HETEROSIS AND GENE ACTION STUDIES FOR FRUIT YIELD AND HORTICULTURAL TRAITS IN CHILLI (*Capsicum annuum* var. *annuum* L.)

thesis

By

MUNISH SHARMA

(A-2008-40-08)

Submitted to

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DOCTOR OF PHILOSOPHY IN AGRICULTURE

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तेरा तुझको अर्पण ...

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CERTIFICATE – I

This is to certify that the thesis entitled **"Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Vegetable Science** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Munish Sharma (Admission No. A-2008-40-08)** son of Shri Krishan Sharma under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

Place : Palampur
Dated : February 27, 2012

(Akhilesh Sharma)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **"Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)"** submitted by **Mr. Munish Sharma (Admission No. A-2008-40-08)** son of Shri Krishan Sharma to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Vegetable Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

(Dr. Akhilesh Sharma) Chairperson Advisory Committee	( ) External Examiner
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"Your right is to work only and never to the fruit thereof,
Do not be the cause of fruit of action; nor let your attachment be to inaction"

The God-The creator-The supreme Power-The Light or whatever He is, has helped me in all adversities, at every step, on each moment, I will remain indebted to HIM always because "He is the cause of every cause". Every effort is motivated by an ambition and all ambitions have an inspiration behind. Words in lexicon would be few exiguous to express my deep sense of gratitude for my loving parents, for their selfless sacrifices and heartfelt blessings throughout my life. I owe all my success to them only.

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Needless, to say, errors and omissions are mine.

Place: Palampur
Dated: 27-02-2012 ***(Munish Sharma)***

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	*et al.*	et alii (and others)
2	*i.e.,*	id est (that is)
3	*viz.*	vi delicet (namely)
4	p.	page
5	pp.	particular Page
6	^{o}C	degree Celsius
7	g	gram
8	m	meter
9	F_1	first filial
10	/	per
11	%	per cent
12	Fig.	figure
13	cm.	centimeter
14	ml	milliliter
15	mg	milligram
16	mm	millimeter
17	ha	hectare
18	nm	nanometer
19	N	normal
20	rpm	revolutions per minute
21	OD	optical density
22	M	molar
23	df	degrees of freedom
24	$	dollar
25	vs	against
26	@	at the rate
27	Vol.	volume

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Department of Vegetable Science and Floriculture
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Title of thesis	:	"Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)"
Name of the student	:	Munish Sharma
Admission number	:	A-2008-40-08
Major discipline	:	Vegetable Breeding
Minor discipline	:	(i) Plant Breeding & Genetics (ii) Plant Pathology
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Major Advisor	:	Dr. Akhilesh Sharma

ABSTRACT

The present investigation entitled "Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)" was carried out at the Experimental Farms of the Department of Vegetable Science and Floriculture, CSKHPKV, Palampur and Hill Agricultural Research and Extension Centre, CSKHPKV, Bajaura, Kullu to gather information on combining ability, gene action and magnitude of heterosis by following 'line × tester' mating design involving 11 lines and three diverse testers. Lines, testers their 33 cross combinations, along with standard check 'CH-1', were evaluated in a Randomized Complete Block Design with three replications during summer-rainy seasons of 2010 and 2011. Data were recorded on fresh and dry fruit yield/plant along with component traits and reaction to bacterial wilt disease. Sufficient genetic variability was observed for all phonological, morphological, yield and yield contributing, and quality traits during both the years over the environments. Significant genotype × environment interactions for all the characters indicated a definite role of environment on the performance of genotypes/crosses. The line × tester analysis revealed significant differences due to lines, testers and line × tester interaction for majority of the traits at both the locations and pooled over environments indicating appreciable diversity in the experimental material. Lines 'Jawahar Mirch 283', 'PAU Selection Long', LCA 436' and 'LCA 443', and tester 'Surajmukhi' were observed to be good general combiners for fresh and dry fruit yield/plant along with related traits. Thus desirable cross combinations involving both or one of these as parents resulted in significant desirable SCA effects and heterosis. 'PAU Selection Long × Surajmukhi', 'LCA 436 × Pant C1', 'Chilli Sonal × Surajmukhi', 'Jawahar Mirch 283 × Anugraha' and 'Pusa Sadabahar × Surajmukhi' were the most promising crosses on the basis of SCA effects for yield and its related traits. The magnitude of non-additive gene action was predominant for majority of the traits with maximum contribution of lines in the expression of gene action. A wide variation in magnitude and direction of heterosis was noticed for majority of the traits with maximum manifestation for fruits/plant, fresh and dry fruit yield/plant. Hybrids 'Jawahar Mirch 283 × Anugraha', 'PAU Selection long × Surajmukhi', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C 1', 'LCA 436 × Anugraha' and 'LCA 443 × Surajmukhi' were the most promising crosses with significant heterobeltiosis and economic heterosis for yield and yield related traits and showed maximum consistency by retaining their ranking among top ten crosses over the environments. Based on *per se* performance, SCA effects and heterosis, 'LCA 436 × Pant C 1', 'Arka Lohit × Surajmukhi', ''PAU Selection Long × Surajmukhi' and 'Jawahar Mirch 283 × Anugraha' were the most promising crosses for obtaining superior progenies. Breeding methods namely, single seed descent, reciprocal recurrent selection, bulk pedigree and diallel selective mating system can be employed to obtain transgressive segregants with high yield and desirable horticultural traits in chilli.

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1. INTRODUCTION

Chilli or Hot Pepper (*Capsicum annuum* var*. annuum* L*.*) is emerging as one of the most important economical and popular vegetable crops grown for its green fruits as vegetable and red form as spice. Besides, it is used in many processing industries for various products such as pepper sauce, pickled pepper, ground pepper and dried pepper. It belongs to family solanaceae and originated in Latin American regions of New Mexico, Guatemala and Bulgaria (Saffarod 1926). It was first introduced in India from Brazil by the Portugese towards the end of 15th century and its cultivation became popular in the 17th century.

Immature chilli fruits contain phytonutrients, ascorbic acid, caretenoids and rutin which are valued for pharmaceutical needs (Purseglove 1977). Chillies have two important qualities; biting pungency and attractive red colour attributed to capsaicin and capsanthin, respectively. Capsaicin, a crystalline acrid volatile alkaloid present in the placenta of fruit, carries diverse prophylactic and therapeutic uses in allopathic and ayurvedic medicines. Red coloured pigment is used as a natural colour additive in food, drugs and cosmetics. These pigments are also rich in bioflavonoids, which are powerful antioxidants and inhibit the progression of chronic diseases such as muscular degeneration, cardiovascular diseases and cancer. Oleoresin extracted from dried and ground chillies is the total flavour extract which has gained industrial importance through its utilization in processed products and pharmaceutical formulations. Oleoresin is gaining more importance especially from export point of view as it offers uniform quality, longer shelf-life, freedom from micro-organisms and lesser freight charges.

Chilli is presently grown extensively throughout the country, both under rainfed and irrigated conditions, in almost all the states covering an area of 767.23 thousand ha with annual production of 1202.94 thousand metric tonnes (Anonymous 2010). In Himachal Pradesh, the acreage under chilli and bellpepper is 2447 ha with annual production of 31810 metric tonnes

(Anonymous 2009). India is the leading producer, consumer and exporter of chillies in the world. It exports chilli to USA, UK, Russia, Canada, Italy, Netherlands, Singapore, Saudi Arabia, UAE and Germany in the form of dried pods, chilli powder and oleoresins. The export of 2,04,000 metric tonnes of chilli resulted in earning $ 258 million in 2008 (Anonymous 2008).

India has immense potential to export different types of chillies around the world. However, the average yield is low due to various constraints such as non-availability of suitable cultivars/hybrids, biotic and abiotic stresses and genetic drift in cultivars. In Himachal Pradesh, bacterial wilt (*Ralstonia solanacearum*) has now assumed serious concern in different areas of Kangra, Kullu, Hamirpur and Mandi districts. The disease manifests at all growth stages with maximum severity at flowering and fruiting stage and results in partial to complete failure of crop. Wilt is a soil borne disease which cannot be managed effectively through chemicals. Consequently, development of resistant cultivar(s) remains the most efficient and eco-friendly approach for the management of this disease.

It is, therefore, imperative to carry out genetic studies on gene action involved in the manifestation of important quantitative and qualitative traits for the improvement of yield and breeding resistant lines to the bacterial wilt disease. To stabilize the production, it is also important to breed varieties having wide adaptability under diversified agro-climatic conditions along with resistance to bacterial wilt. Different genotypes react differently to a specific environment or the same genotype gives different response when grown under diverse environments. This indicates that the yield is the result of virtual multiplicative interactions between various component traits. The most appropriate strategy to combine various desirable attributes *viz*., high yield, resistance to diseases along with responsiveness to better management is the recombinant breeding, the success of which depends upon the ability of the parents to yield desirable recombinants. Therefore, the choice of parents is critical to achieve success (Hallauer and Mirada 1981). Selection of parents on the basis of combining ability, rather than *per se* performance, depends upon the complex interaction among the genes which cannot be judged by the mere yield performance and the adaptation of the parents (Allard 1960). Moreover, the efficiency of recombinant breeding program would mainly depend upon the genetic architecture of the traits under improvement (Cockerham 1961). An objective judgement about a particular cross likely to produce transgressive recombinant lines in self pollinated crops would mainly depend upon the hybrid vigour and combining ability (Fasoulas 1981) and also on the precise estimates of various genetic components namely, additive, dominance, non-allelic interactions, linkage among the polygenes and gene dispersion in the parents of a cross (Jinks 1983).

To achieve this goal, the line × tester mating design (Kempthorne 1957) is useful in deciding the relative ability of number of female and male inbreds to produce desirable hybrid combinations. This mating design can also provide information regarding the usefulness of the male and female inbreds as parents for hybridization to generate segregating population which is accepted to give prodigious selections. There are several studies based on this mating design in literature but those involving bacterial wilt resistant tester/lines are lacking. To bridge this gap, recombinant breeding has been applied to evolve high yielding lines having resistance to bacterial wilt disease. In addition, the non-availability of genetic mechanism in the present study may not allow exploitation of F_1 hybrids and accordingly the relative magnitude of heterosis can be utilized as a guideline to obtain superior segregants in the later generations having desired constellation of the genes.

Based upon these considerations, the proposed investigation was planned by crossing eleven bacterial wilt susceptible lines with three bacterial wilt resistant testers to achieve the following objectives:

1. To estimate the extent of heterosis and gene action for marketable fruit yield and its component traits,
2. To identify good general and specific combiners for marketable fruit yield and its related traits, and
3. To identify promising hybrids for marketable fruit yield and component traits.

2. REVIEW OF LITERATURE

Judicious choice of parents for hybridization and the selection procedure adopted in the early generations are important among the factors on which success of breeding programme primarily depends. Genetic information, especially about the nature of combining ability, the type of gene action governing the inheritance of economic characters and the heterosis, is a pre-requisite in identifying the suitable parents and designing the appropriate breeding programme. Among the different methods, the 'Line × Tester' analysis (Kempthorne 1957) is one of the important methods to study the combining ability and gene action.

A brief review of literature pertaining to the present study in chilli is presented under the following headings:

2.1 Combining ability

2.2 Gene action

2.3 Heterosis

2.4 Genotype environment interactions and stability analysis

2.1 Combining ability

The combining ability analysis provides a guideline for assessment of the relative breeding potential of parents and also elucidates the nature and quantum of different types of gene actions involved. The concept of combining ability, originally developed in maize by Richey and Meyar (1925), is now extensively applied in all crop plants. However, Sprauge and Tatum (1942) were the first to define the terms 'general combining ability' (GCA) and 'specific combining ability' (SCA). GCA designates the performance of a genotype in a series of crosses whereas, SCA designates performance of a specific cross combination. Study of combining ability is, therefore, important for the selection of superior parents for heterosis and recombination breeding programmes. Meaningful genetic analysis of the quantitative traits can be said to have begun with the work of Fisher (1918). He partitioned the hereditary variances into three components, *viz*., additive portion resulting from the average effects of genes, dominance portion arising from intra-allelic interactions and epistatic portion associated with inter-allelic interactions.

Pandey *et al*. (1981) crossed 12 cultivars with three pollen parents and the parents plus their 36 F_1 hybrids were evaluated for nine yield component characters *viz*., yield/plant, number of fruits/plant, fruit length, fruit thickness, days to ripening of 50% fruits, days to 50% flowering, number of primary branches/ plant, number of secondary branches/plant and plant height. Among the female parents 'G4', 'G5' and 'CA1068' had the highest general combining ability (GCA) effects for yield, number of fruits, earliness, height and number of branches and among the males 'Pusa Jwala' and 'Pant C 2' had the highest GCA effects. The estimates of specific combining ability effects showed that the best combinations for yield were 'Kalayanpur Yellow × Pant C2', 'CA960 × Pusa Jwala', 'CAP63 × Sirhind' and 'Patna Red × Sirhind'. In general, crosses involving one or both parents with high GCA effects also exhibited high SCA effects. Khadi and Goud (1986) from an 11 × 11 half-diallel cross observed the parents 'IC18190' and '387 Local' as good general combiners for yield traits, while 'EC76459-2 × IC18190' and 'Purired × 387 Local' were the good specific combiners with high mean yield.

Gaddagimath *et al*. (1988) crossed seven genotypes in all possible combinations and found that the parents 'Jwala' and 'K34-35' exhibited significant GCA effects for most of the characters namely flowers/plant, plant height, primary branches/plant, fruits/plant, average fruit weight and dry fruit yield/plant. A few cross combinations also showed significant SCA effects for yield and its components. Mishra *et al.* (1989) from 10 parents half-diallel revealed that 'J218' and 'B.R. Red' were the best general combiners for dry yield/plant, seed weight/fruit, number of seeds/fruit, number of fruits/plant, number of primary branches/plant, fruit length, 50% flowering, weight of 10 dry fruits, 100-seed weight, weight of 10 fresh fruits, fruit circumference, plant spread, plant height and days to 50% maturity. ‘Pusa Jwala’ and ‘Lam X 235’ were the good general combiners for dry yield/plant and number of fruits/plant. The cross ‘Pusa Jwala × Sindur’ exhibited significant SCA effects for dry yield/plant, weight of 10 fresh fruits, seed weight/ fruit and number of seeds/ fruit.

Sahoo *et al*. (1989) from a 10 × 10 half diallel set of crosses involving divergent parents observed that the crosses ‘S118-2 × Lam X 235’ and ‘Pusa Jwala × Lam X 235’ expressed good SCA in both F_1 and F_2 generations for plant height, plant spread, number of primary branches and fruits/plant. Bhagyalakshmi *et al*. (1991) crossed six chilli cultivars in a non-reciprocal half diallel and reported that cultivars ‘LCA960’, ‘LCA206’ and ‘G4’ were the best general combiners for yield/plant, plant height, branches/plant, days to flowering, time for fruit maturity, fruit length, fruit girth, fruits/plant, fresh fruit weight, 100 dry fruit weight, seeds/fruit, 100 seed weight and ascorbic acid content. On the basis of absolute performance, SCA effects and heterosis, ‘LCA 206 × LCA 960’ was the best yielding hybrid followed by ‘LCA 206 × LA 1079’.

Pandian and Shanmugavelu (1992) crossed 15 chilli lines and six testers (3 inbreds and 3 hybrids) in a line × tester fashion and concluded that the line ‘1777’ and tester ‘K2’ were the best general combiners for plant height, number of branches, number of fruits, fruit length, fruit girth, fruit weight with stalk, fruit weight without stalk, number of seeds/fruit, seed weight/fruit and dry fruit yield/plant. High genetic diversity was indicated by close agreement between GCA and *per se* performance, and stated that performance was a more reliable parameter than SCA effect for hybrid selection. Devi and Arumugam (1999) conducted combining ability analysis in 30 chilli hybrids and their six parents and adjudged the parent pungent chilli ‘K2’ as good general combiner for three economic traits followed by ‘PKM 1’. The hybrids with ‘Low × Low’, ‘High × High’, ‘Low × High’, ‘Low × Medium’ and ‘High × Medium’ GCA parents exhibited high SCA effects for all nine characters, *viz*., plant height, number of primary branches, number of secondary branches, days to first flowering, number of fruits/plant, fruit weight, yield of fresh fruits/ plant, dry fruit yield/plant, fruit length, fruit girth and fruit shape index clearly indicated the role of additive and non-additive gene action.

Shukla *et al.* (1999) reported that parents ‘Jwala’ and ‘Jagudan-103’ were good general combiners for green fruit yield and other important yield contributing components. About one-third of the hybrids depicted significant specific combining ability effects for green fruit yield. Gandhi *et al*. (2001) on the basis of combining ability analysis, identified the ‘IC119769’ and ‘Pusa Jwala’ as the best general combiners and combinations ‘HC44 × IC119769’ and ‘Pusa Jwala × IC119769’ as the best hybrids.

Lohithaswa *et al*. (2001), in his study on 10 parent diallel analysis excluding reciprocals, revealed that the parents ‘IHR-1822-1/3-1/5’, ‘Arka Lohit’ and ‘G-4’ were found to be good general combiners for fruit yield/plant. The heterosis values when considered alone were misleading, as there was no correspondence with *per se* performance. The best specific combiners involving parents with low GCA effects indicated the need for heterosis breeding and recurrent selection in the segregating generations for substantial improvement in fruit yield/plant. Jadhav *et al.* (2002) crossed six hot chilli cultivars (‘G-3’, ‘GAD Sel-35’, ‘Phule Sai’, ‘GCH-1’, ‘Delhi Red’, and ‘M-Sel-11’) with two paprika-type (‘GAD Sel-31’ and ‘Vietnam’) and reported that significant and positive GCA effects were exhibited by ‘G-3’ and ‘Vietnam’ for plant height, ‘GAD Sel-35’ and ‘G-3’ for fruit number, and ‘GCH-1’, ‘Delhi Red’, and ‘M-Sel-11’ for fruit weight. Crossing between ‘G-3’ and ‘Vietnam’ is recommended for developing desirable genotypes.

Nandadevi and Hosamani (2003) from six × six diallel design excluding reciprocals revealed that among the parents, ‘Pant C-1', 'KTPI-19' and 'RHRC-Cluster-Erect' for green fruit yield/plant, and 'RHRC-Cluster-Erect', 'Pant C-1' and 'PMR-52/88/K' for resistance to leaf curl complex were the good general combiners. The superior crosses involving parents with low and high general combining ability effects indicated that heterosis breeding will be appropriate for green fruit weight, green fruit yield/plant and leaf curl complex resistance. Pandey *et al*. (2003) studied combining ability for yield and its component traits in chilli using a line × tester mating system and revealed that the mean squares due to females, males and female × male were highly significant for all the traits namely, plant height, number of primary branches/plant, number of secondary branches/plant, number of fruits/plant, fruit length, fruit width and yield/plant. The higher values of specific combining ability (SCA) involving parents with low general combining ability (GCA) for almost all the characters indicated the preponderance of non-additive gene action for the expression of these characters. The parental cultivars 'A-8', 'NA-12' and '35-2' were good combiners for several characters. The F_1 hybrids '651-61-10 × A-4', 'Assam 5B × A-8' and 'SPS-1 × A-8' were the promising specific combinations for a number of characters including yield. One or both parental lines having high GCA effects were involved in crosses having better SCA effects. The preponderance of non-additive gene action for all the characters suggested that heterosis breeding might be effective for the improvement of yield and its contributing attributes in chilli.

Patel *et al.* (2004) developed 48 chilli hybrids by crossing four genic male sterile lines and 12 male parents in a line × tester mating design and revealed significant differences among the parents, hybrids, parents vs. hybrids, lines and testers and their interactions for days to flower, plant height, primary branches/plant, number of fruits/plant, average fruit length, average fruit weight, average fruit girth and green fruit yield/plant with the exception of days to flower for testers, plant height, fruit girth and fruit weight for lines, and fruit length for both lines and testers. The significance of variance due to parents vs. hybrids and lines × testers for all traits suggested the existence of non-additive gene action. Estimates of GCA effects showed that the male sterile line 'ACMS-4' was a good general combiner for green fruit yield, fruits/plant, fruit length, fruit girth and plant height, whereas the male parents 'ACH-77', 'ACS 92-3', 'ACS 2000-2', 'ACS 2000-3', 'Punjab Guchhedar', 'RHRC-Perendent' and 'Resham Patti' were the good general combiners for green fruit yield and fruits/plant. 'ACS 2000-2' and 'Resham Patti' were also good general combiners for other yield-contributing traits. Out of 48 hybrids, seven were good specific combiners for green fruit yield and important yield contributing traits. Patil *et al*. (2005) evaluated 23 chilli cultivars and their 60 F_1's derived from line × tester analysis and observed genotypes '2591' and 'Pusa Jwala' as good general combiners. The crosses 'IIHR 1822-1/3-1/5 × Arka Lohit' and 'GPC 77 × PMR 57' were identified as good specific combiners for fruit yield and other related traits.

Srivastava *et al*. (2005) by following a line × tester approach in chilli, evaluated 45 crosses (15 × 3) along with 18 parents for plant height, number of branches/plant, fruit length and width, number of fruits/plant, vitamin C content, capsaicin percentage and red ripe fruit yield/plant. Among the testers, 'Pant Chilli 1' exhibited high general combining ability effects for red ripe fruit yield/plant and many other characters, whereas 'Chanchal' was identified as the best general combiner for capsaicin percentage. Among the 15 lines, '8803', 'Sel-12', 'Sel-7' and '399-5-2' were identified as good general combiners for red ripe fruit yield/plant and related characters. The crosses 'Sel-7 × Pant Chilli-1' and 'Sel-12 × Pant Chilli-1' showed high specific combining ability effects for red ripe fruit yield/plant and other yield contributing traits and recommended recurrent selection for the improvement of yield and quality in chilli. Venkatramana *et al*. (2005), from 8 × 8 diallel cross (including reciprocals), noticed the genotype 'VR-27' as the best general combiner for fruit yield/plant, while the crosses 'Punjab Gucchedar × Pant C-1' and 'Tiwari × EG-174' had greater SCA effects for fruit yield which may directly be used for commercial cultivation after further testing over a range of environments.

Zate *et al.* (2005), using two genetic male sterile lines as female and nine testers as males, found that male parents 'PP-977127', 'PP-977116', 'PP-977195-1', 'PP-977268' and 'PP-977421' were the good general combiners for yield/plant. The crosses 'AKC-8625 × PP-977268' and 'CA-960 × PP-977195-1' exhibited significant specific combining ability effects for yield/plant. Shekhawat *et al.* (2007), by following line × tester mating design comprising of nine lines and two testers, revealed that the parents and F_1 crosses differed significantly for GCA and SCA effects for days to flowering, plant height, number of branches/plant, fruit length, fruit width, days to first harvest, number of fruits/plant, 1000-seed weight, pedicel length, number of seeds/fruit, red ripe fruit yield/plant, dry fruit yield/plant, vitamin C and capsaicin content. Lines 'Sel-54', '7722-1' and 'Sel. 16' were good general combiners for red ripe and dry fruit yield/plant whereas, cross combinations namely, '2003 × 7950', 'Sel. 54 × 7950', 'Sel. 16 × Sel. A-4' for red ripe yield and 'Sel. 54 × 7950', 'A-28 × Sel. A-4' and '7722-1 × 7950' were the best specific combinations for dry fruit yield/plant and other yield contributing traits.

Jagadeesha and Wali (2008) studied 18 divergent lines and 45 F_1 hybrids and reported that the parents 'VN-2', 'B-Kaddi', 'Arka Lohit', 'Phule-5' and 'LCA-312' exhibited high GCA which may be utilized in recurrent selection programme for improvement in fruit quality traits. Khereba *et al.* (2008) found '166988' as the best parent for early yield on the basis of general combining ability estimates. Cross combination '166988 × 159236' was the best specific combiner for plant height, number of days to flowering, average fruit weight, fruit length, fruit diameter and total yield. Prasath and Ponnuswami (2008) reported the lines 'Bydagi Kaddi', 'MDUY' and 'Arka Abir' as the good general combiners for yield and quality characters. The cross combination 'MDU Y x CO 4' had desirable SCA effects for fresh yield, dry yield, total extractable colour and capsaicin.

Reddy *et al.* (2008) evaluated 14 parents and their 40 hybrids for fruit yield and yield components and found that the line × tester interaction variance was significant for all the traits. 'Arka Lohit', 'SKAU-SC-965-5', 'GPC-82', 'SKAU-SC-1003' and 'SKAU-SC-304-1' were the good general combiners while 'SKAU-SC-1005 × Kiran', 'SKAU-SC-1003 × Arka Lohit', 'SKAU-SC-65-5 × Kiran', 'SKAU-SC-618-2 × GPC-82' and 'SKAU-SC-814-2 × GPC-82' were the good specific combiners for days to flowering, plant height, number of primary branches, number of secondary branches, plant spread, number of fruits/plant, fruit length, fruit width, average fruit weight, pedicel length, pericarp thickness, number of seeds/fruit, seed weight/fruit and fruit yield/plant. Rego *et al*. (2009) crossed eight lines of *Capsicum baccatum* in a complete diallel way revealed that GCA effects of the parents and SCA effects of the crosses were significant.

2.2 Gene action

Khadi and Goud (1986), from 11 × 11 half-diallel cross, reported that the variances for GCA and SCA were significant for all eleven traits studied with higher magnitude of the former for 10 traits. Singh and Rai (1986) from 8 × 8 half-diallel cross revealed specific combining ability variance was higher than general combining ability variance for all the traits namely, days to flower, plant height, number of branches, fruit length, fruit width, fruits/plant and fruit yield/plant while heritability estimates were relatively low for all traits. Non-additive gene effects were important for all the traits while partial dominance was important for fruit length, fruits/plant and fruit yield/plant and advocated recurrent selection for obtaining desirable segregants.

