, Lam farm, Guntur
T_{14}.	LCA-702	HRS, Lam farm, Guntur
T_{15}.	LCA-703	HRS, Lam farm, Guntur
$T_{16.}$	LCA-704	HRS, Lam farm, Guntur
T_{17}.	LCA-705	HRS, Lam farm, Guntur
$T_{18.}$	LCA-706	HRS, Lam farm, Guntur
$T_{19.}$	LCA-707	HRS, Lam farm, Guntur
T_{20}.	LCA-708	HRS, Lam farm, Guntur
T_{21}.	LCA-709	HRS, Lam farm, Guntur
T_{22}.	LCA-710	HRS, Lam farm, Guntur
T_{23}.	LCA-711	HRS, Lam farm, Guntur
T_{24}.	LCA-712	HRS, Lam farm, Guntur
T_{25}.	LCA-713	HRS, Lam farm, Guntur
T_{26}.	LCA-714	HRS, Lam farm, Guntur
T_{27}.	LCA-715	HRS, Lam farm, Guntur

T_{28}.	LCA-716	HRS, Lam farm, Guntur
T_{29}.	LCA-718	HRS, Lam farm, Guntur
T_{30}.	LCA-720	HRS, Lam farm, Guntur
T_{31}.	LCA-722	HRS, Lam farm, Guntur
T_{32}.	LCA-724	HRS, Lam farm, Guntur
T_{33}.	LCA-726	HRS, Lam farm, Guntur
T_{34}.	LCA-728	HRS, Lam farm, Guntur
T_{35}.	LCA-730	HRS, Lam farm, Guntur
T_{36}.	LCA-732	HRS, Lam farm, Guntur
T_{37}.	LCA-734	HRS, Lam farm, Guntur
T_{38}.	LCA-736	HRS, Lam farm, Guntur
T_{39}.	LCA-738	HRS, Lam farm, Guntur
T_{40}.	LCA-740	HRS, Lam farm, Guntur
T_{41}.	LCA-742	HRS, Lam farm, Guntur
T_{42}.	LCA-744	HRS, Lam farm, Guntur
T_{43}.	LCA-746	HRS, Lam farm, Guntur
T_{44}.	LCA-748	HRS, Lam farm, Guntur
T_{45}.	LCA-750	HRS, Lam farm, Guntur
T_{46}.	LCA-752	HRS, Lam farm, Guntur
T_{47}.	LCA-754	HRS, Lam farm, Guntur
T_{48}.	LCA-756	HRS, Lam farm, Guntur
T_{49}.	LCA-758	HRS, Lam farm, Guntur
T_{50}.	LCA-760	HRS, Lam farm, Guntur
T_{51}.	LCA-762	HRS, Lam farm, Guntur
T_{52}.	CA-960	HRS, Lam farm, Guntur
T_{53}.	HC-28	HAU, Hisar
T_{54}.	KT-I	IARI, Katrain
T_{55}.	Aparna	HRS, Lam farm, Guntur
T_{56}.	Pandava	Local collection, Guntur
T_{57}.	Pant C-1	GBPUA&T, Pantnagar
T_{58}.	Phule Jyoti	MPKV, Rahuri
T_{59}.	Punjab Gucchedar	PAU, Ludhiana
T_{60}.	Pusa Sadabahar	IARI, New Delhi
T_{61}.	Super-10	Local collection, Guntur

T_{62}.	Warangal Chapata	Local collection, Warangal
$T_{63.}$	LCA-334	HRS, Lam farm, Guntur

3.3 CULTURAL PRACTICES

3.3.1 Soil:

The soils of the farm are deep, black clay loams with a depth of 6-7feet, p^H of 8.4, EC of 0.16 m.mhos/cm and have good moisture retentive capacity.

3.3.2 Nursery raising:

Nursery beds of 4m x 1m size were prepared after bringing the soil to a fine tilth. Each bed was mixed with 2kg of FYM. The beds were leveled and seeds of 63 accessions were sown in lines at 5cm spacing on July 28th, 2012. Mulching was done with dry paddy straw. Nursery beds were regularly watered. The mulch was removed after germination of seeds and beds were kept free from weeds. As a precaution against "damping off" disease of the seedlings, the beds were drenched with copper oxychloride (3g/l) on 12th and 21st day after sowing. Six weeks old, uniform and healthy seedlings from each accession were transplanted in the main experimental plots.

3.3.3. Preparation of experimental plot

The experimental fields were brought to fine tilth by ploughing thrice followed by harrowing. Before final harrowing, FYM @ 25 tonnes/ha was applied as basal dose and incorporated in the soil. The recommended dose of fertilizers @ 200:60:80 kg NPK/ha in the form of urea, single super phosphate and murate of potash respectively were applied. Entire dose of P was applied as basal while N and K were applied in three equal splits during the crop growth.

3.3.4 Transplanting and after care

Six weeks old seedlings were transplanted to the main field after allotting entries randomly in each replication. The field was irrigated and the seedlings were transplanted by maintaining a spacing of 75cm between the rows and 30cm between the plants with in a row. Immediately after transplanting the field was irrigated lightly. The plots were kept free of weeds and irrigated regularly. Need based plant protection measures were taken up to keep the plot free from pests / diseases and raise a healthy crop.

3.4 OBSERVATIONS RECORDED

Five randomly selected plants from each entry were tagged in each replication for recording observations on different characters as described below and the mean values were calculated.

3.4.1 QUANTITATIVE CHARACTERS

3.4.1.1 Plant height (PH)

Height of the plant was measured from the ground level to tip of the plant in centimeters at the time of harvest.

3.4.1.2 Number of primary branches (NPBP)

The number of branches arising from the main stem above the ground level at final harvest was counted and expressed as number.

3.4.1.3 Days to 50 per cent flowering (DFF)

Number of days taken from the date of transplanting to 50 per cent plants start flowering in a plot was recorded.

3.4.1.4 Fruit set per cent (FSP)

The number of fruits formed from the known tagged flowers was counted and fruit set per cent was worked out using the formula.

$$\text{Fruit set per cent} = \frac{\text{Number of fruits formed}}{\text{Number of flowers tagged}} \times 100$$

3.4.1.5 Number of fruits per plant (NFP)

The total number of fruits per plant at harvest on five randomly selected plants was counted and the mean was calculated.

3.4.1.6 Fruit diameter (FD)

Average diameter of five fruits from five randomly selected plants was measured at the top shoulder and expressed in centimeters.

3.4.1.7 Fruit length (FL)

Average fruit length of five fruits from five randomly selected plants was measured from base to the tip of the fruit and expressed in centimeters.

3.4.1.8 Average dry fruit weight (ADFW)

Average fruit weight of five dry fruits from five randomly selected plants was recorded in grams.

3.4.1.9 Number of seeds per fruit (NSF)

The number of seeds from five fruits from five randomly selected plants was counted and average was worked out.

3.4.1.10 Yield per plant (YP)

The yield in terms of dry fruit weight was recorded in grams on five randomly selected plants and mean was worked out.

3.4.2 MORPHOLOGICAL CHARACTERS

3.4.2.1 Fruit position

The fruit position of the genotype was noted as pendent and erect.

3.4.2.2 Mature green fruit colour

The fruit color of the genotype at mature green stage was noted as green, dark green and parrot green.

3.4.2.3 Fruits per axil

Fruits per axil were noted as solitary and cluster.

3.4.3 QUALITATIVE CHARACTERS

3.4.3.1 Ascorbic acid (mg /100g)

Ascorbic acid content of mature green fruits was estimated by volumetric method described by Sadasivam and Balasubramanian (1987).

Dye solution: 42 mg of sodium bicarbonate was weighed into a 200 ml volumetric flask in distilled water and 52 mg of 2-6 dichlorophenol indophenols was dissolved in it and then the volume was made up with distilled water.

Standard stock solution: Stock solution was prepared by dissolving 100 mg ascorbic acid in 100 ml of 4% oxalic acid solution. 10 ml of stock solution was diluted to 100 ml with 4% oxalic acid to get the working standard of 100 mg per ml.

Procedure

5 ml of the working standard solution was pipetted into a 100 ml of conical flask to which 10 ml of 4% oxalic acid was added. The contents were titrated against the dye (V_1ml) to get a pink end point which persisted for a few minutes. The chilli sample (5 g) was extracted in 4% oxalic acid and the volume was made up to 100 ml and the contents were centrifuged. 5 ml of this supernatant was pipetted out, to which 10 ml of 4 per cent oxalic acid was added and titrated against the dye (V_2 ml). The ascorbic acid content was calculated using the formula given below.

Amount of ascorbic acid (mg/100 g) sample

$$\frac{0.5 \text{ mg}}{V_1} \times \frac{V_2}{5 \text{ ml}} \times \frac{100 \text{ ml}}{\text{Wt. of the sample}} \times 100$$

3.4.3.2 Oleoresin (%)

The oleoresin content was estimated as per the procedure given by Ranganna (1986).

Principle:

Acetone being an organic solvent, dissolves whole content of chillies when passing acetone from chilli powder. Acetone can be evaporated after dissolving by mild heating at 15^{o}C for 15 min to separate oleoresin that can be quantified.

Procedure:

Finely mashed 25g chilli powder was transferred to a glass column, which was plugged by cotton plug on its narrow end. A thin layer of cotton was placed over chilli powder in the glass column and 25 ml of acetone was added. After all the acetone was decanted, 25 ml acetone was added each time till a total of 250 ml acetone was added to the contents. After decantatation, the resulting red colored liquid in beaker contains all the principle constituents of chilli. The collected filtrate was transferred to a 250 ml volumetric flask and the volume was made up with acetone.

The chilli extract was transferred to a 250 ml beaker of known weight (W_I g) and was kept in water bath at 50-60^{o}C for 15-30 minutes so that acetone gets evaporated. Then, weight of the beaker along with contents was recorded as W_2 g. The weight of the oleoresin content in the 25 g chilli powder was calculated and expressed in percentage using the given formula.

$$\text{Oleoresin content (\%)} = \frac{W_2 - W_1}{\text{Weight of sample}} \times 100$$

3.4.3.3 Capsaicin (%)

The capsaicin content of fruits was estimated by colorimetric method described by Balasubramanian *et al.* (1982).

Principle:

The phenolic group in capsaicin reduces phosphomolybdic acid to lower acids of molybdenum. The resulting component is blue in color and is read at 650nm. The color intensity is directly proportional to the concentration of capsaicin.

Chemicals:

- 0.4% sodium hydroxide
- 3% phosphomolybdic acid
- Dry acetone (add 25g anhydrous sodium sulphate to 500ml of acetone at least one day before use)
- Stock standard capsaicin solution (exactly 50mg capsaicin was dissolved in 50ml of 0.4% NaOH solution (1000µg/ ml)) and working standard (10ml of the stock standard was diluted to 50ml with 0.4% NaOH solution (200µg/ ml)).

Procedure:

0.5g dry chilli powder was weighed into glass-stoppard test tube; 10ml dry acetone was added into the test tube and kept overnight for extraction. Next day samples were centrifuged at 10000 rpm for 10min to get clear supernatant. 1ml of the supernatant was taken into a test tube and evaporated to dryness in a hot water bath. Then, the residue was dissolved in 5ml of 0.4% of NaOH solution and 3ml of 3% phosphomolybdic acid was added. The contents were shaken and left undisturbed for 1hr. After 1hr, the solution was quickly filtered into centrifuge tubes to remove any floating debris, and then centrifuged at 5000rpm for 15min. The clear blue coloured solution was directly transferred into the cuvette and absorbance was read at 650nm along with a reagent blank.

Preparation of standard graph: A standard graph was prepared using 0-200µg pure capsaicin. Simultaneously 0.2, 0.4, 0.6, 0.8 and 1ml of working standard solution were taken into new test tubes and proceeded as mentioned above.

Per cent capsaicin calculated using the formula mentioned below

$$\text{Capsaicin content (\%)} = \frac{\mu g \text{ capsaicin X 100 X 100}}{\text{1000000 X 1 X 0.5}}$$

3.4.3.4 Total color value (ASTA units):

Total extractable color of fruits measured in ASTA (American Spice Trade Association) units was determined using the procedure outlined by ASTA (1986).

Procedure:

100mg of sieved fine chilli powder was weighed into a volumetric flask. Acetone was added and flask was closed tightly with stopper, then contents were kept for 16h at room temperature in dark and shaken intermittently. Solution was filtered using Whatman filter paper and final volume was made up to 100ml. Absorbance of final extract was read at 460nm using acetone as blank.

ASTA color units were calculated as per the formula given below,

$$\text{ASTA} = \frac{\text{Absorbance at 460nm X 16.4}}{\text{Weight of sample in g}}$$

3.4.3.5 Determination of yellow and red fractions in chilli powder:

All the carotenoid pigments present in hot pepper have chromophore properties that allow their grouping in two isochromic families *i.e.* red (R) and yellow (Y). The R fraction contains pigments capsanthin, capsorubin and capsanthin-5, 6-epoxide, whereas Y fraction contains remaining pigments such as zeaxanthin, violaxanthin, antheraxanthin, β-cryptoxanthin, β-carotene and cucurbitaxanthin A, which acts as precursors of the former (Minguez and Perez, 1998). Yellow and red fractions were determined using UV-visible spectrophotometric measurements at two characteristic wavelengths and application of Lambert-Beer law for multi-component mixtures according to procedure developed by Hornero-Mendez and Minguez-Mosquera, 2001.

Procedure:

Dried chilli fruits were ground into a fine powder and 100mg of dried powder was extracted four times with 25ml acetone until the complete exhaustion of the color. The extract was filtered and transferred to 50ml volumetric flask and the volume was made up with acetone. The samples absorbance was read at two wavelengths *i.e.*, 472 and 508nm using acetone as blank. The red and yellow fractions were calculated using the following formulae.

$$C^R\ (\mu g/ml) = \frac{A_{508} \times 2144.0 - A_{472} \times 403.3}{270.9}$$

$$C^Y\ (\mu g/ml) = \frac{A_{472} \times 1724.3 - A_{508} \times 2450.1}{270.9}$$

$$\text{Total colour} = C^R + C^Y$$

µg/ml values were converted into percentage on dry weight basis.

3.5 STATISTICAL ANALYSIS:

The data obtained in respect of all the characters have been subjected to the following statistical analysis.

3.5.1 Analysis of variance (ANOVA):

Data were analyzed by the methods outlined by Panse and Sukhatme (1985) using the mean values of random plants in each replication from all genotypes to find out the significance of genotypes effect.

The data for different characters were statistically analysed on the basis of the model suggested by Cochran and Cox (1950) for RBD.

$$Y_{ij} = \mu + b_i + t_j + e_{ij}$$

Where,

Y_{ij} = Performance of the j^{th} genotype in the i^{th} block

μ = general mean

b_i = true effect of i^{th} block

t_j = true effect of j^{th} genotype

e_{ij} = random error associated with i^{th} block and j^{th} genotype.

The analysis of variance for each character was carried out as indicated below:

Sources of variation	Df	SS	MSS	F ratio
Replications	r-1	RSS	RMSS	RMSS/EMSS
Treatments	t-1	T_rSS	T_rMSS	$T_rMSS/EMSS$
Error	(r-1) (t-1)	ESS	EMSS	
Total	(rt-1)	TSS		

Where,

r = Number of replications

t = Number of genotypes or treatments

df = degrees of freedom

SS = sum of squares

MSS = Mean sum of squares

RSS = Replication sum of squares

T_rSS = Treatment sum of squares

ESS = Error sum of squares

TSS = Total sum of squares

RMSS = Mean squares due to replications

T_rMSS = Mean squares due to treatments

EMSS = Mean squares due to error

The test of significance was carried out by 'F' table values given by Fisher and Yates (1963).

3.5.2 Components of variance:

$$\text{Genotypic variance } (V_g \text{ or } \sigma^2 g) = \frac{\text{Genotype MSS-Error MSS}}{r}$$

Error MSS

Environmental variance (V_e or $\sigma^2 e$) = $\frac{\text{--------------------}}{r}$

Where,

r = number of replications

Phenotypic variance (V_p or $\sigma^2 p$) = $V_g + V_e$

Significance of treatment MSS was assessed with reference to F table values at 1 and 5 percent probabilities. Further, computation was carried out only when the treatment effects were significant.

3.5.3 Estimation of genetic parameters

The genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in broad sense and genetic advance for different characters were worked out by following the standard procedures for all the genotypes under study.

3.5.3.1 Genotypic and phenotypic coefficient of variation

Genotypic and phenotypic coefficients of variation were estimated according to Burton and Devane (1953) by using the following formulae.

$$PCV = \frac{\sqrt{\sigma_p^2}}{\bar{X}} \times 100$$

$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{X}} \times 100$$

Where,

σ_g^2 = Genotypic variance

σ_e^2 = Environment variance

σ_p^2 = Phenotypic variance

$\bar{X}$ = General mean

PCV and GCV were classified as shown below (Sivasubramanian and Menon 1973).

Less than 10%	=	Low
10-20%	=	Moderate
More than 20 %	=	High

3.5.3.2 Heritability in Broad sense [h^2 (b)]

Heritability in broad sense was estimated as per the formulae suggested by Allard (1960).

$$h^2 (b) = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Where,

h^2 (b)	=	Heritability estimates in broad sense
σ_g^2	=	Genotypic variance
σ_p^2	=	Phenotypic variance

The heritability (h^2 (b)) was categorised as suggested by Johnson *et al.* (1955).

0-30%	=	Low
31-60%	=	Medium
61% and above	=	High

3.5.3.3 Genetic advance (GA)

This was estimated as per formula proposed by Allard (1960)

$$GA = K x\ \sigma_p \times h^2 (b)$$

Where,

K = Selection differential at 5 per cent selection intensity which accounts to a constant value 2.06

h^2 (b)	=	Heritability in broad sense
σ_p	=	Phenotypic standard deviation

3.5.3.4 Genetic advance as per cent of mean (GAM)

Genetic advance over mean (GAM) was calculated using the following formula and was expressed in percentage.

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

Where,

GA = genetic advance

$\overline{X}$ = general mean of the character

The genetic advance as per cent over mean was categorized as mentioned below (Johnson *et al.*, 1955).

Less than 10%	=	Low
10-20%	=	Moderate
More than 20 %	=	High

3.5.4 Correlation studies

Phenotypic and genotypic correlations were worked out by using formula suggested by Falconer (1964).

Phenotypic coefficient of correlation (r_p)

$$r(x_i.x_j)_p = \frac{COV\ (x_i.x_j)_p}{\sqrt{V\ (x_i)_p\ .\ V\ (x_j)_p}}$$

Where,

$r(x_i.x_j)_p$ = Phenotypic correlation between i^{th} and j^{th} character.

$COV\ (x_i.x_j)_p$ = Phenotypic covariance between i^{th} and j^{th} character.

$V\ (x_i)_p$ = Phenotypic variance of i^{th} character.

$V\ (x_j)_p$ = Phenotypic variance of j^{th} character.

Genotypic coefficient of correlation (r_g)

$$r(x_i.x_j)_g = \frac{COV\ (x_i.x_j)_g}{\sqrt{V\ (x_i)_g\ .\ V\ (x_j)_g}}$$

Where,

$r(x_i.x_j)_g$ = Genotypic correlation between i^{th} and j^{th} character.

$COV\ (x_i.x_j)_g$ = Genotypic covariance between i^{th} and j^{th} character.

$V\ (x_i)_g$ = genotypic variance of i^{th} character.

$V\ (x_j)_g$ = genotypic variance of j^{th} character.

Test of significance

Significance of correlation coefficients was tested by comparing phenotypic correlation coefficients with the table values (Fisher and Yates, 1963) at (n-2) degrees of freedom at 5 % and 1 % level where ‘n' denotes the total number of pairs of observations used in the calculation.

$$t = \frac{r}{\sqrt{1-r^2}} \sqrt{n-2}$$

Where,

t = test of significance

r = correlation coefficient

n = number of paired observations

3.5.5 Path coefficient analysis

The direct and indirect contribution of various characters to yield were calculated through path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). The following simultaneous equations were formed and solved for estimating various direct and indirect effects.

Path coefficients were obtained by solving the following simultaneous equations.

$$r_{ly} = P_{ly} + r_{12}P_{2y} + r_{13} P_{3y} + \dots\dots\dots + r_{lk} P_{ky}$$

Where,

r_{ly} = Simple correlation coefficient between x_1 and y, the dependent character

P_{ly} = Direct effect of x_1 on y, the dependent character

$r_{12}P_{2y}$ = Indirect effect of x_1 on y through x_2.

r_{12} = Correlation coefficient between x_1 and x_2.

$r_{lk}P_{ky}$ = Indirect effect of x_1 only through k^{th} variable.

In the same way, equations for r_{2y}, r_{3y}, r_{4y}, upto r_{ky} were obtained. Besides the direct and indirect effects, the residual effect was computed by using the formula.

Residual effect (Pr_y) = $1-R^2$

Where, $R^2 = P_{ly}r_{ly} + P_{2y}r_{2y} + P_{3y}r_{3y} + \dots\dots\dots\dots P_{iy}r_{iy}$

Pr_y = Residual effect

P_{ly}	=	Direct effect of x_1 on y.
r_{1y}	=	Correlation coefficient of x1 and y
P_{2y}	=	Direct effect of x_2 on y
r_{2y}	=	Correlation coefficient of x_2 and y.
P_{3y}	=	Direct effect of x_3 on y
r_{3y}	=	Correlation coefficient of x_3 and y
P_{iy}	=	Direct effect of x_i on y
r_{jy}	=	Correlation coefficient of x_i and y

Pry = $\sqrt{1 - P_{1y}\, r_{1y} + P_{2y}\, r_{2y} + \ldots\ldots P_{ky}\, r_{ky}}$

Where P_{ry} = residual effect

P_{ly} = direct effect of x_1 only

r_{ly} = correlation coefficient of x_1 only

Scales for path coefficients

Values of direct (or) indirect effects	**Rate (or) scale**
0.00 to 0.09	Negligible
0.10 to 0.19	Low
0.20 to 0.29	Moderate
0.30 to 0.99	High
> 1.00	Very high

3.6.6 Genetic divergence

3.6.6.1 Mahalanobis' D^2 analysis

The data collected on different yield contributing characters was analyzed using Mahalanobis' D^2 analysis to determine the genetic divergence among the genotypes (Mahalanobis, 1936).

3.6.6.1.1 Test of significance

Variances were calculated for all the characters investigated and test of significance was done. Analysis of covariance for the character pairs was estimated on the basis of mean values (Panse and Sukhatme, 1985). After testing the difference between genotypes for each of the characters, a simultaneous test of significance for differences in the mean values of a number of correlated variables with regard to the pooled effect of characters was carried out using 'V' statistic, which in turn utilizes Wilk's criterion. The sum of squares and sum of products of error and error + variety, variance – covariance matrix were used for this purpose. The estimation of Wilk's criterion was done using the following relationship.

$$\wedge = \frac{(E)}{(E+V)}$$

Where,

$\wedge$	=	Wilk's criterion
(E)	=	Determinant of error matrix and
(E+V)	=	Determinant of error + variety matrix
n	=	degree of freedom for error + varieties and

$$\log e^{'\wedge'} \ V_{(Stat)} = -m \log_e^{\wedge} = -\left(n - \frac{P+Q+1}{2}\right) \log_e^{'\wedge'}$$

Where,

m	=	n - (P+Q+1)/2 = 2.3026 log 10 $^{'\wedge'}$
P	=	number of variables (or) characters (16)
Q	=	number of varieties –1 (or d.f.) / (or) populations (62)

$V_{(stat)}$ is distributed as χ^2 with PQ (992) degrees of freedom.

Transformation of correlated variables

In the present model computation of D^2 values were reduced to simple summation of the differences in the mean values of various characters of the two genotypes *i.e.,* $\sum d^2_i$. Therefore transformation of the correlated variables into uncorrelated ones was done before working out the D^2 values. Transformation was done using pivotal condensation method.

3.6.6.1.2 Computation of D^2 values

For the given combination of i and j genotypes, the mean deviation *i.e.,* Y_{it}-Y_{jt} for t=1, 2…p variables are computed and the D^2 values were calculated as

$$D^2_{ij} = \sum_{t=1} (Y_i^t - Y_j^t)^2$$

Where,

Y_i^t is uncorrelated mean value of ith genotype for character 't'

Y_j^t is uncorrelated mean value of jth genotype for character 't'

D^2_{ij} is D^2 between ith and jth genotypes.

3.6.6.1.3 Testing the significance of D^2 values

The D^2 value obtained for a pair of population is taken as calculated value of χ^2 and is tested against the tabulated value of χ^2 for P degrees of freedom where P is the number of characters considered.

3.6.6.1.4 Contribution of individual characters towards divergence

The character contribution towards genetic divergence was computed using the method given by Singh and Chaudhary (1977). In all combinations, each character was ranked on the basis of their contribution towards divergence between two entries ($d_i=Y_{it}-Y_{jt}$).

Where, di = mean deviation

y_i^j = mean value of the jth genotype for the ith character and

y_i^k = mean value of the kth genotype for the ith character.

Rank 1 is given to the highest mean difference and the rank P to the lowest difference, where, P is the total number of characters.

Percentage contribution towards genetic divergence was calculated using the following formula.

$$\text{Percentage contribution of the character} = x = \frac{N \times 100}{M}$$

Where,

N = Number of genotype combinations where the character was ranked first.

M = All possible combinations of number of genotypes considered.

3.6.6.1.5 Grouping of genotypes into various clusters

The grouping of genotypes into different clusters was done using the Tocher's method as described by Rao (1952). The criterion was that the two varieties belonging to the same cluster at least on an average show a smaller D^2 value than those belonging to different clusters. For this purpose D^2 values of all combinations of each genotype were arranged in ascending order of magnitude in a tabular form as described by Singh and Chaudhary (1977).

To start with, two populations having the closest distance from each other were considered, to which the third population having the smallest D^2 value from the first two populations was added. Similarly, the next nearest fourth population was considered and this procedure was continued. At certain stage when it was felt that after adding a particular population there was an abrupt increase in the average D^2, that population was not considered for including in that cluster.

The genotypes of the first cluster were then eliminated and the rest were treated in a similar way. This procedure was continued till all the genotypes were included into one or other cluster.

3.6.6.1.6 Average intra- cluster distance

The average intra- cluster distances were calculated by the formula given by Singh and Chaudhary (1977).

Square of intra- cluster distance = $\Sigma Di^2 / n$

Where, ΣDi^2 = Sum of distance between all possible combinations.

n = Number of all possible combinations

3.6.6.1.7 Average inter-cluster distance

The average inter-cluster distances were calculated by the formula described by Singh and Chaudhary (1977).

Square of inter- cluster distance = $\Sigma Di^2 / n_i n_j$

Where,

ΣDi^2 = Sum of distances between all possible combinations ($n_i n_j$) of the entries included in the cluster study.

n_i = Number of entries in cluster i

n_j = Number of entries in cluster j

3.6.6.2 Principal component analysis and cluster analysis

Principal component analysis was carried according to procedure described by Banfield (1978). PCA can be performed on two types of data matrices *viz.,* variance-covariance matrix and correlation matrix. With characters of different scale a correlation matrix standardizing the original data set is preferred. If the characters are of same scale, a variance – covariance matrix can be used. In the present study, PCA was performed on the correlation matrix of traits, thereby removing the effects of scale (Jackson, 1991).

3.6.6.2.1 Eigen values and eigen vectors

The eigen values and eigen vectors were computed from data matrix. Eigen values define the amount of total variation that is displayed on principal components. The proportion of variation accounted for each principal component (PC) is expressed as the eigen value divided by the sum of the eigen values.

$$\text{Per cent variance explained for } PC_1 = \frac{\text{Eigen value } (PC_1)}{\text{Sum of eigen values}}$$

The eigen vector (loading) defines the correlation of each variable with the principal components.

The principal components were identified by following procedure.

The j^{th} principal component (Y_j) of the observations X is the linear combination given as follows:

$$Y_j = A_{1j}X_1 + \ldots\ldots\ldots\ldots + A_{pj}X_p$$

Where,

A_{ij} are found such that Y_j is uncorrelated Y_1, $Y_{2}, \ldots\ldots\ldots Y_{j-1}$ the j^{th} largest variance. The A_{ij} are the elements of the normalized eigen vector associated with largest j^{th} eigen value. The variance of the j^{th} principal component of the λ_j and the total system variance trace (S) = $\lambda_1 + \lambda_2 + \ldots + \lambda_p$.

The importance of the j^{th} principal component is given by

$$\frac{\lambda_j}{\text{Trace (S)}}$$

This is informative about the proportion of total variation that can be accounted for the i[th] principal component. The correlation between the i[th] original variable X_i and the jth principal component Y_j is given by

$$\rho(Xi, Y_j) = A_{ij} \frac{\sqrt{\lambda_j}}{\sqrt{S_i}}$$

Where S_i is the standard deviation of X_i.