Gopalakrishnan *et al.* (1987) crossed four chilli lines in half-diallel and found involvement of both additive and non-additive gene action for the control of plant height, primary branches/plant, fruit length and days to flower. Sahoo *et al*. (1989) from a 10 × 10 half diallel set of crosses involving divergent parents in the F_1 and F_2 indicated that plant height, plant spread, number of primary branches and fruits/plant were conditioned by additive and non-additive gene effects and over-dominance played an important part in their expression.

Bhagyalakshmi *et al*. (1991), from six parents non-reciprocal half diallel, observed both additive and non-additive gene action with predominance of latter for days to 50% flowering, fruit length, fresh fruit weight, 100-dry fruit weight and 100-seed weight. Jadhav and Dhumal (1994) from generation mean analysis of two intervarietal crosses observed additive gene effects for fruit length; dominance gene effect for yield and number of fruits/plant, and both additive and dominance gene effects for plant height and fruit perimeter. They suggested the production of hybrids (if feasible) or reciprocal recurrent selection to exploit all types of gene action to achieve genetic improvement in yield and its components.

Devi and Arumugam (1999) crossed six chilli varieties (3 pungent and 3 non-pungent) in a six × six diallel mating design and revealed that additive gene action was more important than non-additive gene action for plant height, number of primary branches, days to first flowering, number of fruits/plant, fruit weight, yield of fresh fruits/plant, dry fruit yield/plant and fruit girth except fruit length and suggested that pedigree breeding together with recurrent selection can be used to exploit additive and dominance effects simultaneously for the improvement of chilli. Shukla *et al.* (1999) studied 24 F_1's,developed from 11 parents and found that non-additive gene effects were responsible for the expression of days to flowering, plant height, number of primary branches, number of secondary branches, number of fruits/plant, days to fruit ripening and fruit yield/plant while additive gene effects were important for fruit length and girth.

Anandanayaki and Natarajan (2000) reported dominant gene action for plant height, days to 50% flowering and dry fruit yield while additive and dominance effects for branches/plant and fruits/plant. Lohithaswa *et al*. (2001) revealed the preponderance of non-additive gene action for days to maturity, plant spread, number of secondary branches, fruit length, fruit diameter, number of seeds/ fruit, number of fruits/plant, dry weight of fruits/plant and capsaicin content except for fruit length and fruit diameter.

Jadhav *et al.* (2002) reported that variances due to general combining ability (GCA) and specific combining ability (SCA) were high for plant height, fruit number, fruit length, fruit weight, and fruit yield with the dominance of non-additive gene actions over additive gene actions in the inheritance of these traits. Doshi (2003) reported that the additive and dominance components were significant for number of days to flowering, plant height, number of primary branches/plant, number of fruits/plant, fruit length, fruit girth, fruit weight, number of days to maturity, total capsaicin content and fruit yield/plant However, the additive component was greater than the dominant component for primary branches/plant, plant height, fruit weight and total capsaicin contents.

Nandadevi and Hosamani (2003) revealed the predominance of non-additive gene effects for six of the 10 characters studied (days to 50% flowering, fruit length, fruit diameter, pedicel length, pericarp thickness, number of seeds/fruit, green fruit weight, number of fruits/plant, green fruit yield/plant and resistance to leaf curl complex). Kumar (2004) found higher magnitude of general combining ability (GCA) variance than specific combining ability (SCA) variance for days to first flowering, number of primary branches, plant height, fruit length, single fruit weight, number of fruits/plant and capsaicin content which indicated the preponderance of additive gene action and pedigree breeding can be used to improve these characters.

Patel *et al*. (2004) from a line × tester mating design, revealed that the variances due to general (GCA) and specific combining ability (SCA) were significant for days to flower, plant height, primary branches/plant, fruits/plant, fruit length, fruit weight, fruit girth and green fruit yield/plant indicating the importance of both genetic variances for the inheritance of these traits. Significance of only GCA for fruit length and fruit weight and that of SCA for primary branches/plant was observed. Additive component was larger than the non-additive components of variance for days to flower, fruits/plant and green fruit yield. Ajith and Anju (2005) noticed the predominance of additive and dominance × dominance interactions in 'Jwalasakhi × Ujwala' for fruit weight and suggested the suitability for improvement through hybridization followed by selection.

Patil *et al*. (2005) observed higher magnitude of specific combining ability variance compared to general combining ability variance for all the traits indicated the predominance of non-additive gene action from a line × tester analysis. Srivastava *et al*. (2005) found greater role of non-additive gene action in the inheritance of plant height, number of branches/plant, fruit width, number of fruits/plant, vitamin C content, capsaicin percentage while, additive gene action played an important role for fruit length and red ripe fruit yield/plant.

Venkataramana *et al*. (2005) observed highly significant variances for general combining ability (GCA) and specific combining ability (SCA) for all the characters suggesting the importance of both additive and non-additive gene action. The SCA variance played an important role in the genetic control of days to 50% flowering, days to 50% ripening, fruit width, plant height, number of fruits/plant and green fruit yield/plant while additive gene action was observed for fruit length. Saritha *et al*. (2005) from a line × tester analysis involving five lines (‘RHRC-50-1’, ‘PMR-14’, ‘PMR-19’, ‘Tiwari’ and ‘AVRDC-95-06’) and nine testers (‘Arka Abhir’, ‘Arka Lohit’, ‘Byadgi Dabbi’, ‘Byadgi Kaddi’, ‘PMR-21’, ‘PMR-39’, ‘PMR-57’, ‘Punjab Guchhedar’ and ‘Punjab Surkh’) revealed significant variance among females for plant height, fresh fruit yield/plant, dry fruit yield/plant and ascorbic acid content and among males for plant height and ascorbic acid content. Variance for line × tester interaction was highly significant for plant height, primary branches, fruit length, fruits/plant, fresh fruit yield/plant, dry fruit yield/plant, number of seeds/fruit, ascorbic acid content, capsanthin and oleoresin contents which indicated the major role of non-additive gene action in the expression of these characters. Significant GCA variance was observed for majority of the traits except primary branches and seeds/fruit whereas all the above characters exhibited significant SCA variance. This indicates that majority of the characters are governed by both additive and non-additive gene action with the predominance of the latter.

Kamboj *et al*. (2006), from generation mean analysis, observed the predominance of additive gene action in the inheritance of fruit length and fruit weight and advocated simple selection, recurrent selection, heterosis breeding and hybridization followed by selection as the appropriate strategy for exploitation of the present genetic material of chilli. Kamboj *et al*. (2007) reported that additive gene effects were important for the expression of plant height, fruits/plant and dried red fruit yield/plant whereas dominance gene effects were found predominant for the control of branches/plant and fresh red fruit yield/plant. They suggested simple or pedigree selection, heterosis breeding and reciprocal recurrent selection or full sib selection in the populations for the improvement of these characters.

Jagadeesha and Wali (2008) observed higher proportion of additive gene effects for fruit related traits and that of non-additive gene action for seed related traits. Khereba *et al.* (2008) utilized seven chilli pepper parental inbreds in a line × tester mating design and observed the major role of non-additive gene effects in the inheritance of plant height, average fruit weight, fruit diameter, fruit length, early yield and total yield.

Marame *et al.* (2008) crossed 12 genotypes in half-diallel fashion and obtained significant variations among the progenies for dry fruit yield/plant, number of branches/plant, plant height, number of fruits/plant, days to maturity, fruit length and single fruit weight. Only dominant component, for days to maturity and dry fruit yield/plant and both dominance and additive genetic components were significant for all other traits. Prasath and Ponnuswami (2008) observed that the estimates of GCA and SCA variance were significant for plant height, branches/plant, days to first flowering, days to 50% flowering, fruits/plant, fruit length, fruit girth, seeds/fruit, individual green fruit weight, individual dry fruit weight, fresh yield/plant, total extractable colour and with the preponderance of additive gene action while non-additive gene action was important for capsaicin content.

Reddy *et al.* (2008) found higher specific combining ability variance than general combining ability variance for days to flowering, plant height, number of primary branches, number of secondary branches, plant spread, number of fruits/plant, fruit length, fruit width, average fruit weight, pedicel length, pericarp thickness, number of seeds/fruit, seed weight/fruit and fruit yield/plant which indicated the predominance of non-additive gene action. The line × tester interaction variance was also significant for all traits. Rego *et al*. (2009) reported that both additive and non-additive effects influenced almost all the characters for the performance of hybrids.

Kamboj *et al.* (2011) from generation mean analysis, estimated gene effects for six characters *viz*., plant height, plant spread, branches/plant, fruits/plant and total fresh and dried red fruit yield/plant. Additive gene effects were important for the expression of plant height, plant spread, fruits/plant and dried red fruit yield/plant. However, dominance gene effects were found predominant for the control of branches/plant and fresh red fruit yield/plant.

2.3 Heterosis

Heterosis is the superiority of F_1 hybrid over the parents in a given characteristic, assessed not by absolute value and appearance but by its usefulness for practical advantages in given environments. Plant hybrids were first described by Koelreuter in 1766. Bruce (1910) reported that hybrid vigour was due to the presence of dominant genes in the hybrids. Heterosis in desirable direction (hybrid vigour) is the ultimate aim of a breeder. From the point of view of commercial exploitation of heterosis, the increased or decreased vigour of the hybrids over the standard check, *i.e*., standard/economic heterosis is of utmost importance than heterobeltiosis (over the better parents) or the average heterosis (over the average performance of parents).

Pandey *et al.* (1981) identified three crosses superior for yield/plant and fruit number/plant over the best parent. A cross was also observed with height less than either of the parents. Rao and Chhonkar (1982) reported significant positive heterosis for thirteen crosses over the mean parental value (2.2 to 30.9%) and three crosses over the better parent (2.1 to 12.5%) for ascorbic acid content. The ascorbic acid content of these three crosses ranged from 185.0 to 284.9 mg/100 g fruit.

Meshram and Mukewar (1986) observed four hybrids with significant heterosis over the superior parent for fruit yield, and suggested the use of male sterile lines in the exploitation of heterosis. Gopalakrishnan *et al*. (1987) crossed the four chilli lines ‘Jwala’, ‘Pant C1’, ‘CA33’ and ‘CA23’ non-reciprocally and found ‘Jwala × Pant C1’ as the best hybrid for yield followed by ‘Jwala × CA23’. All the hybrids showed average heterosis for earliness and three hybrids showed heterobeltiosis.

Ashtankar and Jaipurkar (1988) reported mid heterosis in most of the hybrids for the eight traits studied and also recorded significant heterobeltiosis for yield (up to 23%) in six out of 13 hybrids. Thomas and Peter (1988) reported the significant favourable heterosis for days to flowering, days to green fruit harvest, days to fruit ripening, plant height, fruit length, fruit perimeter, fruit weight and green fruit yield/plant in the intervarietal crosses involving six bell pepper lines and hot chilli line 'KAU Cluster'. The best-yielding cross 'Bell Boy × KAU Cluster' revealed a standard heterosis of 108.3 per cent over 'Pant C1' for yield with desirable plant and fruit characteristics followed by '672 Hungarian Wax × KAU Cluster'.

Mishra *et al*. (1989) reported that hybrid 'Pusa Jwala × Sindhur' showed heterosis over the better parent for dry yield/plant and also for fresh fruit weight, number of seeds/fruit and dry yield/plant. On the other hand, Ram and Lal (1992) observed significant relative and standard heterosis in the desired direction for all the characters except for pods/plant with the highest standard heterosis for pod yield/plant in the cross 'NP46A × Kalyanpur Yellow'.

Subashri and Natarajan (1999) noticed positive residual heterosis for yield/plant in crosses 'CA 94 × CA 86', 'CA 94 × CA 133' and 'CA 133 × CA 84' while only 'CA 133 × CA 84' exhibited positive residual heterosis for number of fruits/ plant and fruit weight. Gandhi *et al*. (2000) reported that out of 15 hybrids, four exhibited significant heterobeltiosis, while 11 were significantly heterotic over the standard check variety for dry fruit weight/plant. Taking into consideration the *per se* performance, heterosis and SCA effects, 'HC44 × IC119769' was the best hybrid followed by 'Jwala × IC 119769'.

Milerue and Nikornpun (2000) observed that 'KY 1-1 × Nhum Khiew Maejo', 'CF21789 × Nhum Khiew' and 'KY 1-1 × Nhum Khiew' showed high percentage of heterosis for pungency. Burli *et al*. (2001) noticed 'P3 × P8' with the highest negative heterobeltiosis (-10.26%) for days to 50% flowering while all the crosses showed negative heterosis over better parent for plant height. Significant positive heterobeltiosis was expressed by 'P6 × P7' for fruit length (3.82%) and for fruit weight (2.25%). Significant heterobeltiosis was recorded for

'P1 × P8' (8.57%) and 'P1 × P7' (6.46%) for number of fruits. All the crosses under study showed significant heterobeltiosis for dry fruit yield/plant except 'P5 × P8'. Hybrids expressing high magnitude of heterobeltiosis also showed high *per se* performance for the number of fruits, fruit weight and dry fruit yield/plant. 'P1 × P8' was identified as the best hybrid for exploiting hybrid vigour.

Kumar and Lal (2001) observed significant heterosis over mid parent, better parent and standard parent for number of fruits/plant, number of seeds/fruit, fresh and dry fruit yield/plant. Superior hybrids with regard to yield and yield components were 'Pant Sel 13 × Sel 1', 'BC 24 × Pant Sel 13' and 'HC 28 whereas, crosses 'Pant Chilli 1 × BC 24' and 'BC1 × LCA 304' were superior for days to harvest. Patel *et al.* (2001) estimated heterosis by crossing three lines ('Jwala', 'S-49', and 'G-4') and eight testers ('Jagudan-103', 'Gujarat Chilli-1', 'Resham Patti', 'Kumathi', 'SG-5', 'Anand Chilli-1', 'DPS-120', and 'ACS 92-1') for yield and yield components (days to flowering, plant height, number of primary branches, number of fruits/plant, fruit length, fruit girth, fruit weight, days to fruit ripening, and fruit yield/plant). The cross 'S-49 × DPS-120' exhibited significant standard heterosis (15.30%) for green fruit yield. However, the maximum relative heterosis (92.04%) and heterobeltiosis (85.38%) for green fruit yield was observed in cross 'G-4 × Anand Chilli-1'. Negative estimates of heterotic effect for most of the characters may be attributed to intra-allelic interactions.

Singh and Hundal (2001) crossed three lines of chilli with 14 pollen parents in a line × tester fashion and noticed that heterosis over better parent was 55 per cent for fruit length, 24.48 per cent for fruit width, 111.27 per cent for fruit weight, 66.55 per cent for fruit number, 316.26 per cent for early yield, and 108.17 per cent for total yield. The crosses 'Punjab Guchhedar × RHCH Up' and 'Lt-2 × Lorai' manifested maximum heterosis for fruit number and total yield, respectively. Thiruvelavan *et al.* (2002) developed 20 male sterile-based hybrids using twenty diverse male parents and these were evaluated along with the control variety for plant height, primary branches/plant, days to 50% flowering, fruit length, fruit girth, dry fruit weight, seeds/fruit, fruits/plant, fresh fruit yield/plant and dry fruit yield/plant. The hybrids performed better than the control cultivar ‘CO 2’ in terms of yield and yield attributes and out of these, ‘MS 1 × CA 119’ was the most heterotic hybrid for number of fruits/plant and yield/plant.

Linganagouda *et al.* (2003) reported maximum heterosis over better parent in desirable direction for plant height (‘10 x 4’) and primary branches/plant (‘11x1’). Prasad *et al*. (2003) from nine × nine half diallel mating design involving one bell pepper cultivar (‘Arka Gaurav’) and eight hot pepper advanced breeding lines reported superior hybrids namely, ‘Arka Gaurav × VR-1’ for earliness, ‘VR-2 × VR-47’ for fruit length, ‘Arka Gaurav × VR-2’ for fruit width, ‘VR-47 × VR-55’ for number of fruits/plant, and ‘VR-2 × VR-55’ for dry fruit yield/plant. Crosses ‘VR-2 × VR-55’ and ‘VR-1 × VR-2’ were superior over the best parent and standard control with respect to dry fruit yield/plant and number of fruits/plant, respectively.

Gondane and Deshmukh (2004) studied heterosis in 33 chilli hybrids obtained by involving three male sterile lines and found that most of the hybrids expressed positive and significant heterosis over mid-parent, better parent and standard check. The cross combinations ‘Jwala × GP-90’, ‘AKC-86-25 × GP-313’, ‘CA-960 × GP-22’ and ‘AKC-86-25 × GP-314’ were the best crosses on the basis of high heterobeltiosis and standard heterosis for most of the characters *viz*., days to 50% flowering, plant height, main branches/plant, fruits/plant, seeds/fruit, 100 seed weight, ascorbic acid and wet red chilli yield/plant and could be used for commercial exploitation of heterosis. Patel *et al*. (2004) from a line × tester mating design using five genetic male sterile lines and eight male genotypes of chilli observed that hybrids ‘ACMS-2 × LCA-206’ and ‘ACMS-2 × LCA-206’ exhibited the greatest positive significant heterosis over the mid and better parents, respectively. None of the hybrids was superior to the control for green fruit yield. Hybrids ‘ACMS-4 × GVC-101’ and ‘ACMS-2 × GVC-101’ exhibited the greatest significant positive heterosis and heterobeltiosis for capsaicin content.

Senevitrne and Kannangara (2004) crossed six parental lines of chilli in all possible combinations including reciprocals (full diallel). Of the crosses assessed, plant height showed the highest average heterosis in the cross ‘IR ×

Pant C1'. 'Pant C1 × PBC 470' expressed 235 and 227 per cent average heterosis and heterobeltiosis for number of fruits/plant, respectively. The crosses 'Pant C1 × Pusa Jwala' and 'IR × Jawahar' recorded the highest commercial heterosis for fruits/plant and fresh fruit yield/plant, respectively. The cross 'Pusa Jwala × MI 1' exhibited the highest heterosis and heterobeltiosis for fresh fruit yield, fruit length and fruit width. Kumar *et al*. (2005) observed that the relative heterosis and heterobeltiosis for capsaicin content ranged from -46.15 to 89.16 and -55.30 to 72.52 per cent, respectively with 14 and ten crosses showed positive and significant relative and economic heterosis, respectively. The relative heterosis, heterobeltiosis and standard heterosis estimates varied from 38.30 to 119.47, 7.88 to 90.78 and -34.35 to 91.94 per cent for yield/plant, respectively.

Singh and Chaudhary (2005) observed considerable heterosis for total fresh yield/plant ranged from 7.40 ('IC-119367 × Pusa Sadabahar') to 33.24 per cent (EC-305591 × Punjab Lal) whereas, only four showed positive and significant heterosis over the better parent for number of fruits/plant. Crosses exhibiting high heterosis for total fresh yield/plant were also good heterotic crosses for number of fruits/plant, fruit length and number of seeds/fruit. Zate *et al.* (2005) noticed that the branch number on the main stem and fruit length were the most important characters contributing to the heterosis over better parent for yield/plant.

Adapawar *et al.* (2006), from line × tester analysis, observed that three hybrids ('CA-960 × GP-172', 'Jwala × GP-150' and 'Jwala × GP-172') consistently exhibited the highest heterosis for yield and number of fruits/plant. Shankarnag and Madalageri (2006) crossed three cytoplasmic genic male sterile lines of chilli with seven diversified pollen parents in a line × tester design and observed that the extent of heterobeltiosis and economic heterosis was 37.22 and 55.10 per cent for plant height, 51.85 and 55.61 per cent for plant spread (east-west), 59.46 and 46.32 per cent for plant spread (north-south), -26.15 and -17.94 per cent for days to first flowering, 9.16 and -14.13 per cent for fruit length, 44.53 and 10.83 per cent for fruit diameter, 94.63 and 84.25 per cent for number of fruit per plant and 181.10 and 27.43 per cent for total green fruit yield, respectively. The cross ‘L5 x T14’ recorded the highest heterosis for fruit number and total green fruit yield.

Satish and Lad (2007) noticed that the magnitude of heterobeltiosis and standard heterosis in desirable direction was the highest for number of secondary branches/plant followed by plant height, days to maturity and days to 50% flowering. Based on considerable beneficial heterotic response, the hybrids ‘Jayanti × G-4’, ‘Phule Suryamukhi × GA’ and ‘Arka Lohit × Phule Jyoti’ could be considered for exploitation of hybrid vigour. Prasath and Ponnuswami (2008) produced Hybrids by utilizing six diverse genotypes, namely ‘Arka Lohit’, ‘MDU Y’, ‘S 1’, ‘Arka Abir’, ‘Bydagi Kaddi’ and ‘Co 4’ and observed heterobeltiosis ranged from 40.35 to 126.32 per cent for dry yield/hectare. Based on *per se* performance, heterosis and SCA effects, the hybrids ‘Bydagi Kaddi × Arka Abir’ and ‘MDU Y × CO 4’ were found superior in respect of total extractable colour and low capsaicin besides dry yield and contributing characters.

Kamble *et al*. (2009) studied the magnitude of heterosis in 45 crosses and reported pronounced hybrid vigour for total fruit yield and most of the yield components. The crosses ‘KCP02 × CW’, ‘KCP12 × CW’, ‘KCP14 × BGM’ and ‘KCP01 × BL’ showed significant heterosis over commercial check for yield/plant, ‘KCP11 × BGM’ for plant height, ‘KCP02 × BL’ for number of tertiary branches/plant, ‘KCP10 × BL’ for days to 50 per cent flowering, ‘KCP05 × BGM’ for per cent fruit set, ‘KCP09 × BL’ for number of fruits/plant and ‘KCP11 × CW’ for early yield/plant. Sitaresmi *et al*. (2010) reported that hybrid ‘IPB C8 × IPB C19’ had the highest heterosis for fruit weight/plant while, hybrid ‘IPB C8 × IPB C15’ have same for number of fruits/plant. Crosses among introduced and local genotypes resulted in a high heterosis values.

2.4 Genotype environment interactions and stability analysis

If a set of plant genotypes is grown over a range of environments, the genotypes do not behave in the same relative way in all the environments. This interplay of genetic and non-genetic forces is known as genotype × environment

(G × E) interactions (Comstock and Moll, 1983). The relative importance of G × E interactions was pointed out by Sprague and Federer (1951). Sprague (1966) has described the usefulness of G × E interactions in detail. The literature on this aspect in chilli is rather limited and available information is presented as under:

Singh *et al*. (1989) observed significant variance effects due to environment and G × E interaction and found 'A8' and 'A36' as the most stable varieties. Roy *et al*. (1997) found that genetic variation among 23 genotypes and genotype × environment interactions were highly significant. 'DC24' and 'DC11' performed best under a wide range of environments and were recommended for future breeding programmes. Reddy and Sadashiva (2003) reported 'MI-2' as the most stable genotype in wide range of environments for its yield potential, earliness and acceptable fruit type in market.

3. MATERIALS AND METHODS

The present investigation on “Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)” was carried out at the Experimental Farms of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur and Hill Agricultural Research and Extension Centre, CSK Himachal Pradesh Krishi Vishvavidyalaya, Bajaura, Kullu during *Kharif*, 2010 and 2011. The details of materials used and methods employed in the present study to understand the nature of combining ability, type of gene action governing the inheritance of economic characters and the nature and extent of heterosis in chilli (*Capsicum annuum* var. *annuum* L.) are presented as under:

3.1 Locations

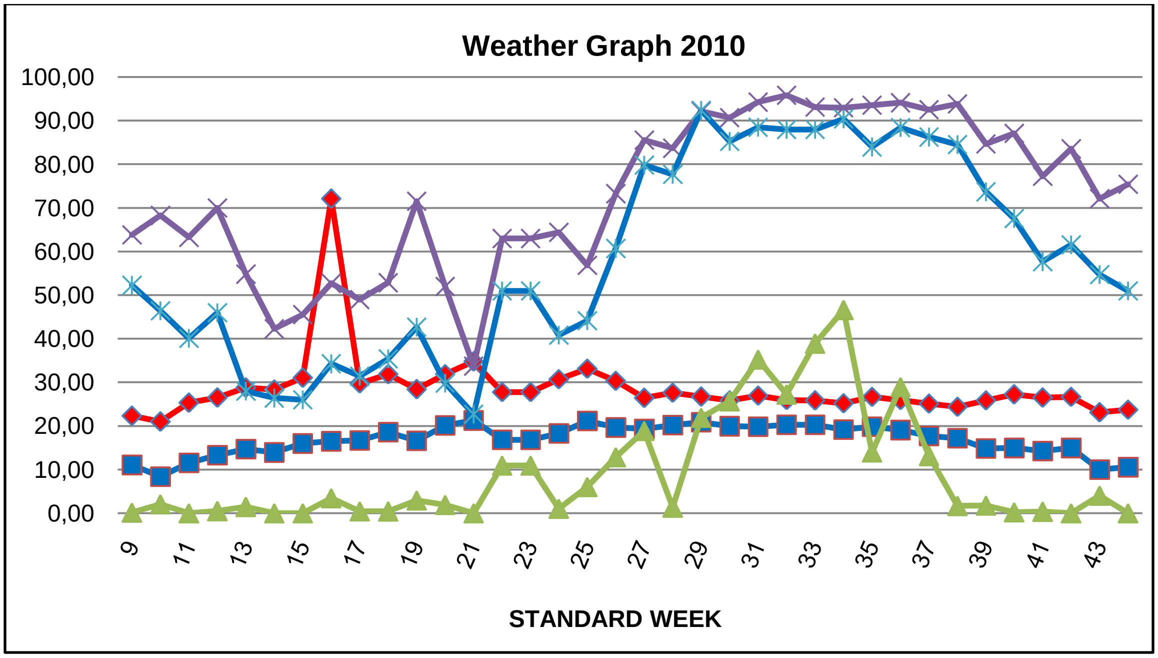
3.1.1 Palampur

The Experimental Farm is located at an elevation of about 1290.8 m above mean sea level with 32^{o} 8' North latitude and 76^{o} 3' East longitude, representing mid hill zone of Himachal Pradesh and has a sub-temperate climate with high rainfall (2500 mm)/annum. The soil of this zone is silty clay loam with acidic reaction.

3.1.2 Bajaura

The Experimental Farm is situated at 31^{o} 8' North latitude and $77^{o'}$ East longitude at an elevation of 1090 m above mean sea level. Bajaura falls under mid-hill, sub-humid zone (Zone-II) of the state and is endowed with mild summer and cool winter with low monsoon rains. The soil of this location is sandy loam with high water-table.

The mean monthly meteorological data, with regard to temperature, relative humidity and rainfall during the cropping period at both the locations are presented in Appendix I and II.



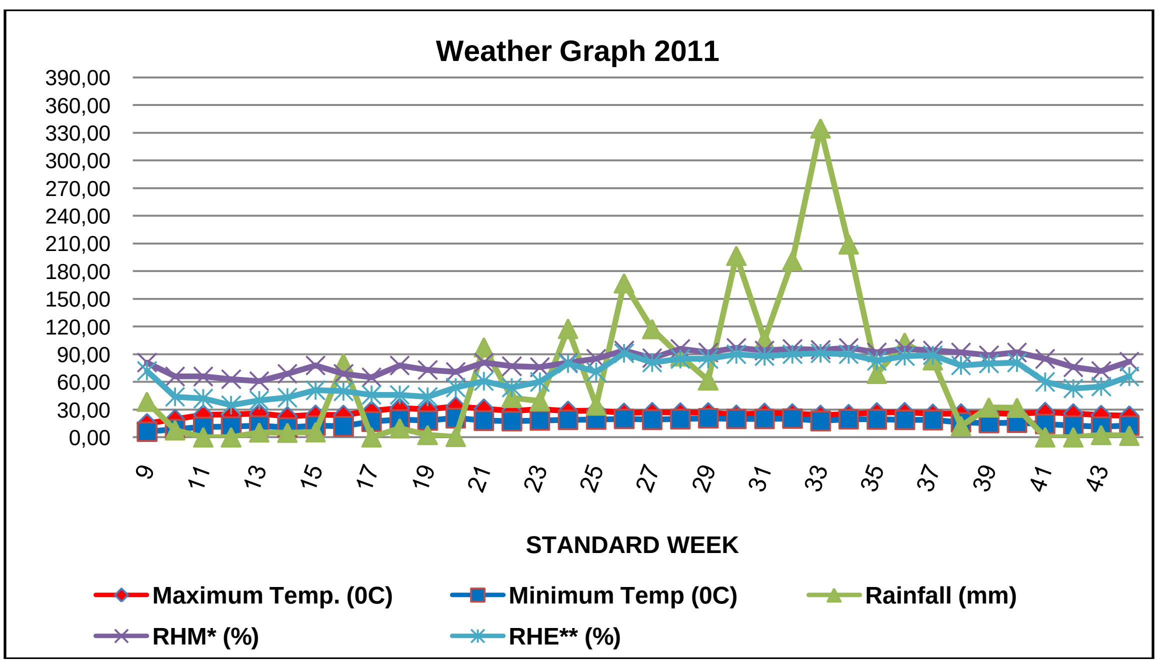
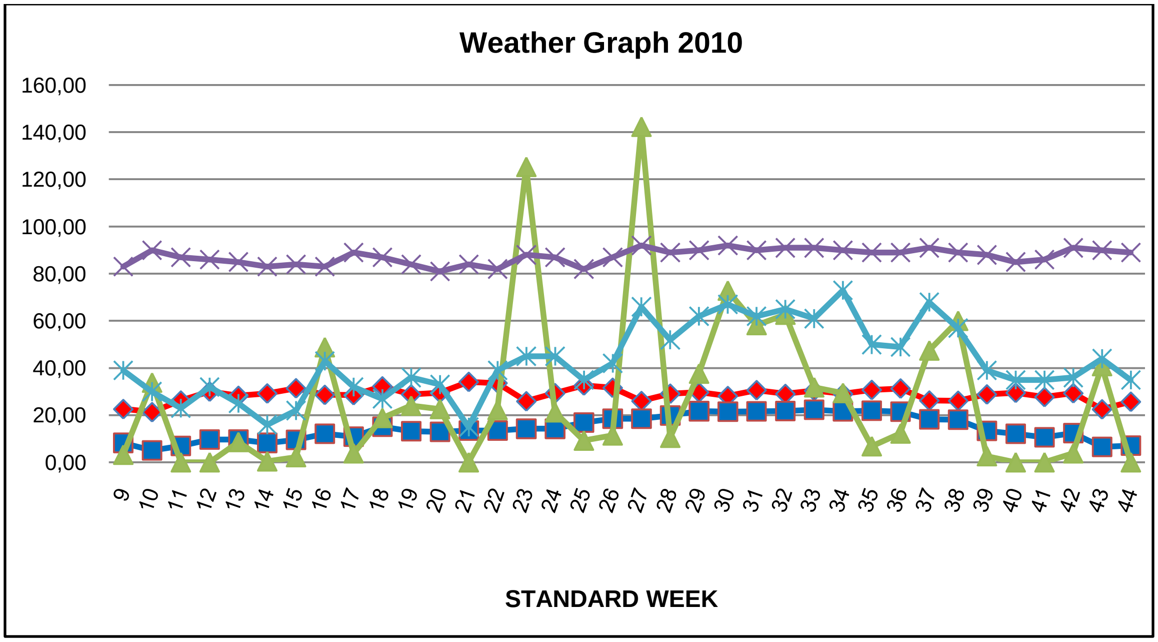


Fig. 1 Mean weekly weather conditions during the cropping season at Palampur



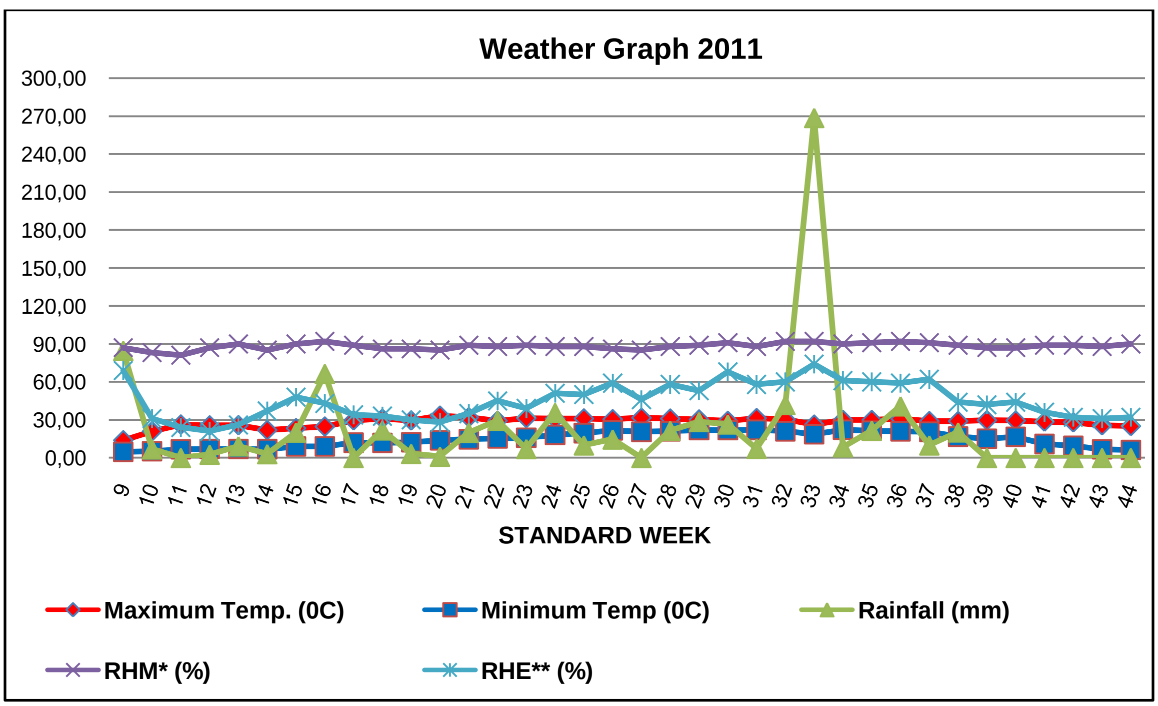


Fig. 2 Mean weekly weather conditions during the cropping season at Bajaura

3.2 Experimental material and layout plan

3.2.1 Experimental material

The experimental material for the present study comprised of F_1 population of 33 crosses which were developed by crossing 11 lines of chilli, *viz*., ‘Jawahar Mirch 283’, ‘Chilli Sonal’ ,‘PAU Selection Long’, ‘Arka Lohit’ ‘LCA 436’, ‘Pusa Jwala’, ‘Pusa Sadabahar’, ‘Kashmir Long’, ‘Selection 352’, ‘LCA 443’ and ‘LCA 206’ and with three testers, *viz*., ‘Pant C 1’, ‘Anugraha’ and ‘Surajmukhi’. Hybrid ‘CH-1’ was used as a standard check. These genotypes were collected from different sources (Table 3.1).

3.2.2 Hybridization programme

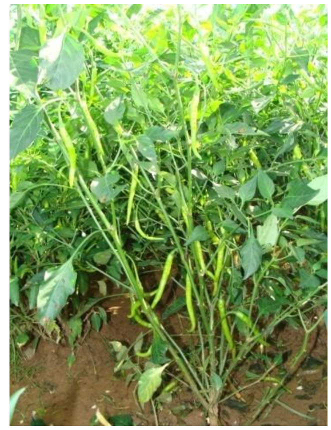
All the lines used as female parents were crossed to each of the testers by hand pollination following line × tester model. These genotypes were grown under naturally ventilated polyhouse at the Vegetable Research Farm, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during summer, 2009 and 2010. The healthy flower buds from new flush, due to open on the next day, were selected for emasculation and pollination. The selected buds were hand emasculated using forceps in the evening hours between 4.00 pm to 6.00 pm. Pollination of the emasculated flowers was done next day morning between 8 am to 12 noon. Well opened flowers with dehisced anthers were collected from the male parents and the stigma of female parent was touched with the respective dehisced anthers of male flowers. The crossed flowers were tagged depicting name of the cross and date of pollination. At maturity, red ripened fruits were harvested and sun dried. Seeds were extracted manually from the fruits, sun dried and stored. Thus, line × tester full-sib crossed true to type seeds were obtained for evaluation in the next season. The self seeds of the parents were also collected during the same seasons.

Table 3.1: List of genotypes along with their source

Sr. No.	Genotype	Source
a) Testers		
1.	Pant C 1	University of Agricultural Sciences and Technology, Pantnagar
2.	Anugraha	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur
3.	Surajmukhi	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur
b) Lines		
1.	Jawahar Mirch 283	Indian Agriculture Research Institute, New Dehli
2.	Chilli Sonal	Punjab Agricultural University, Ludhiana
3.	PAU Selection Long	Punjab Agricultural University, Ludhiana
4.	Arka Lohit	Indian Institute of Horticultural Research, Hessarghatta, Bangaluroo
5.	LCA 436	Regional Agricultural Research Station, Lam, Guntur
6.	Pusa Jwala	Indian Agriculture Research Institute, New Dehli
7.	Pusa Sadabahar	Indian Agriculture Research Institute, New Dehli
8.	Kashmir Long	Shere Kashmir University of Agricultural Sciences and Technology, Srinagar
9.	Selection 352	Indian Agricultural Research Institute, New Dehli
10.	LCA 443	Regional Agricultural Research Station, Lam, Guntur
11.	LCA 206	Regional Agricultural Research Station, Lam, Guntur
c) Standard check		
1.	CH-1	Punjab Agricultural University, Ludhiana

Jawahar Mirch 283

Chilli Sonal



PAU Selection Long

Arka Lohit

LCA 436

Pusa Jwala

Pusa Sadabahar

Kashmir Long

Selection 352

Contd…/

LCA 443 **LCA 206** **CH-1**

Pant C 1 **Anugraha** **Surajmukhi**

Plate 1: Parents and standard check used in the investigation

3.2.3 Experimental layout plan

The thirty three F_1s, fourteen parents and standard check 'CH-1' were grown in a Completely Randomized Block Design with three replications at Palampur and Bajaura for two consecutive summer-rainy seasons during 2010 and 2011. For screening of these crosses and parents for bacterial wilt disease, a separate experiment was laid out simultaneously at Palampur during both the years in bacterial wilt sick plots by planting ten plants of each entry.

3.2.4 Nursery sowing and transplanting

Seeds were sown in nursery beds of size 3 m × 1m on 2^{nd} and 6^{th} March at Palampur and Bajaura during 2010, respectively, whereas, seed sowings in the respective environments were carried out on 7^{th} and 10^{th} April during 2011. Twelve plants of 10-15 cm height were transplanted in the field on 20^{th} and 22^{nd} April during 2010 and 4^{th} and 10^{th} May during 2011at Palampur and Bajaura, respectively, with inter and intra-row spacing of 45 cm each.

3.3 Cultural practices

The experimental fields in the respective environments were ploughed using a 3-disc tractor and twice using a 7-disc tractor followed by power tiller. The recommended farmyard manure @ 20 tonnes/hectare was mixed in the soil at time of field preparation. The fertilizers were applied @ 75: 60: 60 kg N, P_2O_5 and K_2O/hectare with half of recommended N, full P and K at planting time and remaining N in two equal splits at one month interval after planting. Irrigation was provided one week prior to planting and immediately after transplanting for proper establishment of plants in the soil and thereafter, at ten days interval prior to the onset of monsoon. Five hand weeding were carried out at monthly interval to keep the field weed free. Drainage was also provided to keep the fields free from stagnation of water during rainy season. The harvestings were carried out manually.

3.4 Recording of observations

The observations were recorded on randomly taken five competitive plants in each entry and replication followed by computing their means for the following traits.

1) Days to 50% flowering

Calculated from the date of planting to the appearance of first flowering in 50 per cent plants of a genotype.

2) Days to first harvest

The number of days taken from the date of transplanting to the date of first marketable harvest of green fruits were calculated.

3) Primary branches/plant

Number of branches arising from the main stem were counted in randomly taken plants.

4) Fruit length (cm)

Polar length of ten randomly taken fresh fruits was measured in centi meters with a scale and average worked out for each of the parents and crosses.

5) Fruit girth (cm)

Equatorial length of each of the above fruits was measured in centi meters with verniar caliper at middle of the fruit.

6) Average fruit weight (g)

Average fruit weight was calculated by dividing the total marketable fruit yield by total number of marketable fruits/plant.

7) Marketable fruits/plant

The total number of marketable fruits picked from randomly taken plants at each harvest were counted and finally summed-up to work out the total number of fruits/plant.

8) Marketable fruit yield/plant (g)

The number of marketable fruits at each picking were weighed and averaged to get the marketable fruit yield/plant in grams.

9) Harvest duration (days)

Total number of days from first picking to the final picking of marketable fruits for each genotype were worked out.

10) Plant height (cm)

Plant height was measured in centi meters from the base to the top of the central apical shoot at the time of final harvest in each entry over the replications.

11) Average dry fruit weight (g)

Average dry fruit weight was calculated by dividing the total dry fruit yield by total number of dry fruits/plant.

12) Dry fruit yield/plant (g)

Marketable fruits harvested from five randomly selected plants at red ripe stage were dried and weighed to work out the average dry fruit yield/plant in grams.

13) Ascorbic acid (mg/100g)

Ascorbic acid content in chilli was estimated by '2,6-dichlorophenol-indophenol Visual Titration Method' as described by Ranganna (1979).

Reagents:

a) 3% metaphosphoric acid (HPO_3): Prepared by dissolving the sticks or pellets of HPO_3 in glass distilled water.

b) Ascorbic acid standard: 100 mg of L-ascorbic acid was weighed accurately and volume made up to 100 ml with 3 per cent HPO_3. 10 ml of this solution was further diluted to 100 ml with 3 per cent HPO_3. (1 ml = 0.1 mg ascorbic acid)

c) Dye solution: 50 mg of the sodium salt of 2,6-dichlorophenol-indophenol was dissolved in approximately 150 ml of hot glass distilled water containing 42 mg of sodium bicarbonate. The solution was cooled and diluted with glass distilled water to 200 ml. Stored in a refrigerator and standardized every day.

Procedure

Standardization of dye

- Five ml of standard ascorbic acid solution was taken in a beaker and 5 ml of HPO_3 was added to it. This solution was titrated with the dye solution to a pink colour which persisted for 15 seconds. Dye factor (mg of ascorbic acid per ml of the dye) was determined by using the formula:

$$\text{Dye factor} = \frac{0.5}{\text{Titre}}$$

Here,

i. 0.5 means 0.5 mg of ascorbic acid in 5 ml of 100 ppm standard ascorbic acid solution,

ii. Titre = Volume of dye used to neutralize 5 ml of 100 ppm standard ascorbic acid solution along with 5 ml of metaphosphoric acid.

- Ten grams of macerated sample was blended with 3 per cent metaphosphoric acid and the volume finally made up to 100 ml.
- Out of this 100 ml solution, 10 ml of solution was taken and titrated against 2,6-dichlorophenol-indophenol dye till the appearance of rose pink colour.
- The ascorbic acid content was calculated by using the following formula and were expressed as mg of ascorbic acid/100 g of fresh sample.

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up}}{\text{Aliquot of extract taken for estimation} \times \text{Weight of sample taken for estimation}} \times 100$$

Here,

Titre = Volume of dye used to titrate the aliquot of extract of a given sample.

14) Capsaicin content (%)

The capsaicin content in the fruits was determined by calorimetric method using Folin-Ciocalteau reagent described by Bajaj (1980). The capsaicin concentration in different samples was noted from the standard capsaicin curve and finally the results were converted into percentage.

Reagents

a) Acetone

b) Aluminium oxide active basic

c) Folin and ciocalteau phenol (FC) reagent (available as 2N; diluted with equal volume of distilled water just before use).

d) Sodium carbonate anhydrous: 35 g of anhydrous sodium carbonate was dissolved in 100 ml of water at 70-80^{0}C, filtered and allowed to cool overnight. Super saturated solution with crystals of Na_2CO_3 10 H_2O was filtered through glass wool to obtain the mother liquid.

e) Methanol (CH_2O)

Procedure

a) Standard curve: 0 to 1.5 ml of standard capsaicin were taken in small beakers and evaporated to less than 0-5 ml at room temperature. 0-5 ml FC reagent and 6-5 ml of distilled water were added to beaker and allowed to stand for three minutes. Then 1 ml of Na_2CO_3 solution was added and mixed well. Whole quantity was transferred to 10 ml volumetric flask and final volume was made up with distilled water. Centrifugation for 10- 15 minutes at 10,000 rpm was done. Absorbance was measured at 760 nm after one hour rest at room temperature.

b) Extraction:

- 0-5 g of dried powdered capsicum fruits were extracted with 25 ml acetone.
- Mixture was shaken for 10 minutes and allowed to stand for four hours.
- After that mixture was filtered through glass wool plugged in a short stemmed funnel. Volume was made up to 25 ml. Two ml of this extract was passed through basic alumina column. Column is 1.5 g basic

alumina (have layers of glass wool, aluminium oxide and sodium sulphate of 2 fingers height each) in to 10 × 0.9 cm column which is washed with 5 ml of acetone.

- Column was washed with 3 × 5 ml of acetone after loading. These washings were discarded. Pure capsaicin was eluted with acetone; methanol and water mixture in ratio of 75:25:1 and final volume made up to 50 ml.
- 10 ml volume was evaporated to dryness at temperature less than 65^{0}C and the colour was developed as for calibration curve.

c) Calculations: Suppose OD of sample = x. Then from standard curve, concentration of capsaicin against x = y mg. This y mg is in 10 ml which is taken from 50 ml. So, concentration of capsaicin = 5y in 50 ml. Again this 5 y is from 2 ml of extract which is taken from 25 ml of extract made at first step. So, in 25 ml, concentration of capsaicin = (5y × 25 mg)/2. This 25 ml extract was prepared from 0.5 g of sample. Therefore, 0.5 g (500 mg) of sample has 125/2y mg of capsaicin.

- 1g of sample has 125 y mg of capsaicin.
- 100 g of sample has 12500 y mg of capsaicin.
- Therefore, 100 g of sample contains 12500 y mg of capsaicin.
- In per cent capsaicin content will be 12.5 y

15) Capsanthin/ colouring matter (ASTA units)

Capsanthin was determined as per procedure given by A.O.A.C. (1980).

Requirement: Spectrophotometer, Acetone

Procedure

- 100 mg of powdered sample was taken in 100 ml volumetric flask, diluted with acetone and corked tightly.

- The solution prepared was shaken well and allowed to stand in dark for sixteen hours at room temperature.
- The mixture was shaken again and particles were allowed to settle for two minutes.
- A clear portion of the extract was transferred to cell and absorbance was measured at 465 nm using acetone as a blank.

Calculations

ASTA colour value for capsicum = [(A_{ext} at 465 nm) × (16.4 I_f)]/g sample

16) Oleoresin (ASTA units)

Oleoresin was calculated as per procedure given by A.O.A.C. (1980).

Requirements: Spectrophotometer, acetone

Procedure

- 100 mg of powdered sample was transferred to 100 ml volumetric flask.
- The final volume was made up with acetone, shaken well and allowed to stand for two minutes.
- 10 ml extract was pipetted into another 100 ml volumetric flask and final volume made up with acetone and was shaken again.
- Absorbance of this solution was measured at 460 nm against acetone as blank.

Calculations

ASTA colour value for oleoresin = [(A_{ext} at 460 nm) × (164 I_f)]/g sample

Where,

$$I_f \text{ (correction factor)} = \frac{\text{Declared OD of NBS std. at 465 nm}}{\text{Observed OD of NBS std at 465 nm}}$$

Standard of NBS (National Board of Spice) is 1 M Ferrous ammonium sulphate and declared OD is 0.64. In the spectronic, declared OD is equal to observed so, there was no need to multiply with I_f.

q) Bacterial wilt incidence (%)

Bacterial wilt disease incidence in chilli was recorded as per Sinha *et al*. (1990) scale. Mortality (confirmed by ooze test) in each genotype was recorded and expressed in per cent to categorize the genotypes into resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible as per scale:

Rating System for Bacterial Wilt Incidence

Bacterial wilt (%)	Reaction category
0-10	Resistant (R)
11-20	Moderately resistant (MR)
21-30	Moderately susceptible (MS)
31-70	Susceptible (S)
71-100	Highly susceptible (HS)

$$\text{Incidence of Bacterial wilt (\%)} = \frac{\text{Number of plants infested}}{\text{Total number of plants}} \times 100$$

3.5 Statistical analysis

The data recorded on 33 crosses along with 14 parents and one standard check were analyzed as per the design for working out the following values.

3.5.1 Analysis of variance

For working out the analysis of variance, the data were analysed by using the following model as suggested by Panse and Sukhatme (1967).

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

where,

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

μ = General population mean

g_i = Effect of i^{th} genotype

r_j = Effect of j^{th} replication, and

e_{ij} = Error component

Analysis of variance

Source of variation	df	Mean sum of square	Expected mean sum of square
Replication	(r-1)	Mr	$\sigma_e^2+g\sigma_r^2$
Entries	(g-1)	Mg	$\sigma_e^2+r\sigma_g^2$
Error	(r-1) (g-1)	Me	σ_e^2

where,

r = number of replications

g = number of entries

σ_e^2 = error variance

σ_g^2 = variance due to entries

σ_r^2 = variance due to replications

The replication and entries mean sum of square were tested against error mean squares by ‘F’ test for (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom at P = 0.05.

The pooled over environments analysis was done as follows

Analysis of variance

Source of variation	d.f.	Mean sum of square	Expected mean sum of square
Replications (within environments)	E(r-1)	Mr	-
Environment	(E-1)	ME	
Entries	(g-1)	Mg	$\sigma_e^2 + r\,\sigma_g^2 \times E + rE\sigma_g^2$
Entries × Environment	(g-1)(E-1)	Mg × E	$\sigma_e^2 + r\,\sigma_g^2 \times E$
Pooled error	E(g-1)(r-1)	Me(C)	σ_e^2

where,

r = number of replicates

E = number of environments

g = number of entries

σ_e^2 = Error variance

$\sigma_g^2 \times E$ = Variance due to entries × environment interactions , and

σ_g^2 = Variance due to entries

$$\text{Me(C)} = \frac{(\text{Error ss at Env. I} + \text{Error ss at Env. II} + \text{Error ss at Env. III})}{(\text{df at Env. I} + \text{df at Env. II} + \text{df at Env. III})}$$

The replications (within environments), environments, entries, entries × environments mean sum of square were tested against error mean squares by ‘F’ test for E (r-1), E (g-1) (r-1), for (E-1), E(g-1) (r-1), for (g-1), E(g-1) (r-1) and (g-1) (E-1), E (g-1) (r-1) degree of freedom at P = 0.05, respectively.