Thus, a principal component is linear function of the test variables given as follows

Principal component = $ax_1 + bx_2 + \ldots\ldots\ldots + hx_8$

Where, a,b,…. are coefficients and x_1, x_2 ….. etc., are the variables in such a way that the principal component has a unit variance as reported by Ehrenberg (1985).

PCA scores for each genotype under concerned PCs were computed and utilized to derive a 2D or 3D (dimensional) scatter plot of individuals.

3.6.6.2.2 Cluster analysis

Agglomerative hierarchical clustering technique was followed as given by Anderberg (1993).

3.6.6.2.2.1. Obtaining data matrix

PCA scores for 63 genotypes were used as input for clustering because principal component analysis provides variable independence and balanced weighting of traits, which leads to an effective contribution of different characters on the basis of respective variation.

3.6.6.2.2.2. Standardizing the data matrix

To compare the similarities among the genotypes the data matrix was standardized with a column standardizing function *i.e.*, Q analysis. The data matrix is standardize in cluster analysis to make the characters contribute more equally to the similarities among genotypes and to nullify the arbitrarily affect the units chosen for measuring the attributes among the genotypes.

Column standardizing function CA-Q analysis was carried by the following formula.

$$Z_{ij} = \frac{\overline{X}_{ij} - \overline{X}_j}{s_{ij}}$$

Where $\overline{X}_j = \sum_{i=1}^{n} X_{ij} / n$

$$S_{ij} = \sum_{i=1}^{n} \frac{X_{ij} - X_j / n}{n-1}$$

For

i= genotypes *i.e.*, 63

j = total variables *i.e.*,16

The resulting data after standardization is unit less and have mean zero and variance one.

3.6.6.2.2.3. Computing the resemblance matrix

A resemblance coefficient, which measures the overall resemblance (the degree of similarity or distance) between a pair of genotypes, was computed. Here 63 genotypes were taken in data matrix therefore resemblance coefficient was computed for a total of 1953 combinations *i.e.*, ${}^{63}C_2$ ways. The data matrix was transformed to distance matrix (resemblance matrix) based on the dissimilarity coefficients using squared Euclidean distance method.

$$\text{Squared Euclidean distance } [d_{ij}] = \sum_{K=1}^{P} (X_{ik} - X_{jk})^2$$

Where,

P = Number of genotypes *i.e.*,63

X_{ik} = Value of i^{th} genotype for k PCA scores

X_{jk} = Value of j^{th} genotype for k PCA scores

3.6.6.2.2.4 Execution of the clustering method

Distance matrix was converted into dendrogram by using Ward's method where the distance between two clusters is the sum of squares between two clusters summed over all variables. At each stage in the clustering procedure within cluster sum of squares is minimized over all partitions obtained by combining 2 clusters from previous stage.

3.6.6.2.3 Complete linkage diagram

This was one of the hierarchical methods as classified by Everitt (1974), starts with the computation of the 'distance' or similarities of each individual with every other individual. A comparison of such similarity coefficients among the pairs of individuals or objects finally leads to a tree diagram, referred as ‘Dendrogram’. For the dendrogram, the clusters of homogeneous units can be identified.

Sorenson (1948) first developed the method, complete linkage dendrogram. This method was based on the distance matrix D.

Chapter-IV

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

A systematic study was conducted to study the variability, heritability, genetic advance, character association, path coefficient analysis and genetic divergence at Horticultural Research Station, Lam, Guntur, A. P. The results obtained are presented under the following headings.

- Analysis of variance
- Morphological characters of chilli genotypes
- Mean performance of genotypes
- Variability, heritability and genetic advance as per cent of mean
- Character association analysis
- Path coefficient analysis
- Genetic diversity

4.1 ANALYSIS OF VARIANCE

The analysis of variance (Table 4.1) revealed significant differences among the genotypes for all the 16 characters studied indicating the presence of genetic variability among them. These results are in conformity with earlier reports of Vani *et al*. (2007), Farhad *et al.* (2008), Jyothi *et al.* (2008), Tembhurne *et al.* (2008), Gupta *et al*. (2009), Kumari *et al*. (2010), Berhanu *et al*. (2011), Kumar *et al*. (2012) and Lakshmi and Padma (2012) in chilli.

4.2 MORPHOLOGICAL CHARACTERS OF CHILLI GENOTYPES

Morphological characters like fruit position, mature green fruit color and number of fruits per axil of all accessions are given in table 4.2.

4.2.1 Fruit position

All the 63 genotypes, based on fruit position were divided into two groups *viz.*, Pendent and Erect. Among them, maximum number of genotypes had pendent fruits while only nine (HC-28, LCA-714, LCA-724, LCA-756, LCA-760, Pant C-1, Punjab Gucchedar, Pusa Sadabahar and Pandava) produced erect fruits. These results are similar to those reported by Arup *et al*. (2011) who also reported maximum genotypes with pendent fruits.

4.2.2 Mature green fruit colour

Based on immature fruit colour, the 63 genotypes were divided into three groups *viz.,* Green, Parrot Green and Dark Green. Among them, maximum genotypes had green fruits and eleven of them (HC-28, LCA-334, LCA-353, LCA-620, LCA-706, LCA-712, LCA-715, LCA-716, LCA-726, LCA-748 and Punjab Gucchedar) had parrot green fruits while only five (LCA-315, LCA-357, LCA-436, LCA-709 and LCA-762) had dark green fruits and the results are in line with similar observations recorded by Arup *et al*. (2011).

4.2.3 Fruits per axil

The genotypes, based on fruits per axil were divided into two groups *viz.,* Solitary and Cluster. Among them, maximum genotypes produced solitary fruits except HC-28, LCA-710, LCA-714, LCA-724, LCA-756, LCA-758, LCA-760, Phule Jyoti, Punjab Gucchedar, Pusa Sadabahar and Pandava which had cluster bearing habit.

4.3 MEAN PERFORMANCE OF GENOTYPES

The data on the mean performance, which was recorded for ten quantitative and six qualitative characters, are presented in table 4.3 and 4.4.

4.3.1 Plant height (cm)

The plant height ranged from 49.95cm to 127.75cm with a mean of 87.17 cm. The genotype LCA-720 recorded maximum plant height (127.75cm) followed by LCA-707 (117.30cm) while the genotype LCA-305 recorded the minimum plant height (49.95cm).

4.3.2 Number of primary branches per plant

The number of primary branches per plant was in the range of 2.3 to 5.3 with a mean of 3.61. The genotypes, Pusa Sadabahar and Pandava recorded the highest number of primary branches (5.3) followed by LCA-710 (5.2), while the lowest was observed for LCA-708 (2.3).

4.3.3 Days to 50 per cent flowering

Days to 50 per cent flowering ranged from 24 to 42 with a mean of 31.42 days. The genotype HC-28 recorded maximum no. of days to 50 per cent flowering (42) followed by LCA-756 (39), while LCA-709 (24) and Pusa Sadabahar (25.50) were the earliest to flower.

4.3.4 Fruit set per cent

The fruit set per cent varied from 17 to 87 with a mean of 50.50. The maximum fruit set per cent was observed for LCA-746 (87) followed by LCA-720 (78.5) and LCA-353 (78), where as the minimum per cent was recorded G-3 (17) preceded by LCA-728 (18) and LCA-707 (19).

4.3.5 Number of fruits per plant

The number of fruits per plant ranged from 49.8 to 480 with a mean of 172.48. This trait exhibited maximum mean value for the genotype LCA-706 (480) followed by LCA-625 (334.30) while the minimum mean value was recorded for Warangal Chapatta (49.8) preceded by LCA-707 (71.90).

4.3.6 Fruit diameter (cm)

The range of fruit diameter varied from 0.76cm to 3.17cm with a mean of 1.35 cm. The maximum diameter was recorded by the genotype Warangal Chapatta (3.17cm) followed by LCA-702 (2.12cm) and LCA-708 (2.04cm), whereas the minimum diameter was recorded by LCA-756 (0.76cm) preceded by LCA-724 (0.82cm).

4.3.7 Fruit length (cm)

The fruit length had the range of 4.06cm to 12.97cm with a mean of 8.65cm. The maximum fruit length was observed for the genotype LCA-740 (12.97cm) followed by KT-1(11.83cm) and LCA-742 (11.81cm) while the minimum was recorded by Pant C-1 (4.06cm) preceded by G-5 (4.66cm) and HC-28 (4.89cm).

4.3.8 Average dry fruit weight (g)

The range of this character varied from 0.5g to 3.35g with a mean of 1.09g. The maximum fruit weight was noticed in Warangal Chapatta (3.35g) followed by

LCA-720 (1.93g) and LCA-702 (1.86g) and the minimum was in LCA-756 (0.50g) preceded by Punjab Gucchedar (0.51g), LCA-710 (0.54g) and LCA-714 (0.55g).

4.3.9 Number of seeds per fruit

The number of seeds per fruit ranged from 32.8 to 152.5 with a mean of 61.36. The highest mean performance for this trait was recorded for genotype the Warangal Chapatta (152.5) followed by LCA-762 (93.30) whereas the lowest for LCA-712 (32.8) preceded by LCA-758 (35).

4.3.10 Yield per plant

The range of this character varied from 83.95g to 295.10g with a mean of 146.82g. The maximum mean performance was observed for genotype LCA-625 (295.10g) followed by LCA-620 (249.93g) and LCA-722 (244.24g) while the minimum value was observed for LCA-707 (83.95g) preceded by CA-960 (92.77g).

4.3.11 Ascorbic acid (mg/100g)

The ascorbic acid content of fruits ranged from 43.99 to 223.22 with a mean of 114.59. The highest ascorbic acid content was recorded for the genotype Aparna (223.22) followed by LCA-732 (221.71) while the lowest was observed in Phule Jyoti (43.99) preceded by LCA-742 (44.56).

4.3.12 Oleoresin (%)

The oleoresin content ranged from 5.17 to 12.31 with a mean of 8.82 per cent. The highest oleoresin content was recorded by the genotype LCA-724 (12.31) followed by LCA-714 (12.15) while the lowest was observed in Pandava (5.17) preceded by KT-1(5.85) and Aparna (5.96).

4.3.13 Capsaicin (%)

The capsaicin content ranged from 0.14 to 0.64 with a mean of 0.31 per cent. The highest capsaicin content was recorded by the genotype Pusa Sadabahar (0.64) followed by HC-28 and LCA-714 (0.50) while the lowest was observed in G-4 (0.14) preceded by LCA-436 and LCA-748 (0.16).

4.3.14 Total colour value (ASTA units)

The total colour value ranged from 20.58 to 128 with a mean of 74.90 ASTA units. The highest colour value was recorded for the genotype LCA-713 (128) followed LCA-357 (124.23) and the lowest was observed by Aparna (20.58) preceded by G-3 (30.09) and CA-960 (33.21).

4.3.15 Red carotenoids (%)

The range of this character varied from 0.005 to 0.22 with a mean of 0.12 per cent. The maximum per cent was observed for genotypes LCA-357 and KT-1 (0.22) followed by LCA-728 and LCA-713 (0.20) while the minimum per cent was recorded for Aparna (0.005) preceded by Warangal Chapatta (0.04).

4.3.16 Yellow carotenoids (%)

The range of this character varied from 0.01 to 0.15 with a mean of 0.07 per cent. The maximum per cent was observed for the genotype HC-28 (0.15) closely followed by LCA-357, LCA-713 and LCA-738 (0.14) while the minimum per cent was recorded for LCA-724 and LCA-620 (0.01) preceded by LCA-726 (0.02).

In the present study, a high range of variability was observed for all the characters. It was maximum for number of fruits per plant (49.8 to 480) and minimum for yellow carotenoids (0.01 to 0.15). The characters showing wide range of variation provide an ample scope for selecting desired types. These results are in accordance with those reported by earlier workers like Vani *et al*. (2007), Farhad *et al.* (2008), Jyothi *et al.* (2008), Gupta *et al*. (2009), Thul *et al*. (2009), Kumari *et al*. (2010), Kumar *et al*. (2012), Lakshmi and Padma (2012) and Naresh *et al.* (2013). These findings suggest that it is possible to isolate superior genotypes during the selection process.

4.4 VARIABILITY, HERITABILITY AND GENETIC ADVANCE AS PER CENT OF MEAN

In the present investigation estimates of mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in broad sense ($h^2_{(b)}$) and genetic advance as per cent of mean (GAM) were calculated and are presented in table 4.5 and described character-wise here under.

~~4.4.1 Plant height (cm)~~

The observed PCV and GCV were moderate with 19.98 per cent and 18.49 per cent respectively. High heritability (85.65%) coupled with high genetic advance as per cent of mean (35.25 %) was recorded for this character. These results are in agreement with the findings of Smitha and Basvaraja (2007), Gupta *et al*. (2009), Kumar *et al*. (2010), Kumari *et al*. (2010), Munshi *et al*. (2010), Kumar *et al*. (2012), Nehru *et al*. (2012) and Lakshmi and Padma (2012).

4.4.2 Number of primary branches per plant

The estimates of PCV and GCV were high and moderate with 22.64 per cent and 18.55 per cent respectively. High heritability (67.11%) coupled with high genetic advance as per cent of mean (31.30%) was recorded for this trait also. These results are in conformity with those reported by Manju and Sreelathakumary (2002), Singh *et al.* (2005), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Kumar *et al*. (2010) and Munshi *et al*. (2010)

4.4.3 Days to 50 per cent flowering

The observed PCV and GCV were moderate with 12.19 per cent and 10.42 per cent respectively. The heritability recorded was high (73.08 %) coupled with moderate genetic advance as per cent of mean (18.36%) for this character indicating the operation of both additive and non-additive gene action and further improvement of this character would be easier through mass selection, progeny selection or any modified selection procedure aiming to exploit the additive gene effects rather than simple selection. Similar results are also reported by Ajit and Manju (2006), Bendale *et al.* (2006), Bharadwaj *et al*. (2007), Kumar (2008), Tembhurne *et al.* (2008) and Kumari *et al*. (2010).

4.4.4 Fruit set per cent

The estimates of PCV and GCV were high with 32.56 per cent and 30.11 per cent respectively. High heritability (85.50%) coupled with high genetic advance as per cent of mean (57.36%) was recorded for this trait. These results are in conformity with reports of Krishna *et al*. (2007).

4.4.5 Number of fruits per plant

The estimates of PCV and GCV were recorded with 40.50 per cent and 37.77 per cent respectively. The heritability (87.00 %) as well as genetic advance as per cent of mean (72.58 %) for this trait were also high. These results are in agreement with those reported by many earlier workers *viz.*, Farhad *et al.* (2008), Tembhurne *et al.* (2008), Gupta *et al*. (2009), Kumari *et al*. (2010), Padhar and Zaveri (2010), Munshi *et al*. (2010), Arup *et al.* (2011), Kumar *et al*. (2012) and Lakshmi and Padma (2012).

4.4.6 Fruit diameter (cm)

The estimates of PCV and GCV were high with 27.52 per cent and 27.44 per cent respectively. High heritability (99.50%) coupled with high genetic advance as per cent of mean (56.39%) was recorded for this trait. These findings are in agreement with reported by Bendale *et al.* (2006), Dutonde *et al.* (2006), Bharadwaj *et al*. (2007), Krishna *et al*. (2007), Smitha and Basvaraja (2007), Tembhurne *et al.* (2008), Singh *et al.* (2009), Gupta *et al*. (2009) and Kumar *et al*. (2012).

4.4.7 Fruit length (cm)

The estimates of PCV and GCV were high and moderate with 20.42 per cent and 19.64 per cent respectively. The heritability (92.48%) and the genetic advance as per cent of mean (38.92%) were also high for this trait. Similar results are reported by Kashinath (2003), Farhad *et al.* (2008), Tembhurne *et al.* (2008), Gupta *et al*. (2009), Singh *et al*. (2009), Kumari *et al*. (2010), Padhar and Zaveri (2010) and Berhanu *et al.* (2011), Kumar *et al*. (2012) and Lakshmi and Padma (2012).

4.4.8 Average dry fruit weight (g)

The estimates of PCV and GCV were high with 40.75 per cent and 37.77 per cent respectively. The high heritability (85.92 %) coupled with high genetic advance as per cent of mean (72.11%) was recorded for this trait indicating the preponderance of additive gene action making selection effective. These results are in conformity with those reported by Prabhakaran *et al*. (2004), Sreelathakumary and Rajamony (2004), Sood *et al.* (2006), Shirshat *et al*. (2007), Farhad *et al.* (2008), Gupta *et al*. (2009), Singh *et al*. (2009) and Kumar *et al*. (2012).

4.4.9 Number of seeds per fruit

The estimates of PCV and GCV were high with 29.61 per cent and 25.76 per cent respectively. The high heritability (75.68 %) coupled with high genetic advance as per cent of mean (46.17 %) recorded for this trait indicated the preponderance of additive gene action. Similar results are reported by Rao (2005), Singh *et al.* (2005), Bendale *et al.* (2006), Shirshat *et al*. (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Kumari *et al*. (2010) and Arup *et al.* (2011).

4.4.10 Yield per plant

The estimates of PCV and GCV were high with 30.81 per cent and 26.43 per cent respectively. The heritability (73.54 %) as well as genetic advance as per cent of mean (46.69 %) were high for this trait. These results are in agreement with those reported by many earlier workers *viz*., Bharadwaj *et al*. (2007), Vani *et al*. (2007), Farhad *et al.* (2008), Gupta *et al*. (2009), Singh *et al*. (2009), Kumari *et al*. (2010), Padhar and Zaveri (2010), Arup *et al.* (2011) and Kumar *et al*. (2012).

4.4.11 Ascorbic acid (mg/100g)

The estimates of PCV and GCV were high with 41.05 per cent and 40.11 per cent respectively. High heritability (95.44%) coupled with high genetic advance as per cent of mean (80.73%) recorded for this trait. Similar results are reported from earlier works of Manju and Sreelathakumary (2002), Mishra *et al.* (2005), Shirshat *et al*. (2007), Singh *et al*. (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008) and Arup *et al.* (2011).

4.4.12 Oleoresin (%)

The estimates of PCV and GCV were high and moderate with 20.71 per cent and 18.85 per cent respectively. Contrary to the present findings, Manju and Sreelathakumary (2002), Singh *et al*. (2009), Kumari *et al*. (2010) and Kumar *et al*. (2012) have observed high GCV in respect of oleoresin content.

High heritability (82.83%) coupled with high genetic advance as per cent of mean (35.35%) was recorded for this trait also. Similar results are reported by Mallikarjun (2001), Manju and Sreelathakumary (2002), Singh *et al*. (2009) and Kumari *et al*. (2010).

4.4.13 Capsaicin (%)

The estimates of PCV and GCV were high with 33.85 per cent and 32.92 per cent respectively. The heritability (91.66 %) and the genetic advance as per cent of mean (65.97%) recorded for this trait were high. Similar results are observed by Manju and Sreelathakumary (2002), Prabhakaran *et al*. (2004), Bharadwaj *et al*. (2007), Gupta *et al*. (2009), Singh *et al*. (2009), Kumari *et al*. (2010) and Kumar *et al*. (2012).

4.4.14 Total colour value (ASTA units)

The estimates of PCV and GCV were high with 33.61 per cent and 32.72 per cent respectively. High heritability (94.80 %) coupled with high genetic advance as per cent of mean (65.64 %) was recorded for this trait indicating the preponderance of additive gene action making selection effective. These results are in agreement with the earlier reports of Mallikarjun (2001), Khurana *et al*. (2003), Singh *et al*. (2007), Gupta *et al*. (2009), Kumari *et al*. (2010) and Naresh *et al*. (2013).

4.4.15 Red carotenoids (%)

The estimates of PCV and GCV were high with 33.06 per cent and 32.59 per cent respectively. The heritability (97.20 %) as well as genetic advance as per cent of mean (66.19%) were high for this trait. These results are in agreement with the findings of Naresh *et al*. (2013) who also reported high PCV and GCV for this trait.

4.4.16 Yellow carotenoids (%)

The estimates of PCV and GCV were high with 44.93 per cent and 44.23 per cent respectively. High heritability (96.90%) coupled with high genetic advance as per cent of mean (89.71%) was recorded for this trait and these findings are in agreement with those reported by Naresh *et al*. (2013).

As indicated by the results on variability and heritability, the estimates of phenotypic variance were higher than the corresponding genotypic variance for all the characters studied indicating the influence of environment in the expression of these traits. Since these estimates alone do not provide means to assess the nature of genetic variability, the phenotypic and genotypic coefficients of variation are also estimated to draw conclusions. In the present study, the PCV was significantly higher than GCV for all the traits. It is obvious because PCV includes variability due to genotype and genotype and environment interaction.

The difference between the phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) was found to be narrow for fruit diameter, fruit length, ascorbic acid, capsaicin, total colour value, red carotenoids and yellow carotenoids suggesting that these traits were least affected by the environment and selection for these traits based on phenotypic would be rewarding. The difference between PCV and GCV was found wide for rest of the characters indicating that the apparent variation was not only due to genotypes but also due to influence of environment.

High heritability coupled with high genetic advance as per cent of mean was recorded for all the characters except days to 50 per cent flowering indicating the preponderance of additive gene action making the selection more effective. However, operation of both additive and non-additive gene action was indicated for days to 50 per cent flowering through moderate genetic advance. Further improvement of this character would be easier through mass selection, progeny selection or any modified selection procedure aiming to exploit the additive gene effects rather than simple selection.

Similar observations made by Khurana *et al*. (2003), Singh *et al*. (2005), Krishna *et al.* (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Gupta *et al*. (2009), Arup *et al.* (2011), Kumar *et al*. (2012), Laxmi and Padma (2012) and Naresh *et al*. (2013) who also suggested selection based on phenotypic characters which are less influenced by environment.

4.5 CHARACTER ASSOCIATION ANALYSIS

In the present investigation, phenotypic and genotypic correlation coefficients between dry fruit yield per plant and other related component characters and among themselves were estimated and are presented in table 4.6 and 4.7.

4.5.1 Character association analysis among ten quantitative characters

4.5.1.1 Plant height (cm)

Plant height showed significant and positive correlation with fruit length (0.2452** and 0.2839**), average dry fruit weight (0.2415** and 0.2545**), number of seeds per fruit (0.3031** and 0.3769**) and yield per plant (0.3599** and 0.3936**) at both phenotypic and genotypic levels, where increase in one character will lead to increase in second and *vice verse* and indicating simultaneous selection for these traits is possible. Plant height showed significant and positive correlation with number of fruits per plant (0.1915*) at phenotypic level indicating that the apparent association of this character with number of fruits per plant is not only due to genes but also due to favourable influence of environment. Similar results are also reported by Khurana *et al*. (2003), Ajjappalavara *et al*.(2005), Rao *et al*.(2005), Khader and mini (2006), Krishna *et al*. (2007), Reddy *et al.* (2008), Tembhurne *et al.* (2008), Jabeen *et al.* (2009)

4.5.1.2 Number of primary branches per plant

At both phenotypic and genotypic levels this trait showed significant and negative association with fruit diameter (-0.3298** and -0.4046**), average dry fruit weight (-0.3480** and -0.4602**) and number of seeds per fruit (-0.2018** and -0.3627**), where increase in one variable cause decrease in another variable and *vice verse* and indicating simultaneous selection for these traits is possible. At both phenotypic and genotypic levels, this trait showed positive and non- significant association with yield per plant (0.0369 and 0.0041) which clearly indicated the independent nature of these two characters and selection for dry fruit yield based on number of primary branches per plant is not reliable. Similar findings are noticed by Acharya and Rajput (2003), Rao *et al*. (2005) and Tembhurne *et al.* (2008).

4.5.1.3 Days to 50 per cent flowering

At both phenotypic and genotypic levels this trait showed negative and non-significant association with yield per plant (-0.1402 and -0.1358) clearly indicating the independent nature of these two characters and selection for dry fruit yield based on days to 50% flowering is not reliable. These findings are in agreement with those reported by Acharya and Rajput (2003), Choudary and Samadia (2004), Farhad *et al.* (2008), Reddy *et al.* (2008) and Hasanuzzaman and Faruq (2011).

4.5.1.4 Fruit set per cent

Fruit set per cent showed significant and positive association with yield per plant (0.3526** and 0.4537**) at both phenotypic and genotypic levels and indicating that selection for yield per plant based on fruit set per cent is beneficial. This trait showed significant and positive association with number of fruits per plant (0.1811*) at genotypic level indicating that there is strong association between these two traits genetically, where the phenotypic value is lessened by significant interaction of environment. Similar results are reported by Krishna *et al.* (2006) and Krishna *et al.* (2007).

4.5.1.5 Number of fruits per plant

This trait showed significant and positive association with yield per plant (0.5886 ** and 0.6175**) at both phenotypic and genotypic levels suggesting selection for yield based on number of fruits per plant is beneficial. The fruit number had significant and positive association with fruit set per cent (0.1811*) at genotypic level indicating that there is strong association between these two traits genetically where the phenotypic value is lessened by significant interaction of environment. The fruit number also had significant and positive association with plant height (0.1915*) at phenotypic level indicating that the apparent association of this character with plant height is not only due to genes but also due to favourable influence of environment. At both phenotypic and genotypic levels this trait showed significant and negative association with fruit diameter (-0.5058** and -0.5418**), average dry fruit weight (-0.4382 ** and -0.4841**) indicating that simultaneous selection for fruit number, fruit diameter and fruit weight is not possible. Similar association of these characters with yield were noticed by Farhad *et al.* (2008), Reddy *et al*. (2008), Tembhurne *et al*. (2008), Gupta *et al.* (2009), Jabeen *et al*. (2009), Patel *et al*. (2009), Singh *et al*. (2009), Arup *et al*. (2011), Hasanuzzaman and Faruq (2011), Singh and Singh (2011), Kumar *et al*. (2012) and Lahbib *et al*. (2012).

4.5.1.6 Fruit diameter (cm)

At both phenotypic and genotypic levels this trait showed significant and positive association with average dry fruit weight (0.8024** and 0.8587**) and number of seeds per fruit (0.6015** and 0.6917**) indicating that simultaneous selection of these traits is possible. These findings are in conformity with the previous reports of Choudary and Samadia (2004), Jabeen *et al*. (2009), Cankaya *et al*. (2010), Hasanuzzaman and Faruq (2011) and Kumar *et al*. (2012). The fruit diameter showed significant and negative association with number of primary branches per plant (-0.3298** and -0.4046**) and number of fruits per plant (-0.5058** and -0.5418**) at both phenotypic and genotypic levels indicating that simultaneous selection of these traits is not possible. This trait showed significant and negative association with yield per plant (-0.1861*) at genotypic level indicating that there is strong association between these two traits genetically, where the phenotypic value is lessened by significant interaction of environment. These findings are in conformity with the previous reports of Rao *et al.* (2005) and Ajjappalavara *et al*. (2005).

4.5.1.7 Fruit length (cm)

This trait showed significant and positive correlation with plant height (0.2415** and 0.2839**) and average dry fruit weight (0.2371** and 0.2545**) at both phenotypic and genotypic levels indicating that simultaneous improvement of these traits is possible. At genotypic level, it showed significant positive association with yield per plant (0.1988*) indicating strong association between these two characters genetically, but the phenotypic value is lessened by significant interaction of environment. These results are in accordance with the findings of Farhad *et al*. (2008), Hosamani and Shivkumar (2008), Gupta *et al.* (2009), Patel *et al*. (2009), Cankaya *et al*. (2010), Hasanuzzaman and Faruq (2011), Singh and Singh (2011), Kumar *et al*. (2012) and Lahbib *et al*. (2012).

4.5.1.8 Average dry fruit weight (g)

At both phenotypic and genotypic levels this trait showed significant and positive association with plant height (0.2415** and 0.2545**), fruit diameter (0.8024** and 0.8587**), fruit length (0.2371** and 0.2545**) and number of seeds per fruit (0.6944** and 0.8301**). At both phenotypic and genotypic levels, this trait showed significant and negative association with number of primary branches (-0.3480** and -0.4602**) and number of fruits per plant (-0.4382** and -0.4841**) indicating that simultaneous selection of these traits is not possible. At both phenotypic and genotypic levels fruit weight showed positive and non- significant association with yield per plant (0.0714 and 0.0589) which clearly indicated the independent nature of two characters and selection for high dry fruit yield based on average dry fruit weight is not reliable. These results corroborate with the findings of Farhad *et al*. (2008), Tembhurne *et al*. (2008), Gupta *et al.* (2009), Cankaya *et al*. (2010), Hasanuzzaman and Faruq (2011) and Kumar *et al*. (2012).