From these analyses, the following standard error were calculated where the ‘F’ test was significant. Standard error for the entry mean:

SE (m) = Individual environment = $\pm$ (Me/2)$^{1/2}$

Pooled environment = $\pm$ (Me(C)/rE)$^{1/2}$

Standard error for the difference of entry means :

SE (d) = Individual environment = $\pm$ (2Me/r)$^{1/2}$

SE (d) = Pooled environment = $\pm$ (2Me(C)/rE)$^{1/2}$

The critical difference (CD) at 5% level of significance was obtained by multiplying SE (d) by the table value of 't' at error degree of freedom and P = 0.05.

CD = SE (d) ×'t' value at error degree of freedom and P = 0.05

Coefficient of variation (CV) % = (ME$^{1/2}$ or ME(C)$^{1/2}$/general mean) × 100

3.5.2 Line × tester analysis

In this case the replication wise mean values of F_1 generation of 33 crosses for each trait were subjected to statistical analysis using the following model suggested by Kempthorne (1957) and the solved example given by Dabholkar (1992).

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

where,

Y_{ijk} = value of the ijkth observation of the cross involving ith line and jth tester in kth replication,

μ = general mean (an effect common to all hybrids in all replications,

g_i = general combining ability (GCA) effect of ith line,

g_j = general combining ability (GCA) effect of jth tester,

S_{ij} = specific combining ability (SCA) effect of the cross involving i^{th} line and j^{th} tester,

e_{ijk} = error associated with ijk^{th} observation,

i = i^{th} line (1, 2, 3 ………………………11)

j = j^{th} tester (12, 13, 14), and

k = k^{th} replication (1, 2, 3)

Analysis of variance for crosses and for combining ability

(partitioning crosses sum of squares)

Source of variation	d.f.	Sum of squares	Mean squares	Expected mean squares
Replication	(r-1)	$\sum_{k=1}^{r}\frac{(x..k)^2}{fm} - \frac{x^2...}{fmr}$	-	-
Cross	(fm-1)	$\sum_{ij=1}^{fm}\frac{x^2_{ij}.}{r} - \frac{x^2...}{fmr}$	-	-
Lines	(f-1)	$\sum_{i=1}^{f}\frac{x_i^2..}{mr} - \frac{x^2...}{fmr}$	M(f)	$\sigma_e^2+r\sigma_{fm}^2+rm\sigma_f^2$
Testers	(m-1)	$\sum_{j=1}^{m}\frac{x_j^2.}{fr} - \frac{x^2...}{fmr}$	M(m)	$+r\sigma_{fm}^2+rf\sigma_m^2$
Line × tester	(f-1) (m-1)	$\sum_{ij=1}^{fm}\frac{x_{ij}^2.}{r} - \sum_{i=1}^{f}\frac{x_i^2..}{mr} - \sum_{j=1}^{m}\frac{x_j^2..}{fr} + \frac{x^2...}{fmr}$	M(fm)	$\sigma_e^2+r\sigma_{fm}^2$
Error	(fm-1) (r-1)	By difference (for crosses)	Me	σ_e^2
Total	(fmr-1)	$\sum_{i=1}^{f}\sum_{j=1}^{m}\sum_{k=1}^{r} x^2_{ijk} - \frac{x^2...}{fmr}$	-	-

where,

f	=	number of lines,
m	=	number of testers,
$x_{..k}$	=	sum of k[th] replication of crosses,
$x_{...}$	=	sum of all crosses of all lines and testers over all replications,
$x_{ij.}$	=	sum of ij[th] hybrid combination over all replications,
$x_{i..}$	=	sum of i[th] line over all testers and replications,
$x_{j..}$	=	sum of j[th] tester over all lines and replications,
x_{ijk}	=	ij[th] observation in k[th] replication,
M(f)	=	mean squares due to lines,
M(m)	=	mean squares due to testers,
M(f × m)	=	mean squares due to line x tester interactions,
Me	=	error mean squares,
σ_f^2	=	variance due to lines/progeny variance arising from differences among female parents/lines,
σ_m^2	=	variance due to testers/progeny variance arising from differences among male parents/testers,
$\sigma_{f \times m}^2$	=	variance due to lines x testers/progeny variance arising from interaction of the contribution of female and male parents, and
σ_e^2	=	environmental variance/error variance among individuals from same mating

3.5.3 Estimation of general and specific combining ability effects

GCA and SCA effects were obtained from the two way table of female parents vs. male parents in which each figure was total over replications. The individual effects were estimated as follow:

(i) GCA effects of i^{th} line

$$g_i = \frac{X_{i..}}{mr} - \frac{X_{...}}{fmr}$$

where,

$X_{...}$ = sum total of all crosses,

$X_{i..}$ = total of i^{th} female parents over all males and replications,

r = number of replications,

f = number of lines/female parents, and

m = number of testers/male parents

(ii) GCA effects of j^{th} tester

$$g_j = \frac{X_{j..}}{fr} - \frac{X_{...}}{fmr}$$

where,

$X_{j..}$ = total of j^{th} male parent over all females and replications

(iii) SCA effects of ij^{th} cross

$$s_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{mr} - \frac{X_{j..}}{fr} + \frac{X_{...}}{fmr}$$

where,

$X_{ij.}$ = ij^{th} combination total over all replications

(iv) Standard errors for different combining ability effects

(a) SE (g_i) lines = $\pm\sqrt{Me/mr}$

(b) SE (g_j) testers = $\pm\sqrt{Me/fr}$

(c) SE (s_{ij}) crosses = $\pm\sqrt{Me/r}$

(d) SE ($g_i - g_j$) lines = $\pm\sqrt{2Me/mr}$ =SE (D_1)

(e) SE ($g_i - g_j$) testers = $\pm\sqrt{2Me/fr}$ =SE (D_2)

(f) SE ($s_{ij} - s_{kj}$) crosses = $\pm\sqrt{2Me/r}$ =SE (D_3)

where,

Me = mean sum of squares due to error

Pooled analysis of variance for combining ability

Pooled over environments analysis of variance for combining ability was done as per following:

Analysis of variance

Source of variation	df	Sum of squares	Mean squares	Expected MS
Environments	(E-1)	$\sum_{n=1}^{E} \frac{x^2....n}{mfr} - \frac{x^2...}{mfrE}$	---	---
Testers	(m-1)	$\sum_{j=1}^{m} \frac{x^2_{j}}{mrE} - \frac{x^2...}{mfrE}$	M_1	$\sigma_e^2 + r\sigma_{fm}^2E + rE\sigma_{fm}^2 + rEf\sigma_m$
Lines	(f-1)	$\sum_{i=1}^{f} \frac{x^2_{i}}{mrE} - \frac{x^2...}{mfrE}$	M_2	$\sigma_e^2 + r\sigma_{fm}^2E + rE\sigma_{mf}^2 + rEf\sigma_m^2$
Lines × Testers	(f-1) (m-1)	$\sum_{ij=1}^{mf} \frac{x^2_{ij}}{mrE} - \sum_{j=1}^{m} \frac{x^2_{j}}{frE} - \sum_{i=1}^{f} \frac{x^2_{j}}{mrE} + \frac{x^2...}{mrfrE}$	M_3	$\sigma_e^2 + r\sigma_{fm}E + rE\sigma_{mf}^2$
Testers × Env.	(m-1) (E-1)	$\sum_{jn=1}^{mE} \frac{x_{j.n}{}^2...}{fr} - \sum_{n=1}^{E} \frac{x^2{}_{..n}}{mfr} - \sum_{j=1}^{m} \frac{x_j^2...}{frE} + \frac{x^2...}{mfE} = A$	M_4	$\sigma_e^2 + r\sigma_{fm}^2E + rf\sigma_m^2E$
Lines × Env.	(f-1) (E-1)	$\sum_{jn=1}^{fE} \frac{x_i{}^2...}{mr} - \sum_{n=1}^{E} \frac{x^2{}_{..n}}{mfr} - \sum_{j=1}^{f} \frac{x_i^2...}{frE} + \frac{x^2...}{mfrE} = B$	M_5	$\sigma_e^2 + r\sigma_{fm}^2E + rm\sigma_f^2E$
Lines × Testers × Env.)	(m-1) (f-1) (E-1)	$\sum_{ijn=1}^{mfE} \frac{x_{ij.n}{}^2...}{r} - \sum_{ij=1}^{mf} \frac{x^2{}_{ij}}{mfr} - \sum_{n=1}^{E} \frac{x^2...n}{mfr} + \frac{x^2...}{mfrE} = A$ -	M_6	$\sigma_e^2 + r\sigma_{fm}^2E$
Pooled error	E(mf-1) (r-1)	Error as at environment-I + Error as at environment-II +	M_e	σ_e^2

where,

m = number of males,

f = number of females,

E = number of environments,

r = number of replications at each environment,

$x_{\ldots}$ = sum of all crosses of all lines, testers, replications and over all environments,

$x_{\ldots n}$ = sum of all crosses of all lines and testers over replications,

$x_{.j..}$ = sum of j^{th} testers over all lines, replications and environments,

$x_{i\ldots}$ = sum of i^{th} lines over all testers, replications and environments,

$x_{ij\ldots}$ = sum of ij^{th} cross over all replications and environment,

$x_{j.n}$ = sum of j^{th} tester over all lines and replications at n^{th} environment,

$x_{ij.n}$ = sum of ij^{th} cross over replications at n^{th} environment, and

M_e = Pooled error mean square

Pooled general and specific combining ability effects were estimated as follows:

(i) Estimation of general mean

$$\mu = \frac{x_{\ldots}}{mfre}$$

where,

$x_{\ldots}$ = total of all crosses over all replications in all environments

(ii) gca effects of i^{th} line

$$g_i = \frac{x_{i.}}{mre} - \frac{x_{\ldots}}{mfre}$$

where,

$x_{i\ldots}$ = sum of i^{th} lines over all testers, replications and environments

e = number of environments

(iii) gca effects of j^{th} tester

$$g_j = \frac{x_{j..}}{frE} - \frac{x_{\ldots.}}{mfrE}$$

where,

$x_{j}..$ = sum of j^{th} testers over all lines, replications and environments

(iv) sca effects of ij^{th} cross

$$S_{ij} = \frac{x_{ij}}{re} - \frac{x_i}{mre} - \frac{x_j}{fre} + \frac{x...}{mfre}$$

where,

$x_{ij}..$ = ij^{th} cross total over all replications and environments.

(v) Standard error for pooled combining ability effects

(a) SE pooled (g_i) lines = $(Me/rme)^{1/2}$

(b) SE pooled (g_j) testers = $(Me/rfe)^{1/2}$

(c) SE pooled (S_{ij}) crosses = $(Me/re)^{1/2}$

(d) SE ($g_i - g_j$) lines = $(2Me/mre)^{1/2}$ = SE (D1a)

(e) SE (g_i - g_j) testers = $(2Me/fre)^{1/2}$ = SE (D2a)

(f) SE (S_{ij} - S_{kj}) crosses = $(2Me/re)^{1/2}$ = SE (D3a)

(vi) Test of significance for GCA and SCA effects

There are two methods

Method-I

GCA and SCA effects $\geq$ [($SE_{gi}/SE_{gj}/SE_{sij}$) ×'t' tab at error degree of freedom and P = 0.05] were marked significant (*).

Method-II

(a) t_i (cal) for GCA of lines (females) = (g_i – 0)/SE (g_i)

(b) t_j (cal for GCA of testers (males) = (g_j – 0)/SE (g_j)

(c) t_{ij} (cal) for SCA of crosses = (S_{ij} – 0)/SE (S_{ij})

where,

t_i (cal), t_j (cal) and t_{ij} (cal) are the calculaed 't' values,

g_i = GCA effect of i^{th} line,

g_j = GCA effect of j^{th} tester, and

s_{ij} = SCA effect of ij^{th} cross

The GCA effects of lines and testers and SCA effects of crosses were marked significant (*) when the values of t_i (cal), t_j (cal) and t_{ij} (cal) were $\geq$'t' tabulated value at error degree of freedom of individual environment or pooled over environment and P = 0.05.

(vii) Critical differences (CD) for comparing GCA effects of lines/testers and SCA effect of crosses

(a) CD for GCA (lines) = SE (D1a) ×'t' tab (error df, P=0.05)

(b) CD for GCA (testers) = SE (D2a) ×'t' tab (error df, P=0.05)

(c) CD for SCA (crosses) = SE (D3a) ×'t' tab (error df, P=0.05)

The difference between GCA of any two lines/testers and SCA of any two crosses were considered significant when the differences were $\geq$ respective CD values.

3.5.4 Estimation of variance components

1. Individual environment

Cov (HS) = σ_f^2 (females) = $(M_f - M_{fm})$ / mr = σ_{GCA}^2 (lines)

Cov (HS) = σ_m^2 (males) = $(M_m - M_{fm})$ / fr = σ_{GCA}^2 (testers)

Cov HS (average) = 1/r (2fm-f-m) [(f-1) (M_f) + (m-1) (M_m)/1+m-2-M_{fm}]

σ_{fm}^2 (females × males) = $(M_{fm} - Me)$ / r = σ_{SCA}^2

(i) Estimation of Cov HS (average) and Cov (FS)

These were calculated as:

Cov HS (average) = $(m\sigma_f^2 + f\sigma_m^2)$ / (f+m)

Cov (FS) = σ_{fm}^2 + 2 Cov (HS)

These can also be calculated from the expectation of mean squares as:

Cov HS (average) = (Mf + Mm – 2 Mfm) r (f + m)

Cov HS (FS) = [Mf+Mm + Mfm – 3 Me + 6r Cov (HS) – r (f+m) Cov (HS)] / 3r

2. Pooled over environments

Cov (HS) = σ_f^2 (females) = (Mf – Mfm) / mrE

= σ_f^2 × E (female × environment) = (MfE – MfmE)/mr

Cov (HS) = σ_m^2 (males) = (Mm – Mfm) / frE

= σ_m^2 × E (males × environments) = (MmE – mfmE)/fr

σ_{fm}^2 × E [(females x males) × Environment)] = MfmE – Me/R = σ_{SCA}^2× E

(I) Estimation of Cov HS (average) and Cov (FS)

These were calculated as:

Cov HS (average) = $(m\,\sigma_f^{\,2} + f\,\sigma_m^{2}) / (f + m)$

Cov HS (average) × environment = $(m\,\sigma_f^{\,2}E + f\sigma_m^{\,2}\,E) / (f + m)$

Cov (FS) = $\sigma_{fm}^{\,2}$ + 2 Cov (HS)

Cov (FS) × environment = $\sigma\sigma_{fm}^{\,2}$ e+2 Cov (HS) x Environment

These also be calculated from the expectation of mean square as Cov HS (average) = Mf + Mm – 2 Mfm) / rE (f + m).

Cov HS (average) × environment = (MfE + MmE – 2MfmE) / r (f+m)

Cov (FS) = [Mf + Mm + Mfm – 3 Me + 6 rE Cov (HS) – rE (f+m) Cov (HS)]/3rE

Cov (FS) = Mfe + Mme + Mfme – 3Me + 6 r Cov (HS) × Environment – r (f+m) Cov (HS) × Environment]/3 r

(ii) Estimation of GCA and SCA variances

From the estimates of Cov (HS) and Cov (FS), variances due to general combining and specific combining ability were calculated as:

$\sigma_{GCA}^{\,2}$ = Cov (HS) = (Mf + Mm – 2 Mfm)/rE(f + m)

$\sigma_{GCA}^{\,2}$ × Environment = Cov (HS) × environment

= (MfE + MmE – 2 MgmE)/r (f + m)

$\sigma_{SCA}^{\,2}$= Cov (FS) – 2 Cov (HS) = (mfm – Me) / r

$\sigma_{SCA}^{\,2}$ × Environment = Cov (FS) × Environment – 2 Cov (HS) × Environment = (MfME – Me) / r

(iii) Estimation of additive (σ_A^2) and dominance (σ_D^2) component of variances

For computing the additive and dominance components of variances following formulae have been used Singh and Chaudhary (1977) and Dabholkar (1992).

$\sigma_{GCA}^{\,2}$ = $[(1 + F) / 4]\,\sigma_A^{\,2}$= ½ $\sigma_A^{\,2}$

So $\sigma_A^{\,2}$ = 2 $\sigma_{GCA}^{\,2}$

$\sigma_{SCA}^{\,2}$ = $[(1+F) / 2]^2\,\sigma_D^{\,2}$= $\sigma_D^{\,2}$

So $\sigma_D^{\,2}$ = $\sigma_{SCA}^{\,2}$

Where, F = inbreeding coefficient (F = 1.0, since the chilli being the often cross pollinated crop does not suffer from significant inbreeding depression).

σ_A^2 = additive variance, and

σ_D^2 = dominance variance

3.5.5 Per cent contribution of lines, testers and their interactions

These were computed as per the formulae suggested by Singh and Chaudhary (1977).

(i) Per cent contribution of lines

= [SS (lines)/SS (crosses)] × 100

(ii) Per cent contribution to testers

= [SS (testers)/SS (crosses)] × 100

(iii) Per cent contribution of lines × testers

= [SS (lines × testers)/SS (crosses) × 100

3.5.6 Estimation of heterosis

The estimates of heterosis were calculated as the deviation of F_1 mean from the better parent (BP) and standard check [CH-1 (SC)].

1. Heterosis over better parent (%) = $[(\overline{F}_1 - \overline{BP})/\overline{BP}] \times 100$

2. Heterosis over standard check (%) = $[(\overline{F}_1 - \overline{SC}_1)/\overline{SC}_1] \times 100$

1. Calculation of standard errors

(i) SE for testing heterosis over better parents:

Individual environment = $\pm (2Me/r)^{1/2}$ = SE (H_1)

Pooled environment = $\pm (2Me/rE)^{1/2}$ = SE (H_1)

(ii) SE for testing heterosis over Standard check :

Individual environment = $\pm (2Me/r)^{1/2}$ = SE (H_2)

Pooled environment = $\pm (2Me/rE)^{1/2}$ = SE (H_2)

2. Test of significance for heterosis

There are two methods:

Method-I

The difference of $(\bar{F}_1 - \overline{BP})$ or $(\bar{F}_1 - \overline{SC}) \geq [SE(H_1)$ or $SE(H_2)]$ × 't' tab, at error degree of freedom of individual environment analysis of variance or at error degree of freedom of pooled over environments analysis and P=0.05 were considered significant and the asterisk(*) was put on the per cent values only. This method is relatively less time consuming.

Method-II

't' calculated values were worked out as follow

1. 't' calculated values for heterosis over BP = $(\bar{F}_1 - \overline{BP})/SE(H_1)$

2. 't' calculated value for heterosis over SC = $(\bar{F}_1 - \overline{SC})/SE(H_2)$

The 't' calculated values for heterosis over better parent (BP) and standard check (SC) were compared with 't' tabulated values at error degree of freedom and P = 0.05.

't' calculated values $\geq$ 't' tabulated values were marked as significant and asterisk was put on per cent values only.

3.5.7 Stability analysis

Parameters of phenotypic stability were computed, using the regression approach of Eberhart and Russell (1966).

Eberhart and Russell (1966) model

The parameters are defined with the following model:

$Y_{ij} = \mu_i + b_i I_j + \delta_{ij}$

(i = 1, ………..g)

(j = 1, …………n)

where,

Y_{ij}	=	mean of i^{th} variety in the j^{th} environment
μ_i	=	mean of i^{th} genotype over all environments
b_i	=	regression co-efficient of the i^{th} genotype on the environmental index which measures the response of this genotype to varying environments
δ_{ij}	=	The deviation from regression of the i^{th} genotype at the j^{th} environments
I_j	=	The environmental index which is defined as the deviation of the mean of all the varieties at a given location from the overall mean i.e. mean of all genotypes at the j^{th} environment minus grand mean

3.5.7.1 Computation of stability parameters

(i) Mean performance ($\overline{X}$) = $\sum_j Yij/n$

where,

$\sum_j Yij/n$ = The mean of i^{th} genotype over 'n' environments

(ii) Regression coefficient (b_i) = $\sum_j Y_{ij} I_j / \sum_j I^2{}_j$

where,

$\sum_j Y_{ij} I_j$ = sum of products of i^{th} genotype in j^{th} environment and j^{th} environment index

$\sum_j I^2 j_j$ = sum of squares due to environmental index

(iii) Deviation from regression (S^2di) = $[\sum\delta^2_{ij}/(n-2)] - S^2e/r$

(S^2di is the non linear component of genotype x environment interaction of i^{th} genotype).

where,

$$\sum\delta^2_{ij} = (\sum_j Y^2_{ij} - Y^2_{i.}/n) - [\sum_j Y_{ij} I_j)^2 / \sum_j I^2_j]$$

S^2e	=	estimate of the pooled error of the variance of genotypic mean of the i^{th} environment
r	=	number of replications

3.5.7.2 Computation of environment index (I_j)

$$I_j = \sum_i Y_{ij}/g - \sum_i\sum_j Y_{ij}/g.n$$

$$= \frac{\text{Total of all varieties at } j^{th} \text{ location}}{\text{Number of genotypes}} - \frac{\text{Grand total}}{\text{Total number of observations}}$$

Analysis of variance of multi-environment data when stability parameters are estimated following Eberhart and Russell (1966) model

Source of variation	df	SS	MS
Total	(ng-1)	$\sum_i\sum_j Y^2_{ij}$-C.F.*	
Genotypes (G)	(g-1)	$1/n\sum_i Y^2_{i.}$-C.F.	MS_1
Environment (E)	(n-1)	$1/g\sum_j Y^2_{.j}$-C.F.	-
G × E	(g-1)(n-1)	$\sum_i\sum_j Y^2_{ij} - Y^2_{i.}/n - Y^2_{.j}/g + CF$	-
E + (G×E)	g(n-1)	$\sum_i\sum_j Y^2_{ij} - \sum_i Y^2_{i.}/r$	-
Environment (Linear)	1	$1/g(\sum_j Y_{.j}I_j)^2/\sum_j I^2_j$	σ^2e
G × E (Linear)	(g-1)	$\sum_i[(\sum_j Y_{ij}I_j)^2/\sum_j I^2_j]$-Env(L) SS	MS_2
Pooled deviation	g(n-2)	$\sum_i\sum_j \delta^2_{ij}$	MS_3
Pooled deviation due to i^{th} genotype	(n-2)	$\sum_j \delta^2_{ij}$	-
Pooled error	n(r-1)(g-1)	Me'	S^2e or MS_4

* C.F. = $\sum_i\sum_j Y^2_{ij}/gn$

where,

r, n and g indicate the number of replications, environments and genotypes, respectively and S^2e is the mean square due to pooled error which were calculated as:

$$S^2e = \sum_j [S^2_j/(r-1)(g-1)n]/r$$

where,

S^2_j = Error sum of squares at the j^{th} location

3.5.7.3 Test of significance

(i) The significance of pooled deviation was tested against the pooled error mean of squares tested as MS_3/MS_4

$$F = \frac{\text{MS due to pooled deviation}}{\text{MS due to pooled error}} = \frac{MS_3}{MS_4}$$

(ii) The significance of the difference among genotypic means was tested using 'F' test:

$H_o: \mu_1 = \mu_2 = \ldots\ldots\ldots\ldots = \mu g$

$$F = \frac{\text{MS due to genotypes}}{\text{MS due to pooled deviation}} = \frac{MS_1}{MS_3}$$

(iii) The significance of genotype x environment interaction was tested as:

$$F = \frac{\text{MS due to G x E interaction}}{\text{MS due to pooled error}}$$

(iv) To test that there are no differences among genotypes for their regression on the environmental index:

$H_o: b_1 = b_2 = \ldots\ldots\ldots\ldots = b_g$

$$F = \frac{\text{MS due to G x E (Linear)}}{\text{MS due to pooled deviation}} = \frac{MS_2}{MS_3}$$

Note: MS_3 was tested against S^2e. In case MS_3 was not significant, S^2e and MS_3 were pooled to test the remaining sources of variation.

(v) To test that any regression (b_i) does not differ from unity, 't' test was used as follows:

$$t = \frac{b_i - 1}{SE(b)}$$, at g (n-2) d.f. at 5% level of significance

where,

$$SE(b_i) = \pm \frac{(\text{MS due to pooled deviations})}{\sum_{j=1}^{n} I_j^2}$$

(vi) The deviation from regression (S^2di) for each genotype was tested using 'F'-test:

$$F = (\sum_j \delta^2_{ij\ ij}/n\text{-}2)/\text{pooled error MS}$$

3.5.7.4 Standard errors and means

(i) Mean of regression coefficient (b) = $\sum_i b_i/g$

(ii) Grand mean ($\bar{X}$) $= \frac{\text{Grand Total}}{\text{Number of observations}}$

(iii) SE (mean) $= \pm \sqrt{\frac{\text{MS due to pooled deviation}}{(n\text{-}1)}}$

(iv) SE (difference) $= \pm \sqrt{\frac{2 \times \text{MS due to pooled deviation}}{(n\text{-}1)}}$

(v) CD (5%) = SE (d) × 't' (5 %) at pooled error df

4. RESULTS AND DISCUSSION

The present investigation entitled “Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)” was undertaken to ascertain the most promising hybrid(s) for marketable fruit yield and other horticultural traits, to work out the nature and magnitude of gene action, and also to identify the potential parents and cross combination for genetic improvement in chilli. Thirty three cross combinations (F_1’s) along with 14 parents (11 lines and 3 testers) and the standard check hybrid ‘CH-1’ were evaluated at two agro-ecological diverse environments, *i.e.*, Palampur and Bajaura for two consecutive years during 2010 and 2011. The observations were recorded on fresh and dry fruit yield along with related traits. A separate experiment was laid out at Palampur in sick plots to record the incidence of bacterial wilt disease during both the years.