4.5.1.9 Number of seeds per fruit

At both phenotypic and genotypic levels this trait showed significant and positive association with plant height (0.3031** and 0.3769**), fruit diameter (0.6015** and 0.6917**), average dry fruit weight (0.6944** and 0.8301**) and yield per plant (0.1968* and 0.2473**) indicating that simultaneous selection of these traits is possible. This trait showed significant and negative association with number of primary branches (-0.2018* and -0.3627**) at both phenotypic and genotypic levels indicating that simultaneous selection of these traits is not possible. These findings suggested that selection for yield per plant based on number of seeds per fruit is beneficial. These findings are in conformity with the previous reports of Begum (2002), Choudary and Samadia (2004), Rao *et al*.(2005), Vani *et al*. (2007), Farhad *et al*. (2008).

4.5.1.10 Yield per plant (g)

This trait showed significant and positive association with plant height (0.3599** and 0.3936**), fruit set per cent (0.3526** and 0.4537**), number of fruits per plant (0.5886** and 0.6175**) and number of seeds per fruit (0.1968* and 0.2473**) at both phenotypic and genotypic levels. Since most of the important morphological parameters are showing strong significant positive association with dry fruit yield per plant rational improvement in yield is possible through simultaneous selection for these component characters. The yield per plant had significant and positive association with fruit length (0.1988*) and significant and negative association with fruit diameter (-0.1861*) at genotypic level indicating that there is strong association between these characters with dry fruit yield per plant genetically, where the phenotypic value is lessened by significant interaction of environment. These results are in accordance with earlier observations of Farhad *et al*. (2008), Reddy *et al*. (2008), Gupta *et al.* (2009), Jabeen *et al*. (2009), Patel *et al*. (2009), Singh *et al*. (2009), Padhar and Zaveri (2010), Arup *et al*. (2011), Hasanuzzaman and Faruq (2011), Singh and Singh (2011), Kumar *et al*. (2012) and Lahbib *et al*. (2012).

4.5.2 Character association analysis among six qualitative characters and yield per plant

4.5.2.1 Ascorbic acid (mg/100g)

At both phenotypic and genotypic levels this trait showed significant and positive association with yield per plant (0.2495** and 0.2946**) which suggested that selection for yield per plant based on ascorbic acid content is beneficial. At both phenotypic and genotypic levels this trait showed significant and negative association with total colour value (-0.2322** and -0.2441**), red carotenoids (-0.2307** and -0.2431**) and yellow carotenoids (-0.2115* and -0.2181*) indicating that simultaneous selection of these traits is not possible. These results are in line with earlier findings of Arup *et al*. (2011) who also reported positive association of ascorbic acid content with yield.

4.5.2.2 Oleoresin (%)

At genotypic level this trait showed significant and positive association with yield per plant (0.2426**) indicating that there is strong association between these two characters genetically, where the phenotypic value is lessened by significant interaction of environment. This trait showed non-significant and positive association with ascorbic acid (0.0164 and 0.0435), capsaicin content (0.1274 and 0.1477) at both phenotypic and genotypic levels and with yield per plant (0.1516) at phenotypic level. These results are in accordance with earlier observations of Gupta *et al*. (2009).

4.5.2.3 Capsaicin (%)

At both phenotypic and genotypic levels this trait showed non - significant and negative association with yield per plant (-0.1163 and -0.1426). This clearly indicated the independent nature of these two characters and selection for dry fruit yield based on capsaicin content is not reliable. At both phenotypic and genotypic levels this trait showed non - significant and positive association with oleoresin (0.1274 and 0.1477), total colour value (0.0845 and 0.0898). These results are similar to the earlier observations of Gupta *et al*. (2009).

4.5.2.4 Total colour value (ASTA units)

At both phenotypic and genotypic levels, this trait showed significant and positive association with red carotenoids (0.7881** and 0.8162**) and yellow carotenoids (0.6859** and 0.7178**) indicating that simultaneous selection of these traits is possible. At both phenotypic and genotypic levels this trait showed significant and negative association with ascorbic acid (-0.2322** and -0.2441**) and yield per plant (-0.2108* and -0.2709**) indicating that simultaneous selection of these traits is not possible. At both phenotypic and genotypic levels this trait showed non - significant and positive association with capsaicin (0.0845 and 0.0898). These results are in accordance with earlier observations of Gupta *et al*. (2009) and Naresh *et al.* (2013).

4.5.2.5 Red carotenoids (%)

Both at phenotypic and genotypic levels, this trait showed significant and positive association with total colour value (0.7881** and 0.8162**) and yellow carotenoids (0.5527** and 0.5678**) indicating that simultaneous selection of these traits is possible. At both phenotypic and genotypic levels this trait showed significant and negative association with ascorbic acid (-0.2307** and -0.2431**) indicating that simultaneous selection of these traits is not possible. At both phenotypic and genotypic levels this trait showed non - significant and negative association with yield per plant (-0.0784 and -0.0794) which clearly indicated the independent nature of these two characters and selection for yield based on this trait is not reliable. These findings are in accordance with observations of Naresh *et al.* (2013) who reported positive association of red carotenoids with total colour value and yellow carotenoids.

4.5.2.6 Yellow carotenoids (%)

At both phenotypic and genotypic levels, yellow carotenoids showed significant and positive association with total colour value (0.6859** and 0.7178**) and red carotenoids (0.5527** and 0.5678**) indicating that simultaneous selection of these traits is not possible. These results are in conformity with those reported by Naresh *et al.* (2013) in chilli. At both phenotypic and genotypic levels, this trait showed significant and negative association with ascorbic acid (-0.2115* and -0.2181*) and yield per plant (-0.1780* and -0.2047*) indicating that simultaneous selection of these traits is not possible.

4.5.2.7 Yield per plant (g)

The per plant yield showed significant and positive association with ascorbic acid (0.2495** and 0.2946**) at both phenotypic and genotypic levels which suggested that selection for yield per plant based on ascorbic acid is beneficial. This trait showed significant and positive association with oleoresin (0.2426**) at genotypic level indicating that there is strong association between these two characters genetically, where the phenotypic value is lessened by significant interaction of environment. At both phenotypic and genotypic levels, this trait showed significant and negative association with total colour value (-0.2108* and -0.2709**) and yellow carotenoids (-0.1780* and -0.2047*) indicating that simultaneous selection of these traits is not possible. These results are in agreement with earlier observations of Arup *et al*. (2011) and Kumar *et al*. (2012).

From the study it was observed that in general, genotypic correlation coefficients were of higher magnitude than the phenotypic correlation coefficients. The correlation study indicated that plant height, fruit set per cent, number of fruits per plant, number of seeds per fruit and ascorbic acid had positive significant association with yield per plant at both phenotypic and genotypic levels indicating the importance of these traits in selection for yield and are identified as yield attributing characters on which selection can be relied upon for the genetic improvement of yield of chilli.

4.6 PATH COEFFICIENT ANALYSIS

Upon the assessment of apparent relationship between yield and yield components, it is necessary to partition the direct and indirect effects of each character on yield to understand the nature of association at genotypic and phenotypic level.

As a guideline for interpretation of the results of path analysis, the following broad points as suggested by (Singh and Chaudhary, 1977). If the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, then correlation explains the true relationship and a direct selection through this trait will be effective. If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects seem to be the cause of positive correlation. In such situations, the indirect causal factors are to be considered simultaneously for selection. Under the circumstances where correlation coefficient may be negative but the direct effect is positive and high, a restricted simultaneous selection model is to be followed *i.e.,* restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect. If correlation coefficient is negative and direct effect is also negative, then the selection based on that character has to be dropped.

So, in the present study direct and indirect effects of different quantitative and qualitative traits on dry fruit yield per plant were estimated through path analysis at phenotypic and genotypic levels and are presented in table 4.8, 4.9, 4.10 and 4.11 (Fig 4.11, 4.12, 4.13 and 4.14).

4.6.1 Direct and indirect effects of quantitative characters on yield per plant

4.6.1.1 Plant height (cm)

The direct contribution of this character on yield per plant was low and positive (0.1289 P and 0.1446 G).

At phenotypic level, this trait exhibited negligible and positive indirect effect on yield per plant via fruit length (0.0252), average dry fruit weight (0.0834) and number of seeds per fruit (0.0190); low and positive indirect effect through number of fruits per plant (0.1224) and negligible and negative indirect effect via number of primary branches per plant (-0.0003), days to 50 per cent flowering (-0.0014), fruit set per cent (-0.0113) and fruit diameter (-0.0060).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through number of primary branches per plant (0.0001), fruit length (0.0324) and number of seeds per fruit (0.0399); low and positive indirect effect through number of fruits per plant (0.1095) and average dry fruit weight (0.1031) and negligible and negative indirect effect via days to 50 per cent flowering (-0.0055), fruit set per cent (-0.0184) and fruit diameter (-0.0120).

Plant height showed significant and positive correlation with yield per plant (0.3599** and 0.3936**) at both phenotypic and genotypic levels. Positive direct effects and positive correlations indicated that direct selection for yield per plant through this trait will be effective. These findings are in agreement with those reported by Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008), Jabeen *et al*. (2009) and Hasauzzaman and Faruq (2011).

4.6.1.2 Number of primary branches per plant

This trait showed negligible and positive direct effect on yield per plant at phenotypic level (0.0051) and negligible and negative direct effect at genotypic level (-0.0018).

At phenotypic level, this trait exhibited negligible and positive indirect effect on yield per plant via days to 50 per cent flowering (0.0081), fruit set per cent (0.0237), number of fruits per plant (0.0935), fruit diameter (0.0386) and fruit length

(0.0073); negligible and negative indirect effect via plant height (-0.0065) and number of seeds per fruit (-0.0127) and low and negative indirect effect via average dry fruit weight (-0.1201).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through days to 50 per cent flowering (0.0105), fruit set per cent (0.0298), fruit diameter (0.0889) and fruit length (0.0091); low and positive indirect effect through number of fruits per plant (0.1039) and negligible and negative indirect effect through plant height (-0.0115) and number of seeds per fruit (-0.0384) and low and negative indirect effect via average dry fruit weight (-0.1864).

At both phenotypic and genotypic levels this trait showed positive and non-significant association with yield per plant (0.0369 and 0.0041). Negligible direct effects and positive correlation indicating the indirect effects seem to be the cause of positive correlation. In such situations, the indirect causal factors are to be considered simultaneously for selection. These findings are in agreement with observations of Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008).

4.6.1.3 Days to 50 per cent flowering

Days to 50 per cent flowering showed negligible and negative direct effect on yield per plant at phenotypic level (-0.0985) and low and negative direct effect at genotypic level (-0.1061).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant via plant height (0.0018), average dry fruit weight (0.0235) and number of seeds per fruit (0.0022); negligible and negative indirect effect via number of primary branches per plant (-0.0004), fruit set per cent (-0.0152), number of fruits per plant (-0.0433), fruit diameter (-0.0018) and fruit length (-0.0084).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0075), number of primary branches per plant (0.0002), average dry fruit weight (0.0329) and number of seeds per fruit (0.0125) while negligible and negative indirect effect was observed through fruit set per cent (-0.0275), number of fruits per plant (-0.0371), fruit diameter (-0.0042) and fruit length (-0.0149).

At both phenotypic and genotypic levels this trait showed negative and non-significant association with yield per plant (-0.1402 and -0.1358). The present investigation showed negative direct effects and negative correlation, suggesting to drop the selection based on this character. Similar observations of Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al.* (2008) and Hasauzzaman and Faruq (2011) lend support to the findings of this investigation.

4.6.1.4 Fruit set per cent

At both phenotypic and genotypic levels, the direct contribution of this character on yield per plant was moderate and positive (0.2252 and 0.2831). These results are contradictory with the earlier observations of Krishna *et al.* (2007) who reported negligible and positive direct effect.

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant via number of primary branches per plant (0.0005), days to 50 per cent flowering (0.0067), number of fruits per plant (0.0877), fruit diameter (0.0182), fruit length (0.0052), average dry fruit weight (0.0149) and number of seeds per fruit (0.0006) and negligible and negative indirect effect via plant height (-0.0064).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through days to 50 per cent flowering (0.0103), fruit diameter (0.0363), fruit length (0.0056) and average dry fruit weight (0.0133); low and positive indirect effect through number of fruits per plant (0.1169) and negligible and negative indirect effect through plant height (-0.0094), number of primary branches per plant (-0.0002), and number of seeds per fruit (-0.0023).

This trait showed significant and positive association with yield per plant (0.3526** and 0.4537**) at both phenotypic and genotypic levels. Positive direct effects and positive correlations indicated that direct selection for yield per plant through this trait will be rewarding. These findings are supported by the observations of Krishna *et al.* (2007) in chilli.

4.6.1.5 Number of fruits per plant

At both phenotypic and genotypic levels, the direct contribution of this character on yield per plant was high and positive (0.6393 and 0.6457).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant via plant height (0.0247), number of primary branches per plant (0.0007), days to 50 per cent flowering (0.0067), fruit set per cent (0.0309) and fruit diameter (0.0592); negligible and negative indirect effect via fruit length (-0.0137) and number of seeds per fruit (-0.0080) and low and negative indirect effect via average dry fruit weight (-0.1512).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0245), days to 50 per cent flowering (0.0061) and fruit set per cent (0.0513); low and positive indirect effect through fruit diameter (0.1190); negligible and negative indirect effect through number of primary branches per plant (-0.0003), fruit length (-0.0171) and number of seeds per fruit (-0.0157) and low and negative indirect effect via average dry fruit weight (-0.1960).

This trait showed significant and positive association with yield per plant (0.5886 ** and 0.6175**) at both phenotypic and genotypic levels. The high direct effect of this trait and its pronounced association with yield per plant reveals its true relationship with yield and direct selection for this trait will be rewarding. These results are in conformity with the earlier observations of Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al.* (2008), Jabeen *et al*. (2009), Arup *et al.* (2011), Hasauzzaman and Faruq (2011) and Kumar *et al.* (2012) who suggested direct selection for this trait in improving yield.

4.6.1.6 Fruit diameter (cm)

This trait showed low and negative direct effect on yield per plant at phenotypic level (-0.1170) and moderate and negative direct effect at genotypic level (-0.2196).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant via plant height (0.0066), fruit length (0.0024) and number of seeds per fruit (0.0377); moderate and positive indirect effect via average dry fruit weight (0.2769); negligible and negative indirect effect via number of primary branches per plant (-0.0017), days to 50 per cent flowering (-0.0015), fruit set per cent (-0.0350) and high and negative indirect effect through number of fruits per plant (-0.3233).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0079), number of primary branches per plant (0.0007), fruit length (0.0027) and number of seeds per fruit (0.0732); high and positive indirect effect through average dry fruit weight (0.3477); negligible and negative indirect effect through days to 50 per cent flowering (-0.0020), fruit set per cent (-0.0469) and high and negative indirect effect via number of fruits per plant (-0.3498).

This trait showed significant and negative association (-0.1861*) and non significant and negative association (-0.1550) with yield per plant at genotypic and phenotypic levels respectively. The present investigation showed negative direct effects and negative correlation and hence selection based on this character may not be rewarding. These findings are in agreement with those of Smitha and Basvaraja (2007), Reddy *et al*. (2008), Jabeen *et al*. (2009), Hasauzzaman and Faruq (2011) and Kumar *et al.* (2012).

4.6.1.7 Fruit length (cm)

At both phenotypic and genotypic levels, the direct contribution of this character on yield per plant was low and positive (0.1027 and 0.1141).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0316), number of primary branches per plant (0.0004), days to 50 per cent flowering (0.0081), fruit set per cent (0.0114), average dry fruit weight (0.0818) and number of seeds per fruit (0.0057) and negligible and negative indirect effect via number of fruits per plant (-0.0854) and fruit diameter (-0.0028).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0410), days to 50 per cent flowering (0.0139), fruit set per cent (0.0139) and number of seeds per fruit (0.0152); low and positive indirect effect through average dry fruit weight (0.1031) and negligible and negative indirect effect through number of primary branches per plant (-0.0001), number of fruits per plant (-0.0969) and fruit diameter (-0.0053).

This trait showed significant positive (0.1988*) and non significant positive (0.1537) association with yield per plant at genotypic and phenotypic levels respectively. Positive direct effects and positive correlations were observed indicating that direct selection for yield per plant through this trait will be effective. These findings are in agreement with those reported by Krishna *et al.* (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008), Hasauzzaman and Faruq (2011) and Kumar *et al.* (2012).

4.6.1.8 Average dry fruit weight (g)

This trait showed high and positive direct effect on yield per plant at both phenotypic level (0.3451) and genotypic level (0.4049).

At phenotypic level, it exhibited negligible and positive indirect effect on yield per plant through plant height (0.0311), fruit set per cent (0.0097), fruit length (0.0244) and number of seeds per fruit (0.0436); and negligible and negative indirect effect via number of primary branches per plant (-0.0018), days to 50 per cent flowering (-0.0067) and fruit diameter (-0.0939) and moderate and negative indirect effect via number of fruits per plant (-0.2801).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0368), number of primary branches per plant (0.0008), fruit set per cent (0.0093), fruit length (0.0290) and number of seeds per fruit (0.0878); high and negative indirect effect via number of fruits per plant (-0.3126); negligible and negative indirect effect through days to 50 per cent flowering (-0.0086) and low and negative indirect effect through fruit diameter (-0.1886).

At both phenotypic and genotypic levels this trait showed positive and non-significant association with yield per plant (0.0714 and 0.0589). The high direct effect of this trait and its positive association with yield per plant reveals its true relationship with yield and direct selection for this trait will be rewarding. These findings corroborate with the reports of Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008), Jabeen *et al*. (2009), Hasauzzaman and Faruq (2011) and Kumar *et al.* (2012).

4.6.1.9 Number of seeds per fruit

This trait showed negligible and positive direct effect on yield per plant at phenotypic level (0.0627) and low and positive direct effect at genotypic level (0.1058).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0391), fruit set per cent (0.0022) and fruit length (0.0094); moderate and positive indirect effect via average dry fruit weight (0.2396) and negligible and negative indirect effect via number of primary branches per plant (-0.0010), days to 50 per cent flowering (-0.0035), number of fruits per plant (-0.0813) and fruit diameter (-0.0704).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through plant height (0.0545), number of primary branches per plant (0.0006) and fruit length (0.0164); high and positive indirect effect via average dry fruit weight (0.3361); negligible and negative indirect effect through days to 50 per cent flowering (-0.0125), fruit set per cent (-0.0062) and number of fruits per plant (-0.0956) and low and negative indirect effect through fruit diameter (-0.1519).

At both phenotypic and genotypic levels this trait showed significant and positive association with yield per plant (0.1968* and 0.2473**). Positive direct effects and positive correlations indicated that direct selection for yield per plant through this trait will be effective. These findings are in agreement with those of Khurana et al. (2003), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008) and Hasauzzaman and Faruq (2011).

4.6.2 Direct and indirect effects of qualitative characters on yield per plant

4.6.2.1 Ascorbic acid (mg/100g)

At both phenotypic and genotypic levels, the direct contribution of this character on yield per plant was moderate and positive (0.2230 and 0.2604).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant through oleoresin (0.0025), capsaicin (0.0031), total color value (0.0764) and yellow carotenoids (0.0042) and negligible and negative indirect effect through red carotenoids (-0.0596).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through oleoresin (0.0106) and capsaicin (0.0038); low and positive indirect effect via total color value (0.1444); negligible and negative indirect effect through yellow carotenoids (-0.0162) and low and negative indirect effect via red carotenoids (-0.1083).

At both phenotypic and genotypic levels this trait showed significant and positive association with yield per plant (0.2495** and 0.2946**). Positive direct effects and positive correlations indicated that direct selection for yield per plant through this trait will be effective. These results were in conformity with earlier works of Singh *et al*. (2007), Farhad *et al.* (2008) and Kumar *et al*. (2012).

4.6.2.2 Oleoresin (%)

This trait showed low and positive direct effect on yield per plant at phenotypic level (0.1523) and moderate and positive direct effect at genotypic level (0.2424).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant through ascorbic acid (0.0037), total color value (0.0230) and yellow carotenoids (0.0028) and negligible and negative indirect effect through capsaicin (-0.0146) and red carotenoids (-0.0155).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant through ascorbic acid (0.0113) and total color value (0.0474) and negligible and negative indirect effect through capsaicin (-0.0216), red carotenoids (-0.0247) and yellow carotenoids (-0.0123).

This trait showed significant and positive association (0.2426**) and positive non significant association (0.1516) with yield per plant at genotypic and phenotypic levels respectively. Positive direct effects and positive correlations indicated that direct selection for yield per plant through this trait will be effective. These results are in conformity with the earlier observations of Singh *et al.* (2007).

4.6.2.3 Capsaicin (%)

At both phenotypic and genotypic levels, the direct contribution of this character on yield per plant was low and negative (-0.1147 and -0.1464).

At phenotypic level, this trait showed negligible and positive indirect effect on yield per plant through oleoresin (0.0194) and red carotenoids (0.0141) and negligible and negative indirect effect through ascorbic acid (-0.0061), total color value (-0.0278) and yellow carotenoids (-0.0012).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant via oleoresin (0.0358), red carotenoids (0.0226) and yellow carotenoids

(0.0052) and negligible and negative indirect effect through ascorbic acid (-0.0067) and total color value (-0.0531).

At both phenotypic and genotypic levels, capsaicin content showed non - significant and negative association with yield per plant (-0.1163 and -0.1426). The present investigation showed negative direct effect and negative correlation, so selection based on this character may not be possible. These results are supported by the reports of Arup *et al.* (2011).

4.6.2.4 Total colour value (ASTA units)

This trait showed high and negative direct effect on yield per plant at both phenotypic level (-0.3290) and genotypic level (-0.5917).

At phenotypic level, this trait showed moderate and positive indirect effect on yield per plant through red carotenoids (0.2038) and negligible and negative indirect effect through ascorbic acid (-0.0518), oleoresin (-0.0107), capsaicin (-0.0097) and yellow carotenoids (-0.0135).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant via yellow carotenoids (0.0533), high and positive indirect effect via red carotenoids (0.3636) and negligible and negative indirect effect through ascorbic acid (-0.0636), oleoresin (-0.0194) and capsaicin (-0.0132).

At both phenotypic and genotypic levels this trait showed significant and negative association with yield per plant (-0.2108* and -0.2709**). The present investigation showed negative direct effect and negative correlation, so we have to drop the selection based on this character. However, contrary to the findings of the present investigation, Khurana *et al.* (2003) reported positive direct effect of total colour value on yield per plant.

4.6.2.5 Red carotenoids (%)

This trait showed moderate and positive direct effect on yield per plant at phenotypic level (0.2586) and high and positive direct effect at genotypic level (0.4455).

At phenotypic level, this trait showed moderate and negative indirect effect on yield per plant via total color value (-0.2593) and negligible and negative indirect effect via ascorbic acid (-0.0514), oleoresin (-0.0091), capsaicin (-0.0063) and yellow carotenoids (-0.0109).

At genotypic level, this trait showed negligible and positive indirect effect on yield per plant via yellow carotenoids (0.0422); high and negative indirect effect via total colour value (-0.4829) and negligible and negative indirect effect through ascorbic acid (-0.0633), oleoresin (-0.0134) and capsaicin (-0.0074).

At both phenotypic and genotypic levels this trait showed non - significant and negative association with yield per plant (-0.0784 and -0.0794). The present investigation showed high direct effect and negative correlation; Under these circumstances, a restricted simultaneous selection model is to be followed i.e., restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect.

4.6.2.6 Yellow carotenoids (%)

This trait showed negligible and negative direct effect on yield per plant at phenotypic level (-0.0196) and negligible and positive direct effect at genotypic level (0.0743).

At phenotypic level, this trait showed low and positive indirect effect on yield per plant through red carotenoids (0.1429); moderate and negative indirect effect via total colour value (-0.2257) and negligible and negative indirect effect via ascorbic acid (-0.0472), oleoresin (-0.0214), capsaicin (-0.0071).

At genotypic level, this trait showed moderate and positive indirect effect on yield per plant via red carotenoids (0.2529) and high and negative indirect effect via total colour value (-0.4247) and negligible and negative indirect effect through ascorbic acid (-0.0568), oleoresin (-0.0402) and capsaicin (-0.0102).

At both phenotypic and genotypic levels this trait showed significant and negative association with yield per plant (-0.1780* and -0.2047*). The present investigation showed negligible negative direct effect and negative correlation and the selection based on this character has to be dropped.

The path analysis thus revealed that plant height, fruit set per cent, number of fruits per plant, fruit length, ascorbic acid, oleoresin, red carotenoids, average dry fruit weight, number of seeds per fruit had positive direct effect on yield per plant indicating that direct selection based on these traits may be helpful in evolving high yielding varieties of chilli.

Based on the results of correlation and path analysis, the present study revealed that major emphasis should be laid on selection process with plant height, fruit set per cent, number of fruits per plant, ascorbic acid and number of seeds per fruit and there should be economic balance among these traits to get higher fruit yield per plant.

4.7 GENETIC DIVERGENCE

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.

Generally, geographical diversity was considered as a measure of genetic diversity when no scientific tools were available. But geographical distribution of genotypes is not the only factor that causes genetic diversity. This may be due to exchange of breeding material over the locations and further selections at different locations which could result in genetic drift. So, selection of parents for hybridization programme should be based on genetic diversity rather than geographical diversity as there is no parallelism between genetic divergence and geographical divergence of genotypes.

The data collected on 16 yield and quality contributing characters from 63 genotypes of chilli were subjected to multivariate analysis like Mahalanobis' D^2 statistic, principal component and cluster analysis. The magnitude of values suggested that there was considerable variability in the material studied, which led to genetic diversity.

4.7.1 Mahalanobis' D^2 analysis

~~4.7.1.1 Test with *Wilk's* criterion~~

~~Significant differences among the genotypes for individual characters were first determined and later the statistically significant differences between the genotypes based on the pooled effects of all the~~

~~characters were carried out using the Wilk's criterion '∧'. The Wilk's criterion thus obtained was used in calculations of 'V' statistic. The statistic was highly significant indicating that genotypes differed significantly when all the characters were considered simultaneously. The value of 'V' statistic was 3101.61 in the present investigation.~~

~~4.7.1.2 Mahalanobis' D^2 values~~

~~To estimate the D^2 values, correlated mean of characters were transformed into standardized uncorrelated characters by using pivotal condensation method. It measures the degree of diversification and determines the relative proportion of each component character to total divergence. The statistical differences (D^2) between pairs of genotypes was obtained as the sum of squares of the differences between the pairs of corresponding uncorrelated values of any two genotypes considered at a time.~~

4.7.1.3 Relative contribution of different characters towards genetic divergence

The per cent contribution towards genetic divergence by all the 16 contributing characters is presented in table 4.12 (Fig 4.15). The maximum contribution towards genetic divergence was by fruit diameter (44.14%) followed by yellow carotenoids (16.90%), red carotenoids (10.45%), ascorbic acid (10.19%), capsaicin (9.17%), fruit length (3.07%), total color value (2.10%), number of fruits per plant (1.43%), oleoresin (0.87%), number of seeds per fruit (0.61%), plant height (0.51%), fruit set per cent (0.31%), yield per plant (0.20%), average dry fruit weight (0.05%) whereas, remaining characters like number of primary branches per plant and days to 50 per cent flowering had no contribution towards genetic divergence. Hence, selection for divergent parents based on these characters will be useful for heterosis breeding in chilli.

~~4.7.1.4 Grouping of genotypes into various clusters~~

~~The 63 genotypes were grouped into eight clusters using the Tocher's method (Table 4.13) with the criterion that the intra-cluster average D^2 values should be less than the inter-cluster D^2 values.~~

~~The distribution of 63 genotypes into 8 clusters was at random with maximum number of genotypes in cluster III (17 genotypes) and V (17 genotypes) from different locations. Cluster IV was the second largest with 11 genotypes followed by cluster I with 8 genotypes, cluster II with 7 genotypes. The clusters VI, VII and VIII were solitary clusters with nil intra-cluster D^2 values. The formation of distinct solitary clusters may be due to the fact that geographic barriers preventing gene flow or intensive natural and human selection for diverse and adoptable gene complexes must be responsible for this genetic diversity.~~

This pattern of grouping has indicated that the diversity need not be necessarily related to geographical diversity and it may be the outcome of several other factors like natural selection, exchange of breeding material, genetic drift and environmental variation. Therefore, selection of varieties for hybridization programme should be based on genetic diversity rather than geographical diversity.

The tree like structure called dendrogram was constructed based on clustering by Tocher's method (Fig 4.16). The mutual relationships between the clusters were presented diagrammatically by taking average intra and inter-cluster D^2 values (Fig 4.17).