The results obtained on the above aspects have been presented and discussed in the light of available literature under the following heads:

4.1 Mean performance

4.2 Combining ability studies

4.3 Gene action

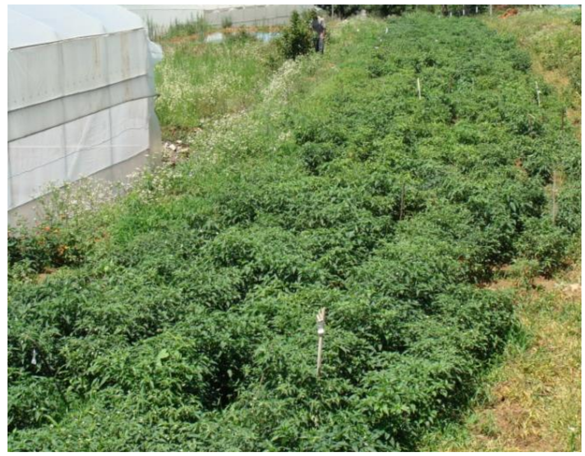
4.4 Heterosis studies

4.5 Stability analysis

4.1 Mean performance

Existence of sufficient genetic variability among treatments was evident from the analysis of variance (Table 4.1, 4.2 and 4.3) for all the characters namely, days to 50% flowering, days to first harvest, primary branches/plant, fruit length, fruit girth, average fruit weight, marketable fruits/plant, marketable fruit yield/plant, plant height, harvest duration, average dry fruit weight, dry fruit

Plate 2: General view of the experiment at Palampur during 2010

Visit of Respected Dr. S. P. Sharma, Director of Research (third from left) and a view of the experiment during 2011 at Palampur

Bajaura

Plate 3: A view of healthy and uniform crop

Table 4.1: Analysis of variance for various traits in chilli at Palampur during 2010 and 2011

Source of variation/Traits	2010			2011		
	Replication	Treatments	Error	Replication	Treatments	Error
df	2	47	94	2	47	94
Days to 50% flowering	1.71	105.13*	0.67	12.77	43.11*	3.44
Days to first harvest	8.77	130.58*	1.51	0.80	120.42*	2.10
Primary branches/plant	1.02	1.62*	0.27	1.08	1.11*	0.15
Fruit length (cm)	0.04	4.14*	0.12	0.21	3.94*	0.06
Fruit girth (cm)	0.008	0.09*	0.001	0.003	0.08*	0.001
Average fruit weight (g)	0.02	4.50*	0.004	0.005	4.15*	0.000
Marketable fruits/ plant	483.58	7132.75*	27.62	99.15	6424.07*	33.44
Marketable fruit yield/plant (g)	4882.00	79490.47*	312.02	1344.50	33529.52*	322.51
Harvest duration (days)	6.21	97.70*	0.61	0.64	99.57*	0.82
Plant height (cm)	66.15	213.96*	9.36	10.32	139.52*	10.97
Average dry fruit weight (g)	0.03	0.54*	0.01	0.006	0.47*	0.009
Dry fruit yield/ plant (g)	18.66	806.49*	8.73	7.10	594.85*	11.45
Ascorbic acid (mg/100g)	23.27	438.30*	2.20	17.96	344.81*	4.28
Capsaicin content (%)	0.000	0.09*	0.000	0.002	0.07*	0.000
Capsanthin (ASTA units)	2.21	509.03*	2.29	8.23	471.38*	3.18
Oleoresin (ASTA units)	25.16	633.66*	1.65	24.61	594.28*	3.55

* Significant at $P \leq 0.05$

Table 4.2: Analysis of variance for various traits in chilli at Bajaura during 2010 and 2011

Source of variation/Traits	2010			2011		
	Replication	Treatments	Error	Replication	Treatments	Error
df	2	47	94	2	47	94
Days to 50% flowering	4.88*	114.45*	1.30	3.23	105.12*	1.16
Days to first harvest	6.36	89.73*	2.13	1.51	119.84*	1.37
Primary branches/plant	0.72*	3.05*	0.12	2.29*	1.54*	0.22
Fruit length (cm)	0.03	6.19*	0.04	0.04	5.11*	0.04
Fruit girth (cm)	0.003	0.09*	0.001	0.002	0.07*	0.001
Average fruit weight (g)	0.004	4.21*	0.002	0.01*	4.16*	0.002
Marketable fruits/ plant	40.56	6755.44*	46.23	12.58	4667.66*	28.43
Marketable fruit yield/plant (g)	469.00	44131.42*	392.27	39.83	30755.65*	303.50
Harvest duration (days)	2.82*	87.46*	0.69	12.27*	100.48*	0.65
Plant height (cm)	1.16	200.82*	12.58	10.99*	269.87*	2.56
Average dry fruit weight (g)	0.04*	0.41*	0.005	0.000	0.35*	0.007
Dry fruit yield/ plant (g)	53.34*	597.56*	3.95	39.81*	378.40*	9.33
Ascorbic acid (mg/100g)	3.23	379.10*	6.03	15.54	345.04*	6.63
Capsaicin content (%)	0.002*	0.08*	0.000	0.000	0.07*	0.000
Capsanthin (ASTA units)	16.13*	434.76*	4.06	54.60*	367.31*	2.62
Oleoresin (ASTA units)	43.30*	537.92*	2.24	41.08*	461.22*	3.64

* Significant at $P \leq 0.05$

Table 4.3: Pooled over environment analysis of variance for various traits in chilli

Source of variation/Traits	Locations	Replications	Treatments	Location × Treatments	Pooled Error
df	3	8	47	141	376
Days to 50% flowering	912.29*	5.65*	302.95*	21.62*	1.64
Days to first harvest	699.50*	4.36*	400.31*	20.09*	1.78
Primary branches/plant	26.87*	1.28*	4.03*	1.10*	0.19
Fruit length (cm)	13.92*	0.08	13.24*	2.05*	0.06
Fruit girth (cm)	0.02*	0.004*	0.27*	0.02*	0.001
Average fruit weight (g)	0.24*	0.009*	16.83*	0.07*	0.002
Marketable fruits/ plant	13639.33*	158.97*	19628.16*	1783.92*	33.93
Marketable fruit yield/plant (g)	191597.30*	1683.83*	146673.90*	13744.32*	332.58
Harvest duration (days)	38.17*	5.49*	377.24*	2.66*	0.69
Plant height (cm)	4386.42*	22.15*	522.42*	100.58*	8.87
Average dry fruit weight (g)	0.04*	0.02*	1.69*	0.03*	0.008
Dry fruit yield/ plant (g)	591.04*	29.73*	2043.58*	111.24*	8.37
Ascorbic acid (mg/100g)	54.17*	15.00*	1381.34*	41.97*	4.79
Capsaicin content (%)	0.02*	0.001	0.31*	0.003*	0.000
Capsanthin (ASTA units)	55.67*	20.42*	1684.98*	32.50*	3.04
Oleoresin (ASTA units)	250.17*	33.54*	2119.98*	35.70*	2.77

* Significant at $P \leq 0.05$

yield/plant, ascorbic acid, capsaicin content, capsanthin and oleoresin in both the environments at Palampur and Bajaura during both the years and pooled over environments. The pooled analysis of variance over the four environments also exhibited significant G × E interaction for all the characters studied indicating that performance of genotypes/crosses was greatly influenced by environments.

A wide variation was observed in the mean performance of 14 parents and their 33 crosses derived from these parents for different traits both at Palampur and Bajaura during 2010 and 2011 and also pooled over environments. High yield is the basic objective of all crop improvement programs. For marketable fruit yield/plant, 16 and 14 cross combinations in the respective years at Palampur, 19 crosses each during both the years at Bajaura and 18 crosses in pooled over environments significantly surpassed the commercial hybrid 'CH-1' (Appendix III, IV, V, VI and VII). Cross 'LCA 436 × Pant C 1' recorded the highest marketable fruit yield (615.23 g) and dry fruit yield (70.59 g) which was 68.37 per cent and 47.27 per cent higher over the standard check 'CH-1', respectively in pooled over environments. This cross also produced maximum fresh and dry yield /plant in the respective environments over the years except at Palampur during 2010 where it secured second position with respect to fresh fruit yield and third position for dry fruit yield. 'Jawahar Mirch 283 × Anugraha' significantly outperformed all the crosses and ranked first during 2010 and second in 2011 at Palampur for marketable fruit yield.

On the other hand, 'Arka Lohit × Surajmukhi' was the top ranking cross combination for dry fruit yield during 2010 and also secured second position in 2011 at Palampur and pooled over environments. In addition to these top performing crosses, 'LCA 436 × Anugraha, 'PAU Selection Long × Surajmukhi', 'Arka Lohit × Surajmukhi' and 'LCA 443 × Surajmukhi' also significantly outyielded 'CH-1' (standard check) with consistency by retaining positions among top ten crosses in both the years at respective locations and also pooled over environments for fresh fruit yield/plant. Moreover, 'Jawahar Mirch 283 × Surajmukhi' and 'Pusa Jwala × Surajmukhi' at Palampur and 'Chilli Sonal × Surajmukhi' at Bajaura during both the years were the other promising crosses with high fresh fruit yield.

For dry fruit yield/plant, ‘PAU Selection Long × Surajmukhi’ and ‘Jawahar Mirch 283 × Anugraha’ were the other promising crosses with consistent performance among top ten over the years and environments which was similar to their performance for fresh fruit yield. Further, cross combinations ‘Arka Lohit × Anugraha’, ‘LCA 443 × Surajmukhi’ and ‘Kashmir Long × Surajmukhi’ at Palampur and ‘Chilli Sonal × Surajmukhi’, ‘Selection 352 × Surajmukhi’ and ‘Jawahar Mirch 283 × Pant C 1’ at Bajaura also outperformed the standard check ‘CH-1’ during both the years by securing position among top ten crosses for dry fruit yield/plant.

The superior performance of all these crosses for both fresh and dry fruit yield /plant was mainly attributed to fruit length, marketable fruits/plant, harvest duration and plant height which was evident from the significant better performance for these traits compared to check ‘CH-1’. However, at Palampur, the performance of ‘Arka Lohit × Surajmukhi’ during 2010 and ‘PAU Selection Long × Surajmukhi’, ‘Arka Lohit × Surajmukhi’, ‘Kashmir Long × Surajmukhi’ and ‘LCA 443 × Surajmukhi’ during 2011 for plant height and ‘Arka Lohit × Anugraha’ for marketable fruits/plant during 2010 was at par with ‘CH-1’. Similarly, ‘Selection 352 × Surajmukhi’ for fruit length during both the years and ‘Jawahar Mirch 283 × Pant C 1’ for plant height during 2010 at Bajaura and ‘Jawahar Mirch 283 × Anugraha’ for harvest duration over the years and environments performed at par with ‘CH-1’.

For quality traits, among these promising crosses, ‘PAU Selection Long × Surajmukhi’ for ascorbic acid, ‘LCA 436 × Pant C 1’, ‘LCA 436 × Anugraha’ and ‘LCA 443 × Surajmukhi’ for capsanthin also outperformed significantly the standard check ‘CH-1’ , while the performance of ‘Arka Lohit × Surajmukhi’ for capsaicin was similar to ‘CH-1’ on the basis of pooled over environments.

4.1.2 Analysis of variance for line × tester design

In the present study, analysis of variance for parents and hybrids for line × tester design at Palampur and Bajaura for 2010 and 2011, respectively, and pooled over environments (Table 4.4, 4.5 and 4.6) revealed significant

Table 4.4: Analysis of variance for line × tester design in chilli at Palampur during 2010 and 2011

Source of variation	Replication		Treatment		Parents		Lines		Tester		Lines × Tester		Parents vs Crosses		Crosses		Error	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Traits df	2		46		13		10		2		1		1		32		92	
Days to 50% flowering	1.47	13.04*	107.40*	43.94*	155.95*	64.10*	117.69*	60.27*	221.77*	57.69*	406.92*	115.15*	1390.98*	454.38*	47.57*	22.92*	0.66	3.51
Days to first harvest	9.24*	1.04	132.97*	122.27*	174.61*	139.41*	157.80*	134.01*	189.77*	201.44*	312.38*	69.34*	242.67*	524.28*	112.62*	102.75*	1.50	2.12
Primary branches/plant	1.08*	1.10*	1.55*	0.98*	2.06*	1.19*	0.69*	0.83*	6.77*	2.46*	6.32*	2.29*	1.99*	0.18	1.34*	0.91*	0.28	0.15
Fruit length (cm)	0.06	0.20*	4.13*	3.96*	7.32*	8.08*	6.44*	7.05*	7.97*	7.13*	14.77*	20.33*	4.20*	0.13	2.84*	2.41*	0.12	0.06
Fruit girth (cm)	0.01	0.003	0.08*	0.08*	0.16*	0.16*	0.19*	0.17*	0.02	0.09*	0.14*	0.26*	0.30*	0.31*	0.04*	0.04*	0.01	0.001
Average fruit weight (g)	0.02*	0.005	4.45*	4.13*	6.42*	5.47*	6.46*	5.52*	5.82*	5.03*	7.12*	5.78*	2.00*	1.10*	3.73*	3.67*	0.005	0.000
Marketable fruits/ plant	498.04*	100.68	7231.22*	6487.10*	1354.33*	2597.49*	1309.36*	2640.52*	663.70*	3207.91*	3185.24*	946.30*	104248.69*	55626.49*	6586.91*	6531.64*	27.71	34.08
Marketable fruit yield/ plant (g)	5018.87*	1378.66*	81056.42*	34253.52*	13782.84*	3209.45*	14233.00*	3557.55*	18383.09*	743.08	80.87	4661.25*	1107775.66*	554560.49*	76301.33*	30605.58*	311.09	327.43
Harvest duration (days)	5.62*	0.77	99.51*	101.59*	135.41*	117.74*	84.75*	63.36*	1.44	0.78	909.90*	895.38*	11.43*	1.69	87.69*	98.15*	0.61	0.83
Plant height (cm)	67.88*	10.10	212.36*	140.15*	192.07*	126.75*	196.82*	137.68*	257.65*	112.03*	13.30	46.88*	100.54*	228.57*	224.10*	142.83*	9.44	10.98
Average dry fruit weight (g)	0.03	0.005	0.52*	0.46*	1.13*	0.99*	1.29*	1.15*	0.02	0.01	1.74*	1.34*	0.01	0.01	0.29*	0.26*	0.01	0.01
Dry fruit yield/ plant (g)	19.96	6.01	820.37*	604.35*	94.72*	107.12*	106.39*	132.21*	82.58*	31.71	2.32	7.10	15780.58*	11985.36*	647.65*	450.69*	8.81	11.52
Ascorbic acid (mg/100g)	21.66*	19.26*	447.22*	352.84*	396.25*	293.82*	245.97*	172.91*	850.53*	327.03*	990.53*	1436.45*	225.60*	659.40*	474.86*	366.15*	2.23	4.33
Capsaicin content (%)	0.000	0.002	0.09*	0.07*	0.12*	0.09*	0.12*	0.09*	0.16*	0.11*	0.13*	0.13*	0.06	0.06*	0.07*	0.06*	0.03	0.000
Capsanthin (ASTA units)	2.17	7.28	520.07*	480.86*	328.67*	206.61*	288.63*	177.23*	419.30*	280.78*	547.86*	352.02*	3293.70*	4704.44*	511.15*	460.29*	2.18	3.20
Oleoresin (ASTA units)	24.91*	23.98*	611.61*	585.65*	574.93*	456.90*	717.61*	556.54*	21.58*	20.25*	254.83*	333.72*	1138.93*	816.29*	610.03*	630.75*	1.66	3.60

* Significant at P ≤ 0.05

Table 4.5: Analysis of variance for line × tester design in chilli at Bajaura during 2010 and 2011

Source of variation	Replication		Treatment		Parents		Lines		Tester		Lines × Tester		Parents vs Crosses		Crosses		Error	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Traits df	2		46		13		10		2		1		1		32		92	
Days to 50% flowering	5.13	2.97	116.72	107.17*	175.24	105.31*	186.82	76.68*	95.44	257.53*	219.05	87.13*	1621.33*	2196.76*	1469.66*	42.63*	119.06	1.17
Days to first harvest	5.79	1.04	91.49*	120.59*	155.99*	125.05*	163.08*	119.12*	114.33*	179.11*	168.32*	76.21*	703.38*	1646.04*	46.17*	71.11*	2.16	1.36
Primary branches/plant	0.75*	2.15*	3.11*	1.57*	4.33*	1.81*	2.88*	1.57*	2.17*	1.08*	23.22*	5.66*	18.95*	1.71*	2.11*	1.47*	0.13	0.22
Fruit length (cm)	0.03	0.03	6.23*	5.18*	5.39*	4.99*	5.10*	4.95*	7.76*	6.71*	3.55*	1.98*	4.81*	3.43*	6.62*	5.31*	0.04	0.05
Fruit girth (cm)	0.002	0.002	0.09*	0.07*	0.15*	0.10*	0.15*	0.10*	0.09*	0.09*	0.25*	0.13*	0.02*	0.02*	0.07*	0.06*	0.001	0.001
Average fruit weight (g)	0.003	0.01	4.16*	4.14*	5.94*	5.95*	5.90*	6.14*	6.22*	5.77*	5.72*	4.37*	1.98*	0.82*	3.50*	3.51*	0.002	0.003
Marketable fruits/ plant	39.19	14.16	6797.65*	4701.80*	1695.54*	1603.77*	1834.89*	1389.82*	1028.83*	1910.33*	1635.43*	3130.12*	98577.10*	64855.33*	6002.28*	4080.58*	47.22	28.93
Marketable fruit yield/plant (g)	427.60	60.99	45086.09*	31423.79*	14233.59*	3570.93*	12613.78*	3378.99*	29420.64*	4647.00*	57.62	3338.24*	888000.34*	730917.41*	31278.84*	20879.84*	400.26	307.37
Harvest duration (days)	2.75*	12.96*	89.16*	102.17*	111.99*	115.87*	62.76*	59.09*	8.78*	6.78*	810.68*	901.82*	0.05	0.55	82.68*	99.78*	0.69	0.65
Plant height (cm)	1.97	9.28*	200.31*	271.71*	128.84*	159.52*	138.71*	109.54*	91.90*	84.42*	104.02*	809.61*	2291.02*	2780.34*	164.01*	238.89*	12.46	2.57
Average dry fruit weight (g)	0.03*	0.000	0.40*	0.33*	0.75*	0.67*	0.83*	0.75*	0.02*	0.02	1.37*	1.25*	0.30*	0.19*	0.26*	0.19*	0.005	0.01
Dry fruit yield/ plant (g)	49.40*	36.02*	609.65*	386.47*	33.92*	70.93*	28.14*	74.60*	58.11*	51.44*	43.31*	73.19*	16874.53*	8084.11*	335.27*	274.11*	3.98	9.47
Ascorbic acid (mg/100g)	2.57	12.43	385.39*	351.89*	293.89*	216.32*	153.08*	145.47*	771.36*	462.58*	746.97*	432.23*	776.36*	1185.28*	410.34*	380.93*	6.08	6.58
Capsaicin content (%)	0.002	0.000	0.08*	0.07*	0.12*	0.09*	0.10*	0.08*	0.14*	0.10*	0.22*	0.12*	0.13*	0.15*	0.07*	0.06*	0.000	0.000
Capsanthin (ASTA units)	15.14*	52.99*	442.60*	375.12*	367.10*	220.51*	210.94*	90.95*	492.44*	504.36*	1677.94*	948.39*	3115.13*	3200.24*	389.77*	349.65*	4.14	2.67
Oleoresin (ASTA units)	42.05*	37.32*	520.12*	449.20*	536.05*	423.60*	646.29*	533.87*	103.39*	45.08*	298.95*	77.86*	1420.33*	1317.03*	485.52*	432.47*	2.28	3.56

* Significant at P ≤ 0.05

Table 4.6: Pooled over environments analysis of variance for line × tester design in chilli

Source of variation	Locations	Replications	Parents	Lines	Testers	Lines vs Testers	Crosses	Parents vs Crosses	Parent × Location	Line × Location	Tester × Location	(L vs T) × Location	Crosses × Location	(Par vs Crosses) × Location	Error
Traits df	3	8	13	10	2	1	32	1	39	30	6	3	96	3	368
Days to 50% flowering	881.67*	5.65*	405.98*	369.01*	415.19*	757.28*	113.97*	5310.53*	31.54*	24.15*	72.42*	23.68*	15.03*	117.65*	1.66
Days to first harvest	671.63*	4.26*	554.66*	529.30*	674.33*	568.88*	271.55*	2786.25*	13.47*	14.91*	3.44	19.12*	20.37*	110.04*	1.79
Primary branches/plant	26.16*	1.27*	5.31*	1.60*	10.80*	31.50*	3.07*	14.07*	1.36*	1.45*	0.56*	0.20	0.92*	2.92*	0.19
Fruit length (cm)	13.79*	0.08	19.36*	16.38*	26.98*	33.89*	10.83*	10.44*	2.14*	2.39*	0.87*	2.25*	2.12*	0.71*	0.07
Fruit girth (cm)	0.02*	0.004	0.51*	0.53*	0.27*	0.76*	0.16*	0.50*	0.02*	0.03*	0.01*	0.01*	0.02*	0.05*	0.001
Average fruit weight (g)	0.28*	0.01*	23.56*	23.80*	22.72*	22.82*	14.22*	5.70*	0.07*	0.08*	0.04*	0.06*	0.07*	0.07*	0.003
Marketable fruits/ plant	13297.80*	163.40*	6075.79*	5974.23*	5408.36*	8426.20*	15998.19*	317738.60*	391.78*	400.12*	467.47*	156.92*	2401.06*	1857.35*	34.47
Marketable fruit yield/plant (g)	182722.00*	1721.87*	16997.33*	15904.98*	30940.35*	35.13	107529.50*	3230050.00*	5933.12*	5959.38*	7417.82*	2701.13*	17178.67*	17069.29*	335.90
Harvest duration (days)	38.10*	5.52*	469.40*	257.86*	3.86*	3515.91*	361.54*	7.94*	3.87*	4.04*	4.64*	0.63	2.25*	1.92*	0.69
Plant height (cm)	4312.57*	22.59*	404.36*	401.89*	316.94*	603.78*	454.90*	3952.63*	67.61*	60.29*	76.36*	123.33*	104.98*	482.80*	8.87
Average dry fruit weight (g)	0.03*	0.02*	3.46*	3.92*	0.06*	5.68*	0.91*	0.35*	0.03*	0.03*	0.001	0.01	0.03*	0.05*	0.01
Dry fruit yield/ plant (g)	535.29*	27.84*	166.10*	189.72*	84.36*	93.36*	1310.56*	51736.34*	46.87*	50.54*	46.50*	10.85	132.39*	329.47*	8.45
Ascorbic acid (mg/100g)	67.09*	14.04*	1008.45*	530.35*	2177.53*	3451.31*	1535.94*	2652.00*	63.93*	62.36*	77.98*	51.59*	32.08*	64.74*	4.78
Capsaicin content (%)	0.02*	0.001	0.41*	0.38*	0.50*	0.58*	0.26*	0.38*	0.004	0.004	0.002	0.003	0.01*	0.006	0.000
Capsanthin (ASTA units)	60.60*	19.37*	1026.05*	683.03*	1631.63*	3245.00*	1614.12*	14204.00*	32.28*	28.24*	21.75*	93.69*	32.23*	36.40*	3.05
Oleoresin (ASTA units)	259.43*	32.06*	1849.04*	2298.20*	72.53*	910.38*	2062.61*	4644.19*	47.48*	52.04*	39.26*	18.33*	32.04*	16.10*	2.79

* Significant at P ≤ 0.05

differences among the parents for majority of the traits except days to 50% flowering for parents at Bajaura during 2010, thereby indicating that the parents used in the study were highly divergent. Among the parents, differences within lines and testers were also found to be significant for all the traits at both the locations during both the years and pooled over environments with few exceptions, *viz*., harvest duration and average dry fruit weight during both the years and dry fruit yield/plant during 2011 at Palampur in case of testers and days to 50% flowering for both the lines and testers during 2010 and average dry fruit weight for testers in 2011 at Bajaura. Mean squares due to line × tester interactions were also significant for most of the characters except marketable fruit yield/plant at both the locations during 2010 and also in pooled environments, plant height during 2010 and dry fruit yield during both the years at Palampur and days to 50% flowering at Bajaura during 2010. Significant differences among hybrids have also been observed for all the traits in the respective locations in the respective years and pooled over environments, thereby indicating varying performance of different cross combinations.

Similarly, mean squares for parent × location, line × location, tester × location, (line vs tester) × location, crosses × location, (parents vs crosses) × location were significant for all the traits except for capsaicin content with respect to parent × location, line × location, tester × location, (line vs tester) × location and (parents vs crosses) × location, days to first harvest and average dry fruit weight for tester × location and primary branches/plant, harvest duration, average dry fruit weight and dry fruit yield/plant with respect to (line vs tester) × location revealing thereby that the performance is influenced by environments (Table 4.6).