~~4.7.1.5 Average intra and inter- cluster D^2 values~~

The average intra and inter-cluster D^2 values estimated as per the procedure given by Singh and Chowdhary (1977) are presented in the table 4.14. The proximity and divergence among eight clusters are indicated in table 4.15.

The mean intra-cluster D^2 values ranged from 0.00 to 434.43, where the maximum intra-cluster distance was 434.43 in cluster V followed by 259.50 in cluster

IV followed by 163.60 in cluster III, 93.56 in cluster II, 62.86 in cluster I , while, it was zero for clusters VI, VII and VIII.

The inter- cluster D^2 values varied from 117.25 to 4139.41 and maximum genetic divergence existed between cluster IV and VIII (4139.41) followed by cluster II and VIII (3633.27) indicating wider genetic diversity among the genotypes included in these groups. The minimum genetic divergence was registered between cluster I and III (117.25) preceded by clusters I and II (134.54).

Cluster I comprised of 8 genotypes. It was nearest to cluster III (117.25) preceded by cluster II (134.54) and farthest from cluster VIII (2842.57) followed by cluster V (331.58).

Cluster II comprised of 7 genotypes. It was nearest to cluster I (134.54) preceded by cluster III (206.58) and farthest from cluster VIII (3633.27) followed by cluster V (551.16).

Cluster III comprised of 17 genotypes was the largest of all clusters. It was closest to cluster I (117.25) preceded by cluster II (206.58) and farthest from cluster VIII (2967.46), followed by cluster VII (431.22).

~~Cluster IV comprised of 11 genotypes was the second largest of all clusters. It was closest to the cluster II (265.05) preceded by cluster I (292.68) and farthest from cluster VIII (4139.41) followed by cluster V (668.82).~~

~~Cluster V comprised of 17 genotypes was the largest of all clusters. It was nearest to the cluster I (331.58) preceded by cluster III (364.72) and farthest from cluster VIII (2343.89) followed by cluster VII (722.07).~~

~~Cluster VI was mono genotypic (LCA-706). It was closest to the cluster I (260.02) preceded by cluster II (272.09) and farthest from cluster VIII (3323.09) followed by cluster V (600.47).~~

~~Cluster VII comprised of one genotype (Aparna). It was nearest to cluster I (309.56) preceded by cluster II (337.29) and farthest from cluster VIII (3149.32) followed by cluster V (722.07).~~

Cluster VIII was mono genotypic (Warangal Chapatta). It was nearest to the cluster V (2343.89) preceded by cluster I (2842.57) and farthest from cluster IV (4139.41) followed by cluster II (3633.27).

The intra and inter-cluster distances revealed that inter-cluster distance values were greater than intra-cluster distance values. Maximum intra-cluster D^2 distance was recorded by cluster V (434.43) followed by cluster IV (259.50) and cluster III (163.60). The high intra-cluster distance in cluster V indicates the presence of wide genetic diversity among the genotypes present within this cluster.

The maximum inter-cluster distance was observed between cluster IV and VIII (4139.41) followed by cluster II and VIII (3633.27) and cluster VI and VIII (3323.09), cluster VII and VIII (3149.32), cluster III and VIII (2967.46), cluster I and VIII (2842.57) and cluster V and VIII (2343.89). This suggested wide genetic diversity between these clusters. Based on these studies, crosses can be made between genotypes of these clusters to obtain heterotic hybrids and desirable segregants.

Genotypes grouped into the same cluster presumably differ little from one another as the aggregate of characters measured. General notion exists that the larger is the divergence between the genotypes, the higher will be the heterosis (Falconer, 1964). Therefore, it would be desirable to attempt crosses between genotypes belonging to distant clusters for getting highly heterotic crosses which are likely to yield a wide range of segregants on which selection can be practiced.

The minimum inter-cluster distance was observed between cluster I and III (117.25) preceded by cluster I and II (134.54), cluster II and III (206.58). The lowest inter-cluster distance between these cluster pairs suggested that the genetic constitution of these genotypes in one cluster were in close proximity with the genotypes in other cluster of the pair.

Choice of the particular cluster and selection of particular genotype from selected cluster are the two important points to be considered before initiating the crossing programme. The hybrids between genotypes of different clusters will express high heterosis and throw more useful segregants. Further, one or two varieties from different clusters may be chosen for further genetic studies either by diallel or line x tester analysis.

~~4.7.1.6 Cluster Mean Values~~

Cluster means indicate average performance of all varieties clubbed in a cluster. The relative importance of yield components contributing towards divergence can be judged by comparing the group means of 16 characters. The clusters mean values for all the 16 characters are presented in table 4.16.

The maximum plant height was observed in cluster VI (107.35) followed by cluster VIII (106.30) while minimum plant height exhibited in cluster VII (82) preceded by cluster IV (84.37) and cluster III (84.44).

The number of primary branches per plant exhibited maximum mean value in cluster IV (3.95) followed by cluster II (3.77) while minimum mean value recorded in cluster VIII (2.8) preceded by cluster VI (3.00).

Days to 50 per cent flowering showed highest mean in cluster VIII (34) followed by cluster III (32.68) and lowest mean value observed in cluster VI (28.50) preceded by cluster IV (30.50) and cluster I (30.63).

The maximum fruit set per cent was observed in cluster VII (56) followed by cluster I (55.13) while it was minimum in cluster VIII (32.50) preceded by cluster III (47.44).

The maximum number of fruits per plant was observed in cluster VI (480) followed by cluster II (199.99) and cluster IV (197.86) while minimum mean value observed in cluster VIII (49.80) preceded by cluster V (140.30).

The fruit diameter showed highest mean in cluster VIII (3.18) and lowest mean in cluster IV (0.99) preceded by cluster II (1.09).

The fruit length exhibited maximum mean value in cluster VII (9.92) followed by cluster III (9.12), cluster I (9.11) and cluster II (9.09) while minimum mean value in cluster VI (6.98) preceded by cluster IV (7.66).

The ascorbic acid exhibited maximum mean value in cluster VII (223.22) followed by cluster IV (143.41) while minimum mean value in cluster VIII (90) preceded by cluster I (99.44) and cluster III (99.77).

The oleoresin recorded maximum mean value in cluster VIII (9.61) followed by cluster IV (9.53) while the minimum mean value in cluster VII (5.96).

The capsaicin showed highest mean in cluster VI (0.45) followed by cluster IV (0.37) and lowest mean in cluster II (0.24) preceded by cluster VII (0.27) and cluster I (0.28).

The total color value showed highest mean in cluster VIII (105) and lowest mean in cluster VII (20.58) preceded by cluster VI (43.14).

Red carotenoids recorded highest mean in cluster V (0.14) followed by cluster III (0.13) and cluster IV (0.13) and lowest mean in cluster VII (0.01) preceded by cluster VIII (0.04).

Yellow carotenoids recorded highest mean in cluster III (0.08), cluster IV (0.08) and cluster V (0.08) and lowest mean in cluster VI (0.03) preceded by cluster II (0.04), cluster VII (0.04) and cluster VIII (0.04).

The average dry fruit weight recorded highest mean in cluster VIII (3.35) followed by cluster V (1.28) and lowest mean in clusters IV and cluster VI (0.77).

The number of seeds per fruit exhibited maximum mean value in cluster VIII (152.50) while minimum mean value in cluster IV (50.89).

The yield per plant exhibited maximum mean value in cluster VI (204.18) followed by cluster II (166.78) while minimum mean value in cluster VIII (107.30) preceded by cluster VII (132.34).

The clusters VI, VII, VIII, V and IV were found superior for one or more characters. Therefore, it is proposed to arrange a multiple crossing programme involving genotypes from these clusters to isolate superior segregants in advanced generations with high genetic yield potential and other desirable characters in chilli.

The success and usefulness of Mahalanobis' D^2 analysis in quantifying genetic divergence has been studied by Prabhudeva (2003), Senapati *et al.* (2003), Gogate *et al*. (2006), Vani *et al*. (2007), Dutonde *et al*. (2008), Ajjapplavara (2009), Thul *et al*.

(2009), Farhad *et al.* (2010), Finger *et al.* (2010), Kumar *et al.* (2010), Kumari *et al*. (2010), Pandit *et al.* (2010), Singh and Singh (2010) and Shrilekha *et al*. (2011).

4.7.2 Principal component analysis (PCA) in genetic divergence

~~Principal component analysis or canonical (vector) analysis is a sort of multivariate analysis where canonical vectors or roots representing different axes of differentiation and amount of variation accounted by each of such axes, respectively are derived (Rao, 1952).~~

~~Results obtained from PCA on the correlation matrix of the traits reduce the dimensionality of the data set by creating six significant principal components having eigen value more than one. The PCA scores for individual genotypes were used for clustering the genotypes as suggested by Anderberg (1993). Results of PCA and cluster analysis are discussed here under~~.

~~Principal components (eigen value greater than one), eigen values (Latent Root), per cent variability, cumulative per cent variability and component loading of different characters are presented in table 4.17.~~

In the present study, the six principal components with eigen values more than one contributed 76.83 per cent towards the total variability. The principal component with eigen values less than one were considered as non-significant. It was therefore inferred that the essential features of data set had been represented in the first six principal components.

The first principal component (PC_1) contributed maximum towards the total variability (25.059%). The characters *viz*., number of seeds per fruit (0.419), total color value (0.397), fruit diameter (0.316), red carotenoids (0.197), yellow carotenoids (0.149), fruit length (0.136), plant height (0.126) and days to 50 per cent flowering (0.064) were positively loaded. Ascorbic acid (-0.374), number of fruits per plant (-0.339), average dry fruit weight (-0.335), capsaicin (-0.190), fruit set per cent (-0.180), number of primary branches per plant (-0.162), oleoresin (-0.074) and yield per plant (-0.012) were negatively loaded.

The second principal component (PC_2) was characterized by 16.141 per cent contribution towards the total variability. The characters *viz*., yield per plant (0.509), red carotenoids (0.397), fruit length (0.358), yellow carotenoids (0.250), average dry fruit weight (0.184), total color value (0.133), number of fruits per plant (0.133), number of primary branches per plant (0.130), number of seeds per fruit (0.098), ascorbic acid (0.098), plant height (0.092) and fruit set per cent (0.076) were positively loaded. Fruit diameter (-0.411), oleoresin (-0.299), capsaicin (-0.124) and days to 50 per cent flowering (-0.019) were negatively loaded.

The third principal component (PC_3) was characterized by 12.197 per cent contribution towards the total variability. The characters *viz.*, fruit length (0.327), average dry fruit weight (0.325), yield per plant (0.224), plant height (0.182), number of seeds per fruit (0.127), fruit diameter (0.100) and days to 50 per cent flowering (0.046) were positively loaded. Yellow carotenoids (-0.517), capsaicin (-0.402), total color value (-0.298), red carotenoids (-0.264), number of primary branches per plant (-0.247), ascorbic acid (-0.131), number of fruits per plant (-0.095), fruit set per cent (-0.030) and oleoresin (-0.017) were negatively loaded.

The fourth principal component (PC_4) was characterized by 9.525 per cent contribution towards the total variability. The characters *viz.*, oleoresin (0.533), plant height (0.522), days to 50 per cent flowering (0.474), ascorbic acid (0.272), yield per plant (0.171), yellow carotenoids (0.121), number of fruits per plant (0.109), red carotenoids (0.100), number of seeds per fruit (0.050), total color value (0.018) and fruit set per cent (0.010) were positively loaded. Fruit length (-0.194), number of primary branches per plant (-0.181), capsaicin (-0.053), average dry fruit weight (-0.038) and fruit diameter (-0.019) were negatively loaded.

The fifth principal component (PC_5) was characterized by 7.329 per cent contribution towards the total variability. The characters *viz.*, capsaicin (0.375), days to 50 per cent flowering (0.262), number of primary branches per plant (0.249), average dry fruit weight (0.235), number of seeds per fruit (0.156), plant height (0.139), fruit length (0.064) and red carotenoids (0.007) were positively loaded. Fruit set per cent (-0.711), fruit diameter (-0.219), ascorbic acid (-0.166), yield per plant (-0.157), total color value (-0.098), yellow carotenoids (-0.082), oleoresin (-0.059) and number of fruits per plant (-0.013) were negatively loaded.

The sixth principal component (PC_6) was characterized by 6.574 per cent contribution towards the total variability. The characters *viz.*, number of primary branches per plant (0.512), plant height (0.445), fruit length (0.412), fruit set per cent (0.214), yellow carotenoids (0.139), ascorbic acid (0.106), capsaicin (0.079), oleoresin (0.023) and fruit diameter (0.017) were positively loaded. Red carotenoids (-0.378), number of fruits per plant (-0.257), average dry fruit weight (-0.232), yield per plant (-0.105), days to 50 per cent flowering (-0.077), total color value (-0.062) and number of seeds per fruit (-0.053) were negatively loaded.

The characters *viz*., number of seeds per fruit, total color value, ascorbic acid, number of fruits per plant, average dry fruit weight and fruit diameter significantly loaded in PC_1 and contributed more towards variability. It is important for studying the variance as the relative contributions are more important than the signs (indicative of direction) in principal component analysis.

The PCA scores for 63 chilli genotypes in the first three principal components were computed. Principal component I, II and III were considered as three axes as X, Y and Z and squared distance of each genotype from these three axes were calculated and presented in table 4.18. These PCA scores for 63 chilli genotypes were plotted on graph to get two dimensional and three dimensional scattered diagrams (Fig.4.18 and Fig.4.19) and revealed diversity between the genotypes. These genotypes may be used in crop improvement programmes for generating transgressive segregants.

Thul *et al.* (2009), Kadri *et al.* (2009), Farhad *et al*. (2010), Sudre *et al*. (2010), Shrilekha *et al.* (2011) and Lahbib *et al.* (2012) studied the utilization of principal component analysis in genetic divergence studies in chilli.

4.7.3 Cluster analysis

To group the 63 genotypes into clusters, agglomerative hierarchical cluster analysis was followed. Principal component scores for genotypes were used as an input for clustering using Ward's minimum variance method. The tree like structure called dendrogram (Fig 4.20) was constructed based on Euclidean ^{2} distance computed from PCA scores of genotypes.

The 63 genotypes of chilli were grouped into eight clusters. The distribution of genotypes into 8 clusters is presented in table 4.19. Among all the clusters, cluster II was the largest containing 18 genotypes followed by cluster III with 15 genotypes, cluster IV with 10 genotypes, cluster V with 6 genotypes, cluster VII with 5 genotypes, cluster I and VI with 4 genotypes and cluster VIII with 1 genotype. The random distribution of genotypes indicated absence of parallelism between geographical and genetic diversity. The mutual relationship between clusters is represented diagrammatically (Fig. 4.21) by taking average intra and inter-cluster Euclidean^2 distances.

4.7.3.1 Average intra and inter- cluster Euclidean^2 distance values

The average intra and inter-cluster Euclidean^2 distance were estimated based on Ward's minimum variance and are presented in table 4.20. The proximity and divergence among eight clusters are indicated in table 4.21.

By Ward's method, the 63 genotypes were grouped into 8 clusters. Of the 8 clusters formed, the mean intra-cluster D^2 values ranged from 0.00 to 614.548, where cluster VIII had minimum intra-cluster Euclidean^2 distance value of 0.00 followed by cluster VI (236.271), cluster II (278.175), cluster III (291.256), cluster V (301.821), cluster IV (370.385), cluster I (464.183) and cluster VII (614.548).

The inter-cluster Euclidean^2 distances varied from 420.652 (between cluster II and cluster III) to 7941.635 (cluster IV and VIII). All the inter-cluster Euclidean^2 values were lying between these values.

Cluster I comprised of 4 genotypes. It was closest to cluster II (578.721) preceded by cluster III (605.103) and farthest from cluster VIII (5913.015) followed by cluster VII (1567.917).

Cluster II consisted of 18 genotypes was the largest of all clusters. It was nearest to cluster III (420.652) preceded by cluster I (578.721) and farthest from cluster VIII (5358.971) followed by cluster VII (754.180).

Cluster III consisted of 15 genotypes. It was closest to cluster II (420.652) preceded by cluster IV (547.233) and farthest from cluster VIII (6889.590) followed by cluster VI (1263.919).

Cluster IV consisted of 10 genotypes. It was nearest to cluster III (547.233) preceded by cluster II (647.227) and farthest from cluster VIII (7941.635) followed by cluster VI (1749.573).

Cluster V comprised of 6 genotypes. It was nearest to cluster III (611.918) preceded by cluster II (646.62) and farthest from cluster VIII (7542.904) followed by cluster VI (1715.499).

Cluster VI comprised 4 genotypes. It was nearest to cluster II (697.290) preceded by cluster VII (837.344) and farthest from cluster VIII (2836.497) followed by cluster IV (1749.573).

Cluster VII comprised 5 genotypes. It was closest to cluster II (754.180) preceded by cluster VI (837.344) and farthest from cluster VIII (4293.503) followed by cluster IV (1623.893).

Cluster VIII consisted of one genotype (Warangal Chapatta). It was closest to cluster VI (2836.497) preceded by cluster VII (4293.503) and farthest from cluster IV (7941.635) followed by cluster V (7542.904).

Of the eight clusters formed, maximum intra-cluster Euclidean^2 distance was recorded by cluster VII (614.548) followed by cluster I (464.183) and cluster IV (370.385) and cluster V (301.821). The high intra-cluster distance in cluster VII indicates the presence of wide genetic diversity among the genotypes present within this cluster.

The maximum inter-cluster distance was observed between cluster IV and cluster VIII (7941.635) followed by cluster V and cluster VIII (7542.904) and cluster III and cluster VIII (6889.590), cluster III and cluster VIII (6889.59), cluster I and cluster VIII (5913.015), cluster II and cluster VIII (5358.971), cluster VII and cluster VIII (4293.503) and cluster VI and cluster VIII (2836.497). This suggested that there was wide genetic diversity between these clusters. Based on these studies, crosses can be made between genotypes of these clusters to obtain heterotic hybrids and desirable segregants. The minimum inter-cluster distance was observed between cluster II and cluster III (420.652) followed by cluster III and cluster IV (547.233); cluster I and cluster II (578.721). The lowest inter-cluster distance between these cluster pairs suggested that the genetic constitution of these genotypes in one cluster were in close proximity with the genotypes in other cluster of the pair.

Results of cluster analysis based on PCA scores were compared with the results of the principal component analysis on a visual aid in desecrating clusters in the 2 D and 3 D scattered diagrams. The genotypes falling in same cluster were present closer to each other in scattered diagram.

4.7.3.2 Cluster means

The cluster mean values for all the 16 characters studied on pooled basis are presented in table 4.22.

The maximum plant height was observed for cluster VII (107.090) followed by cluster VIII (106.30) while the minimum plant height for cluster VI (69.375) preceded by cluster II (80.303) and cluster IV (80.785).

The number of primary branches per plant exhibited maximum mean value for cluster IV (4.14) followed by cluster V (4.00) while minimum mean value for cluster VI (2.75) preceded by cluster VIII (2.80).

Days to 50 per cent flowering showed highest mean for cluster VIII (34) followed by cluster VII (32.70) and cluster III (32.50) and lowest mean for cluster VI (28.875) preceded by cluster V (28.917) and cluster I (30.50).

The maximum fruit set per cent was observed for cluster IV (55.80) followed by cluster II (53.333) while it was minimum for cluster VIII (32.50) preceded by cluster I (43.75).

The number of fruits per plant exhibited maximum mean value for cluster I (245.925) followed by cluster III (196.493) while minimum for cluster VIII (49.80) preceded by cluster VII (102.820).

The fruit diameter showed highest mean for cluster VIII (3.175) and lowest mean for cluster IV (1.026).

The fruit length exhibited maximum mean value for cluster V (9.675) followed by cluster III (9.49) and cluster I (9.378) while minimum for cluster VI (7.178) preceded by cluster IV (7.322).

The ascorbic acid exhibited maximum mean value for cluster IV (142.443) followed by cluster I (141.889) while minimum mean value for cluster VII (78.713) preceded by cluster III (90).

The oleoresin recorded maximum mean value for cluster IV (9.687) followed by cluster VIII (9.61) while minimum mean value for cluster VI (7.69) preceded by cluster VII (7.964).

The capsaicin showed highest mean for cluster IV (0.448) followed by cluster I (0.377) while lowest mean for cluster VI (0.255) preceded by cluster III (0.257) and cluster VIII (0.295).

The total color value showed highest mean for cluster V (118.284) followed by cluster VII (107.112) while lowest mean for cluster I (39.415).

Red carotenoids recorded highest mean for cluster V (0.181) followed by cluster VII (0.168) and lowest mean for cluster VIII (0.04) preceded by cluster I (0.065).

Yellow carotenoids recorded highest mean for cluster V (0.119) followed by cluster VII (0.111) and lowest mean for cluster I (0.026) preceded by cluster VIII (0.035).

The average dry fruit weight recorded highest mean for cluster VIII (3.35) followed by cluster VII (1.478) and lowest mean for cluster IV (0.688), cluster V (0.935) and cluster I (0.945).

The number of seeds per fruit exhibited maximum mean value for cluster VIII (152.50) while minimum mean value for cluster IV (48.32).

The yield per plant exhibited maximum mean value for cluster III (174.847) followed by cluster I (170.701) while minimum mean value for cluster VIII (107.30) preceded by cluster VII (117.981).

In general, the clusters I, III, IV, V, VII and VIII were found superior for one or more characters. Therefore, it is proposed to arrange a multiple crossing programme involving genotypes from these clusters to isolate superior segregants in advanced generations with high genetic yield potential and other desirable characters in chilli.

Pandey *et al.* (2008), Kadri *et al.* (2009), and Sudre *et al.* (2010), studied the utilization of Ward's minimum variance method in genetic divergence studies in chilli.

Comparative study of D^2 analysis, principal component analysis and cluster analysis

The grouping of clustering pattern using D^2 analysis, principal component analysis and cluster analysis were compared and their implications are discussed here under.

All the three methods of grouping revealed a single concept of non correspondence of genetic divergence and geographical diversity. In D^2 analysis, the intra-and inter-cluster distances were low compared to the cluster analysis. This is same with the utilization of correlation matrix in principal component analysis derived from covariance matrix. The standardization made the principal component analysis to support the cluster analysis.

Mahalanobis' D^2 statistic and Jackson's principal component analysis both are the tools for analyzing multivariate data. PCA confirms the group constellations obtained by D^2 analysis. It determines the effective number of axes of differentiation primary and secondary or based on number of canonical vectors. The advantage of PCA over D^2 analysis is that it reduces the dimensionality of the data set by creating significant principal components which contributed towards maximum variability of the genotypes. The largest element (absolute value) in each vector constitute the greatest contributor for divergence. In PCA, standardization of data made attributes to contribute equally towards the divergence studies irrespective of the units taken.

The principal component analysis sorted only significant principal components out of the total 16 attributes. The contribution of the main characters for variance easily identified by the characters loaded on the PC_1 with high loading values. PCA facilitates the in depth analysis for genetic diversity. In D^2 analysis, fruit diameter followed by yellow carotenoids, red carotenoids, ascorbic acid and capsaicin contributed maximum for the divergence, while in PCA the characters viz., number of seeds per fruit, total color value, ascorbic acid, number of fruits per plant, average dry fruit weight and fruit diameter significantly loaded in PC_1 and contributed more towards variability.

Both D^2 analysis and PCA grouped the 63 chilli genotypes into eight clusters. In D^2 analysis, cluster III and cluster V were the largest with 17 genotypes followed by cluster IV (11 genotypes), cluster I (8 genotypes) and cluster II (7 genotypes). As per Ward's method, the cluster II was the largest comprising of 18 genotypes followed by cluster III (15genotypes) and cluster IV (10 genotypes).

The pattern of distribution of genotypes into different clusters was at random. Furthermore, the two clustering methods grouped the genotypes differently and clustering pattern for genotypes were not same. There was one solitary cluster formed in Ward's minimum variance method, whereas in case of D^2 analysis, cluster VI, VII and cluster VIII represented solitary clusters. Genetic diversity was the outcome of several factors along with geographic diversity. Hence, the selection for hybridization should be based on genetic diversity rather than geographic diversity.

Ward's minimum variance dendrogram (cluster analysis) created sub group within a cluster, so relative position of the genotypes within the clusters can be examined by seeing the dendrogram distance. In case of D^2 analysis, one can only know the intra-cluster distance but not the genotypes relative position in the respective cluster.

Chapter-V

Summary and Conclusions

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation was carried out during *kharif* 2012-13 at Horticultural Research Station, Lam Farm, Guntur, with 63 genotypes of chilli (*Capsicum annuum* L.).

The mean, genetic variability, heritability, genetic advance as per cent of mean, genetic divergence, character association and the magnitude of direct and indirect effects of yield component traits on dry fruit yield per plant were studied for 16 characters *viz.*, plant height , number of primary branches per plant, days to 50 per cent flowering, fruit set per cent, number of fruits per plant, fruit diameter, fruit length, ascorbic acid, oleoresin, capsaicin, total color value, red carotenoids, yellow carotenoids, average dry fruit weight, number of seeds per fruit and yield per plant.

The analysis of variance revealed significant differences among the genotypes for all the characters studied indicating the presence of variability in the studied material.

The observations on three morphological characters revealed high variation among the genotypes. Maximum number of genotypes (54) were observed to be with pendent fruit position, 47 genotypes had green mature fruits while 52 genotypes recorded solitary fruit bearing habit.

The genotypic coefficients of variation for all the characters studied were lesser than the phenotypic coefficients of variation indicating the interaction of genotypes with environment. High magnitude of PCV and GCV were observed for fruit set per cent, number of fruits per plant, fruit diameter, ascorbic acid, capsaicin, total color value, red carotenoids, yellow carotenoids, average dry fruit weight, number of seeds per fruit and yield per plant indicating the existence of wide range of genetic variability in the germplasm for these traits. This also indicated broad genetic base, less environmental influence and these traits are under the control of additive genes and hence there is a good scope for the further improvement of these characters through selection.

High heritability coupled with high genetic advance as per cent of mean was observed for plant height, number of primary branches per plant, fruit set per cent, number of fruits per plant, fruit diameter, fruit length, ascorbic acid, oleoresin, capsaicin, total color value, red carotenoids, yellow carotenoids, average dry fruit weight, number of seeds per fruit and yield per plant indicating the predominance of additive gene action and hence direct phenotypic selection is useful with respect to these traits.

High heritability coupled with moderate genetic advance as per cent of mean was observed for days to 50 per cent flowering indicating the role of additive and non additive gene action and further improvement of this character would be easier through mass selection, progeny selection or any modified selection procedure aiming to exploit the additive gene effects rather than simple selection.

Studies on character association indicated that plant height, fruit set per cent, number of fruits per plant, number of seeds per fruit and ascorbic acid had positive significant association with yield per plant indicating the importance of these traits in selection for yield and were identified as yield attributing characters on which selection can be relied upon for the genetic improvement of yield of chilli.

The path analysis revealed that plant height, fruit set per cent, number of fruits per plant, fruit length, ascorbic acid, oleoresin, red carotenoids, average dry fruit weight, number of seeds per fruit had positive direct effect on yield per plant indicating that direct selection based on these traits may be helpful in evolving high yielding varieties of chilli.

From the results of multivariate analysis, the presence of considerable genetic divergence among the 63 genotypes was revealed. The 63 genotypes were grouped into 8 clusters in both D^2 analysis and Ward's minimum variance method and clearly indicated that the genetic diversity and geographical diversity were not related.

By Mahalanobis' D^2 statistic, it could be inferred that fruit diameter followed by yellow carotenoids, red carotenoids, ascorbic acid and capsaicin contributed maximum towards genetic divergence. Based on intra and inter-cluster distance, it is suggested to make crosses between the genotypes of cluster V (LCA-357, LCA-713, LCA-728, KT-1, HC-28, Pandava, LCA-707, LCA-720, LCA-732, LCA-711, G-5,

LCA-746, LCA-708, LCA-702, CA-960, LCA-620 and G-3), cluster IV (LCA-353, LCA-716, LCA-756, LCA-724, LCA-714, Pusa Sadabahar, Pant C-1, LCA-758, G-4, LCA-738 and LCA-760) and the cluster VIII (Warangal chapatta) after confirming their general combining ability.

Principal component analysis identified six principal components (PCs), which contributed 76.83 per cent of cumulative variance. The significant factors loaded in PC_1 towards maximum genetic divergence were number of seeds per fruit, total color value, ascorbic acid, number of fruits per plant, average dry fruit weight and fruit diameter. 2D and 3D graphs showed wide divergence between Warangal chapatta and LCA-724, LCA-756, LCA-353, LCA-716, Aparna which are also distantly placed with LCA-702 signifying their usefulness in chilli breeding to develop high heterotic hybrids.

Agglomerative cluster analysis revealed wide genetic distance between the genotypes of cluster VII (LCA-707, HC-28, LCA-720, KT-1 and LCA-702), cluster IV (LCA-353, LCA-716, LCA-756, LCA-724, LCA-703, Punjab Gucchedar, Pusa Sadabahar, LCA-714, Pant C-1 and LCA-710) and the cluster VIII (Warangal chapatta).

The genotypes Warangal chapatta, LCA-702, LCA-724, LCA-756, LCA-353 and LCA-716 showed maximum inter-cluster distance in Mahalanobis' D^2 analysis, principal component analysis and cluster analysis. So they can be exploited for the development of heterotic hybrids in future breeding programmes.

FUTURE LINE OF WORK

- In the present study, high heritability coupled with high genetic advance as per cent of mean was observed for all the characters studied except for days to 50 per cent flowering and positive significant correlation along with positive direct effects were observed for plant height, fruit set per cent, number of fruits per plant, number of seeds per fruit and ascorbic acid and these findings need to be validated in the subsequent generations for the improvement of these traits through direct selection.
- Number of fruits per plant showed high heritability, high genetic advance as per cent of mean with positive significant correlation and high positive direct effect on yield.

Therefore, this character shall be given prime importance for further improvement in yield in future breeding programme.

- The superior accessions over checks need to be evaluated in comparison with checks under multilocational trials to know the stable expression of the characters and for their use in future hybridization programme.
- Genotypes of clusters IV and V which showed better performance for quality traits can be used in breeding programme for introgression of their desired genes into the high yielding varieties.
- The genetically divergent genotypes may be used as mapping populations to detect diversity at molecular level and also to identify molecular markers linked to desirable traits for marker assisted selection (MAS).

Table 2.1: Review of literature on variability, heritability and genetic advance for quantitative and qualitative parameters in chilli (*Capsicum annuum* L.)

Character	Materials used for study	GCV (%)	PCV (%)	h^2 (b) (%)	GA (%)	GAM (%)	References
1.Plant height (cm)	52 genotypes	Moderate 16.51	Moderate 18.66	78.33 High	-	30.11 High	Gogoi and Gautam (2002)
	32 accessions	Moderate 18.82	High 20.09	87.77 High	-	36.32 High	Manju and Sreelathakumary (2002)
	46 genotypes	Low 6.13	Moderate 11.90	26.56 Low	-	6.52 Low	Begum (2002)
	27 genotypes	Moderate 18.00	Moderate 18.97	90.00 High	-	35.16 High	Kashinath (2003)
	48 genotypes	11.51 Moderate	12.77 Moderate	81.20 High		21.36 High	Khurana *et al*. (2003)
	36 genotypes	Moderate 16.14	High 21.90	56.18 Moderate	-	25.35 High	Prabhudeva (2003)
	35 genotypes	High 22.44	High 22.78	96.98 High	-	45.52 High	Sreelathakumary and Rajamony (2004)
	12 genotypes	High 27.80	High 29.97	86.09 High	-	96.19 High	Verma *et al*. (2004)
	13 genotypes	Moderate 13.44	Moderate 13.90	93.50 High	-	8.82 Low	Rao (2005)
	31 genotypes	High 25.20	High 27.93	81.00 High	-	42.04 High	Singh *et al*.(2005)

		Moderate	Moderate	High	-	High	Bendale *et al.*(2006)
		High	High	High	-	High	Dutonde *et al.* (2006)
	27 genotypes	Moderate	Moderate	High	Moderate	-	Bharadwaj *et al.*(2007)
	80 accessions	Moderate 19.89	High 20.57	93.5 High	23.19 High	39.62 High	Krishna *et al.* (2007a)
	40 genotypes	Moderate 17.89	Moderate 18.36	94.92 High	28.46 High	35.90 High	Smitha and Basvaraja (2007)
	45 genotypes	High 26.78	High 28.52	88.17 High	21.75 High	16.69 Moderate	Farhad *et al.* (2008)
	37 genotypes	Low	Low	High	-	Low	Patil *et al.* (2008)
	11 genotypes	Moderate 10.52	Moderate 13.98	56.60 Moderate	-	16.30 Moderate	Tembhurne *et al.* (2008)
	40 hybrids	Moderate 11.70	Moderate 13.79	72.05 High	-	20.46 High	Gupta *et al.* (2009)
	30 genotypes	Moderate	Moderate	-	-	-	Singh *et al.* (2009)
	94 paprika accessions	Moderate 14.84	Moderate 15.23	95.00 High	28.37 High	29.79 High	Kumari *et al.* (2010)
		High	High	High	-	High	Kumar *et al.* (2010)
		High	High	High	-	High	Munshi *et al.* (2010)
	23 bell pepper genotypes	Moderate 10.44	Moderate 11.98	75.88 High	9.89 Low	18.72 Moderate	Sharma *et al.* (2010)
	20 capsicum genotypes	Moderate 11.50	Moderate 14.69	61.26 High	9.21 Low	18.55 Moderate	Berhanu *et al.* (2011a)
		High	High	High	-	High	Singh and Singh (2011)
	20 genotypes	21.08 High	21.17 High	99.10 High	20.67 High	43.23 High	Kumar *et al.* (2012)

		Moderate	Moderate	High	-	High	Nehru *et al.* (2012)
	7 varieties	Moderate 15.14	Moderate 16.69	82.27 High	22.50 High	28.29 High	Lakshmi and Padma (2012)
2. Number of primary branches per plant	17 genotypes	Moderate 15.21	Moderate 15.36	98.12 High	-	69.05 High	Ibrahim *et al*. (2001)
	52 genotypes	Low 8.64	Moderate 15.93	29.39 Low	-	9.65 Low	Gogoi and Gautam (2002)
	80 genotypes	High 20.57	Moderate 19.89	93.50	-	39.62	Krishna (2002)
	32 accessions	Moderate 19.17	High 30.56	39.35 Moderate	-	24.77 High	Manju and Sreelathakumary (2002)
	46 genotypes	Low 8.32	Moderate 13.47	38.18 Moderate	-	10.59 Moderate	Begum (2002)
	70 genotypes	Moderate 18.22	Moderate 18.69	95.69 High	-	36.61 High	Sreelathakumary and Rajamony (2002)
	27 genotypes	Moderate 13.38	Moderate 14.56	84.40 High	-	25.36 High	Kashinath (2003)
	36 genotypes	Moderate 14.31	Moderate 16.39	76.22 High	-	25.82 High	Prabhudeva (2003)
	13 genotypes	High 23.84	High 24.24	96.70 High	-	20.03 High	Rao (2005)
	31 genotypes	Moderate 13.90	High 21.74	41.00 Moderate	-	1.28 Low	Singh *et al*.(2005)
		Moderate	Moderate	Moderate	-	Moderate	Bendale *et al*.(2006)

	40 genotypes	High 24.60	High 27.33	81.00 High	3.85 Low	45.02 High	Smitha and Basvaraja (2007)
	45 genotypes	High 41.06	High 41.51	97.86 High	2.794 Low	83.684 High	Farhad *et al.* (2008)
	11 genotypes	Low 5.55	Moderate 12.46	19.80 Low	-	5.09 Low	Tembhurne *et al.* (2008)
	30 genotypes	High	High	-	-	-	Singh *et al.* (2009)
		High	High	High	-	High	Kumar *et al.* (2010)
		High	Moderate	High	-	High	Munshi *et al.* (2010)
	20 capsicum genotypes	High 21.02	High 25.01	70.62 High	3.20 Low	36.38 High	Berhanu *et al.* (2011a)
		Moderate	Moderate	High	-	Low	Singh and Singh (2011)
3. Days to 50 % flowering	46 genotypes	Low 6.28	Moderate 11.41	30.34 Moderate	-	7.13 Low	Begum (2002)
	27 genotypes	Low 7.42	Low 9.76	57.80 Moderate	-	11.63 Moderate	Kashinath (2003)
	36 genotypes	Low 4.17	Low 9.78	76.19 High	-	7.48 Low	Prabhudeva (2003)
		Low	Low	High	-	Low	Choudhary and Samadia (2004)
	12 genotypes	Low 3.76	Low 4.05	86.04 High	-	7.18 Low	Verma *et al.* (2004)
		Low	Low	Low	-	Low	Wasule *et al.* (2004)
	13 genotypes	Low 6.07	Low 6.30	92.60 High	-	3.20 Low	Rao (2005)

	31 genotypes	Moderate 16.56	High 20.47	65.00 High	-	21.55 High	Singh *et al*. (2005)
		Moderate	Moderate	High	-	High	Dutonde *et al*. (2006)
	27 genotypes	Low	Low	High	-	Moderate	Bharadwaj *et al*.(2007)
	80 accessions	Low 5.07	Moderate 13.79	13.50 Low	-	1.70 Low	Krishna *et al.* (2007a)
	72 genotypes and 3 varieties	Low 4.20	Moderate 7.34	32.70 Moderate	-	1.73 Low	Shirshat *et al*. (2007)
	40 genotypes	High 33.13	High 43.71	54.06 Moderate	19.08 Moderate	50.32 High	Smitha and Basvaraja (2007)
	45 genotypes	Low 6.42	Low 8.86	52.60 Moderate	7.262 Low	9.599 Low	Farhad *et al.* (2008)
	37 genotypes	Low	Low	High	-	Low	Patil *et al*. (2008)
	11 genotypes	Low 7.95	Low 8.06	97.20 High	-	16.14 Moderate	Tembhurne *et al.* (2008)
	94 paprika accessions	Low 5.24	Low 5.62	87.02 High	7.57 Low	10.01 Moderate	Kumari *et al*. (2010)
	23 bell pepper genotypes	Low 4.59	Low 8.18	31.50 Moderate	2.06 Low	5.30 Low	Sharma *et al*. (2010)
	34 genotypes	High 27.47	High 27.97	96.50 High	-	25.33 High	Arup *et al.* (2011)
4. Fruit set per cent	80 accessions	High 32.43	High 38.58	70.7 High	-	22.78 High	Krishna *et al.* (2007a)
	37 genotypes	-	-	Low	-	Low	Patil *et al.* (2008)

	22 genotypes (Brinjal)	High 26.97	Moderate 19.68	Moderate 53.25	Moderate 14.07	High 29.59	Patel and Sarnaik (2004)
5. Number of fruits per plant	30 genotypes	High 54.94	High 57.05	95.8 High	52.26 High	108.98 High	Munshi and Behara (2000)
	17 genotypes	Moderate 19.93	Moderate 13.28	96.18 High	-	13.76 Moderate	Ibrahim *et al*. (2001)
	52 genotypes	High 37.64	High 40.37	86.94 High	-	72.30 High	Gogoi and Gautam (2002)
	32 accessions	High 89.54	High 90.08	98.82 High	-	183.37 High	Manju and Sreelathakumary (2002)
	46 genotypes	High 24.76	High 25.95	91.07 High	-	48.71 High	Begum (2002)
	70 genotypes	High 72.15	High 72.39	99.34 High	-	148.14 High	Sreelathakumary and Rajamony (2002)
	27 genotypes	High 29.29	High 36.90	63.00 High	-	47.88 High	Kashinath (2003)
	48 genotypes	High 54.05	High 59.51	82.51 High		101.14 High	Khurana *et al*. (2003)
	36 genotypes	High 42.49	High 44.32	91.92 High	-	83.93 High	Prabhudeva (2003)
	25 genotypes	High	High				Mini and Khader (2004)
	35 genotypes	High 63.70	High 63.88	99.42 High	-	130.84 High	Sreelathakumary and Rajamony (2004)
		High	High	High	-	High	Wasule *et al*. (2004

	22 genotypes	High	High				Mishra *et al.*(2005)
	13 genotypes	High 36.50	High 36.84	98.20 High	-	48.51 High	Rao (2005)
	31 genotypes	High 30.90	High 33.88	83.00 High	-	52.51 High	Singh *et al*. (2005)
		High	High	High	-	High	Bendale *et al*. (2006), Sharma and Sharma (2006)
	22 genotypes	High	High	High	High	High	Sood *et al*. (2006)
	27 genotypes	High	High	High	High	-	Bharadwaj *et al*.(2007)
	80 accessions	High 35.63	High 37.96	88.1 High	122.6 High	70.05 High	Krishna *et al.* (2007a)
	72 genotypes and 3 varieties	High 32.36	High 48.72	44.10 Moderate	33.10 High	44.29 High	Shirshat *et al*. (2007)
	40 genotypes	High 39.02	High 40.04	95.00 High	59.54 High	77.93 High	Smitha and Basvaraja (2007)
	55 genotypes	High	High	High	High	High	Vani *et al*. (2007)
	45 genotypes	High 35.58	High 37.19	91.53 High	8.320 Low	70.134 High	Farhad *et al.* (2008)
	37 genotypes	Low	Low	High	-	Moderate	Patil *et al*. (2008)
	11 genotypes	High 33.70	High 37.68	80.00 High	-	62.08 High	Tembhurne *et al.* (2008)
	40 genotypes	High 30.35	High 31.38	High 93.55	-	High 60.47	Gupta *et al*.(2009)
	94 paprika accessions	High 32.46	High 32.82	97.80 High	83.36 High	66.13 High	Kumari *et al*. (2010)
	50 genotypes	High	High	-	-	-	Padhar and Zaveri (2010)

	23 bell pepper genotypes	High 24.82	High 29.47	70.95 High	2.80 Low	43.07 High	Sharma *et al*. (2010)
	34 genotypes	High 85.02	High 86.05	97.60 High	-	74.75 High	Arup *et al.* (2011)
	20 capsicum genotypes	High 48.47	High 50.44	92.32 High	27.10 High	95.93 High	Berhanu *et al*. (2011a)
		High	High	High	-	High	Singh and singh (2011)
	20 genotypes	39.93 High	40.34 High	98 High	92.68 High	81.43 High	Kumar *et al.* (2012)
	7 varieties	High 30.34	High 32.30	88.24 High	53.76 High	58.7 High	Lakshmi and Padma (2012)
6. Fruit diameter (cm)	52 genotypes	High 28.68	High 32.96	75.69 High	-	51.39 High	Gogoi and Gautam (2002)
	46 genotypes	Moderate 15.65	Moderate 16.84	86.33 High	-	30.00 High	Begum (2002)
	70 genotypes	High 49.12	High 49.21	99.65 High	-	161.02 High	Sreelathakumary and Rajamony (2002)
	27 genotypes	Moderate 19.14	High 23.09	68.17 High	-	33.18 High	Kashinath (2003)
	48 genotypes	High 33.13	High 38.83	72.81 High		58.24 High	Khurana *et al.* (2003)
	36 genotypes	High 45.97	High 49.50	86.20 High	-	87.70 High	Prabhudeva (2003)
	97 genotypes	High	High	High	High	High	Prabhakaran *et al*. (2004)

	12 genotypes	High 31.76	High 33.81	88.00 High	-	8.86 Low	Verma *et al*. (2004)
	31 genotypes	High 20.41	High 21.43	90.00 High	-	40.17 High	Singh *et al*. (2005)
	40 genotypes	High 30.33	High 36.43	49.30 Moderate	0.57 Low	51.81 High	Smitha and Basvaraja (2007)
	11 genotypes	Moderate 15.08	Moderate 17.64	73.10 High	-	26.55 High	Tembhurne *et al.* (2008)
	40 genotypes	14.43 Moderate	18.06 Moderate	63.88 High	-	23.76 High	Gupta *et al*.(2009)
	30 genotypes	High	High	High	-	High	Singh *et al*. (2009)
		Low	Low	High	Low	Moderate	Munshi *et al*. (2010)
	23 bell pepper genotypes	Low 9.14	Low 9.95	84.29 High	0.94 Low	9.86 Low	Sharma *et al*. (2010)
	20 capsicum genotypes	High 37.94	High 39.46	92.43 High	0.82 Low	75.23 High	Berhanu *et al*. (2011a)
	20 genotypes	18.81 Moderate	19.39 Moderate	94.10 High	3.45 Low	37.59 High	Kumar *et al*. (2012)
7. Fruit length (cm)	30 genotypes	Low 5.32	Low 5.50	93.6 High	9.69 Low	10.60 Moderate	Munshi and Behara (2000)
	17 genotypes	High 26.21	High 26.64	96.74 High	-	47.31 High	Ibrahim *et al*. (2001)
	52 genotypes	High 34.29	High 35.53	93.18 High	-	68.19 High	Gogoi and Gautam (2002)

	32 accessions	Moderate 17.51	Moderate 18.07	93.95 High	-	34.97 High	Manju and Sreelathakumary (2002)
	46 genotypes	Moderate 15.54	Moderate 16.94	84.11 High	-	29.30 High	Begum (2002)
	70 genotypes	High 47.45	High 47.52	99.74 High	-	97.63 High	Sreelathakumary and Rajamony (2002)
	27 genotypes	Moderate 19.68	High 20.51	92.10 High	-	38.87 High	Kashinath (2003)
	48 genotypes	High 22.33	High 27.73	88.57 High		43.29 High	Khurana *et al*. (2003)
	97 genotypes	High	High	High	High	High	Prabhakaran *et al*. (2004)
	35 genotypes	High 38.50	High 38.56	99.68 High	-	79.19 High	Sreelathakumary and Rajamony (2004)
	12 genotypes	High 38.41	High 42.11	83.19 High	-	72.92 High	Verma *et al*. (2004)
	22 genotypes	High	High	-	-	-	Mishra *et al*.(2005)
	31 genotypes	High 34.35	High 35.21	95.00 High	-	30.85 High	Singh *et al*. (2005)
	27 genotypes	High	High	High	High	-	Bharadwaj *et al*.(2007)
	80 accessions	High 26.66	High 27.74	92.40 High	4.62 Low	52.80 High	Krishna *et al.* (2007a)
	72 genotypes and 3 varieties	High 21.28	High 23.88	79.50 High	2.79 Low	39.08 High	Shirshat *et al*. (2007)
	40 genotypes	High 224.58	High 29.45	69.70 High	3.75 Low	41.57 High	Smitha and Basvaraja (2007)
	45 genotypes	High 25.97	High 27.16	91.41 High	3.115 Low	51.156 High	Farhad *et al.* (2008)

	11 genotypes	Low 9.81	Moderate 14.19	47.80 Moderate	-	13.96 Moderate	Tembhurne *et al.* (2008)
	40 genotypes	High 21.81	High 22.83	High 91.29	-	High 42.94	Gupta *et al.*(2009)
	30 genotypes	High	High	High	-	High	Singh *et al.* (2009)
	94 paprika accessions	High 22.69	High 24.37	86.68 High	3.74 Low	43.50 High	Kumari *et al.* (2010)
	50 genotypes	High	High	High	-	High	Padhar and Zaveri (2010)
	23 bell pepper genotypes	Low 7.88	Low 9.31	71.70 High	1.31 Low	11.85 Moderate	Sharma *et al.* (2010)
	34 genotypes	High 38.75	High 38.85	99.50 High	-	6.05 Low	Arup *et al.* (2011)
	20 capsicum genotypes	Moderate 19.69	High 21.61	83.05 High	3.52 Low	36.94 High	Berhanu *et al.* (2011a)
	20 genotypes	29.21 High	29.90 High	95.40 High	4.68 Low	58.79 High	Kumar *et al.* (2012)
	7 varieties	High 38.50	High 38.56	93.69 High	1.77 Low	27.7 High	Lakshmi and Padma (2012)
8. Average dry fruit weight (g)	30 genotypes	High 20.47	High 23.10	78.5 High	0.73 Low	37.24 High	Munshi and Behara (2000)
	52 genotypes	High 30.59	High 36.61	69.82 High	-	52.65 High	Gogoi and Gautam (2002)
	80 accessions	High 44.96	High 46.17	94.80 High	-	90.20 High	Krishna (2002)
	32 accessions	High	High	97.75	-	67.28	Manju and

		33.03	33.41	High		High	Sreelathakumary (2002)
	46 genotypes	High 24.35	High 26.32	85.60 High	-	46.42 High	Begum (2002)
	70 genotypes	High 66.99	High 67.18	99.41 High	-	137.57 High	Sreelathakumary and Rajamony (2002)
	27 genotypes	High 29.53	High 29.56	99.90 High	-	60.79 High	Kashinath (2003)
	25 genotypes	High	High	-	-	-	Mini and Khader (2004)
	97 genotypes	High	High	High	High	High	Prabhakaran *et al*. (2004)
	35 genotypes	High 50.89	High 51.04	98.86 High	-	104.48 High	Sreelathakumary and Rajamony (2004)
	22 genotypes	High	High	High	High	High	Sood *et al*. (2006)
	72 genotypes and 3 varieties	High 23.84	High 24.80	92.40 High	0.44 Low	47.31 High	Shirshat *et al*. (2007)
	45 genotypes	High 28.54	High 29.28	95.00 High	0.277 Low	57.30 High	Farhad *et al*. (2008)
	11 genotypes	Moderate 19.37	High 25.17	59.20 Moderate	-	30.71 High	Tembhurne *et al*. (2008)
	40 genotypes	High 22.98	High 24.67	High 86.74	-	High 44.09	Gupta *et al*.(2009)
	30 genotypes	High	High	High	-	High	Singh *et al*. (2009)
	34 genotypes	High 110.97	High 111.63	98.80 High	-	2.57 Low	Arup *et al*. (2011)
	20 genotypes	20.43 High	20.96 High	95 High	1.30 Low	41.03 High	Kumar *et al*. (2012)

9. Number of seeds per fruit	52 genotypes	High 27.89	High 32.27	74.70 High	-	49.67 High	Gogoi and Gautam (2002)
	32 accessions	High 37.44	High 38.01	97.04 High	-	75.99 High	Manju and Sreelathakumary (2002)
	46 genotypes	High 25.10	High 34.77	52.13 Moderate	-	37.20 High	Begum (2002)
	27 genotypes	High 22.69	High 24.68	84.50 High	-	42.95 High	Kashinath (2003)
	48 genotypes	High 46.62	High 50.51	85.17 High		88.63 High	Khurana *et al*. (2003)
	22 genotypes	High	High				Mishra *et al*.(2005)
	13 genotypes	High 27.46	High 27.92	96.70 High	-	22.55 High	Rao (2005)
	31 genotypes	High 32.55	High 34.25	90.00 High	-	43.05 High	Singh *et al*. (2005)
	72 genotypes and 3 varieties	High 26.37	High 27.77	90.20 High	37.40 High	51.60 High	Shirshat *et al*. (2007)
	40 genotypes	Moderate 10.19	High 20.91	80.27 High	19.38 Moderate	26.10 High	Smitha and Basvaraja (2007)
	45 genotypes	High 24.41	High 26.84	82.701 High	30.17 High	45.723 High	Farhad *et al*. (2008)
	30 genotypes	Moderate	Moderate	-	-	-	Singh *et al*. (2009)
	94 paprika accessions	High 41.81	High 42.30	97.71 High	60.89 High	85.13 High	Kumari *et al*. (2010)

	34 genotypes	High 34.93	High 35.18	98.60 High	-	53.43 High	Arup *et al*. (2011)
10. yield per plant (g)	30 genotypes	High 53.80	High 55.67	93.4 High	98.10 High	107.07 High	Munshi and Behara (2000)
	17 genotypes	High 53.80	High 55.67	93.40 High	-	107.07 High	Ibrahim *et al*. (2001)
	52 genotypes	High 51.06	High 58.30	76.70 High	-	92.11 High	Gogoi and Gautam (2002)
	32 accessions	High 89.12	High 89.39	99.38 High	-	183.01 High	Manju and Sreelathakumary (2002)
	70 genotypes	High 40.03	High 40.29	98.72 High	-	81.93 High	Sreelathakumary and Rajamony (2002)
	97 genotypes	High	High	High	High	High	Prabhakaran *et al*. (2004)
	35 genotypes	High 38.99	High 39.21	94.45 High	-	79.87 High	Sreelathakumary and Rajamony (2004)
	22 genotypes	High	High	-	-	-	Mishra *et al*.(2005)
	31 genotypes	High 35.30	High 40.23	77.00 High	-	44.78 High	Singh *et al*. (2005)
	22 genotypes	High	High	High	High	High	Sood *et al*. (2006)
	27 genotypes	High	High	High	High	-	Bharadwaj *et al*.(2007)
	72 genotypes and 3 varieties	High 20.31	High 38.10	28.40 Low	10.92 Moderate	22.30 High	Shirshat *et al*. (2007)
	40 genotypes	High 30.40	High 35.37	73.90 High	160.3 High	52.73 High	Smitha and Basvaraja (2007)
	55 genotypes	High	High	High	High	High	Vani *et al*. (2007)

	45 genotypes	High 40.66	High 42.27	92.77 High	4.694 Low	80.682 High	Farhad *et al.* (2008)
	11 genotypes	High 26.17	High 34.88	56.30 Moderate	-	40.44 High	Tembhurne *et al.* (2008)
	40 genotypes	High 25.98	High 26.79	High 94.03	-	High 51.89	Gupta *et al.*(2009)
	30 genotypes	High	High	High	-	High	Singh *et al*. (2009)
	94 paprika accessions	High 30.62	High 30.96	97.82 High	100.0 High	62.39 High	Kumari *et al*. (2010)
	50 genotypes	High	High	High	-	High	Padhar and Zaveri (2010)
	34 genotypes	High 50.60	High 50.87	99.00 High	-	24.59 High	Arup *et al.* (2011)
	20 capsicum genotypes	High 55.90	High 59.29	88.89 High	0.17 Low	106.25 High	Berhanu *et al*. (2011a)
	20 genotypes	43.28 High	43.36 High	99.60 High	317.44 High	88.98 High	Kumar *et al*. (2012)
11. Ascorbic acid (mg/100g)		High	High	High	-	High	Mallikarjun (2001)
	32 accessions	Moderate 17.04	Moderate 17.07	99.71 High	-	35.05 High	Manju and Sreelathakumary (2002)
	22 genotypes	High	High	High	-	High	Mishra *et al.*(2005)
	27 genotypes	Low	Low	High	Moderate	-	Bharadwaj *et al.*(2007)
	72 genotypes and 3 varieties	High 35.36	High 36.43	94.20 High	138.2 High	70.70 High	Shirshat *et al*. (2007)
	40 genotypes	High	High	High	-	High	Singh *et al*. (2007)

	40 genotypes	Moderate 14.31	Moderate 14.84	93.03 High	54.88 High	28.43 High	Smitha and Basvaraja (2007)
	45 genotypes	High 45.55	High 46.48	96.06 High	1.479 Low	91.983 High	Farhad *et al.* (2008)
	30 genotypes	Moderate	Moderate	-	-	-	Singh *et al*. (2009)
	23 bell pepper genotypes	High 26.68	High 27.98	90.89 High	68.98 High	52.39 High	Sharma *et al*. (2010)
	34 genotypes	High 61.70	High 61.79	99.00 High	-	102.60 High	Arup *et al.* (2011)
	20 genotypes	8.73 Low	8.91 Low	96 High	25.93 High	17.61 Moderate	Kumar *et al.* (2012)
12. Oleoresin (%)		High	High	High	-	High	Mallikarjun (2001)
	32 accessions	High 35.46	High 36.07	96.65 High	-	71.81 High	Manju and Sreelathakumary (2002)
	40 genotypes	Low	Low	High	-	Low	Singh *et al.* (2007)
	40 genotypes	Moderate 10.63	Moderate 11.14	High 91.12	-	High 20.90	Gupta *et al*.(2009)
	30 genotypes	High	High	High	-	High	Singh *et al*. (2009)
	94 paprika accessions	High 36.71	High 36.86	99.20 High	6.13 Low	75.32 High	Kumari *et al*. (2010)
	34 genotypes	High 40.29	High 40.57	98.60 High	-	17.55 Moderate	Arup *et al.* (2011)

13. Capsaicin (%)	32 accessions	High 27.52	High 27.57	99.62 High	-	56.58 High	Manju and Sreelathakumary (2002)
	48 genotypes	Moderate 18.59	Moderate 19.13	94.46 High	-	37.23 High	Khurana *et al*. (2003)
	97 genotypes	High	High	High	High	High	Prabhakaran *et al*. (2004)
		High	High	High	-	High	Dutonde *et al*.(2006)
	27 genotypes	High	High	High	High	-	Bharadwaj *et al*.(2007)
	40 genotypes	Low	Low	High	-	Low	Singh *et al*. (2007)
		Low	Low	Low	-	Low	Kumar *et al*.(2008)
	40 genotypes	High 21.23	High 22.41	High 89.68	-	High 41.41	Gupta *et al*.(2009)
		High	High	High	-	High	Singh *et al*. (2009)
		High	High	High	-	High	Sood *et al*.(2009)
	94 paprika accessions	High 39.83	High 40.31	97.62 High	0.15 Low	81.05 High	Kumari *et al*. (2010)
		Moderate	Moderate	Low		Moderate	Munshi *et al*. (2010)
	34 genotypes	High 45.97	High 46.32	98.50 High	-	0.15 Low	Arup *et al.* (2011)
	20 genotypes	High 41.60	High 41.79	99.10 High	0.30 Low	85.32 High	Kumar *et al.* (2012)
14. Total colour value (ASTA units)		High	High	High	-	High	Mallikarjun (2001)
	48 genotypes	21.34 High	21.40 High	99.44 High	-	43.83 High	Khurana *et al*. (2003)

	40 genotypes	High	High	High	-	High	Singh *et al*. (2007)
		Low	Low	Low	-	Low	Kumar *et al*.(2008)
	40 genotypes	Moderate 18.65	Moderate 18.82	High 98.27	-	High 38.09	Gupta *et al*.(2009)
	30 genotypes	Moderate	Moderate	-	-	-	Singh *et al*. (2009)
	94 paprika accessions	High 58.61	High 58.89	High 99.10	-	High 120.20	Kumari *et al*. (2010)
	103 genotypes	High 58.47	High 58.50	99.90 High	20 High	121 High	Naresh *et al*. (2013)
15. Red carotenoids (%)	103 genotypes	High 70.82	High 70.90	99.80 High	13 Moderate	139 High	Naresh *et al*. (2013)
16. Yellow carotenoids (%)	103 genotypes	High 60.31	High 60.60	99.00 High	9 Low	122 High	Naresh *et al*. (2013)

Table 2.2: Review of literature on character association for quantitative and qualitative characters in chilli (*Capsicum annuum* L.)