4.2 Combining ability studies

The success of a breeding programme depends upon the choice of suitable parents and their utilization by adopting an appropriate breeding method. The combining ability analysis has been extensively used to identify potential parents either to be used in the development of hybrids or recombinant breeding

Jawahar Mirch 283 | Chilli Sonal | PAU Sel Long | Arka Lohit | LCA 436 | Pusa Jwala | Pusa Sadabahar | Kashmir Long | Selection 352 | LCA 443 | LCA 206

Pant C1

Anugraha

Surajmukhi

Top row and extreme left column depicts lines and testers, respectively ; extreme left 'CH-1' (top); below each line and parallel to each tester is their resultant F_1

Plate 4: Fruit shape and size of 33 cross combinations in comparison to their parents and standard check (CH-1)

for getting elite purelines. This analysis facilitates the partitioning of genotypic variation of crosses into variation due to general combining ability (GCA) and specific combining ability (SCA). GCA effects are the measure of additive gene action which represent the fixable components of genetic variance and are used to classify the parents for the breeding behavior in hybrid combinations. On the other hand, SCA effects are the measure of non-additive gene action which is related to non-fixable component of genetic variance (Sprague 1966).

The common approach of choosing the parents on the basis of performance, adaptation and genetic variability does not necessarily lead to useful results because of the differential ability of the parents. This ability of the parents depends upon the complex interaction among the genes and hence cannot be judged by *per se* performance alone (Allard 1960). Therefore, it is important to assess the general and specific combining ability effects in the selection of the parents and the formulation of an appropriate crossing plan. Among the various breeding methods, line × tester method (Kempthorne 1957) which has been used in the present study is very useful in isolating the parental lines by attempting lesser number of crosses.

4.2.1 Analysis of variance for combining ability

The analysis of variance for combining ability in 2010, 2011 and pooled over environments revealed that there were significant differences among crosses for all the traits during 2010 and 2011 both at Palampur and Bajaura locations (Table 4.7 and 4.8 and 4.9). Mean squares due to crosses were further partitioned into lines (L), testers (T), line × tester (L × T) interactions in the individual years and lines (L), testers (T), line × testers (L × T), Line × environment (L × E), tester × environment (T × E) and line × tester × environment (L × T × E) interaction in the pooled environment.

Mean squares due to lines, testers and line × tester were observed to be significant for majority of the traits in both the locations in the respective years and pooled over environments when tested against mean squares due to error

Table 4.7: Analysis of variance for combining ability in chilli at Palampur during 2010 and 2011

Source of variation/ Traits	Replication		Crosses		Lines		Testers		Lines vs Testers		Error	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
df	2		32		10		2		20		64	
Days to 50% flowering	1.85	16.57*	47.57*	22.92*	103.27*	48.92*	16.03*	3.76	22.87*	11.84*	0.78	2.91
Days to first harvest	5.95*	0.39	112.62*	102.75*	266.93*	224.81*	6.68*	13.21*	46.07*	50.67*	1.50	1.94
Primary branches / plant	1.31*	0.47	1.34*	0.91*	2.32*	0.77*	2.54*	2.72*	0.73*	0.80*	0.28	0.16
Fruit length (cm)	0.03	0.35*	2.84*	2.41*	6.05*	3.31*	5.29*	7.36*	0.98*	1.46*	0.10	0.05
Fruit girth (cm)	0.01*	0.002	0.05*	0.04*	0.11*	0.10*	0.05*	0.05*	0.01*	0.02*	0.001	0.001
Average fruit weight (g)	0.01*	0.01*	3.73*	3.67*	8.67*	8.31*	0.51*	0.39*	1.59*	1.69*	0.003	0.000
Marketable fruits/ plant	349.61*	73.96	6586.91*	6531.64*	9860.23*	8664.40*	15754.58*	4653.47*	4033.48*	5653.08*	34.50	39.26
Marketable fruit yield/plant (g)	3458.78*	1467.52*	76301.33*	30605.58*	164946.42*	39753.48*	191529.29*	44695.59*	20455.99*	24622.63*	349.17	380.31
Harvest duration (days)	5.16*	0.28	87.69*	98.15*	168.71*	199.09*	177.62*	213.65*	38.18*	36.12*	0.46	0.81
Plant height (cm)	48.30*	13.36	224.10*	142.83*	359.79*	203.05*	714.06*	53.89*	107.26*	121.62*	8.94	12.70
Average dry fruit weight (g)	0.02	0.00	0.29*	0.26*	0.51*	0.27*	0.19*	0.50*	0.20*	0.22*	0.01	0.01
Dry fruit yield/ plant(g)	22.31	5.21	647.65*	450.69*	1291.42*	771.04*	1528.69*	1163.76*	237.66*	219.22*	9.34	12.63
Ascorbic acid (mg/100g)	13.41*	5.28	474.86*	366.15*	820.45*	538.57*	141.85*	117.90*	335.36*	304.77*	2.09	4.99
Capsaicin content (%)	0.000	0.001	0.07*	0.06*	0.19*	0.16*	0.03*	0.04*	0.02*	0.01*	0.000	0.000
Capsanthin (ASTA units)	3.35	6.96	511.15*	460.29*	910.86*	874.06*	746.57*	694.23*	287.76*	230.02*	2.00	3.54
Oleoresin (ASTA units)	14.34*	11.66	610.03*	630.75*	1629.04*	1587.41*	386.88*	578.33*	122.84*	157.66*	1.72	4.03

* Significant at $P \leq 0.05$

Table 4.8: Analysis of variance for combining ability in chilli at Bajaura during 2010 and 2011

Source of variation/	Replication		Crosses		Lines		Testers		Lines vs Testers		Error	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Traits df	2		32		10		2		20		64	
Days to 50% flowering	1.83	1.09	45.93*	42.63*	105.32*	63.09*	29.10*	0.94	17.91*	36.56*	1.40	1.15
Days to first harvest	3.07	1.04	46.17*	71.11*	89.47*	119.76*	22.19*	23.40*	26.91*	51.55*	2.31	1.44
Primary branches/plant	1.13*	1.52*	2.11*	1.47*	3.27*	1.62*	0.83*	0.85*	1.66*	1.46*	0.12	0.24
Fruit length (cm)	0.03	0.08	6.61*	5.31*	10.24*	8.24*	7.69*	8.51*	4.70*	3.53*	0.05	0.05
Fruit girth (cm)	0.003	0.002	0.07*	0.06*	0.14*	0.13*	0.04*	0.02*	0.05*	0.03*	0.001	0.001
Average fruit weight (g)	0.003	0.01*	3.50*	3.51*	7.97*	7.80*	0.54*	0.65*	1.56*	1.66*	0.002	0.003
Marketable fruits/ plant	40.35	13.26	6002.28*	4080.58*	5859.12*	5052.97*	9917.14*	4783.01*	5682.37*	3524.14*	54.17	33.98
Marketable fruit yield/ plant (g)	410.47	7.85	31278.84*	20879.84*	39037.44*	34309.56*	72686.92*	22924.58*	23258.74*	13960.51*	469.72	363.75
Harvest duration (days)	4.74*	11.10*	82.68*	99.78*	166.70*	208.52*	188.40*	190.19*	30.09*	36.37*	0.57	0.64
Plant height (cm)	1.20	1.21	164.01*	238.89*	206.91*	326.82*	635.97*	1082.83*	95.37*	110.53*	14.24	2.52
Average dry fruit weight (g)	0.04*	0.007	0.26*	0.19*	0.50*	0.32*	0.09*	0.07*	0.16*	0.14*	0.01	0.01
Dry fruit yield/ plant (g)	40.27*	33.59	335.27*	274.11*	501.14*	547.18*	785.35*	179.45*	207.33*	147.04*	4.16	11.44
Ascorbic acid (mg/100g)	2.83	10.73	410.34*	380.93*	606.44*	633.42*	186.51*	153.10*	334.68*	277.47*	6.19	7.42
Capsaicin content (%)	0.002	0.000	0.07*	0.06*	0.18*	0.17*	0.04*	0.05*	0.02*	0.02*	0.000	0.000
Capsanthin (ASTA units)	16.20*	41.65*	389.77*	349.65*	703.36*	681.69*	548.97*	292.73*	217.04*	189.32*	3.66	2.70
Oleoresin (ASTA units)	32.39*	26.61*	485.52*	432.47*	1281.01*	1071.77*	334.14*	101.69*	102.91*	145.90*	2.81	3.51

* Significant at P ≤ 0.05

Table 4.9: Pooled over environments analysis of variance for combining ability in chilli

Source of variation / Traits	Locations	Replica-tions	Lines	Testers	Line vs Testers	Line × Location	Tester × Location	Line vs Tester × Location	Error
df	3	8	10	2	20	30	6	60	256
Days to 50% flowering	827.22*	5.33*	246.63*	247.13*	565.59*	246.59*	8.37*	10.88*	1.56
Days to first harvest	584.11*	2.59	586.50*	48.87*	136.35*	38.16*	5.52*	12.95*	1.80
Primary branches/plant	26.50*	1.11*	5.46*	5.40*	1.64*	0.84*	0.52*	1.00*	0.20
Fruit length (cm)	8.37*	0.12*	17.11*	26.34*	6.13*	3.58*	0.84*	1.51*	0.06
Fruit girth (cm)	0.003	0.004	0.36*	0.12*	0.06*	0.03*	0.01*	0.01*	0.001
Average fruit weight (g)	0.30*	0.01*	32.56*	1.68*	6.30*	0.06*	0.13*	0.07*	0.002
Marketable fruits/ plant	13389.12*	119.49*	18700.33*	23633.67*	13883.57*	3578.81*	3825.03*	1669.82*	40.47
Marketable fruit yield/plant (g)	176222.10*	1335.92*	194953.70*	253479.00*	49222.50*	27698.09*	26119.26*	11024.73*	390.36
Harvest duration (days)	33.14*	5.32*	731.81*	768.92*	135.67*	3.74*	0.30	1.70*	0.62
Plant height (cm)	4394.75*	16.00	67.13*	1993.10*	192.88*	141.75*	164.50*	80.64*	9.60
Average dry fruit weight (g)	0.003	0.01	1.50*	0.71*	0.63*	0.03*	0.05*	0.03*	0.01
Dry fruit yield/ plant (g)	838.41*	25.33*	2553.61*	3026.17*	517.49*	185.72*	210.36*	97.92*	9.39
Ascorbic acid (mg/100g)	12.53	8.08	2451.93*	580.09*	1173.56*	48.98*	6.42	26.19*	5.17
Capsaicin content (%)	0.02	0.000	0.69*	0.14*	0.06*	0.002	0.002	0.002	0.000
Capsanthin (ASTA units)	65.69*	17.01*	3051.07*	2179.67*	839.10*	39.62*	34.27*	28.34*	2.98
Oleoresin (ASTA units)	208.02*	21.25*	5440.20*	1197.81*	460.31*	42.99*	67.75*	22.99*	3.02

* Significant at P ≤ 0.05

except days to 50% flowering with respect to testers at Palampur and Bajaura during 2011 which showed considerable diversity among the parents (lines and testers) and manifestation of this diversity in the crosses. Pandey *et al*. (1981 Lohithaswa *et al*. (2001), Singh and Hundal (2001), Patel *et al.* (2004), Prasath and Ponnuswami (2008) and Reddy *et al*. (2008) also observed diversity in their respective parental material and their manifestation in the crosses/hybrids.

The mean sum of squares due to interaction effects of lines × location, tester × location and line × tester × location were found significant for most of the traits with few exceptions, *viz*., capsaicin content with respect to all these interactions while harvest duration and ascorbic acid for tester × location interaction only. The significance of these interaction effects suggested that lines, testers and their interactions were influenced by the environment.

4.2.2 Estimation of general combining ability (GCA) effects of lines

Days to 50% flowering

Lines ‘Kashmir Long’, ‘Chilli Sonal’, ‘LCA 436’, ‘Pusa Jwala’ and ‘LCA 443’ were found to be good general combiners for earliness on the basis of significant negative GCA effects during both the years and pooled over years along with ‘Jawahar Mirch 283’ and ‘PAU Selection Long’ during 2010 and 2011, respectively at Palampur. At Bajaura, ‘Kashmir Long’, ‘Jawahar Mirch 283’, ‘Chilli Sonal’, ‘Pusa Jwala’ and ‘LCA 436’ exhibited similar trends during both the years and pooled over years except ‘Pusa Jwala’ and ‘LCA 436’ during 2010 and 2011, respectively while ‘Arka Lohit’ also had significant negative GCA effects during 2011. Pooled data over the years and environments indicated significant negative GCA effects for lines ‘Kashmir Long’, ‘Chilli Sonal’, ‘Jawahar Mirch 283’, ‘LCA 436’ and ‘Pusa Jwala’ (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Pandey *et al*. (1981), Bhagyalakshmi *et al*. (1991), Pandian and Shanmugavelu (1992), Gandhi *et al*. (2000) and Reddy *et al*. (2008) also found good general combiners for days to flowering in their respective lines.

Table 4.10: Estimates of general combining ability (GCA) effects of lines for yield and related traits in chilli at Palampur during 2010

Traits/Lines	Jawahar Mirch 283	Chilli Sonal	PAU Sel Long	Arka Lohit	LCA 436	Pusa Jwala	Pusa Sadabahar	Kashmir Long	Sel 352	LCA 443	LCA 206	SE (gi)±	SE (gi-gj)±	CD 5 %
Days to 50% flowering	-1.17*	-4.73*	2.38*	2.16*	-1.17*	-1.06*	3.83*	-5.39*	1.27*	-1.62*	5.50*	0.27	0.38	0.54
Days to first harvest	0.87*	-2.69*	5.20*	1.20*	-3.02*	-6.58*	8.98*	-9.80*	-1.69*	3.87*	3.65*	0.41	0.58	0.82
Primary branches/ plant	0.13	0.06	0.11	0.55*	-0.16	0.08	0.97*	-0.98*	-0.52*	-0.07	-0.16	0.18	0.25	0.35
Fruit length (cm)	0.12	-0.61*	0.04	0.02	1.55*	1.00*	-1.18*	0.22*	-1.17*	-0.27*	0.27*	0.11	0.16	0.22
Fruit girth (cm)	0.01	-0.02	-0.05*	-0.03*	0.12*	-0.13*	-0.13*	0.03*	0.08*	0.23*	-0.10*	0.01	0.02	0.02
Average fruit weight (g)	-0.28*	-0.84*	-0.75*	1.71*	0.56*	-0.56*	-0.96*	0.36*	0.71*	1.28*	-1.24*	0.02	0.03	0.05
Marketable fruits/ plant	57.48*	-26.40*	53.72*	-18.73*	22.91*	17.81*	-1.04	-21.77*	-22.15*	-30.39*	-31.42*	1.75	2.48	3.51
Marketable fruit yield/plant (g)	147.44*	-173.63*	61.66*	127.10	176.66*	-8.23*	-139.56*	-16.79*	14.21*	51.10*	-239.96*	5.88	8.31	11.75
Harvest duration (days)	-2.47*	-4.13*	4.65*	3.54*	5.65*	-2.24*	6.76*	-5.35*	-2.47*	-3.58*	-0.35	0.26	0.37	0.52
Plant height (cm)	8.50*	0.55	5.63*	-7.55*	2.17*	-9.55*	-6.37*	-4.75*	-0.81	7.65*	4.52*	1.02	1.45	2.05
Average dry fruit weight (g)	-0.24*	-0.10*	0.01	0.25*	0.48*	-0.09*	-0.27*	-0.22*	0.10*	0.22*	-0.13*	0.03	0.05	0.07
Dry fruit yield/ plant (g)	13.13*	-13.95*	8.06*	13.23*	14.87*	-1.15*	-16.43*	-0.68	0.90	0.31	-18.28*	0.99	1.40	1.98
Ascorbic acid (mg/100g)	-4.41*	-2.08*	8.31*	0.06	-5.97*	-10.30*	13.09*	17.14*	-14.47*	-1.58*	0.20	0.50	0.70	0.99
Capsaicin content (%)	-0.15*	-0.27*	-0.06*	0.12*	-0.16*	0.22*	0.11*	0.03*	0.09*	0.02*	0.05*	0.01	0.01	0.01
Capsanthin (ASTA units)	16.07*	-8.40*	5.58*	0.68	15.40*	-5.65*	-13.46*	-1.10*	2.00*	2.63*	-13.75*	0.49	0.70	0.98
Oleoresin (ASTA units)	-16.55*	-22.44*	0.00	11.61*	-16.94*	19.34*	13.69*	0.40	5.72*	1.39*	3.78*	0.43	0.61	0.86

* Significant at $P \leq 0.05$

Table 4.11: Estimates of general combining ability (GCA) effects of lines for yield and related traits in chilli at Palampur during 2011

Traits/Lines	Jawahar Mirch 283	Chilli Sonal	PAU Sel Long	Arka Lohit	LCA 436	Pusa Jwala	Pusa Sadabahar	Kashmir Long	Sel 352	LCA 443	LCA 206	SE (gi)±	SE (gi-gj)±	CD 5 %
Days to 50% flowering	1.93*	-1.52*	-0.85	0.60	-2.63*	-1.40*	4.37*	-3.40*	0.82	-0.52	2.60*	0.62	0.88	1.25
Days to first harvest	-0.32	0.46	5.34*	1.46*	-0.10	-6.77*	8.23*	-10.10*	0.01	1.79*	0.01	0.48	0.69	0.97
Primary branches/plant	0.32*	-0.26*	-0.21*	-0.03*	0.12	0.26	0.43*	-0.46*	-0.32*	0.23	-0.10	0.13	0.18	0.26
Fruit length (cm)	0.03	-0.50*	-0.05	0.18*	0.65*	1.06*	-0.93*	0.00	-0.75*	-0.29*	0.59*	0.08	0.11	0.16
Fruit girth (cm)	0.02	-0.04*	-0.06*	-0.03*	0.12*	-0.09*	-0.013*	0.07*	0.09*	0.19*	-0.13*	0.01	0.02	0.02
Average fruit weight (g)	-0.36*	-0.82*	-0.79*	1.67*	0.48*	-0.53*	-0.87*	0.43*	0.73*	1.26*	-1.20*	0.01	0.01	0.02
Marketable fruits/ plant	33.69*	21.31*	21.20*	-40.69*	3.73	27.78*	-21.21*	-13.27*	-40.66*	-33.59*	41.71*	1.95	2.75	3.89
Marketable fruit yield/plant (g)	83.69*	-13.14*	-1.94*	-23.36*	98.11*	42.36*	-127.44*	31.67*	-55.89*	28.11*	-62.17*	6.03	8.53	12.05
Harvest duration (days)	-2.25*	-4.70*	2.97*	3.86*	6.08*	-2.70*	8.30*	-5.59*	-2.81*	-4.14*	0.97*	0.30	0.43	0.61
Plant height (cm)	4.12*	1.93	-3.50*	0.37	1.23	-8.56*	7.98*	-2.85*	-0.52	-4.87*	4.68*	1.10	1.56	2.21
Average dry fruit weight (g)	-0.21*	-0.01	-0.05	0.12*	0.30*	-0.09*	-0.16*	-0.19*	0.09*	0.26*	-0.06	0.03	0.05	0.07
Dry fruit yield/ plant (g)	7.79*	-12.28*	-0.93	10.41*	6.24*	2.99*	-15.67*	2.58*	6.94*	4.77*	-12.84*	1.13	1.60	2.26
Ascorbic acid (mg/100g)	-4.42*	-1.86*	4.53*	3.86*	-3.98*	-7.20*	12.03*	13.25*	-11.98*	-2.03*	-2.20*	0.69	0.98	1.39
Capsaicin content (%)	-0.15*	-0.24*	-0.04*	0.08*	-0.14*	0.23*	0.08*	0.04*	0.08*	0.04*	0.03*	0.01	0.01	0.01
Capsanthin (ASTA units)	16.36*	-6.98*	7.80*	3.91*	9.30*	-3.48*	-15.40*	-2.09*	3.47*	2.01*	-14.92*	0.60	0.84	1.19
Oleoresin (ASTA units)	-18.86*	-23.36*	-0.48	10.69*	-15.31*	15.08*	12.08*	3.19*	10.08*	4.91*	1.97*	0.63	0.89	1.26

* Significant at $P \leq 0.05$

Table 4.12: Estimates of general combining ability (GCA) effects of lines for yield and related traits in chilli at Bajaura during 2010

Traits/Lines	Jawahar Mirch 283	Chilli Sonal	PAU Sel Long	Arka Lohit	LCA 436	Pusa Jwala	Pusa Sadabahar	Kashmir Long	Sel 352	LCA 443	LCA 206	SE (gi)±	SE (gi-gj)±	CD 5 %
Days to 50% flowering	-1.10*	-3.66*	1.68*	1.12*	-1.66*	-0.32	1.23*	-5.43*	0.45	-0.32	8.01*	0.38	0.54	0.76
Days to first harvest	4.27*	-1.95*	3.83*	1.83*	-2.17*	-3.84*	2.27*	-4.73*	-2.62*	0.94	2.16*	0.49	0.69	0.98
Primary branches/plant	0.20	0.69*	0.02	-0.16	0.07	0.64*	0.31	-1.60*	0.000	-0.04	-0.13	0.12	0.17	0.24
Fruit length (cm)	0.75*	-1.23*	0.48*	-0.95*	0.07	-0.91*	-0.31*	2.02*	-1.36*	0.33*	1.11*	0.07	0.10	0.14
Fruit girth (cm)	0.19*	-0.05*	-0.17*	0.04*	0.06*	-0.13*	0.10*	-0.09*	0.04*	0.15*	-0.14*	0.01	0.02	0.02
Average fruit weight (g)	-0.09*	-0.85*	-0.67*	1.68*	0.63*	-0.56*	-1.05*	0.17*	0.69*	1.15*	-1.11*	0.01	0.02	0.03
Marketable fruits/ plant	14.65*	30.64*	28.69*	-35.97*	1.48	-12.57*	38.07*	-24.74*	-19.03*	-25.29*	4.06	2.29	3.24	4.58
Marketable fruit yield/plant (g)	63.94*	-21.58*	20.22*	26.36*	101.47*	-78.04*	-40.75*	-43.69*	31.22*	57.14*	-116.29*	6.67	9.43	13.32
Harvest duration (days)	-2.43*	-3.88*	4.45*	3.34*	5.34*	-2.99*	7.12*	-5.10*	-1.99*	-3.88*	0.01	0.28	0.39	0.55
Plant height (cm)	1.06	1.97	-1.09	1.23	-3.50*	-10.44*	1.56	-4.19*	5.49*	7.09*	0.82	1.18	1.66	2.35
Average dry fruit weight (g)	-0.27*	-0.18*	-0.05	0.25*	0.49*	-0.11*	-0.22*	-0.17*	0.15*	0.18*	-0.05*	0.02	0.03	0.05
Dry fruit yield/ plant (g)	6.40*	-2.45*	1.37*	3.72*	9.62*	-7.84*	-5.05*	-3.80*	9.06*	3.36*	-14.38*	0.66	0.94	1.33
Ascorbic acid (mg/100g)	-6.61*	0.39	6.00*	2.17*	-8.78*	-7.17*	13.28*	12.56*	-10.33*	2.33*	-3.83*	0.82	1.16	1.64
Capsaicin content (%)	-0.17*	-0.25*	-0.04*	0.13*	-0.17*	0.21*	0.06*	0.05*	0.11*	0.03*	0.05*	0.01	0.01	0.01
Capsanthin (ASTA units)	12.85*	-11.87*	8.83*	-2.62*	13.81*	-4.62*	-9.12*	-0.73	-0.26	3.10*	-10.06*	0.68	0.96	1.36
Oleoresin (ASTA units)	-15.85*	-16.91*	0.26	13.04*	-16.85*	-16.54*	11.20*	-0.02	5.20*	1.31*	2.09*	0.50	0.71	1.01

* Significant at P ≤ 0.05

Table 4.13: Estimates of general combining ability (GCA) effects of lines for yield and related traits in chilli at Bajaura during 2011

Traits/Lines	Jawahar Mirch 283	Chilli Sonal	PAU Sel Long	Arka Lohit	LCA 436	Pusa Jwala	Pusa Sadabahar	Kashmir Long	Sel 352	LCA 443	LCA 206	SE (gi)±	SE (gi-gj)±	CD 5 %
Days to 50% flowering	-1.89*	-1.00*	-0.78*	-0.78*	-0.44	-1.78*	-0.44	-4.00*	3.22*	2.67*	5.22*	0.36	0.51	0.72
Days to first harvest	3.05*	0.72	4.16*	4.38*	-1.51*	-3.73*	1.38*	-7.39*	-3.28*	1.72*	0.49	0.39	0.55	0.78
Primary branches/plant	0.22	0.46*	0.11	0.00	0.04	-0.43*	0.46*	-1.03*	0.15	0.17	-0.16	0.16	0.22	0.32
Fruit length (cm)	0.57*	-1.15*	0.34*	-0.79*	0.18*	-0.78*	-0.43*	1.60*	-1.33*	0.92*	0.87*	0.07	0.10	0.14
Fruit girth (cm)	0.19*	-0.04*	-0.15*	0.06*	0.03*	-0.15*	-0.04*	-0.05*	0.02	0.21*	-0.09*	0.01	0.02	0.02
Average fruit weight (g)	-0.10*	-0.89*	-0.64*	1.63*	0.57*	-0.44*	-1.05*	0.19*	0.70*	1.17*	-1.12*	0.02	0.03	0.04
Marketable fruits/ plant	0.32	31.77*	35.93*	-31.45*	11.50*	-14.93*	25.50*	-15.63*	-15.95*	-28.60*	1.53	1.79	2.54	3.58
Marketable fruit yield/plant (g)	10.53	-18.59*	58.86*	9.64	123.41*	-73.14*	-42.47*	-12.47*	28.64*	17.75*	-102.14*	5.84	8.26	11.67
Harvest duration (days)	-3.77*	-4.32*	2.34*	4.23*	6.12*	-3.10*	8.90*	-4.99*	-2.77*	-3.88*	1.23*	0.27	0.38	0.54
Plant height (cm)	5.45*	3.99*	-1.53*	0.93	-1.98*	-14.92*	0.00	-2.09*	6.36*	6.12*	-2.33*	0.53	0.76	1.07
Average dry fruit weight (g)	-0.22*	-0.16*	-0.04	0.22*	0.38*	-0.06*	-0.15*	-0.20*	0.09*	0.10*	0.04	0.03	0.04	0.06
Dry fruit yield/ plant (g)	5.53*	-4.64*	5.64*	1.80	14.79*	-9.58*	-9.81*	0.86	3.25*	2.08*	-9.92*	1.03	1.45	2.05
Ascorbic acid (mg/100g)	-11.59*	-0.81	6.19*	0.64	-5.03*	-6.59*	13.25*	12.91*	-7.97*	4.75*	-5.75*	0.85	1.21	1.71
Capsaicin content (%)	-0.18*	-0.21*	-0.04*	0.10*	-0.17*	0.21*	0.06*	0.04*	0.12*	0.03*	0.06*	0.01	0.01	0.01
Capsanthin (ASTA units)	12.79*	-12.10*	6.24*	1.24*	11.68*	-4.65*	-10.15*	-0.43	3.35*	3.18*	-11.15*	0.54	0.77	1.09
Oleoresin (ASTA units)	-13.80*	-16.35*	1.15	9.15*	-14.52*	17.31*	9.65*	-0.41	3.65*	5.42*	-1.24	0.63	0.89	1.26