Character	Association	S/NS	Correlated character	References
1.plant height (cm)	Positive	S	Yield per plant, number of fruits per plant and capsaicin	Devi and Arumugam (1999)
	Negative	-	Fruit weight, fruit length and fruit diameter	Chaim and Paran (2000)
	Negative Positive	NS S	Number of primary branches per plant Fruit length, fruit diameter, days to 50 % flowering number of seeds per fruit and yield per plant	Begum (2002)
	Positive Positive Negative	NS S NS	Oleoresin Ascorbic acid Capsaicin	Manju and Sreelathakumary (2002)
	Positive Negative Positive	S NS NS	Number of primary branches per plant, days to 50 % flowering, fruit length and fruit diameter. Number of fruits per plant Number of seeds per fruit and per plant	Acharya and Rajput (2003)

	Positive	S	Number of fruits per plant, fruit length, number of seeds per fruit, capsaicin and coloring matter	Khurana *et al*. (2003)
	Negative	-	Yield per plant	Nehru *et al* .(2003)
	Negative Positive	NS NS	Number of fruits per plant and days to 50 % flowering Number of seeds per fruit	Choudary and Samadia (2004)
	Positive	-	Yield per plant, number of fruits per plant and fruit diameter	Singh and Singh (2004)
	Positive Negative Negative	S NS S	Yield per plant, number of fruits per plant, fruit length and fruit diameter Number of primary branches per plant Days to 50 % flowering	Ajjappalavara *et al*. (2005)
	Positive Positive Negative	NS S S	Number of primary branches per plant, number of fruits per plant, and number of seeds per fruit, fruit length and fruit diameter. Yield per plant Days to 50 % flowering	Rao *et al*. (2005)
	Positive	NS	Yield per plant	Ajit and Manju (2006)

	Negative	NS	Yield per plant	Ahmed *et al*. (2006)
	Positive	S	Number of fruits per plant and number of primary branches per plant	Khader and Mini (2006)
	Positive	S	Yield per plant	Jajashree *et al*. (2007)
	Positive Negative	NS NS	Fruit length and number of fruits per plant Per cent fruit set	Krishna *et al*.(2007b)
	Positive	-	Yield per plant	Smitha and Basvaraja (2007)
	Positive Negative	NS NS	Days to 50% flowering, fruit length, fruit weight, number of seeds per fruit and yield per plant. Number of primary branches per plant, number of fruits per plant and ascorbic acid	Farhad *et al*. (2008)
	Positive	NS	Yield per plant	Hosamani and Shivkumar (2008)
	Positive Positive	S NS	Yield per plant, number of primary and secondary branches per plant and number of fruits per plant Fruit length and number of seeds per fruit	Reddy *et al*.(2008)

	Negative	NS	Days to 50 % flowering and average fruit weight	
	Positive Positive Negative Negative	NS S S NS	Number of primary and secondary branches per plant Days to 50% flowering and fruit length Fruit diameter Fruit weight, number of fruits per plant and yield per plant	Tembhurne *et al*. (2008)
	Negative Negative	S NS	Number of fruits per plant, yield per plant and coloring matter Fruit length, capsaicin and oleoresin	Gupta *et al.* (2009)
	Positive Positive Negative	S NS NS	Yield per plant, number of fruits per plant and number of branches per plant Fruit length, Average fruit weight	Jabeen *et al.(*2009)
	Negative	NS	Number of fruits per plant, fruit length and number of seeds per fruit	Kaur and Singh (2009)
	Positive Positive	S NS	Number of fruits per plant Fruit width and average fruit weight	Cankaya *et al.* (2010)

	Negative	NS	Fruit length and days to 50% flowering	
	Positive Negative Negative	NS S NS	Days to 50% flowering, fruit length and number of fruits per plant Average fruit weight, fruit diameter and ascorbic acid Yield per plant	Sharma *et al*. (2010)
	Positive Negative	NS NS	Days to 50% flowering and number of seeds per fruit Fruit length, number of fruits per plant and yield per plant	Hasanuzzaman and Faruq (2011)
	Positive	S	Number of primary and secondary branches per plant and fruit length	Singh and Singh (2011)
	Positive Negative	NS NS	Fruit length Number of fruits per plant, average fruit weight, fruit diameter and yield per plant.	Berhanu *et al.* (2011b)
	Negative Positive	NS NS	Number of fruits per plant, average fruit weight, ascorbic acid , capsaicin, fruit length and yield per plant. Fruit diameter	Kumar *et al.* (2012)

2. Number of primary branches	Positive	S	Yield per plant	Das and Choudhary (1999)
	Positive Negative Positive	S NS NS	Number of fruits per plant Fruit length, plant height and number of seeds per fruit Yield per plant	Begum (2002)
	Positive Positive Negative	S NS NS	Capsaicin Oleoresin Ascorbic acid	Manju and Sreelathakumary (2002)
	Negative Positive Negative Positive	NS S S NS	Number of fruits per plant Fruit length, plant height and days to 50 % flowering Fruit diameter Number of seeds per fruit and yield per plant	Acharya and Rajput (2003)
	Positive	S	Yield per plant	Kumar *et al*. (2003)
	Positive Negative	S NS	Secondary branches per plant Number of fruits per plant, plant height and fruit length	Ajjappalavara *et al*. (2005)

	Positive Negative	NS S	Fruit diameter and days to 50 % flowering Yield per plant	
	Positive Negative Negative Positive	S NS S NS	Number of fruits per plant, days to 50 % flowering and yield per plant Fruit length Fruit diameter Number of seeds per fruit and plant height	Rao (2005)
	Positive	NS	Yield per plant	Ahmed *et al.* (2006)
	Positive	S	Number of fruits per plant	Khader and Mini (2006)
	Positive	-	Yield per plant	Smitha and Basvaraja (2007)
	Positive Positive Negative	S NS NS	Secondary branches per plant, number of fruits per plant and number of seeds per fruit Fruit length and yield per plant Days to 50 % flowering, plant height, fruit weight and ascorbic acid	Farhad *et al*.(2008)
	Positive Positive	S NS	Plant height, number of fruits per plant and yield per plant Average fruit weight and number of seeds per	Reddy *et al.* (2008)

	Negative Negative	S NS	fruit Days to 50 % flowering Fruit length	
	Positive Positive Negative Negative	NS S NS S	Secondary branches per plant Days to 50% flowering, fruit diameter, number of fruits per plant and yield per plant Fruit length Fruit weight	Tembhurne *et al.* (2008)
	Positive	S	Secondary branches per plant, number of fruits per plant and yield per plant	Patel *et al.* (2009)
	Positive Positive	S NS	Yield per plant, plant height and fruit length Number of fruits per plant	Singh and Singh (2011)
3. Days to 50% flowering	Positive Negative	S S	Plant height, fruit length, fruit diameter and number of seeds per fruit Yield per plant	Begum (2002)
	Positive Positive	S NS	Plant height and number of primary branches per plant Fruit length and number of seeds per fruit	Acharya and Rajput (2003)

	Negative	NS	Fruit diameter and yield per plant	
	Negative	S	Yield per plant	Khurana *et al.* (2003)
	Negative	NS	Plant height , fruit length, yield per plant and number of seeds per fruit	Choudary and Samadia (2004)
	Negative Positive Negative	S NS NS	Plant height and yield per plant Number of primary branches per plant Fruit diameter	Ajjappalavara *et al*. (2005)
	Negative	NS	Yield per plant	Ahmed *et al*. (2006)
	Negative	S	Yield per plant	Jayashree *et al.* (2007)
	Positive	S	Yield per plant	Hosamani and Shivkumar (2008)
	Positive Positive Negative	S NS NS	Plant height, number of primary branches, yield per plant and number of fruits per plant Fruit weight and Fruit length Fruit diameter	Tembhurne *et al.* (2008)
	Positive Negative	NS NS	Plant height and ascorbic acid Number of primary branches, fruit weight, number of fruits per plant, number of seeds	Farhad *et al.* (2008)

	Negative	S	per fruit and yield per plant Fruit length	
	Negative Negative	S NS	Number of primary branches per plant Plant height, number of fruits per plant, fruit length, average fruit weight, number of seeds per fruit and yield per plant	Reddy *et al*. (2008)
	Positive Negative Negative	NS NS S	Fruit length and average fruit weight Plant height and fruit width Number of fruits per plant	Cankaya *et al*.(2010)
	Positive Positive Negative Negative	S NS S NS	Fruit diameter Plant height and ascorbic acid Fruit length Number of fruits per plant, average fruit weight and yield per plant	Sharma *et al.* (2010)
	Positive	S	Yield per plant	Arup *et al.* (2011)
	Positive Negative	NS NS	Plant height, number of fruits per plant, number of seeds per fruit and fruit width Fruit length, fruit weight and yield per plant	Kumar *et al*. (2012)

4. Fruit set per cent	Positive Negative	S NS	Yield per plant Plant height , fruit length and number of fruits per plant	Krishna *et al.* (2006) Krishna *et al.* (2007b)
5. Number of fruits per plant	Positive	S	Yield per plant	Das and Choudhary (1999)
	Positive	S	Yield per plant	Devi and Arumugam (1999)
	Positive Negative	S S	Yield per plant Fruit weight	Munshi *et al*. (2000)
	Positive	S	Fruit length, number of primary branches per plant and yield per plant	Begum (2002)
	Positive	-	Oleoresin	Mini and vahab (2002)
	Positive Negative	NS NS	Yield per plant Plant height and number of primary branches per plant	Acharya and Rajput (2003)
	Positive Negative	S NS	Number of seeds per fruit, plant height and coloring matter Fruit length and capsaicin	Khurana *et al.* (2003)

	Positive	S	Yield per plant	Nandadevi and Hosamani (2003)
	Positive Positive Negative	S NS NS	Fruit length Yield per plant Plant height	Choudary and Samadia (2004)
	Positive	-	Yield per plant	Singh and Singh (2004)
	Positive Negative	S NS	Fruit length, plant height and yield per plant Number of primary branches per plant	Ajjappalavara *et al*. (2005)
	Positive Positive	S NS	Yield per plant and number of primary branches per plant Plant height	Rao *et al*. (2005)
	Negative	NS	Yield per plant	Ahmed *et al*. (2006)
	Positive Negative	S -	Plant height and number of primary branches Fruit length	Khader and Mini (2006)
	Positive	S	Yield per plant	Krishna *et al.* (2006)
	Positive	S	Yield per plant and number of branches per plant	Bharadwaj et al. (2007)
	Positive	S	Yield per plant and number of branches per plant	Jayashree *et al.* (2007)

	Positive Positive Negative Negative	S NS S NS	Yield per plant Plant height Fruit length Fruit set per cent	Krishna *et al*. (2007b)
	Positive	S	Yield per plant	Singh *et al*. (2007)
	Positive	S	Yield per plant	Vani *et al*. (2007a)
	Positive Positive Negative Negative	S NS S NS	Number of primary and secondary branches per plant and yield per plant Number of seeds per fruit Ascorbic acid Days to 50 % flowering, plant height, fruit length and fruit weight	Farhad *et al*. (2008)
	Positive	S	Yield per plant	Hosamani and Shivkumar (2008)
	Positive Negative Positive Negative	S S NS NS	Yield per plant, plant height, and number of primary and secondary branches per plant Fruit length Number of seeds per fruit Days to 50 % flowering and average fruit	Reddy *et al*. (2008)

			weight	
	Positive Positive Negative Negative	S NS S NS	Number of primary branches, yield per plant and fruit diameter Days to 50 % flowering Fruit length Plant height and fruit weight	Tembhurne *et al.* (2008)
	Positive Positive Negative Negative	S NS S NS	Yield per plant and coloring matter Oleoresin Plant height Fruit length, fruit weight and capsaicin	Gupta *et al.* (2009)
	Positive Negative Negative	S S NS	Yield per plant Fruit length Average fruit weight	Jabeen *et al.* (2009)
	Negative	NS	Plant height	Kaur and Singh (2009)
	Positive	S	Yield per plant and number of primary and secondary branches per plant	Patel *et al.* (2009)
	Positive	S	Yield per plant	Singh *et al.* (2009)
	Positive Negative	S S	Fruit width and plant height Days to 50 % flowering	Cankaya *et al.* (2010)

	Negative	NS	Fruit length and average fruit weight	
	Positive	S	Yield per plant and number of branches / plant	Padhar and Zaveri (2010)
	Positive Positive Negative	S NS NS	Yield per plant Fruit length, fruit diameter, average fruit weight and plant height Days to 50 % flowering and ascorbic acid	Sharma *et al.* (2010)
	Positive	S	Yield per plant	Arup *et al.* (2011)
	Positive Positive Negative	S NS NS	Yield per plant Days to 50 % flowering, fruit length and number of seeds per fruit Plant height and fruit width	Hasanuzzaman and Faruq (2011)
	Positive Positive	S NS	Fruit length and yield per plant Number of primary branches per plant	Singh and Singh (2011)
	Positive Negative Negative	S S NS	Fruit length, ascorbic acid, capsaicin and yield per plant Fruit diameter Average fruit weight and plant height	Kumar *et al.* (2012)
	positive	-	Yield per plant	Lahbib *et al*. (2012)

6. Fruit diameter (cm)	Negative	-	Fruit length	Das and Choudhary (1999)
	Positive Negative	- -	Fruit weight Plant height	Chaim and paran (2000)
	Positive Positive	S NS	Number of seeds per fruit, days to 50 % flowering, plant height and yield per plant Fruit length	Begum (2002)
	Negative Negative	NS S	Number of seeds per fruit, days to 50 % flowering, number of primary branches per plant, plant height and yield per plant Fruit length	Acharya and Rajput (2003)
	Positive Negative	S S	Yield per plant Number of seeds per fruit and fruit length	Khurana *et al.* (2003)
	Positive Positive	NS S	Number of seeds per fruit and fruit length Yield per plant	Choudary and Samadia (2004)
	Positive	S	Yield per plant	Patil *et al.* (2004)
	Positive	S	Yield per plant	Singh and Singh (2004)

	Negative Positive Positive	NS S NS	Yield per plant and days to 50 % flowering Plant height Number of primary branches per plant and fruit length	Ajjappalavara *et al*. (2005)
	Positive Negative Positive	S S NS	Yield per plant Days to 50 % flowering and number of primary branches per plant Plant height	Rao *et al*. (2005)
	Positive	S	Yield per plant	Singh *et al*. (2007)
	Positive	-	Yield per plant	Smitha and Basvaraja (2007)
	Negative	NS	Yield per plant	Hosamani and Shivkumar *et al*. (2005)
	Positive Positive Negative Negative	S NS S NS	Yield per plant, number of fruits per plant and number of primary branches Fruit weight Plant height Days to 50 % flowering and fruit length	Tembhurne *et al*. (2008)
	Positive	S	Average fruit weight	Jabeen *et al*. (2009)

	Positive Negative	NS NS	Yield per plant Plant height , number of fruits per plant and fruit length	
	Positive Positive Negative	S NS NS	Number of fruits per plant and average fruit weight Fruit length and plant height Days to 50 % flowering	Cankaya *et al.* (2010)
	Positive Positive Negative	S NS S	Days to 50 % flowering, average fruit weight and yield per plant Number of fruits per plant, fruit length and ascorbic acid Plant height	Sharma *et al*. (2010)
	Positive Positive Negative	S NS NS	Yield per plant, fruit weight and fruit length Days to 50 % flowering and number of seeds per fruit Plant height and number of fruits per plant	Hasanuzzaman and Faruq (2011)
	Positive Negative	S S	Fruit length, average fruit weight and yield per plant Number of fruits per plant	Berhanu *et al.* (2011b)

	Negative	NS	Plant height	
	Positive Positive Negative Negative	S NS S NS	Average fruit weight Plant height, fruit length and yield per plant Number of fruits per plant and capsaicin Ascorbic acid	Kumar *et al.* (2012)
	Negative	-	Fruit length	Lahbib *et al.* (2012)
7. Fruit length(cm)	Negative	-	Fruit diameter	Das and Choudhary (1999)
	Positive Negative	- -	Fruit weight Plant height and fruit diameter	Chaim and Param (2000)
	Positive	S	Fruit weight	Munshi *et al.* (2000)
	Positive Positive	NS S	Fruit diameter and number of seeds per fruit Yield per plant, plant height and days to 50 % flowering	Begum (2002)
	Positive Positive	S NS	Ascorbic acid Oleoresin and capsaicin	Manju and Sreelathakumary (2002)
	Negative Positive	S NS	Fruit diameter Number of seeds per fruit, days to 50 %	Acharya and Rajput (2003)

			flowering and yield per plant	
	Positive	S	Plant height	
	Positive	S	Plant height	Khurana *et al*. (2003)
	Positive	NS	Coloring matter	
	Negative	NS	Number of seeds per fruit, number of fruits per plant and capsaicin content	
	Negative	-	Yield per plant	Nehru *et al*. (2003)
	Positive	NS	Fruit diameter, yield per plant and number of seeds per fruit	Choudary and Samadia (2004)
	Negative	NS	Days to 50 % flowering	
	Positive	NS	Fruit diameter	Ajjappalavara *et al*. (2005)
	Positive	S	Yield per plant and plant height	
	Negative	S	Days to 50 % flowering	Rao *et al*. (2005)
	Positive	NS	Plant height	
	Positive	S	Yield per plant	Ahmed *et al*. (2006)
	Negative	-	Number of fruits per plant	Khader and Mini (2006)
	Positive	S	Yield per plant	Krishna *et al*. (2006)
	Positive	S	Yield per plant	Jayashree *et al*. (2007)
	Positive	S	Yield per plant	Krishna *et al*. (2007b)

	Positive Negative Negative	NS S NS	Plant height Number of fruits per plant Per cent fruit set	
	Positive	S	Yield per plant	Singh *et al*. (2007)
	Positive	S	Yield per plant	Vani *et al*. (2007a)
	Positive Positive Negative Negative	S NS S NS	Fruit weight Plant height, number of primary branches per plant, number of seeds per fruit, ascorbic acid and yield per plant Days to 50 % flowering Number of fruits per plant	Farhad *et al*. (2008)
	Positive	NS	Yield per plant	Hosamani and Shivkumar (2008)
	Positive Negative Negative	NS S NS	Plant height and average fruit weight Number of fruits per plant Yield per plant, days to 50 % flowering, number of primary branches per plant and number of seeds per fruit	Reddy *et al.* (2008)
	Positive	NS	Plant height	Tembhurne *et al.* (2008)

	Negative Negative	S NS	Number of fruits per plant Number of primary branches per plant, days to 50 % flowering, fruit weight, yield per plant and fruit diameter	
	Positive Negative	S NS	Yield per plant, fruit weight and capsaicin Number of fruits per plant, plant height, oleoresin and coloring matter	Gupta *et al.* (2009)
	Negative Positive Negative	S NS NS	Number of fruits per plant Average fruit weight and plant height Yield per plant	Jabeen *et al.* (2009)
	Negative	NS	Plant height	Kaur and Singh (2009)
	Positive	S	Yield per plant	Patel *et al*. (2009)
	Positive Positive Negative	S NS NS	Average fruit weight Fruit width and days to 50 % flowering Plant height and number of fruits per plant	Cankaya *et al*. (2010)
	Positive Positive Negative	S NS S	Yield per plant Fruit diameter, average fruit weight, number of fruits per plant and plant height Fruit length	Sharma *et al.* (2010)

	Negative	NS	Ascorbic acid	
	Positive Negative Positive	S NS NS	Fruit width, fruit weight and yield per plant Plant height, number of seeds per fruit and days to 50 % flowering Number of fruits per plant	Hasanuzzaman and Faruq (2011)
	Positive	S	Yield per plant and plant height	Singh and Singh (2011)
	Positive Positive Negative	S NS NS	Yield per plant, fruit weight and fruit diameter Plant height Number of fruits per plant	Berhanu *et al.* (2011b)
	Positive Positive Negative Negative	S NS S NS	Average fruit weight, number of fruits per plant and yield per plant Fruit diameter Ascorbic acid and capsaicin Plant height	Kumar *et al.* (2012)
	Negative	-	Fruit diameter	Lahbib *et al.* (2012)
8. Average dry fruit weight (g)	Positive	S	Yield per plant	Das and Choudhary (1999)

	Positive Negative	- -	Fruit diameter and fruit length Plant height	Chaim and Paran (2000)
	Positive	S	Yield per plant	Munshi *et al*. (2000)
	Positive Negative	NS S	Oleoresin and ascorbic acid Capsaicin	Manju and Sreelathakumary (2002)
	Positive	-	Yield per plant	Patil *et al*. (2004)
	Positive	-	Yield per plant	Smitha and Basvaraja (2007)
	Positive Positive Negative	S NS NS	Fruit length, number of seeds per plant and yield per plant Plant height and ascorbic acid Days to 50 % flowering, number of primary branches and number of fruits per plant	Farhad *et al*. (2008)
	Positive Positive Negative	S NS NS	Yield per plant Number of primary branches per plant and fruit length Days to 50 % flowering, plant height, number of fruits per plant and number of seeds per fruit	Reddy *et al*. (2008)

	Positive Negative Negative	NS NS S	Yield per plant, fruit diameter and days to 50 % flowering Number of fruits per plant, fruit length and plant height Number of primary branches per plant	Tembhurne *et al.* (2008)
	Positive Positive Negative	S NS NS	Fruit length Capsaicin and coloring matter Number of fruits per plant, yield per plant, plant height and oleoresin	Gupta *et al.*(2009)
	Positive Positive Negative	S NS NS	Fruit breadth Fruit length and yield per plant Plant height and number of fruits per plant	Jabeen *et al.* (2009)
	Positive Positive Negative	S NS NS	Fruit length and fruit width Plant height and days to 50 % flowering Number of fruits per plant	Cankaya *et al.* (2010)
	Positive Positive Negative	S NS NS	Yield per plant and fruit diameter Fruit length, ascorbic acid and number of fruits per plant Days to 50 % flowering	Sharma *et al.* (2010)

	Negative	S	Plant height	
	Negative	NS	Yield per plant	Arup *et al*. (2011)
	Positive Negative	S NS	Fruit length and fruit width Days to 50 % flowering	Hasanuzzaman and Faruq (2011)
	Positive Positive Negative	S NS NS	Yield per plant, fruit length and fruit diameter Plant height Number of fruits per plant	Berhanu *et al.* (2011b)
	Positive Positive Negative Negative	S NS S NS	Fruit length, fruit diameter and yield per plant Ascorbic acid Capsaicin Plant height and number of fruits per plant	Kumar *et al.* (2012)
9. Number of seeds per fruit	Positive Positive	S NS	Yield per plant, days to 50 % flowering, plant height, number of primary branches per plant, fruit diameter Fruit length	Begum (2002)
	Positive	NS	Yield per plant, days to 50 % flowering, plant height, number of primary branches per plant, fruit length	Acharya and Rajput (2003)

	Negative	NS	Fruit diameter	
	Positive Negative	S NS	Number of fruits per plant and plant height Fruit length, capsaicin and coloring matter	Khurana *et al.* (2003)
	Positive Negative Positive	S NS NS	Yield per plant Days to 50 % flowering Fruit length, plant height and fruit diameter	Choudary and Samadia (2004)
	Positive	S	Yield per plant and plant height	Ajjappalavara *et al*. (2005)
	Positive Positive	S NS	Yield per plant Days to 50 % flowering, plant height and fruit diameter	Rao *et al*. (2005)
	Positive	S	Yield per plant	Vani *et al*. (2007a)
	Positive Positive Negative	S NS NS	Number of primary and secondary branches , fruit weight and fruit yield per plant Plant height, fruit length and number of fruits per plant Days to 50 % flowering and ascorbic acid	Farhad *et al*. (2008)
	Positive	NS	Plant height, number of primary branches per plant, number of fruits per plant and yield per	Reddy *et al*. (2008)

	Negative	NS	plant Days to 50 % flowering, fruit length and average fruit weight	
	Negative	NS	Plant height	Kaur and Singh (2009)
	Negative	NS	Yield per plant	Arup *et al.* (2011)
	Positive Negative	NS NS	Days to 50 % flowering, fruit width, number of fruits per plant and plant height Fruit length and yield per plant	Hasanuzzaman and Faruq (2011)
10. yield per plant (g)	Positive	S	Number of primary branches per plant, number of fruits per plant and fruit weight	Das and Choudhary (1999)
	Positive	S	Plant height, number of fruits per plant and capsaicin	Devi and Arumugam (1999)
	Positive	S	Number of fruits per plant and fruit weight	Munshi *et al.* (2000)
	Positive Positive Negative	S NS S	Plant height, number of fruits per plant, fruit length, fruit diameter and number of seeds per fruit Number of primary branches per plant Days to 50 % flowering	Begum (2002)

	Positive Negative	NS NS	Plant height, number of primary branches per plant, number of fruits per plant, fruit length and number of seeds per fruit. Days to 50 % flowering and fruit diameter	Acharya and Rajput (2003)
	Positive Negative Positive	S S NS	Plant height, number of fruits per plant, fruit length, fruit diameter, coloring matter and capsaicin Days to 50 % flowering Number of seeds per fruit	Khurana *et al*. (2003)
	Positive	S	Number of fruits per plant and number of primary and secondary branches	Kumar *et al*. (2003)
	Positive	-	Number of fruits per plant	Nandadavi and Hosamani (2003)
	Negative	-	Plant height and fruit length	Nehru *et al*. (2003)
	Positive Positive Negative	NS S NS	Number of fruits per plant and fruit length Fruit diameter and number of seeds per fruit Days to 50 % flowering	Choudary and Samadia (2004)
	Positive	-	Average fruit weight	Patil *et al*. (2004)
	Positive	-	Plant height, number of fruits per plant and	Singh and Singh (2004)

			fruit diameter	
	Positive Negative Negative	S S NS	Plant height, number of fruits per plant and fruit length Days to 50 % flowering and number of primary branches per plant Fruit diameter	Ajjappalavara *et al*. (2005)
	Positive	S	Plant height, number of fruits per plant, number of primary branches per plant, fruit diameter, number of seeds per fruit and fruit length	Rao *et al*. (2005)
	Negative Positive Positive Positive	NS NS S NS	Plant height, days to 50 % flowering and number of fruits per plant Number of primary branches per plant Fruit length and Capsaicin Capsanthin	Ahmed et al. (2006)
	Positive Negative	NS NS	Plant height Number of seeds per fruit	Ajit and Manju (2006)
	Positive	S	Plant height, number of fruits per plant, per cent fruit set and fruit diameter	Krishna *et al.* (2006)