* Significant at P ≤ 0.05

Table 4.14: Pooled over environments estimates of general combining ability (GCA) effects of lines for yield and related traits in chilli

Traits/Lines	Jawahar Mirch 283	Chilli Sonal	PAU Sel Long	Arka Lohit	LCA 436	Pusa Jwala	Pusa Sadabahar	Kashmir Long	Sel 352	LCA 443	LCA 206	SE (gi)±	SE (gi-gj) ±	CD 5 %
Days to 50% flowering	-0.56*	-2.72*	0.61*	0.78*	-1.47*	-1.14*	2.25*	-4.56*	1.44*	0.05	5.33*	0.17	0.24	0.34
Days to first harvest	1.97*	-0.87*	4.63*	2.22*	-1.70*	-5.23*	5.22*	-8.01*	-1.89*	2.08*	1.58*	0.18	0.25	0.36
Primary branches/plant	0.22*	0.24*	0.01	0.09	0.02	0.14*	0.54*	-1.02*	-0.17*	0.07	-0.14*	0.06	0.08	0.12
Fruit length (cm)	0.36*	-0.87*	0.20*	-0.39*	0.61*	0.09*	-0.71*	0.96*	-1.15*	0.17*	0.71*	0.03	0.04	0.06
Fruit girth (cm)	0.10*	-0.04*	-0.11*	0.01*	0.08*	-0.12*	-0.05*	-0.01*	0.06*	0.19*	-0.11*	0.000	0.000	0.00
Average fruit weight (g)	-0.21*	-0.85*	-0.71*	1.67*	0.56*	-0.52*	-0.98*	0.29*	0.71*	1.21*	-1.71*	0.01	0.01	0.02
Marketable fruits/ plant	26.54*	14.33*	34.89*	-31.17*	9.90*	4.52*	10.33*	-18.85*	-24.45*	-29.47*	3.97*	0.85	1.20	1.70
Marketable fruit yield/plant (g)	76.40*	-56.73*	34.70*	34.93*	124.91*	-29.26*	-87.56*	-10.32*	4.55*	38.52*	-130.14*	2.63	3.71	5.26
Harvest duration (days)	-2.73*	-4.26*	3.60*	3.74*	5.80*	-2.76*	7.77*	-5.26*	-2.51*	-3.87*	0.46*	0.11	0.16	0.22
Plant height (cm)	4.78*	2.11*	-0.12	-1.26*	-0.52	-10.87*	0.79	-3.47*	2.63*	4.00*	1.92*	0.41	0.58	0.82
Average dry fruit weight (g)	-0.23*	-0.11*	-0.03*	0.21*	0.41*	-0.09*	-0.20*	-0.20*	0.11*	0.19*	-0.05*	0.01	0.01	0.02
Dry fruit yield/ plant (g)	8.21*	-8.33*	3.53*	7.29*	11.38*	-3.90*	-11.74*	-0.26	5.03*	2.63*	-13.85*	0.41	0.58	0.82
Ascorbic acid (mg/100g)	-6.76*	-1.09*	6.26*	1.68*	-5.94*	-7.81*	12.91*	13.97*	-11.19*	0.87*	-2.90*	0.30	0.42	0.60
Capsaicin content (%)	-0.17*	-0.24*	-0.05*	0.11*	-0.16*	0.22*	0.08*	0.04*	0.10*	0.03*	0.05*	0.000	0.000	0.00
Capsanthin (ASTA units)	14.52*	-9.66*	7.11*	0.80*	12.55*	-4.60*	-12.03*	-1.09*	2.14*	2.73*	-12.47*	0.23	0.32	0.46
Oleoresin (ASTA units)	-16.27*	-19.77*	0.23	11.12*	-15.91*	17.07*	11.66*	0.79*	6.16*	3.26*	1.65*	0.23	0.32	0.46

* Significant at P ≤ 0.05

Days to first harvest

The lines 'LCA 436', 'Pusa Jwala', 'Kashmir Long', 'Selection 352' and 'Chilli Sonal' were found to be good general combiners for early harvest having significant negative GCA effects in both the environments and years along with pooled over environments except 'Selection 352' at Palampur during 2011 and 'Chilli Sonal' at Palampur and Bajaura during 2011 (Table 4.10, 4.11, 4.12, 4.13 and 4.14). In addition, line 'Jawahar Mirch 283' had also significant negative GCA effects at Palampur during 2011. Good general combiner lines for early harvest have also been reported by Pandey *et al*. (1981), Bhagyalakshmi *et al.* (1991) and Gandhi *et al.* (2000) in their respective studies in different sets of locations.

Primary branches/plant

For this trait, 'Jawahar Mirch 283' and 'Pusa Sadabahar' during both the years, 'Arka Lohit' in 2010 and 'LCA 436', 'Pusa Jwala' and 'LCA 443' in 2011 at Palampur, 'Chilli Sonal' during both the years, 'Pusa Jwala' in 2010 and 'Pusa Sadabahar' in 2011 at Bajaura, and 'Jawahar Mirch 283', 'Pusa Sadabahar', 'Pusa Jwala' and 'Chilli Sonal' in pooled over environments showed significant positive GCA effects indicating their good general combining ability for this trait (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Pandian and Shanmugavelu (1992) and Reddy *et al*. (2008) have also observed significant effects in their respective lines for primary branches/plant.

Fruit length (cm)

The lines 'Jawahar Mirch 283', 'LCA 436' and 'Pusa Jwala' during both the years along with 'Kashmir Long' in 2010 and 'Arka Lohit' and 'LCA 206' in 2011 at Palampur were observed to be good general combiners having significant positive GCA effects for longer fruit length at Palampur. On the other hand, 'Jawahar Mirch 283', 'Kashmir Long', 'LCA 206', 'PAU Selection Long' and 'LCA 443' during both the years and 'LCA 436' in 2011 were the good general combiners at Bajaura. All the lines except 'Arka Lohit' which had good GCA effects at both the locations in one or the other year showed similar GCA effects upon pooling of data over years and environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Good general combiner lines for fruit length have also been reported by Pandey *et al*. (1981), Bhagyalakshmi *et al*. (1991), Pandian and Shanmugavelu (1992) and Patel *et al*. (2004).

Fruit girth (cm)

The lines ‘Jawahar Mirch 283’, ‘LCA 436’, ‘Kashmir Long’, ‘Selection 352’ and ‘LCA 443’ at Palampur, and ‘Jawahar Mirch 283’, ‘LCA 443’, ‘Arka Lohit’ and ‘LCA 436’ at Bajaura during both the years were found to be good general combiners for fruit girth. In addition, ‘Selection 352’ and ‘Pusa Sadabahar’ had also similar effects during 2010 at Bajaura. The lines ‘Jawahar Mirch 283’, ‘Selection 352’, ‘LCA 443’, ‘Arka Lohit’ and ‘LCA 436’ exhibited significant positive GCA effects in pooled over years and environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Significant and positive GCA effects for fruit girth have substantiated the findings of Patel *et al*. (2004) and Reddy *et al*. (2008).

Average fruit weight (g)

The lines ‘Arka Lohit’, ‘LCA 436’, ‘Kashmir Long’, ‘Selection 352’ and ‘LCA 443’ both at Palampur and Bajaura during both the years and pooled over environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14) were observed to had significant positive GCA effects, thereby indicating their good general combining ability. Jadhav *et al*. (2002) and Reddy *et al*. (2008) have also noticed lines with good GCA effects for average fruit weight with different sets of genotypes and environmental conditions.

Marketable fruits/plant

Good general combining ability lines, having significant positive GCA effects, were ‘Jawahar Mirch 283’ and ‘PAU Selection Long’ in both the locations and years, ‘Pusa Jwala’ at Palampur and ‘Chilli Sonal’ and ‘Pusa Sadabahar’ at Bajaura during both the years, ‘LCA 436’ in 2010 and ‘Chilli Sonal’ and ‘LCA 206’ in 2011 at Palampur along with ‘LCA 436’ in 2011 at Bajaura. All these lines also showed good general combining ability effects in pooled over environments

(Table 4.10, 4.11, 4.12, 4.13 and 4.14). These findings are in consonance with those of earlier workers who have also revealed good general combiner lines in their respective studies for marketable fruits/plant (Gaddagimath *et al*. 1988; Bhagyalakshmi *et al*. 1991; Lohithaswa *et al*. 2001; Jadhav *et al*. 2002; Patel *et al*. 2004; Reddy *et al*. 2008).

Marketable fruit yield/plant (g)

In this case, 'Jawahar Mirch 283' and 'LCA 436' during 2010 at Palampur, 'PAU Selection Long', 'LCA 436', 'LCA 443' and 'Selection 352' during both the years along with 'Jawahar Mirch 283' and 'Arka Lohit' in 2010 at Bajaura were the most promising lines as they showed significant positive GCA effects indicating thereby their good general combining ability for marketable fruit yield/plant. Upon pooling of data over years and environment, the lines 'Jawahar Mirch 283', 'PAU Selection Long', 'Arka Lohit', 'LCA 436', 'LCA 443' and 'Selection 352' were the good general combiners (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Lohithaswa *et al*. (2001), Patel *et al*. (2004), Venkataramana *et al*. (2005), Zate *et al*. (2005), Shekhawat *et al*. (2007) and Reddy *et al*. (2008) have also observed significant GCA effects for different sets of lines under varied environmental conditions.

Harvest duration (days)

For this trait, the lines 'PAU Selection Long', 'Arka Lohit', 'LCA 436', 'Pusa Sadabahar' and 'LCA 206' exhibited significant positive GCA effects at Palampur and Bajaura in the respective years and pooled over environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14) except 'LCA 206' at Palampur and Bajaura during 2010, thereby revealing their good general combining ability.

Plant height (cm)

For plant height, the lines 'Jawahar Mirch 283', 'PAU Selection Long', 'LCA 443' and 'LCA 206' during 2010 and 'Pusa Sadabahar' during 2011 at Palampur, 'LCA 443' and 'Selection 352' during both the years along with 'Jawahar Mirch 283' and 'Chilli Sonal' in 2011 at Bajaura, and 'Jawahar Mirch

283', 'LCA 443', 'LCA 206', 'Chilli Sonal' and 'Selection 352' in pooled over environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14) showed good general combining ability as depicted from their significant positive GCA effects. Significant and positive GCA effects for lines have also been noticed by Jadhav *et al*. (2002), Patel *et al*. (2004) and Reddy *et al*. (2008).

Average dry fruit weight (g)

Lines 'Arka Lohit', 'LCA 436', 'Selection 352' and 'LCA 443' during both the years at Palampur, Bajaura and pooled over environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14) except 'LCA 443' during 2011 at Palampur were good general combiners as revealed from their significant positive GCA effects, revealing their good general combining ability. Also, 'PAU Selection Long' was found to be good general combiner during 2010 at Palampur.

Dry fruit yield/plant

In respect of this trait, the lines 'Jawahar Mirch 283', 'PAU Selection Long', 'Arka Lohit', 'LCA 436', 'Selection 352' and 'LCA 443' were good general combiner for dry yield as revealed from their significant positive GCA effects during both the years at Palampur and Bajaura along with pooled over environments except 'LCA 443' during both the years and 'Selection 352' and 'PAU Selection Long' in 2010 and 2011, respectively and at Palampur along with 'Arka Lohit' in 2011 at Bajaura (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Similarly, Gaddagimath *et al*. (1988), Pandian and Shanmugavelu (1992) and Shekhawat *et al*. (2007) also found different sets of lines with good general combining ability for dry fruit yield/plant.

Ascorbic acid (mg/100g)

Good general combining ability lines having significant positive GCA effects (Table 4.10, 4.11, 4.12, 4.13 and 4.14) were 'PAU Selection Long', 'Pusa Sadabahar' and 'Kashmir Long' during both the years in the respective locations and pooled over environments. In addition, lines 'Arka Lohit' in 2010 and 2011 at Bajaura and Palampur, respectively along with pooled over environments and 'LCA 443' during both the years at Bajaura and pooled over environments had significant positive GCA effects.

Capsaicin content (%)

The significant positive GCA effects were observed in the lines 'Arka Lohit', 'Pusa Jwala', 'Pusa Sadabahar', 'Kashmir Long', 'Selection 352', 'LCA 443' and 'LCA 206' in the respective years in both the locations and pooled over environments, thereby depicted as good general combiners for capsaicin content (Table 4.10, 4.11, 4.12, 4.13 and 4.14).

Capsanthin (ASTA units)

For this trait, the lines 'Jawahar Mirch 283', 'PAU Selection Long', 'LCA 436', 'Selection 352', 'LCA 443' and 'Arka Lohit' were the good general combining lines having significant positive GCA effects during both the years in the respective locations and pooled over environments except 'Arka Lohit' in 2010 at both the locations and 'Selection 352' in 2010 at Bajaura (Table 4.10, 4.11, 4.12, 4.13 and 4.14).

Oleoresin (ASTA units)

For oleoresin, the significant positive GCA effects were observed for lines 'Arka Lohit', 'Pusa Jwala', 'Pusa Sadabahar', 'Selection 352', 'LCA 443' and 'LCA 206' at both Palampur and Bajaura during 2010, 2011 and pooled over environments (Table 4.10, 4.11, 4.12, 4.13 and 4.14) revealed as good general combiner for obtaining high oleoresin contents except 'Pusa Jwala' in 2010, and 'Arka Lohit' and 'LCA 206' in 2011 at Bajaura. In addition, lines 'Kashmir Long' in 2011 at Palampur and pooled over environments and 'PAU Selection Long' in 2011 at Bajaura had also showed good general combining ability effects.

Good general combiner lines for capsaicin content, capsanthin and oleoresin have also been observed by Singh and Hundal (2001) and Prasath and Ponnuswami (2008) in their respective studies. Besides, Lohithaswa *et al*. (2001) also noticed lines with good GCA effects for capsaicin content.

4.2.3 Estimation of general combining ability (GCA) effects of testers

Among the testers, 'Surajmukhi' was observed to be good general combiner for primary branches/plant, average fruit weight, number of marketable fruits/plant, Marketable fruit yield/plant, harvest duration, plant height, average dry fruit weight ,dry fruit yield/plant, ascorbic acid, capsaicin content, capsanthin and oleoresin over the environments during both the years and pooled over environments except average fruit weight in 2011 and average dry fruit weight during both the years at Bajaura. In addition it also showed significant positive GCA effects for fruit length at Bajaura during both the years and pooled over the environments, and for fruit girth during 2010 and 2011 at Bajaura and Palampur, respectively along with pooled over environments (Table 4.16, 4.17 and 4.18).

For earliness, the tester 'Anugraha' found to be promising for earliness as it showed significant negative GCA effects for flowering in 2010 at both the locations along with pooled over environments, and for days to first harvest during both the years at both the locations and pooled over environments (Table 4.16, 4.17 and 4.18). In addition, it also revealed significant positive GCA effects for fruit length at both the locations in the respective years and pooled over environments, primary branches/plant and number of marketable fruits/plant during 2011 at Palampur along with average fruit weight at both the locations during both the years and pooled over environments except 2011 at Palampur. Also, it had shown promise for ascorbic acid at Palampur during 2010 and pooled environments. On the other hand, 'Pant C 1' was found to have good general combining ability effects for fruit girth, at both the locations during 2010 and 2011 and pooled over environments except 2010 at Bajaura, oleoresin during both the years at Palampur and pooled over environments, average dry fruit weight during 2010 and 2011 at Bajaura and Palampur, respectively and pooled over environments, and capsaicin content in 2010 at Bajaura. Significance of GCA effects for majority of these traits for different sets of testers was also reported earlier by Pandian and Shanmugavelu (1992), Singh and Hundal (2001), Patel *et al*. (2004), Srivastava *et al.* (2005) and Reddy *et al.* (2008).

On the basis of GCA effects, it can be concluded that lines 'LCA 436' and 'LCA 443' were good general combiners for 11 traits out of 16 studied followed by 'Selection 352' and 'Arka Lohit' for 10 traits each and 'Jawahar Mirch 283' for nine traits on the basis of pooled analysis over environments. Lines 'Jawahar

Table 4.15 Trait-wise list of promising three lines exhibiting significant desirable GCA at Palampur, Bajaura and pooled over the environments

Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Days to 50% flowering	Kashmir Long Chilli Sonal LCA 443	Kashmir Long LCA 436 Chilli Sonal	Kashmir Long Chilli Sonal LCA 436	Kashmir long Jawahar Mirch 283 Pusa Jwala	Kashmir Long Chilli Sonal LCA 436
Days to first harvest	Kashmir Long Pusa Jwala LCA 436	Kashmir Long Pusa Jwala -	Kashmir Long Pusa Jwala Sel 352	Kashmir Long Pusa Jwala Sel 352	Kashmir Long Pusa Jwala Sel 352
Primary branches/plant	Pusa Sadabahar Arka Lohit -	Pusa Sadabahar Jawahar Mirch 283 -	Chilli sonal Pusa Jwala -	Chilli Sonal Pusa Sadabahar -	Pusa Sadabahar Chilli Sonal Jawahar Mirch 283
Fruit length (cm)	LCA 436 Pusa Jwala LCA 206	Pusa Jwala LCA 436 LCA 206	Kashmir Long LCA 206 Jawahar Mirch 283	Kashmir Long LCA 443 LCA 206	Kashmir Long LCA 206 LCA 436
Fruit girth (cm)	LCA 443 LCA 436 Sel 352	LCA 443 LCA 436 Sel 352	Jawahar Mirch 283 LCA 443 Pusa Sadabahar	LCA 443 Jawahar Mirch 283 Arka Lohit	LCA 443 Jawahar Mirch 283 LCA 436
Average fruit weight (g)	Arka Lohit LCA 443 Sel 352	Arka Lohit LCA 443 Sel 352	Arka Lohit LCA 443 Sel 352	Arka Lohit LCA 443 Sel 352	Arka Lohit LCA 443 Sel 352
Marketable fruits/plant	Jawahar Mirch 283 PAU Sel Long LCA 436	LCA 206 Jawahar Mirch 283 Pusa Jwala	Pusa Sadabahar Chilli Sonal PAU Sel Long	PAU Sel Long Chilli Sonal Pusa Sadabahar	PAU Sel Long Jawahar Mirch 283 Chilli Sonal
Marketable fruit yield/plant (g)	LCA 436 Jawahar Mirch 283 Arka Lohit	LCA 436 Jawahar Mirch 283 Pusa Jwala	LCA 436 Jawahar Mirch 283 LCA 443	LCA 436 PAU Sel Long Sel 352	LCA 436 Jawahar Mirch 283 LCA 443
Harvest duration (days)	Pusa sadabahr LCA 436 PAU Sel Long	Pusa sadabahr LCA 436 Arka Lohit	Pusa sadabahr LCA 436 PAU Sel Long	PusaSadabahar LCA 436 Arka Lohit	Pusa Sadabahar LCA 436 Arka Lohit
Plant height (cm)	Jawahar Mirch 283 LCA 443 PAU Sel Long	Pusa Sadabahar LCA 206 Jawahar Mirch 283	LCA 443 Sel 352 -	Sel 352 LCA 443 Jawahar Mirch 283	Jawahar Mirch 283 LCA 443 Sel 352
Average dry fruit weight (g)	LCA 436 Arka Lohit LCA 443	LCA 436 LCA 443 Sel 352	LCA 436 Arka Lohit LCA 443	LCA 436 Arka Lohit LCA 443	LCA 436 Arka Lohit LCA 443
Dry fruit yield/plant (g)	LCA 436 Arka Lohit Jawahar Mirch 283	Arka Lohit Jawahar Mirch 283 Sel 352	LCA 436 Sel 352 Jawahar Mirch 283	LCA 436 PAU Sel Long Jawahar Mirch 283	LCA 436 Jawahar Mirch 283 Arka Lohit
Ascorbic acid (mg/100g)	Kashmir Long Pusa Sadabahar PAU Sel Long	Kashmir Long Pusa Sadabahar PAU Sel Long	Pusa Sadabahar Kashmir Long PAU Sel Long	Pusa Sadabahar Kashmir Long PAU Sel Long	Kashmir Long Pusa Sadabahar PAU Sel Long
Capsaicin content (%)	Pusa Jwala Arka Lohit Pusa Sadabahar	Pusa Jwala Arka Lohit LCA 443	Pusa Jwala Arka Lohit Sel 352	Pusa Jwala Sel 352 Arka Lohit	Pusa Jwala Arka Lohit Sel 352
Capsanthin (ASTA units)	Jawahar Mirch 283 LCA 436 PAU Sel Long	Jawahar Mirch 283 LCA 436 PAU Sel Long	LCA 436 Jawahar Mirch 283 PAU Sel Long	Jawahar Mirch 283 LCA 436 PAU Sel Long	Jawahar Mirch 283 LCA 436 PAU Sel Long
Oleoresin (ASTA units)	Pusa Jwala Pusa Sadabahar Arka Lohit	Pusa Jwala Pusa Sadabaha Arka Lohit	Arka Lohit Pusa Sadabahar Sel 352	Pusa Jwala Pusa Sadabahar Arka Lohit	Pusa Jwala Pusa Sadabahar Arka Lohit

Table 4.16: Estimates of GCA effects of testers for yield and related traits in chilli at Palampur during 2010 and 2011

	2010						2011					
Traits/Testers	Pant C 1	Anugraha	Surajmukhi	SE (gj)±	SE (gi-gj)	CD 5 %	Pant C1	Anugraha	Surajmukhi	SE (gj)±	SE (gi-gj)	CD 5 %
Days to 50 % flowering	0.00	-0.69*	0.69*	0.14	0.20	0.28	0.36	-0.06	-0.30	0.33	0.46	0.65
Days to first harvest	0.38	-0.49*	0.11	0.21	0.30	0.43	0.42	-0.73*	0.30	0.25	0.36	0.51
Primary branches/ plant	-0.29*	0.03	0.26*	0.35	0.10	0.13	-0.33*	0.15*	0.18*	0.07	0.10	0.13
Fruit length (cm)	-0.30*	0.46*	-0.16*	0.06	0.08	0.12	-0.43*	0.51*	-0.08	0.04	0.06	0.08
Fruit girth (cm)	0.04*	-0.04*	0.002	0.01	0.01	0.01	0.03*	-0.04*	0.02*	0.01	0.01	0.01
Average fruit weight (g)	-0.14*	0.04*	0.10*	0.01	0.03	0.04	-0.10*	-0.02*	0.12*	0.004	0.01	0.01
Marketable fruits/ plant	-21.22*	-1.20	22.43*	0.92	1.30	1.83	-13.02*	10.24*	2.77*	1.02	1.44	2.03
Marketable fruit yield/plant (g)	-72.30*	-7.25*	79.55*	3.07	4.34	6.13	-37.92*	2.35	35.57*	3.15	4.45	6.29
Harvest duration (days)	-2.14*	-0.32*	2.46*	0.14	0.19	0.27	-2.29*	-0.44*	2.74*	0.16	0.22	0.32
Plant height (cm)	-4.72*	0.14	4.58*	0.53	0.76	1.07	-1.03	-0.41	1.43*	0.58	0.82	1.15
Average dry fruit weight (g)	0.03	-0.09*	0.06*	0.01	0.03	0.04	0.09*	-0.14*	0.05*	0.02	0.02	0.03
Dry fruit yield/ plant (g)	-5.63*	-1.94*	7.57*	0.52	0.73	1.03	-5.39*	-0.97	6.36*	0.59	0.84	1.18
Ascorbic acid (mg/100g)	-2.39*	1.32*	1.07*	0.26	0.37	0.52	-2.03*	0.31	1.72*	0.36	0.51	0.72
Capsaicin content (%)	-0.004	-0.03*	0.03*	0.003	0.004	0.01	-0.01*	-0.03*	0.04*	0.003	0.004	0.01
Capsanthin (ASTA units)	-3.75*	-1.61*	5.35*	0.26	0.36	0.51	-2.98*	-2.30*	5.28*	0.31	0.44	0.62
Oleoresin (ASTA units)	1.43*	-3.91*	2.48*	0.22	0.32	0.45	1.56*	-4.74*	3.18*	0.33	0.47	0.66