	Positive	S	Number of branches per plant and number of fruits per plant	Bharadwaj *et al*. (2007)
	Positive Negative	S S	Number of branches per plant, plant height, fruit length and number of fruits per plant Days to 50 % flowering	Jayashree *et al*. (2007)
	Positive	S	Fruit length, fruit breadth and number of fruits per plant	Singh *et al*. (2007)
	Positive	-	Fruit length, plant height, fruit weight, number of primary branches and fruit diameter	Smitha and Basvaraja (2007)
	Positive	S	Fruit length, number of seeds per plant and number of fruits per plant	Vani *et al*. (2007a)
	Positive Positive Negative Negative	S NS S NS	Fruit weight, number of seeds per plant and number of fruits per plant Number of primary branches, fruit length and plant height Ascorbic acid Days to 50 % flowering	Farhad *et al*. (2008)
	Positive	NS	Plant height, number of seeds per fruit and	Hosamani and Shivkumar

			fruit length	(2008)
	Positive	S	Days to 50 % flowering, number of fruits per plant and fruit diameter	
	Positive	S	Plant height, number of primary branches per plant, number of fruits per plant and average fruit weight	Reddy *et al*. (2008)
	Negative	NS	Days to 50 % flowering and fruit length	
	Positive	NS	Number of seeds per fruit	
	Positive	S	Number of primary branches, fruit diameter, days to 50 % flowering and number of fruits per plant	Tembhurne *et al*. (2008)
	Positive	NS	Fruit weight	
	Negative	NS	Plant height	
	Positive	S	Number of fruits per plant and fruit length	Gupta *et al*. (2009)
	Positive	NS	Capsaicin, oleoresin and coloring matter	
	Negative	S	Plant height	
	Negative	NS	Fruit weight	
	Positive	S	Number of branches per plant, plant height and number of fruits per plant	Jabeen *et al*. (2009)

	Positive Negative	NS NS	Average fruit weight and fruit breadth Fruit length	
	Positive	S	Number of primary and secondary branches per plant, fruit length, fruit weight and number of fruits per plant	Patel *et al*. (2009)
	Positive	S	Average dry fruit weight, Capsanthin and number of fruits per plant	Singh *et al*. (2009)
	Positive	S	Number of branches per plant and number of fruits per plant	Padhar and Zaveri (2010)
	Positive Negative Positive	S NS NS	Fruit length, fruit diameter, average fruit weight and number of fruits per plant Plant height and days to 50 % flowering Ascorbic acid	Sharma *et al.* (2010)
	Positive Negative	S NS	Ascorbic acid, days to 50 % flowering and number of fruits per plant Number of seeds per fruit, average dry fruit weight, oleoresin and capsaicin	Arup *et al*. (2011)
	Positive	S	Fruit length, fruit width and number of fruits per plant	Hasanuzzaman and Faruq (2011)

	Negative	NS	Plant height, number of seeds per fruit and days to 50 % flowering	
	Positive Positive	S NS	Fruit length, plant height, fruit diameter and fruit weight Number of fruits per plant	Berhanu *et al*. (2011b)
	Positive	S	Fruit length, number of fruits per plant and number of branches per plant	Singh and Singh (2011)
	Positive Positive Negative	S NS NS	Number of fruits per plant, average fruit weight, fruit length, ascorbic acid and capsaicin Fruit diameter Plant height	Kumar *et al*. (2012)
	Positive	S	Number of fruits per plant	Lahbib *et al*. (2012)
11. Ascorbic acid (mg/100g)	Positive Positive Negative	S NS NS	Plant height and fruit length Fruit weight and oleoresin Number of primary branches per plant	Manju and sreelathakumary (2002)
	Positive	NS	Days to 50 % flowering and fruit length	Farhad *et al*. (2008)

	Negative Negative	S NS	Number of fruits per plant and yield per plant Plant height, fruit weight, number of primary and secondary branches per plant and number of seeds per fruit	
	Positive Negative Negative	NS S NS	Days to 50 % flowering, fruit diameter, average fruit weight and yield per plant Plant height Number of fruits per plant and fruit length	Sharma *et al.* (2010)
	Positive	S	Yield per plant	Arup *et al.* (2011)
	Positive Negative	S S	Days to 50% flowering Fruit girth	Cheema and Pant (2011)
	Positive Positive Negative Negative	S NS S NS	Capsaicin, number of fruits per plant and yield per plant Average fruit weight Fruit length Plant height	Kumar *et al.* (2012)
12. Oleoresin (%)	Positive	NS	Plant height, fruit length, fruit weight and number of primary branches per plant	Manju and sreelathakumary (2002)

	Positive Negative	- -	Number of fruits per plant Number of days to flowering, fruit set and harvesting	Mini and Vahab (2002)
	Positive Negative	NS NS	Number of fruits per plant, yield per plant, capsaicin and coloring matter Fruit length, fruit weight and plant height	Gupta *et al.* (2009)
	Negative	NS	Yield per plant	Arup *et al.* (2011)
13. Capsaicin (%)	Positive	S	Yield per plant	Devi and Arumugam (1999)
	Positive Positive Negative Negative	S NS S NS	Number of primary branches per plant and oleoresin Fruit length Fruit weight Plant height	Manju and sreelathakumary (2002)
	Positive Negative	S NS	Plant height and coloring matter Fruit length, number of fruits per plant and number of seeds per fruit	Khurana *et al.* (2003)
	Negative	-	Fruit width	Patil *et al.* (2004)

	Positive Positive Negative	S NS NS	Fruit length Fruit weight, yield per plant, oleoresin and coloring matter Number of fruits per plant and plant height	Gupta *et al*. (2009)
	Negative	NS	Yield per plant	Arup *et al*. (2011)
	Positive Negative Negative	S S NS	Ascorbic acid, number of fruits per plant and yield per plant Average fruit weight, fruit length and fruit diameter Plant height	Kumar *et al*. (2012)
14. Total colour value (ASTA units)	Positive Positive Negative	S NS NS	Number of fruits per plant, plant height and capsaicin Fruit length and yield per plant Number of seeds per fruit	Khurana *et al*. (2003)
	Positive Negative Positive Negative	S S NS NS	Number of fruits per plant Plant height Fruit weight, yield per plant, capsaicin and oleoresin Fruit length	Gupta *et al*. (2009)

	Positive	S	Yield per plant	Singh *et al.* (2009)
	Positive	S	Yellow carotenoids and red carotenoids	Naresh *et al*. (2013)
15. Red carotenoids (%)	Positive	S	Yellow carotenoids and total carotenoids	Naresh *et al*. (2013)
16. Yellow carotenoids (%)	Positive	S	Red carotenoids and total carotenoids	Naresh *et al*. (2013)

Table 2.3: Review of literature on direct effects of yield component characters on yield per plant

Character	Positive direct effect	Negative direct effect
1. Plant height (cm)	Subashri and Natarajan (1999), Khurana *et al.* (2003), Choudhary and Samadia (2004), Rao (2005), Krishna *et al.* (2007b), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Hosamani and Shivkumar (2008), Reddy *et al*. (2008), Jabeen *et al*. (2009), Padhar and Zaveri (2010), Berhanu *et al*. (2011b), Kumar *et al.* (2012).	Nandadevi (1999), Devi and Arumugam (1999), Begam (2002), Ajjappalavara *et al*. (2005), Farhad *et al.* (2008), Kaur and singh (2009), Sharma *et al.* (2010), Hasanuzzaman and Faruq (2011).
2. Number of primary branches per plant	Begam (2002), Rao (2005), Bharadwaj *et al*. (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al.* (2008).	Ajjappalavara *et al.* (2005), Ahmed *et al.* (2006), Farhad *et al.* (2008).
3. Days to 50 % flowering	Nandadevi (1999), Rao (2005), Ahmed *et al*. (2006), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Reddy *et al*. (2008), Sharma *et al.* (2010).	Begam (2002), Choudhary and Samadia (2004), Ajjappalavara *et al*. (2005), Smitha and Basvaraja (2007), Farhad *et al*. (2008), Hosamani and Shivkumar (2008), Reddy *et al*. (2008), Sharma *et al.* (2010), Arup *et al.* (2011),

		Hasanuzzaman and Faruq (2011).
4. Fruit set Per cent	Krishna et al. (2007b).	
5. Number of fruits per plant	Nandadevi (1999), Devi and Arumugam (1999), Subashri and Natarajan (1999), Munshi *et al*.(2000), Khurana *et al.* (2003), Begam (2002), Choudhary and Samadia (2004), Ajjappalavara *et al*. (2005), Rao (2005), Nazir *et al*. (2005), Ahmed *et al.* (2006), Krishna *et al*. (2007b), Singh *et al*. (2007), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Hosamani and Shivkumar (2008), Kaur and singh (2007), Reddy *et al*. (2008), Jabeen *et al*. (2009), Padhar and Zaveri (2010), Sharma *et al*. (2010), Arup *et al.* (2011), Berhanu *et al.* (2011b), Hasanuzzaman and Faruq (2011), Kumar *et al*. (2012).	Prasannakumar *et al*. (1995), Berhanu *et al*. (2011b).
6. Fruit diameter (cm)	Nandadevi (1999), Subashri and Natarajan (1999), Munshi *et al*.(2000), Ajjappalavara *et al.* (2005), Nazir *et al.* (2005), Krishna *et al*. (2007b), Singh *et al.* (2007), Bharadwaj *et al.*	Begam (2002), Khurana *et al.* (2003), Choudhary and Samadia (2004), Rao (2005), Ahmed *et al*. (2006), Smitha and Basvaraja (2007), Hosamani and

	(2007), Smitha and Basvaraja (2007), Sharma *et al.* (2010), Berhanu *et al*. (2011b), Kumar *et al*. (2012).	Shivkumar (2008), Jabeen *et al.* (2009), Sharma *et al.* (2010), Berhanu *et al.* (2011b).
7. Fruit length (cm)	Nandadevi (1999), Subashri and Natarajan (1999), Khurana *et al.* (2003), Ajjappalavara *et al*. (2005), Krishna *et al*. (2007b), Singh *et al*. (2007), Smitha and Basvaraja (2007), Vani *et al.* (2007a), Kaur and singh (2007), Reddy *et al*. (2008), Berhanu *et al.* (2011b), Hasanuzzaman and Faruq (2011), Kumar *et al*. (2012).	Prasannakumar *et al*. (1995), Munshi *et al*. (2000), Begam (2002), Rao (2005), Ahmed *et al.* (2006), Farhad *et al.* (2008), Hosamani and Shivkumar (2008), Reddy *et al.* (2008), Jabeen *et al.* (2009), Sharma *et al.* (2010), Berhanu *et al.* (2011b).
8. Average dry fruit weight (g)	Subashri and Natarajan (1999), Munshi *et al*.(2000), Begam (2002), Rao (2005), Smitha and Basvaraja (2007), Vani *et al.* (2007a), Farhad *et al*. (2008), Reddy *et al*. (2008), Jabeen *et al*. (2009), Sharma *et al.* (2010), Arup *et al.* (2011), Berhanu *et al*. (2011b), Hasanuzzaman and Faruq (2011), Kumar *et al*. (2012).	Choudhary and Samadia (2004), Berhanu *et al.* (2011b).
9. Number of seeds per fruit	Subashri and Natarajan (1999), Devi and	Nandadevi (1999), Begam (2002),

	Arumugam (1999), Smitha and Basvaraja (2007), Hosamani and Shivkumar (2008), Kaur and singh (2007), Reddy *et al.* (2008), Hasanuzzaman and Faruq (2011).	Khurana *et al.* (2003), Choudhary and Samadia (2004), Rao (2005), Smitha and Basvaraja (2007), Farhad *et al.* (2008), Arup *et al.* (2011), Hasanuzzaman and Faruq (2011).
10.Ascorbic acid content (mg/100g)	Singh *et al*. (2007), Farhad *et al.* (2008), Sharma *et al.* (2010), Arup *et al*. (2011), Kumar *et al*. (2012).	
11. Oleoresin content (%)	Singh *et al.* (2007).	Arup *et al.* (2011).
12. Capsaicin content (%)	Khurana *et al*. (2003), Singh *et al*. (2007), Kumar *et al.* (2012).	Singh *et al*. (2009), Arup *et al.* (2011).
13. Color value (ASTA units)	Khurana *et al.* (2003), Singh *et al*. (2009).	

Table 4.1: Analysis of variance for various characters in chilli (*Capsicum annuum* L.)

S.No.	Character	Mean sum of squares		
		Replications	Genotypes	Error
1	Plant height (cm)	28.097	563.376**	43.543
2	Number of primary branches per plant	0.701	1.117**	0.219
3	Days to 50 per cent flowering	1.341	25.422**	3.954
4	Fruit set per cent	176.198*	501.725**	39.198
5	Number of fruits per plant	409.320	9125.453**	634.339
6	Fruit diameter (cm)	0.024**	0.276**	0.0007
7	Fruit length (cm)	0.956*	6.022**	0.234
8	Ascorbic acid (mg/100g)	4.371	4326.548**	100.724
9	Oleoresin (%)	0.944	6.103**	0.572
10	Capsaicin (%)	0.000007	0.022**	0.0006
11	Total colour value (ASTA Units)	35.914	1234.578**	32.894
12	Red carotenoids (%)	0.000096	0.0032**	0.000046
13	Yellow carotenoids (%)	0.000179*	0.0020**	0.000032
14	Average dry fruit weight (g)	0.00002	0.369**	0.028
15	Number of seeds per fruit	1.28	580.326**	80.323
16	Yield per plant (g)	2143.226	3553.576**	541.662

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

Table 4.2: Variation in morphological features of chilli *(Capsicum annuum* L.*)*

GENOTYPES	FRUIT POSITION	FRUITS PER AXIL	MATURE GREEN FRUIT COLOR
G-3	PENDENT	SOLITARY	GREEN
G-4	PENDENT	SOLITARY	GREEN
G-5	PENDENT	SOLITARY	GREEN
LCA-206	PENDENT	SOLITARY	GREEN
LCA-235	PENDENT	SOLITARY	GREEN
LCA-305	PENDENT	SOLITARY	GREEN
LCA-315	PENDENT	SOLITARY	DARK GREEN
LCA-353	PENDENT	SOLITARY	PARROT GREEN
LCA-357	PENDENT	SOLITARY	DARK GREEN
LCA-424	PENDENT	SOLITARY	GREEN
LCA-436	PENDENT	SOLITARY	DARK GREEN
LCA-620	PENDENT	SOLITARY	PARROT GREEN
LCA-625	PENDENT	SOLITARY	GREEN
LCA-702	PENDENT	SOLITARY	GREEN
LCA-703	PENDENT	SOLITARY	GREEN
LCA-704	PENDENT	SOLITARY	GREEN
LCA-705	PENDENT	SOLITARY	GREEN
LCA-706	PENDENT	SOLITARY	PARROT GREEN
LCA-707	PENDENT	SOLITARY	GREEN
LCA-708	PENDENT	SOLITARY	GREEN
LCA-709	PENDENT	SOLITARY	DARK GREEN
LCA-710	PENDENT	CLUSTER	GREEN
LCA-711	PENDENT	SOLITARY	GREEN
LCA-712	PENDENT	SOLITARY	PARROT GREEN
LCA-713	PENDENT	SOLITARY	GREEN
LCA-714	ERECT	CLUSTER	GREEN
LCA-715	PENDENT	SOLITARY	PARROT GREEN
LCA-716	PENDENT	SOLITARY	PARROT GREEN
LCA-718	PENDENT	SOLITARY	GREEN
LCA-720	PENDENT	SOLITARY	GREEN
LCA-722	PENDENT	SOLITARY	GREEN
LCA-724	ERECT	CLUSTER	GREEN
LCA-726	PENDENT	SOLITARY	PARROT GREEN
LCA-728	PENDENT	SOLITARY	GREEN
LCA-730	PENDENT	SOLITARY	GREEN
LCA-732	PENDENT	SOLITARY	GREEN
LCA-734	PENDENT	SOLITARY	GREEN
LCA-736	PENDENT	SOLITARY	GREEN

LCA-738	PENDENT	SOLITARY	GREEN
LCA-740	PENDENT	SOLITARY	GREEN
LCA-742	PENDENT	SOLITARY	GREEN
LCA-744	PENDENT	SOLITARY	GREEN
LCA-746	PENDENT	SOLITARY	GREEN
LCA-748	PENDENT	SOLITARY	PARROT GREEN
LCA-750	PENDENT	SOLITARY	GREEN
LCA-752	PENDENT	SOLITARY	GREEN
LCA-754	PENDENT	SOLITARY	GREEN
LCA-756	ERECT	CLUSTER	GREEN
LCA-758	PENDENT	CLUSTER	GREEN
LCA-760	ERECT	CLUSTER	GREEN
LCA-762	PENDENT	SOLITARY	DARK GREEN
CA-960	PENDENT	SOLITARY	GREEN
HC-28	ERECT	CLUSTER	PARROT GREEN
KT-1	PENDENT	SOLITARY	GREEN
APARNA	PENDENT	SOLITARY	GREEN
PANDAVA	ERECT	CLUSTER	GREEN
PANTC-1	ERECT	SOLITARY	GREEN
PHULE JYOTHI	PENDENT	CLUSTER	GREEN
PUNJAB GUCCHEDAR	ERECT	CLUSTER	PARROT GREEN
PUSA SADABAHAR	ERECT	CLUSTER	GREEN
SUPER-10	PENDENT	SOLITARY	GREEN
WARANGAL CHAPATA	PENDENT	SOLITARY	GREEN
LCA-334	PENDENT	SOLITARY	PARROT GREEN

Table 4.3: Mean performance of various quantitative characters in chilli (*Capsicum annuum* L.) genotypes

Genotype	PH	NPBP	DFF	FSP	NFP	FD	FL	ADFW	NSF	YP
G-3	88.20	2.80	31.00	**17.00**	116.70	1.32	6.69	0.87	59.50	96.35
G-4	112.50	2.70	31.50	44.50	229.00	1.13	6.89	0.86	60.80	196.91
G-5	66.95	3.00	32.50	28.00	129.50	1.98	4.66	1.25	68.10	142.77
LCA-206	71.50	4.50	29.00	59.00	183.00	1.28	9.83	0.87	60.00	142.06
LCA-235	64.90	3.50	36.00	34.00	197.70	0.97	8.12	0.83	43.60	99.66
LCA-305	**49.95**	2.90	34.00	46.00	167.70	1.37	6.41	1.01	42.40	129.91
LCA-315	80.40	2.90	30.50	55.00	140.80	1.52	9.25	1.21	57.50	153.46
LCA-353	89.05	3.90	28.50	78.00	266.80	1.00	9.17	0.70	48.00	171.02
LCA-357	86.30	3.60	29.50	62.00	181.20	1.27	10.94	0.91	61.80	199.98
LCA-424	84.55	3.00	35.00	41.00	253.60	1.34	9.28	0.88	48.80	163.22
LCA-436	68.10	3.10	32.00	76.00	133.65	1.46	8.81	1.42	57.70	160.67
LCA-620	81.65	4.50	31.50	54.00	228.00	1.48	9.57	1.09	76.70	249.93
LCA-625	99.80	3.10	28.00	70.00	334.30	1.05	8.42	1.23	74.05	**295.10**
LCA-702	101.80	2.90	30.00	47.00	82.40	2.12	10.81	1.86	64.50	120.40
LCA-703	98.85	4.10	32.00	44.00	156.80	1.26	8.59	0.98	42.60	160.12
LCA-704	98.85	3.60	33.00	37.00	124.80	1.41	8.71	0.95	60.60	105.56
LCA-705	90.30	3.70	32.50	49.00	137.30	1.38	9.24	1.14	57.00	132.93
LCA-706	107.35	3.00	28.50	48.00	**480.00**	1.24	6.98	0.77	73.30	204.18
LCA-707	117.30	3.60	28.50	19.00	71.90	1.72	8.73	1.40	50.20	**83.95**
LCA-708	60.60	**2.30**	25.00	58.00	89.40	2.04	7.41	1.62	73.70	124.32
LCA-709	90.90	3.60	**24.00**	23.00	263.80	1.40	6.98	0.69	58.10	142.17
LCA-710	64.90	5.20	27.00	38.00	169.00	1.03	8.31	0.54	39.40	101.68
LCA-711	78.00	2.90	30.50	64.50	144.00	1.86	7.79	1.43	73.30	156.75
LCA-712	83.50	3.30	32.50	38.00	187.00	1.27	9.84	0.98	**32.80**	165.02
LCA-713	83.50	4.40	29.00	61.00	210.60	1.32	10.35	1.22	72.40	145.52
LCA-714	68.10	3.30	34.00	77.00	158.30	0.90	5.57	0.55	51.30	95.25
LCA-715	74.80	4.10	34.00	69.00	176.80	1.35	8.90	1.37	58.30	185.33
LCA-716	81.60	3.70	28.00	64.00	185.60	0.98	8.04	1.18	60.50	186.11
LCA-718	79.40	3.20	28.00	73.00	192.20	1.31	10.33	1.25	73.30	166.49
LCA-720	**127.75**	2.70	31.00	78.50	101.40	1.76	10.63	1.93	65.30	160.56
LCA-722	107.55	3.90	28.50	63.00	220.30	1.24	8.34	1.32	76.40	244.24
LCA-724	83.15	5.10	28.00	43.00	206.10	0.82	8.70	0.57	41.00	112.82
LCA-726	92.50	4.80	28.00	37.00	194.80	1.05	10.34	1.01	63.10	170.53
LCA-728	113.30	3.30	28.00	18.00	179.60	1.20	7.84	0.77	62.00	151.88
LCA-730	116.95	3.70	29.50	46.00	162.40	1.26	7.94	0.96	62.10	158.23
LCA-732	78.80	3.30	35.00	47.00	176.00	1.69	7.18	1.32	56.30	166.11
LCA-734	86.45	3.10	36.00	37.00	102.70	1.31	11.34	1.52	57.70	115.06
LCA-736	115.75	2.90	35.00	56.00	169.70	1.23	10.43	1.51	77.00	190.86
LCA-738	99.90	3.50	26.00	46.00	137.20	1.08	11.08	1.23	60.00	151.12
LCA-740	100.85	3.70	35.00	42.00	179.00	1.17	**12.97**	1.08	76.00	141.76
LCA-742	94.55	3.90	35.50	39.50	193.60	1.25	11.81	0.87	70.70	171.99

LCA-744	90.05	3.40	35.00	62.00	151.60	1.08	9.85	1.04	62.30	136.64
LCA-746	103.00	5.00	27.00	**87.00**	197.60	1.52	9.32	1.32	73.30	218.29
LCA-748	93.00	4.30	33.00	61.00	248.50	1.04	8.74	0.86	56.70	187.27
LCA-750	62.60	2.60	28.00	52.00	120.70	1.27	8.80	0.91	46.20	95.10
LCA-752	74.65	2.80	34.00	49.00	141.70	1.43	8.40	1.15	61.80	121.86
LCA-754	88.65	2.70	31.00	56.00	145.30	1.36	9.11	1.06	57.30	133.95
LCA-756	114.30	3.80	39.00	49.00	313.30	**0.76**	6.84	**0.50**	48.20	145.25
LCA-758	73.40	4.40	28.00	56.00	134.80	0.99	8.72	0.67	35.00	103.80
LCA-760	75.30	4.80	33.00	26.00	217.90	0.96	9.12	0.81	54.50	145.61
LCA-762	80.25	3.00	36.00	38.00	96.10	1.53	9.21	1.57	93.30	125.82
CA-960	71.95	2.80	27.50	33.00	82.40	1.96	8.85	1.43	81.20	92.77
HC-28	104.10	3.80	**42.00**	48.00	160.20	1.41	4.89	1.13	84.80	126.20
KT-1	84.50	4.10	32.00	38.00	98.20	1.64	11.83	1.06	50.60	98.79
Aparna	82.00	3.60	31.00	56.00	159.00	1.32	9.92	1.05	58.40	132.34
Pandava	75.05	**5.30**	37.00	70.00	136.00	1.52	6.54	1.10	45.80	102.04
Pant C-1	56.85	2.90	34.00	51.00	194.30	1.10	**4.06**	0.72	44.20	100.71
Phule Jyoti	69.35	4.40	32.00	46.00	166.40	1.38	8.23	0.70	48.70	105.84
Punjab Gucchedar	77.10	4.10	34.00	50.00	125.00	1.25	7.82	0.51	51.70	96.97
Pusa Sadabahar	73.95	**5.30**	25.50	64.00	133.20	1.15	6.12	0.63	56.30	111.49
Super-10	99.15	4.10	35.50	56.00	179.70	1.51	8.74	1.24	70.20	185.86
Warangal Chapatta	106.30	2.80	34.00	32.50	**49.80**	**3.17**	8.71	**3.35**	**152.50**	107.30
LCA-334	95.55	3.20	30.00	74.00	200.00	0.98	8.42	0.95	65.00	164.10
Mean	**87.18**	**3.61**	**31.42**	**50.50**	**172.48**	**1.35**	**8.66**	**1.09**	**61.36**	**146.82**
C.V.	7.57	12.99	6.33	12.40	14.60	2.00	5.60	15.30	14.60	15.85
F ratio	12.94	5.08	6.43	12.80	14.39	375.84	25.66	13.17	7.22	6.56
S.E.	4.67	0.33	1.41	4.43	17.81	0.02	0.34	0.11	6.33	16.45
C.D. 5%	13.19	0.94	3.97	12.52	50.35	0.05	0.97	0.33	17.91	46.52

Bold values indicate maximum and minimum mean performance

Where

PH – Plant Height (cm), NPBP – Number of Primary Branches per Plant, DFF – Days to 50 per cent Flowering , FSP – Fruit Set Per cent, NFP – Number of Fruits per Plant, FD – Fruit Diameter (cm), FL – Fruit Length (cm), ADFW –Average Dry Fruit Weight (g), NSF – Number of Seeds per Fruit, YP –Yield per Plant (g).

Table 4.4: Mean performance of various qualitative characters in chilli (*Capsicum annuum* L.) genotypes

Genotype	Ascorbic Acid (mg /100g)	Oleoresin (%)	Capsaicin (%)	Total Colour Value (ASTA Units)	Red Carotenoids (%)	Yellow Carotenoids (%)
G-3	90.00	10.45	0.34	30.09	0.08	0.03
G-4	174.00	10.25	**0.14**	73.64	0.14	0.09
G-5	130.00	7.94	0.21	84.63	0.16	0.06
LCA-206	120.32	9.76	0.22	71.58	0.12	0.09
LCA-235	115.71	9.72	0.25	64.78	0.12	0.05
LCA-305	116.55	9.42	0.28	71.34	0.13	0.06
LCA-315	107.55	6.53	0.25	95.78	0.14	0.08
LCA-353	206.27	8.59	0.35	54.94	0.09	0.04
LCA-357	68.77	7.33	0.44	124.23	**0.22**	0.14
LCA-424	77.33	8.94	0.43	76.51	0.14	0.08
LCA-436	69.33	6.86	0.16	66.42	0.12	0.08
LCA-620	135.99	10.13	0.46	63.85	0.06	**0.01**
LCA-625	115.00	11.29	0.32	76.43	0.12	0.09
LCA-702	61.66	7.75	0.28	120.62	0.19	0.11
LCA-703	135.88	11.29	0.42	66.10	0.09	0.08
LCA-704	86.00	10.05	0.38	65.03	0.10	0.06
LCA-705	117.00	9.40	0.31	65.51	0.09	0.06
LCA-706	118.35	9.15	0.45	43.13	0.12	0.03
LCA-707	48.33	7.18	0.47	104.22	0.14	0.13
LCA-708	150.33	6.68	0.29	75.93	0.13	0.05
LCA-709	69.66	7.05	0.44	96.68	0.19	0.09
LCA-710	52.34	9.07	0.37	80.77	0.12	0.10
LCA-711	72.11	8.18	0.26	55.27	0.10	0.06
LCA-712	64.77	6.69	0.31	60.03	0.13	0.03
LCA-713	106.63	9.96	0.31	**128.00**	0.20	0.14
LCA-714	78.00	12.15	0.50	84.79	0.14	0.09
LCA-715	86.66	9.13	0.38	59.94	0.13	0.04
LCA-716	176.88	8.91	0.47	54.21	0.10	0.06
LCA-718	121.18	6.58	0.26	59.69	0.09	0.08
LCA-720	145.70	9.55	0.19	85.78	0.16	0.09
LCA-722	127.61	9.88	0.25	38.79	0.12	0.03
LCA-724	189.50	**12.31**	0.49	86.60	0.14	**0.01**
LCA-726	118.68	9.93	0.19	45.26	0.10	0.02
LCA-728	115.81	12.05	0.24	121.85	0.20	0.09
LCA-730	57.33	11.57	0.28	52.81	0.10	0.05
LCA-732	221.71	10.55	0.36	97.67	0.19	0.07
LCA-734	96.57	6.55	0.25	87.08	0.14	0.07
LCA-736	198.32	6.18	0.31	68.47	0.12	0.07
LCA-738	119.71	9.13	0.32	112.42	0.16	0.14

LCA-740	66.09	9.67	0.30	86.10	0.14	0.09
LCA-742	44.56	7.47	0.22	55.44	0.09	0.06
LCA-744	87.81	7.75	0.31	49.53	0.09	0.03
LCA-746	210.85	9.18	0.26	52.97	0.06	0.08
LCA-748	146.46	7.58	0.16	54.04	0.08	0.06
LCA-750	59.81	7.90	0.22	74.62	0.12	0.06
LCA-752	143.42	6.98	0.38	97.00	0.16	0.08
LCA-754	147.23	10.18	0.23	68.79	0.11	0.06
LCA-756	184.75	11.61	0.35	55.60	0.07	0.08
LCA-758	111.04	7.63	0.19	107.75	0.14	0.09
LCA-760	64.57	9.31	0.17	115.46	0.17	0.13
LCA-762	101.92	7.23	0.26	79.62	0.13	0.09
CA-960	71.25	7.96	0.25	33.21	0.07	0.05
HC-28	62.88	9.49	0.50	103.81	0.14	**0.15**
KT-1	75.00	5.85	0.28	121.14	**0.22**	0.09
Aparna	**223.22**	5.96	0.26	**20.58**	**0.00**	0.04
Pandava	182.65	**5.17**	0.26	86.02	0.14	0.10
Pant C-1	140.83	7.68	0.43	78.56	0.11	0.12
Phule Jyoti	**43.99**	11.55	0.46	71.50	0.12	0.06
Punjab Gucchedar	127.99	8.04	0.47	63.71	0.10	0.09
Pusa Sadabahar	131.99	7.22	**0.64**	73.96	0.13	0.06
Super-10	129.65	10.77	0.29	41.58	0.09	0.03
Warangal Chapatta	90.00	9.61	0.29	105.00	0.04	0.04
LCA-334	107.81	9.72	0.18	51.91	0.10	0.07
Mean	**114.59**	**8.82**	**0.32**	**74.90**	**0.12**	**0.07**
C.V.	8.76	8.58	7.88	7.66	5.54	7.89
F ratio	42.95	10.66	35.96	37.53	70.21	63.95
S.E.	7.10	0.54	0.02	4.06	0.00	0.00
C.D. 5%	20.06	1.51	0.05	11.46	0.01	0.01

Bold values indicate maximum and minimum mean performance

Table 4.5: Estimates of mean, range, components of variance, heritability and genetic advance for yield per plant and it's component characters in chilli (*Capsicum annuum* L.)

S.No.	Character	Mean	Range	V_g	V_p	GCV (%)	PCV (%)	h^2(b) (%)	GA @ 5%	GAM @ 5%
1	**PH**	87.17	49.95-127.75	259.91	303.46	18.49	19.98	85.65	30.73	35.25
2	**NPBP**	3.61	2.3-5.3	0.44	0.66	18.55	22.64	67.11	1.13	31.30
3	**DFF**	31.42	24-42	10.73	14.68	10.42	12.19	73.08	5.77	18.36
4	**FSP**	50.50	17-87	231.26	270.46	30.11	32.56	85.50	28.96	57.36
5	**NFP**	172.48	49.8-480	4245.55	4879.89	37.77	40.50	87.00	125.19	72.58
6	**FD**	1.35	0.76-3.17	0.13	0.13	27.44	27.52	99.50	0.76	56.39
7	**FL**	8.65	4.06-12.97	2.89	3.12	19.64	20.42	92.48	3.37	38.92
8	**AA**	114.59	43.99-223.22	2112.91	2213.63	40.11	41.05	95.44	92.51	80.73
9	**O**	8.82	5.17-12.31	2.76	3.33	18.85	20.71	82.83	3.11	35.35
10	**C**	0.31	0.13-0.64	0.01	0.012	32.92	33.85	91.66	0.20	65.97
11	**TCV**	74.90	20.58-128	600.84	633.73	32.72	33.61	94.80	49.16	65.64
12	**RC**	0.12	0.005-0.215	0.002	0.002	32.59	33.06	97.20	0.08	66.19
13	**YC**	0.07	0.01-0.145	0.001	0.001	44.23	44.93	96.90	0.06	89.71
14	**ADFW**	1.09	0.5-3.35	0.17	0.19	37.77	40.75	85.92	0.78	72.11
15	**NSF**	61.36	32.8-152.5	250.00	330.32	25.76	29.61	75.68	28.33	46.17
16	**YP**	146.82	83.95-295.10	1505.95	2047.61	26.43	30.81	73.54	68.55	46.69

Where

PH- Plant Height (cm), NPBP – Number of Primary Branches per Plant, DFF – Days to 50 per cent Flowering , FSP – Fruit Set Per cent, NFP – Number of Fruits per Plant, FD – Fruit Diameter (cm), FL – Fruit Length (cm), AA – Ascorbic Acid (mg/100g), O – Oleoresin (%), C – Capsaicin (%), TCV – Total Color Value (ASTA units), RC – Red Carotenoids (%), YC – Yellow Carotenoids (%), ADFW –Average Dry Fruit Weight (g), NSF – Number of Seeds per Fruit, YP –Yield per Plant (g), V_g - Genotypic variance, V_p - Phenotypic variance, GCV - Genotypic co efficient of variation, PCV - Phenotypic co efficient of variation, h^2(b) **-** Heritability at broad sence, GA - Genetic Advance, GAM - Genetic Advance as a per cent of mean.

Table 4.6: Phenotypic (above diagonal) and genotypic (below diagonal) correlation coefficients among ten quantitative characters in chilli (*Capsicum annuum* L.)

Character	Plant height (cm)	Number of primary branches per plant	Days to 50% flowering	Fruit set per cent	Number of fruits per plant	Fruit diameter (cm)	Fruit length (cm)	Average dry fruit weight (g)	Number of seeds per fruit	Yield per plant (g)
Plant Height (cm)	**1.0000**	-0.0503	0.0140	-0.0500	0.1915*	0.0513	0.2452**	0.2415**	0.3031**	**0.3599****
Number of primary branches per plant	-0.0797	**1.0000**	-0.0817	0.1050	0.1462	-0.3298**	0.0708	-0.3480**	-0.2018*	**0.0369**
Days to 50% Flowering	0.0522	-0.0993	**1.0000**	-0.0677	-0.0677	0.0157	-0.0822	0.0680	0.0358	**-0.1402**
Fruit set per cent	-0.0649	0.1053	-0.0973	**1.0000**	0.1372	-0.1556	0.0508	0.0431	0.0096	**0.3526****
Number of fruits per plant	0.1696	0.1609	-0.0575	0.1811*	**1.0000**	-0.5058**	-0.1335	-0.4382**	-0.1271	**0.5886****
Fruit diameter (cm)	0.0547	-0.4046**	0.0193	-0.1655	-0.5418**	**1.0000**	0.0236	0.8024**	0.6015**	**-0.1550**
Fruit length (cm)	0.2839**	0.0799	-0.1309	0.0490	-0.1501	0.0240	**1.0000**	0.2371**	0.0916	**0.1537**
Average dry fruit weight (g)	0.2545**	-0.4602**	0.0812	0.0329	-0.4841**	0.8587**	0.2545**	**1.0000**	0.6944**	**0.0714**
Number of seeds per fruit	0.3769**	-0.3627**	0.1180	-0.0218	-0.1480	0.6917**	0.1434	0.8301**	**1.0000**	**0.1968***
Yield per plant (g)	**0.3936****	**0.0041**	**-0.1368**	**0.4537****	**0.6175****	**-0.1861***	**0.1988***	**0.0589**	**0.2473****	**1.0000**

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

Table 4.8: Phenotypic path analysis showing direct (diagonal) and indirect effects of quantitative characters on yield per plant in chilli (*Capsicum annuum* L.)

Character	Plant height (cm)	Number of primary branches per plant	Days to 50% flowering	Fruit set per cent	Number of fruits per plant	Fruit diameter (cm)	Fruit length (cm)	Average dry fruit weight (g)	Number of seeds per fruit
Plant Height (cm)	**0.1289**	-0.0065	0.0018	-0.0064	0.0247	0.0066	0.0316	0.0311	0.0391
Number of primary branches per plant	-0.0003	**0.0051**	-0.0004	0.0005	0.0007	-0.0017	0.0004	-0.0018	-0.0010
Days to 50% Flowering	-0.0014	0.0081	**-0.0985**	0.0067	0.0067	-0.0015	0.0081	-0.0067	-0.0035
Fruit set per cent	-0.0113	0.0237	-0.0152	**0.2252**	0.0309	-0.0350	0.0114	0.0097	0.0022
Number of fruits per plant	0.1224	0.0935	-0.0433	0.0877	**0.6393**	-0.3233	-0.0854	-0.2801	-0.0813
Fruit diameter (cm)	-0.0060	0.0386	-0.0018	0.0182	0.0592	**-0.1170**	-0.0028	-0.0939	-0.0704
Fruit length (cm)	0.0252	0.0073	-0.0084	0.0052	-0.0137	0.0024	**0.1027**	0.0244	0.0094
Average dry fruit weight (g)	0.0834	-0.1201	0.0235	0.0149	-0.1512	0.2769	0.0818	**0.3451**	0.2396
Number of seeds per fruit	0.0190	-0.0127	0.0022	0.0006	-0.0080	0.0377	0.0057	0.0436	**0.0627**
‘r’ with Yield per Plant (g)	**0.3599****	**0.0369**	**-0.1402**	**0.3526****	**0.5886****	**-0.1550**	**0.1537**	**0.0714**	**0.1968***

‘r’ – Correlation coefficient , *: Significant at 5 per cent level;   **: Significant at 1 per cent level

Table 4.7: Phenotypic (above diagonal) and genotypic (below diagonal) correlation coefficients among six qualitative characters and yield per plant in chilli (*Capsicum annuum* L.)

Character	Ascorbic acid (mg /100g)	Oleoresin (%)	Capsaicin (%)	Total colour value (ASTA Units)	Red carotenoids (%)	Yellow carotenoids (%)	Yield per Plant (g)
Ascorbic acid (mg /100g)	**1.0000**	0.0164	-0.0272	-0.2322**	-0.2307**	-0.2115*	**0.2495****
Oleoresin (%)	0.0435	**1.0000**	0.1274	-0.0700	-0.0599	-0.1407	**0.1516**
Capsaicin (%)	-0.0256	0.1477	**1.0000**	0.0845	0.0546	0.0616	**-0.1163**
Total colour value (ASTA Units)	-0.2441**	-0.0801	0.0898	**1.0000**	0.7881**	0.6859**	**-0.2108***
Red carotenoids (%)	-0.2431**	-0.0554	0.0508	0.8162**	**1.0000**	0.5527**	**-0.0784**
Yellow carotenoids (%)	-0.2181*	-0.1657	0.0698	0.7178**	0.5678**	**1.0000**	**-0.1780***
Yield per Plant (g)	**0.2946****	**0.2426****	**-0.1426**	**-0.2709****	**-0.0794**	**-0.2047***	**1.0000**

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

Table 4.10: Phenotypic path analysis showing direct (diagonal) and indirect effects of qualitative characters on yield per plant in chilli (C*apsicum annuum* L.)

Character	Ascorbic acid (mg /100g)	Oleoresin (%)	Capsaicin (%)	Total colour value (ASTA Units)	Red carotenoids (%)	Yellow carotenoids (%)
Ascorbic acid (mg /100g)	**0.2230**	0.0037	-0.0061	-0.0518	-0.0514	-0.0472
Oleoresin (%)	0.0025	**0.1523**	0.0194	-0.0107	-0.0091	-0.0214
Capsaicin (%)	0.0031	-0.0146	**-0.1147**	-0.0097	-0.0063	-0.0071
Total colour value (ASTA Units)	0.0764	0.0230	-0.0278	**-0.3290**	-0.2593	-0.2257
Red carotenoids (%)	-0.0596	-0.0155	0.0141	0.2038	**0.2586**	0.1429
Yellow carotenoids (%)	0.0042	0.0028	-0.0012	-0.0135	-0.0109	**-0.0196**
'r' with Yield per Plant (g)	**0.2495****	**0.1516**	**-0.1163**	**-0.2108***	**-0.0784**	**-0.1780***

'r' – Correlation coefficient , *: Significant at 5 per cent level;   **: Significant at 1 per cent level

Table 4.9: Genotypic path analysis showing direct (diagonal) and indirect effects of quantitative characters on yield per plant in chilli (*Capsicum annuum* L.)

Character	Plant height (cm)	Number of primary branches per plant	Days to 50% flowering	Fruit set per cent	Number of fruits per plant	Fruit diameter (cm)	Fruit length (cm)	Average dry fruit weight (g)	Number of seeds per fruit
Plant Height (cm)	**0.1446**	-0.0115	0.0075	-0.0094	0.0245	0.0079	0.0410	0.0368	0.0545
Number of primary branches per plant	0.0001	**-0.0018**	0.0002	-0.0002	-0.0003	0.0007	-0.0001	0.0008	0.0006
Days to 50% Flowering	-0.0055	0.0105	**-0.1061**	0.0103	0.0061	-0.0020	0.0139	-0.0086	-0.0125
Fruit set per cent	-0.0184	0.0298	-0.0275	**0.2831**	0.0513	-0.0469	0.0139	0.0093	-0.0062
Number of fruits per plant	0.1095	0.1039	-0.0371	0.1169	**0.6457**	-0.3498	-0.0969	-0.3126	-0.0956
Fruit diameter (cm)	-0.0120	0.0889	-0.0042	0.0363	0.1190	**-0.2196**	-0.0053	-0.1886	-0.1519
Fruit length (cm)	0.0324	0.0091	-0.0149	0.0056	-0.0171	0.0027	**0.1141**	0.0290	0.0164
Average dry fruit weight (g)	0.1031	-0.1864	0.0329	0.0133	-0.1960	0.3477	0.1031	**0.4049**	0.3361
Number of seeds per fruit	0.0399	-0.0384	0.0125	-0.0023	-0.0157	0.0732	0.0152	0.0878	**0.1058**
'r' with Yield per Plant (g)	**0.3936****	**0.0041**	**-0.1368**	**0.4537****	**0.6175****	**-0.1861***	**0.1988***	**0.0589**	**0.2473****

'r' – Correlation coefficient , *: Significant at 5 per cent level; **: Significant at 1 per cent leve

Table 4.11: Genotypic path analysis showing direct (diagonal) and indirect effects of qualitative characters on yield per plant in chilli (*Capsicum annuum* L.)

Character	Ascorbic acid (mg /100g)	Oleoresin (%)	Capsaicin (%)	Total colour value (ASTA Units)	Red carotenoids (%)	Yellow carotenoids (%)
Ascorbic acid (mg /100g)	**0.2604**	0.0113	-0.0067	-0.0636	-0.0633	-0.0568
Oleoresin (%)	0.0106	**0.2424**	0.0358	-0.0194	-0.0134	-0.0402
Capsaicin (%)	0.0038	-0.0216	**-0.1464**	-0.0132	-0.0074	-0.0102
Total colour value (ASTA Units)	0.1444	0.0474	-0.0531	**-0.5917**	-0.4829	-0.4247
Red carotenoids (%)	-0.1083	-0.0247	0.0226	0.3636	**0.4455**	0.2529
Yellow carotenoids (%)	-0.0162	-0.0123	0.0052	0.0533	0.0422	**0.0743**
'r' with Yield per Plant (g)	**0.2946****	**0.2426****	**-0.1426**	**-0.2709****	**-0.0794**	**-0.2047***

'r' – Correlation coefficient , *: Significant at 5 per cent level; **: Significant at 1 per cent level

Table 4.12: Relative contribution of different characters towards genetic divergence in chilli (*Capsicum annuum* L.)

Source	Times Ranked 1st	Contribution %
1. Plant height (cm)	10	0.51
2. Number of primary branches per plant	0	0.00
3. Days to 50 per cent flowering	0	0.00
4. Fruit set per cent	6	0.31
5. Number of fruits per plant	28	1.43
6. Fruit diameter (cm)	862	44.14
7. Fruit length (cm)	60	3.07
8. Ascorbic acid (mg /100g)	199	10.19
9. Oleoresin (%)	17	0.87
10. Capsaicin (%)	179	9.17
11. Total colour value (ASTA Units)	41	2.10
12. Red carotenoids (%)	204	10.45
13. Yellow carotenoids (%)	330	16.90
14. Average dry fruit weight (g)	1	0.05
15. Number of seeds per fruit	12	0.61
16 Yield per plant (g)	4	0.20

Table 4.15: Nearest and farthest clusters from each cluster based on D^2 values using Tocher's method in chilli (*Capsicum annuum* L.)

Cluster No.	Nearest cluster with D^2 values	Farthest cluster with D^2 values
I	III (117.25)	VIII (2842.57)
II	I (134.54)	VIII (3633.27)
III	I (117.25)	VIII (2967.46)
IV	II (265.05)	VIII (4139.41)
V	I (331.58)	VIII (2343.89)
VI	I (260.02)	VIII (3323.09)
VII	I (309.56)	VIII (3149.32)
VIII	V (2343.89)	IV (4139.41)

Note: Values in parentheses indicate D2 values

Table 4.16: Mean performance of yield per plant and its component characters in various clusters of chilli (Tocher' method)

Cluster No.					PC_1		PC_2		PC_3		PC_4		PC_5	PC_6		
	PH	NPBP	DFF	FSP	NFP	FD	FL	AA	O	C	TCV	RC	YC	ADFW	NSF	YP
1 Cluster	85.38	3.51	30.63	55.13	155.31	1.33	9.11	99.44	9.32	0.28	64.75	0.11	0.06	1.06	59.35	139.97
2 Cluster	89.58	3.77	31.86	52.71	199.99	1.09	9.09	109.83	8.75	**0.24**	52.05	0.11	0.04	1.00	57.13	166.78
3 Cluster	84.44	3.52	32.68	47.44	174.91	1.32	9.12	99.77	8.52	0.33	75.32	0.13	**0.08**	1.07	60.45	150.73
4 Cluster	84.37	**3.95**	30.50	54.41	197.86	**0.99**	7.66	143.41	9.53	0.37	81.63	0.13	**0.08**	**0.77**	**50.89**	138.19
5 Cluster	89.57	3.55	31.00	48.82	140.30	1.64	8.47	114.68	8.55	0.32	87.60	**0.14**	**0.08**	1.28	65.85	143.33
6 Cluster	**107.35**	3.00	**28.50**	48.00	**480.00**	1.24	**6.98**	118.35	9.15	**0.45**	43.14	0.12	**0.03**	**0.77**	73.30	**204.18**
7 Cluster	**82.00**	3.60	31.00	**56.00**	159.00	1.32	**9.92**	**223.22**	**5.96**	0.27	**20.58**	**0.01**	0.04	1.05	58.40	132.34
8 Cluster	106.30	**2.80**	**34.00**	**32.50**	**49.80**	**3.18**	8.71	**90.00**	**9.61**	0.30	**105.00**	0.04	0.04	**3.35**	**152.50**	**107.30**

Bold values indicate maximum and minimum mean performance

Where

PH – Plant Height (cm), NPBP –Number of Primary Branches per Plant (no.) , DFF – Days to 50 per cent Flowering , FSP – Fruit Set Per cent, NFP – Number of Fruits per Plant, FD – Fruit Diameter (cm), FL – Fruit Length (cm), AA – Ascorbic Acid (mg/100g), O – Oleoresin (%), C – Capsaicin (%), TCV – Total Color Value (ASTA units), RC – Red Carotenoids (%), YC – Yellow Carotenoids (%), ADFW – Average Dry Fruit Weight (g), NSF – Number of Seeds per Fruit, YP –Yield per Plant (g)

Eigene Value (Root)	4.010	2.583	1.952	1.524	1.173	1.052
% Var. Exp.	**25.059**	**16.141**	**12.197**	**9.525**	**7.329**	**6.574**
Cum. Var. Exp.	**25.059**	**41.201**	**53.398**	**62.923**	**70.252**	**76.826**
Plant height (cm)	0.126	0.092	0.182	0.522	0.139	0.445
Number of primary branches per plant	-0.162	0.130	-0.247	-0.181	0.249	0.512
Days to 50 per cent flowering	0.064	-0.019	0.046	0.474	0.262	-0.077
Fruit set per cent	-0.180	0.076	-0.030	0.010	-0.711	0.214
Number of fruits per plant	-0.339	0.133	-0.095	0.109	-0.013	-0.257
Fruit diameter (cm)	0.316	-0.411	0.100	-0.019	-0.219	0.017
Fruit length (cm)	0.136	0.358	0.327	-0.194	0.064	0.412
Ascorbic acid (mg/100g)	-0.374	0.098	-0.131	0.272	-0.166	0.106
Oleoresin (%)	-0.074	-0.299	-0.017	0.533	-0.059	0.023
Capsaicin (%)	-0.190	-0.124	-0.402	-0.053	0.375	0.079
Total colour value (ASTA Units)	0.397	0.133	-0.298	0.018	-0.098	-0.062
Red carotenoids (%)	0.197	0.397	-0.264	0.100	0.007	-0.378
Yellow carotenoids (%)	0.149	0.250	-0.517	0.121	-0.082	0.139
Average dry fruit weight (g)	-0.335	0.184	0.325	-0.038	0.235	-0.232
Number of seeds per fruit	0.419	0.098	0.127	0.050	0.156	-0.053
Yield per plant (g)	-0.012	0.509	0.224	0.171	-0.157	-0.105

Table 4.17: Eigen values, proportion of the total variance, cumulative per cent variance and component loading of different characters in chilli (*Capsicum annuum* L.)

Table 4.18: PCA scores of 63 genotypes of chilli (C*apsicum annuum* L.)

Genotype	PCA I X VECTOR	PCA II Y VECTOR	PCA III Z VECTOR
G-3	22.913	-12.844	-4.330
G-4	25.459	-0.417	-12.287
G-5	34.387	-16.765	-10.759
LCA-206	26.164	-4.978	-11.201
LCA-235	19.681	-3.107	-8.645
LCA-305	23.779	-9.488	-11.312
LCA-315	32.458	-6.315	-10.327
LCA-353	15.193	-4.614	-11.257
LCA-357	35.786	3.484	-20.031
LCA-424	27.483	-6.831	-12.361
LCA-436	29.791	-6.102	-7.540
LCA-620	21.963	-13.260	-5.929
LCA-625	21.469	-0.377	-12.566
LCA-702	46.878	-11.313	-11.647
LCA-703	23.806	-7.925	-12.783
LCA-704	29.125	-10.164	-9.454
LCA-705	26.870	-8.980	-8.752
LCA-706	17.769	-10.340	-11.061
LCA-707	39.711	-11.236	-16.401
LCA-708	32.499	-19.300	-8.230
LCA-709	30.383	-6.697	-16.775
LCA-710	24.296	-3.308	-16.043
LCA-711	32.693	-16.071	-7.034
LCA-712	25.989	-4.973	-5.388
LCA-713	33.849	0.858	-19.358
LCA-714	21.025	-2.922	-19.034
LCA-715	24.290	-7.042	-8.043
LCA-716	15.871	-3.948	-13.104
LCA-718	25.559	-5.742	-8.779
LCA-720	37.252	-6.961	-8.370
LCA-722	22.069	-4.157	-4.602
LCA-724	14.280	-2.369	-12.494
LCA-726	20.901	-2.273	-2.838
LCA-728	33.072	1.439	-15.045
LCA-730	27.203	-6.867	-6.007
LCA-732	28.669	-10.175	-15.281
LCA-734	31.426	-2.234	-7.231

LCA-736	25.740	-2.157	-9.376
LCA-738	30.658	3.248	-16.676
LCA-740	32.522	1.257	-9.730
LCA-742	30.064	-2.992	-4.312
LCA-744	22.831	-3.959	-4.942
LCA-746	23.609	-10.818	-11.070
LCA-748	20.371	-2.669	-8.440
LCA-750	27.897	-5.900	-8.236
LCA-752	29.408	-6.761	-13.786
LCA-754	26.436	-7.436	-8.312
LCA-756	14.387	-3.123	-14.895
LCA-758	25.989	1.343	-14.039
LCA-760	29.639	4.983	-15.941
LCA-762	33.628	-7.285	-9.268
LCA-960	32.873	-20.462	-2.251
HC-28	34.097	-7.651	-22.164
KT-1	40.943	-2.900	-11.983
Aparna	17.024	-13.376	-5.021
Pandava	28.161	-8.746	-17.976
Pant C-1	19.836	-8.049	-20.740
Phule Jyoti	26.794	-10.842	-11.992
Punjab Gucchedar	24.367	-8.900	-15.853
Pusa Sadabahar	19.887	-9.045	-18.871
Super-10	25.493	-11.066	-4.957
Warangal Chapatta	51.694	-39.939	0.310
LCA-334	22.021	-0.847	-8.617

Table 4.22: Mean performance of yield per plant and its component characters in various clusters of chilli (Ward minimum variance method)

Bold values indicate maximum and minimum mean performance

Cluster No.	PH	NPBP	DFF	FSP	NFP	FD	FL	AA	O	C	TCV	RC	YC	ADFW	NSF	YP
I	89.800	3.475	30.500	43.750	**245.925**	1.336	8.290	141.889	8.921	0.377	**39.415**	0.065	**0.026**	0.945	66.975	170.701
II	80.303	3.539	31.861	53.333	164.242	1.429	8.576	118.119	8.561	0.303	74.351	0.124	0.072	1.101	59.350	141.749
III	95.247	3.573	32.500	51.533	196.493	1.159	9.490	107.158	8.892	**0.257**	61.616	0.114	0.056	1.093	62.437	**174.847**
IV	80.785	**4.140**	31.000	**55.800**	190.840	**1.026**	7.322	**142.443**	**9.687**	**0.448**	69.922	0.109	0.074	**0.688**	**48.320**	128.144
V	88.617	4.000	28.917	44.833	176.883	1.138	**9.675**	97.753	9.235	0.279	**118.284**	**0.181**	**0.119**	0.935	57.617	149.652
VI	**69.375**	**2.750**	**28.875**	45.875	111.325	1.955	**7.178**	105.921	**7.690**	**0.255**	62.259	0.112	0.056	1.432	74.075	129.154
VII	**107.090**	3.420	32.700	46.100	102.820	1.730	9.378	**78.713**	7.964	0.343	107.112	0.168	**0.111**	1.478	63.080	117.981
VIII	1060.30	2.800	**34.000**	**32.500**	**49.800**	**3.175**	8.710	90.000	9.610	0.295	1050.00	**0.040**	0.035	**3.350**	**152.500**	**107.300**

Where

PH – Plant Height (cm), NPBP – Number of Primary Branches per Plant, DFF – Days to 50 per cent Flowering , FSP – Fruit Set Per cent, NFP – Number of Fruits per Plant, FD – Fruit Diameter (cm), FL – Fruit Length (cm), AA – Ascorbic Acid (mg/100g), OC – Oleoresin (%), CC – Capsaicin (%), TCV – Total Colour Value (ASTA units), RC – Red Carotenoids (%), YC – Yellow Carotenoids (%), ADFW – Average Dry Fruit Weight (g), NSF – Number of Seeds per Fruit, YP –Yield per Plant (g)

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Appendices

APPENDIX

Season and Crop condition at Horticultural Research Station, Lam during the crop season 2012-13

The weather conditions prevailed during the season under report and their impact on chilli crop growth and yield are as detailed below

Meteorological data: AICCIP Main centre, RARS, Lam during 2012-2013

Month & year	Rainfall (mm)	No. of rainy days	Decennial average		Mean temperature (^{0}C)		Relative humidity (%)	
			Rainfall (mm)	Rainy days	Max.	Min.	I	II
June, 11	133.60	7.00	107.10	6.20	38.94	27.50	71.60	45.20
July, 11	225.50	14.00	157.00	9.30	32.90	25.20	87.30	68.20
Aug., 11	156.60	15.00	151.30	9.30	33.20	24.60	88.40	65.10
Sep.,11	213.40	8.00	185.20	7.90	32.38	24.86	88.60	70.30
Oct.,11	105.40	8.00	120.10	6.60	31.46	23.10	91.60	66.30
Nov.,11	210.60	4.00	54.18	3.36	30.35	19.34	93.20	61.20
Dec.,11	0.00	0.00	15.91	0.09	30.55	18.34	94.90	56.00
Jan., 12	0.00	0.00	11.30	3.80	31.10	18.14	96.60	51.60
Fab., 12	115.00	1.00	9.30	0.40	31.42	19.24	94.90	53.10
Mar., 12	0.00	0.00	20.00	1.20	34.94	21.63	93.16	44.26
April.,13	12.00	2.00	9.40	0.50	38.00	25.90	87.20	41.30
Total/Mean	**1172.10**	**59.00**	**840.79**	**48.65**	**33.20**	**22.53**	**89.76**	**56.59**