* Significant at $P \leq 0.05$

Table 4.17: Estimates of GCA effects of testers for yield and related traits in chilli at Bajaura during 2010 and 2011

	2010						2011					
Traits/ Testers	Pant C 1	Anugraha	Surajmukhi	SE (gj)±	SE (gi-gj)	CD 5 %	Pant C 1	Anugraha	Surajmukhi	SE (gj)±	SE (gi-gj)	CD 5 %
Days to 50% flowering	0.62*	-1.08*	0.46*	0.20	0.28	0.40	0.18	-0.15	-0.03	0.19	0.27	0.38
Days to first harvest	0.66*	-0.92*	0.26	0.26	0.36	0.51	-0.29	-0.66*	0.95*	0.20	0.29	0.41
Primary branches/plant	-0.10	-0.09	0.18*	0.06	0.09	0.12	-0.09	-0.09	0.19*	0.08	0.12	0.16
Fruit length (cm)	-0.55*	0.35*	0.20*	0.04	0.05	0.07	-0.56*	0.42*	0.14*	0.04	0.05	0.07
Fruit girth (cm)	-0.01	-0.03*	0.04*	0.01	0.01	0.01	0.02*	-0.02*	-0.003	0.01	0.01	0.01
Average fruit weight (g)	-0.14*	0.10*	0.04*	0.01	0.01	0.01	-0.14*	0.14*	-0.003	0.01	0.01	0.02
Marketable fruits/ plant	-9.55*	-10.46*	20.01*	1.20	1.69	2.39	-2.88*	-10.34*	13.22*	0.94	1.32	1.87
Marketable fruit yield/plant (g)	-23.43*	-30.60*	54.03*	3.48	4.93	6.96	-4.06	-24.09*	28.15*	3.05	4.32	6.10
Harvest duration (days)	-2.16*	-0.40*	2.57*	0.14	0.20	0.29	-2.19*	-0.37*	2.57*	0.14	0.20	0.28
Plant height (cm)	-2.38*	-2.69*	5.07*	0.61	0.87	1.23	-3.36*	-3.25*	6.61*	0.28	0.40	0.56
Average dry fruit weight (g)	0.04*	-0.06*	0.02	0.01	0.02	0.03	0.03	-0.05*	0.02	0.01	0.02	0.03
Dry fruit yield/ plant (g)	-1.45*	-3.99*	5.44*	0.35	0.49	0.69	-0.70	-1.90*	2.60*	0.54	0.76	1.07
Ascorbic acid (mg/100g)	-2.68*	0.83	1.85*	0.43	0.61	0.86	-2.38*	0.56	1.82*	0.45	0.63	0.89
Capsaicin content (%)	0.01*	-0.04*	0.03*	0.003	0.004	0.005	0.000	-0.04*	0.04*	0.003	0.004	0.01
Capsanthin (ASTA units)	-2.19*	-2.51*	4.71*	0.35	0.50	0.71	-1.28*	-2.13*	3.40*	0.28	0.40	0.57
Oleoresin (ASTA units)	-0.26	-3.05*	3.30*	0.26	0.37	0.53	-0.82*	-1.20*	2.02*	0.33	0.47	0.66

* Significant at $P \leq 0.05$

Table 4.18: Pooled over environments estimates of GCA effects of testers for yield and related traits in chilli

Traits/Testers	Pant C 1	Anugraha	Surajmukhi	SE (gj)±	SE (gi-gj)	CD 5 %
Days to 50% flowering	0.29*	-0.50*	0.21*	0.07	0.10	0.14
Days to first harvest	0.29*	-0.70*	0.41*	0.08	0.11	0.16
Primary branches/plant	-0.20*	0.000	0.20*	0.03	0.04	0.06
Fruit length (cm)	-0.46*	0.43*	0.03*	0.01	0.01	0.02
Fruit girth (cm)	0.02*	-0.03*	0.01*	0.000	0.000	0.00
Average fruit weight (g)	-0.13*	0.07*	0.06*	0.000	0.000	0.00
Marketable fruits/ plant	-11.67*	-2.94*	14.61*	0.38	0.54	0.76
Marketable fruit yield/plant (g)	-34.43*	-14.90*	49.33*	1.18	1.66	2.36
Harvest duration (days)	-2.20*	-0.39*	2.58*	0.05	0.07	0.10
Plant height (cm)	-2.87*	-1.55*	4.42*	0.18	0.25	0.36
Average dry fruit weight (g)	0.05*	-0.08*	0.04*	0.01	0.01	0.02
Dry fruit yield/ plant (g)	-3.29	-2.20	5.49*	0.18	0.25	0.36
Ascorbic acid (mg/100g)	-2.37*	0.75*	1.61*	0.14	0.20	0.28
Capsaicin content (%)	0.000	-0.03*	0.03*	0.000	0.000	0.00
Capsanthin (ASTA units)	-2.55*	-2.14*	4.69*	0.10	0.14	0.20
Oleoresin (ASTA units)	0.48*	-3.22*	2.74*	0.10	0.14	0.20

* Significant at $P \leq 0.05$

Table 4.19 Trait-wise list of best tester exhibiting significant desirable GCA at Palampur, Bajaura and pooled over the environments

Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Days to 50% flowering	Anugraha	-	Anugraha	-	Anugraha
Days to first harvest	Anugraha	Anugraha	Anugraha	Anugraha	Anugraha
Primary branches/plant	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Fruit length (cm)	Anugraha	Anugraha	Anugraha	Anugraha	Anugraha
Fruit girth (cm)	Pant C1	Pant C1	Surajmukhi	Pant C1	Pant C1
Average fruit weight (g)	Surajmukhi	Surajmukhi	Anugraha	Anugraha	Anugraha
Marketable fruits/plant	Surajmukhi	Anugraha	Surajmukhi	Surajmukhi	Surajmukhi
Marketable fruit yield/plant (g)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Harvest duration (days)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Plant height (cm)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Average dry fruit weight (g)	Surajmukhi	Pant C1	Pant C1	Pant C1	Pant C1
Dry fruit yield/plant (g)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Ascorbic acid (mg/100g)	Anugraha	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Capsaicin content (%)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Capsanthin (ASTA units)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi
Oleoresin (ASTA units)	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi	Surajmukhi

Mirch 283', 'PAU Selection Long', 'LCA 436' and 'LCA 443' were found to be the most promising for marketable fruit yield/plant and dry fruit yield/plant which could be the result of their good general combining ability effects for related horticultural traits *viz*., fruit length, marketable fruits/plant and harvest duration (Table 4.10, 4.11, 4.12, 4.13 and 4.14). Hence, the parental lines showing consistency of GCA effects for yield and other related traits appear to have higher frequency of desirable additive genes which can be exploited for high yields in chilli. Similarly, lines 'Chilli Sonal', 'LCA 436', 'Pusa Jwala' and 'Kashmir Long' were the most suitable for earliness having significant negative GCA effects for days to 50% flowering and days to first harvest. For quality traits, 'Arka Lohit' and 'LCA 443' observed to be good general combiner for all four traits *viz*., ascorbic acid, capsaicin content, capsanthin and oleoresin. Beside this, 'Pusa Sadabahar' and 'Kashmir Long' were also good general combiners for these quality traits except capsanthin. Amongst the testers, 'Surajmukhi' was the most promising having good general combining ability effects for majority of the traits. However, 'Anugraha' showed promise for some of the traits namely earliness, fruit length and average fruit weight while, 'Pant C 1' was good general combiner for fruit girth (Table 4.19).

Table 4.20: Elite lines and testers identified on the basis of overall performance in chilli

Traits	Lines	Testers
Fruit Yield and related traits	Jawahar Mirch 283	Surajmukhi
	PAU Selection Long	
	LCA 436	
	LCA 443	
Earliness	Chilli Sonal	Anugraha
	LCA 436	
	Pusa Jwala	
	Kashmir Long	
Quality traits	Arka Lohit	Surajmukhi
	LCA 443	

Jawahar Mirch 283

PAU Selection Long

Surajmukhi

LCA 436

LCA 443

Plate 5: Promising general combiners for yield and its related traits

4.2.4 Estimation of specific combining ability (SCA) effects of crosses

Specific combining ability (SCA) is the deviation in performance of a cross combination which is estimated on the basis of general combining abilities of the parents involved in the cross combination. In contrast to GCA effects, SCA effects represent dominance and epistasis components of variation which are non-fixable and related to hybrid vigour. Hence, specific combining ability effects could contribute more towards the improvement of self-pollinated crops only where the commercial exploitation of heterosis is feasible. However, in the production of homozygous lines, the interest of the breeders usually rests upon the transgressive segregants which can be obtained from these crosses in the segregating generations. In the present investigation, specific combining ability effects revealed a very wide range of variation for all the characters which are described trait wise as under (Table 4.21, 4.22, 4.23, 4.24 and 4.25):

Days to 50% flowering

Out of the 33 crosses, seven and four at Palampur and eight and 10 at Bajaura during 2010 and 2011, respectively and 14 crosses in pooled over environments expressed significant negative SCA effects indicating their good specific combining ability for early flowering. Crosses ‘Selection 352 × Anugraha’ and ‘LCA 206 × Anugraha’ showed consistency over the years and locations along with pooled over the environments by remaining among the top five cross combinations with significant negative SCA effects except ‘LCA 206 × Anugraha’ during 2011 at Palampur. One of the parents of these crosses happened to be good general combiner. Majority of cross combination, in general, were fallen in the range of good and average specific combining ability effects (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Days to first harvest

For this trait, significant negative SCA effects were observed for seven and nine crosses at Palampur, and six and 12 crosses at Bajaura in the respective years, while 14 cross combinations showed similar negative SCA effects in pooled over environments revealing their good specific combining

Table 4.21: Estimates of specific combining ability (SCA) effects for yield and related traits in chilli at Palampur during 2010

S. No.	Traits/ Crosses	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	-0.22	-1.05	0.12	-0.21	-0.001	**0.64***	-34.05*	-20.81*	-2.41*	-11.46*	-0.02	2.95	**12.72***	-0.06*	-4.32*	-4.37*
2	Jawahar Mirch 283 × Anugraha	0.81	-0.17	0.46	0.07	0.01	-0.18*	**47.95***	**135.81***	1.10*	**11.61***	-0.09	**9.60***	-11.65*	0.01	**11.04***	**5.80***
3	Jawahar Mirch 283 × Surajmukhi	-0.59	1.22	-0.57	0.14	-0.01	-0.47*	-13.90*	-114.99*	1.31*	-0.16	0.10	-12.54*	-1.07	**0.05***	-6.72*	-1.42
4	Chilli Sonal × Pant C 1	-0.67	**-4.50***	**0.72***	0.02	-0.01	-0.08	-23.07*	-54.28*	-0.08	-4.31*	0.002	2.06	8.89*	-0.07*	-4.32*	-1.99*
5	Chilli Sonal × Anugraha	0.37	**-3.28***	-0.35	-0.37	**0.09***	0.35*	-22.35*	-15.79	-6.57*	0.22	-0.10	-9.96*	3.85*	-0.00	-7.06*	-5.15*
6	Chilli Sonal × Surajmukhi	0.30	7.78*	-0.37	0.34	-0.08*	-0.28*	**45.42***	70.07*	**6.65***	**4.09***	0.10	**7.90***	-12.74*	**0.07***	**11.38***	**7.13***
7	PAU Sel Long × Pant C 1	-0.44	-0.38	0.27	**0.81***	0.000	-0.02	-4.01	-26.70*	-2.53*	0.08	-0.31*	-3.25	-9.33*	-0.06*	-2.60*	-1.10
8	PAU Sel Long × Anugraha	0.92	0.50	0.41	-1.21*	-0.01	-0.14*	-8.47*	-42.08*	0.99*	-1.66	-0.10	-0.64	-1.71	0.03*	-1.97*	0.07
9	PAU Sel Long × Surajmukhi	-0.48	-0.11	-0.68*	**0.40***	0.01	0.16*	12.48*	68.78*	1.54*	1.58	**0.41***	3.89*	**11.04***	0.04*	4.57*	1.02
10	Arka Lohit × Pant C 1	1.78*	3.62*	-0.17	0.31	-0.10*	-1.59*	**40.13***	-42.48*	0.92*	**7.39***	**0.20***	-2.79	8.32*	-0.03*	9.90*	-5.21*
11	Arka Lohit × Anugraha	2.48*	4.50*	-0.10	0.15	0.07*	**1.70***	-25.62*	56.14*	**3.10***	3.46	0.09	1.86	**10.55***	0.02	-0.07	**8.30***
12	Arka Lohit × Surajmukhi	**-4.25***	**-8.11***	0.28	-0.46*	0.03	-0.11*	-14.51*	-13.66	-4.02*	-10.84*	-0.29*	0.92	-18.87*	0.002	-9.83*	-3.09*
13	LCA 436 × Pant C 1	**-2.56***	-0.83	-0.33	-0.77*	-0.02	0.16*	27.19*	**107.63***	2.81*	0.14	0.02	**11.50***	-5.72*	0.03*	2.18*	**7.18***
14	LCA 436 × Anugraha	-1.52*	-0.28	0.01	**0.64***	-0.07*	-0.48*	26.82*	36.25*	**3.32***	-0.19	-0.08	4.79*	-1.59	-0.03*	2.91*	-7.32*
15	LCA 436 × Surajmukhi	4.08*	1.11	0.32	0.13	**0.09***	0.32*	-54.02*	-143.88*	-6.13*	0.04	0.06	-16.29*	7.32*	-0.01	-5.09*	0.13
16	Pusa Jwala × Pant C 1	0.67	-0.27	-0.77*	-0.39	**0.08***	-0.51*	19.18*	-34.81*	**3.36***	1.99	-0.03	-5.71*	-4.72*	0.03*	-4.37*	4.07*
17	Pusa Jwala × Anugraha	2.36*	2.27*	0.30	0.14	0.01	-0.26*	-1.41	-35.86*	-0.12	-2.88	0.13*	2.61	8.91*	-0.02*	8.26*	-0.93
18	Pusa Jwala × Surajmukhi	**-3.03***	-2.00*	0.48	0.25	-0.09*	**0.77***	-17.77*	**70.67***	-3.24*	0.89	-0.11	3.10	-4.19*	-0.01	-3.90*	-3.14*
19	Pusa Sadabahar × Pant C 1	0.11	-1.16	-0.46	0.22	-0.09*	0.42*	-45.14*	-53.81*	-2.30*	-3.46	**0.47***	-7.80*	-5.78*	0.01	-1.12	-3.95*
20	Pusa Sadabahar × Anugraha	0.80	2.05*	0.28	-0.40*	0.04	0.07	-34.02*	-48.53*	1.55*	**5.34***	-0.14*	-7.18*	1.52	**0.08***	-1.09	3.39*
21	Pusa Sadabahar × Surajmukhi	-0.92	-0.89	0.19	0.18	**0.04***	-0.49*	**79.16***	**102.34***	0.76	-1.89	-0.33*	**14.98***	4.26*	-0.09*	2.22*	0.57
22	Kashmir Long × Pant C 1	-0.67	**-2.38***	0.56	0.30	0.01	0.08*	9.11*	18.41	0.14	1.72	**0.36***	**5.49***	-3.17*	**0.18***	**17.01***	**13.70***
23	Kashmir Long × Anugraha	0.03	1.50*	-0.63*	-0.48*	0.02	-0.68*	5.00	-56.31*	-1.01*	-1.01	-0.07	-9.23*	5.46*	-0.13*	-3.96*	-8.16*
24	Kashmir Long × Surajmukhi	0.64	0.89	0.08	0.18	-0.02	**0.60***	-14.11*	37.90*	0.87	-0.71	-0.29*	3.73*	-2.30*	-0.05*	-13.05*	-5.54*
25	Sel 352 × Pant C 1	2.67*	6.51*	-0.11	-0.19	**0.05***	0.18*	23.50*	**92.74***	1.25*	-5.86*	-0.23*	3.55*	2.95*	-0.000	-5.09*	-4.99*
26	Sel 352 × Anugraha	**-3.30***	**-6.28***	-0.23	0.24	-0.06*	0.37*	-23.52*	-51.31*	1.43*	-8.48*	0.13*	2.36	-6.26*	0.01	-5.56*	1.85*
27	Sel 352 × Surajmukhi	0.64	-0.22	0.34	-0.04	0.01	-0.55*	0.02	-41.44*	-2.69*	2.62	0.10	-5.91*	3.32*	-0.01	**10.65***	3.13*
28	LCA 443 × Pant C 1	-0.78	-0.72	0.38	0.12	0.03	-0.11*	3.44	-37.48*	0.36	2.26	-0.30*	-8.10*	**9.56***	**0.06***	-11.68*	3.35*
29	LCA 443 × Anugraha	2.25*	0.83	-0.08	0.27	-0.08*	-0.17*	5.44	9.81	-2.46*	-5.61*	0.04	3.15	-7.98*	-0.02	-5.02*	-2.82*
30	LCA 443 × Surajmukhi	-1.48*	-0.11	-0.30	-0.39	**0.05***	0.28*	-8.88*	27.67*	2.09*	3.36	**0.26***	4.95*	-1.57	-0.04*	**16.69***	-0.53
31	LCA 206 × Pant C 1	0.11	1.17	-0.20	-0.22	**0.05***	**0.84***	-16.27*	51.59*	-1.53*	-0.21	-0.16*	2.09	-13.72*	-0.09*	4.40*	-6.71*
32	LCA 206 × Anugraha	**-5.19***	-1.62*	-0.06	**0.94***	-0.02	-0.59*	**30.16***	11.87	-1.34*	-0.81	0.18*	2.64	-1.09	0.05*	2.53*	4.96*
33	LCA 206 × Surajmukhi	5.08*	0.44	0.25	-0.72*	-0.03	-0.25*	-13.90*	-63.46*	**2.87***	1.02	-0.02	-4.73*	**14.82***	0.04*	-6.93*	1.74*
	SE (Sij) ±	0.47	0.71	0.30	0.20	0.02	0.04	3.04	10.18	0.45	1.77	0.06	1.71	0.86	0.01	0.85	0.74
	SE (Sij-Skl) ±	0.66	1.00	0.43	0.28	0.03	0.06	4.30	14.40	0.64	2.51	0.09	2.42	1.22	0.01	1.21	1.05
	CD 5 %	0.94	1.42	0.61	0.39	0.04	0.08	6.07	20.34	0.90	3.54	0.12	3.42	1.72	0.02	1.70	1.48

* Significant at $P \leq 0.05$ Bold digits means top five

Table 4.22: Estimates of specific combining ability (SCA) effects for yield and related traits in chilli at Palampur during 2011

S. No.	Traits/ Crosses	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	-1.14	2.02*	-0.000	-0.39*	0.02	**0.54***	-40.24*	-73.00*	-1.93*	-14.32*	0.22*	-0.34	7.19*	-0.06*	-3.02*	-8.56*
2	Jawahar Mirch 283 × Anugraha	1.28	-1.83*	**0.51***	0.22	0.03	-0.15*	**27.97***	**95.49***	0.57	**6.96***	0.03	**7.00***	-5.48*	0.02	**9.14***	3.74*
3	Jawahar Mirch 283 × Surajmukhi	-0.14	-0.19	-0.51*	0.16	-0.05*	-0.39*	12.27*	-22.49*	1.37*	**7.36***	0.19*	-6.66*	-1.72	**0.05***	-6.12*	4.82*
4	Chilli Sonal × Pant C 1	0.30	**-6.09***	-0.22	0.39*	0.03	-0.14*	6.62	-4.91	0.85	3.40	0.23*	-2.00	7.47*	-0.03*	-6.19*	0.61
5	Chilli Sonal × Anugraha	2.39*	**-3.94***	0.29	-0.72*	**0.07***	0.50*	-31.91*	2.48	-7.33*	-2.02	-0.24*	-6.59*	0.14	-0.02	-6.70*	-9.59*
6	Chilli Sonal × Surajmukhi	**-2.70***	10.03*	-0.27	0.33*	-0.11*	-0.36*	**25.30***	2.43	**6.49***	-1.39	0.001	**8.58***	-7.61*	**0.50***	**12.89***	**8.99***
7	PAU Sel Long × Pant C 1	1.30	**-2.98***	-0.47*	**0.81***	**0.05***	-0.10*	20.53*	26.48*	-2.15*	**7.03***	-0.25*	2.88	-9.92*	-0.05*	-4.47*	-3.12*
8	PAU Sel Long × Anugraha	1.06	2.51*	0.38	-1.38*	-0.03	-0.17*	-30.57*	-81.87*	0.33	-6.66*	0.06	-10.28*	-1.75	0.04*	-2.48*	1.69
9	PAU Sel Long × Surajmukhi	**-2.36***	0.48	0.09	**0.57***	-0.02	0.27*	10.04*	55.40*	1.82*	-0.37	0.20*	**7.39***	**11.67***	0.01	6.94*	1.43
10	Arka Lohit × Pant C 1	0.86	2.91*	0.09	0.32*	-0.08*	-1.66*	**51.58***	**76.48***	0.63	3.96*	**0.37***	-2.68	**9.08***	-0.05*	**9.92***	-2.12
11	Arka Lohit × Anugraha	-2.05	2.73*	-0.53*	-0.16	0.04*	**1.64***	-51.41*	-109.96*	**2.78***	3.41	-0.15*	2.06	**11.75***	0.03*	0.25	**8.52***
12	Arka Lohit × Surajmukhi	1.19	**-5.64***	0.44	-0.15	0.04	0.02	-0.18	33.48*	**3.40***	-7.37*	-0.22*	0.63	-20.83*	0.02	-10.17*	-6.40*
13	LCA 436 × Pant C 1	-0.92	0.13	-0.20	-0.73*	0.00	0.38*	**24.59***	**127.34***	2.40*	5.47*	-0.03	**16.98***	-12.42*	0.02*	2.87*	**9.05***
14	LCA 436 × Anugraha	-0.50	-0.38	-0.55*	**1.53***	-0.06*	-0.53*	13.26*	17.74	**3.22***	2.42	-0.20*	-2.54	4.41*	-0.02	0.86	-9.64*
15	LCA 436 × Surajmukhi	1.41	0.25	**0.76***	-0.80*	**0.06***	0.14*	-37.85*	-145.07*	-5.63*	-7.89*	0.23*	-14.44*	8.01*	-0.01	-3.73*	0.60
16	Pusa Jwala × Pant C 1	-0.81	1.13	-0.47*	-0.46*	**0.07***	-0.53*	23.18*	-22.02*	1.85*	-3.77	0.08	-6.27*	-5.20*	0.03*	-4.52*	0.50
17	Pusa Jwala × Anugraha	-1.72	-0.05	**0.58***	-0.07	-0.02	-0.28*	-1.69	-14.01	1.00	-2.13	0.07	-0.70	7.47*	-0.04*	5.14*	5.13*
18	Pusa Jwala × Surajmukhi	2.53*	-1.08	-0.11	**0.53***	-0.05*	**0.81***	-21.50*	36.09*	-2.85*	**5.90***	-0.15*	6.97*	-2.27	0.01	-0.62	-5.63*
19	Pusa Sadabahar × Pant C 1	-0.59	-2.87*	0.29	0.39*	-0.13*	0.43*	2.57	42.48*	-1.49*	-0.59	**0.35***	6.23*	-1.09	0.01	1.07	-6.17*
20	Pusa Sadabahar × Anugraha	2.84*	4.62*	0.34	-0.28*	**0.05***	0.04*	-14.06*	-7.54	1.67*	-3.71	-0.14*	-3.70	-0.92	0.04*	-2.38*	**7.80***
21	Pusa Sadabahar × Surajmukhi	**-2.25***	-1.75*	-0.62*	-0.11	**0.08***	-0.47*	11.49*	-34.93*	-0.18	4.29*	-0.21*	-2.53	2.01	-0.05*	1.31	-1.63
22	Kashmir Long × Pant C 1	-0.14	0.47	**0.71***	-0.19	0.04*	0.05*	1.11	-12.64	0.74	-3.29	**0.29***	-0.43	0.53	**0.18***	**15.26***	**12.55***
23	Kashmir Long × Anugraha	0.62	0.28	-0.64*	-0.22	0.04	-0.67*	-2.12	-47.49*	-0.11	4.63*	-0.04	-3.12	3.70*	-0.10*	-3.25*	-8.81*
24	Kashmir Long × Surajmukhi	-0.48	-0.75	-0.07	0.41*	-0.08*	**0.62***	1.01	60.12*	-0.63	-1.34	-0.25*	3.55	-4.22*	-0.08*	-12.00*	-3.74*
25	Sel 352 × Pant C 1	1.97	7.02*	-0.49*	0.34*	0.00	0.31*	-11.68*	-50.08*	1.29*	-3.75	-0.20*	-7.05*	0.91	0.01	-5.47*	-2.17
26	Sel 352 × Anugraha	**-2.94***	**-4.16***	0.09	0.13	-0.07*	0.33*	-3.44	56.90*	1.78*	-0.51	0.15*	6.53*	-5.75*	0.01	-5.14*	1.80
27	Sel 352 × Surajmukhi	0.97	-2.86*	0.40	-0.46*	**0.06***	-0.65*	15.12*	-6.82	-3.07*	4.26*	0.05	0.53	4.84*	-0.02	**10.61***	0.37
28	LCA 443 × Pant C 1	-1.36	-0.76	**0.49***	-0.45*	-0.05*	-0.21*	4.14	-32.66*	-0.37	**6.00***	-0.40*	-5.05*	**12.64***	**0.06***	-7.88*	3.33*
29	LCA 443 × Anugraha	0.73	-0.27	-0.27	0.47*	-0.11	-0.16*	-23.43*	-82.68*	-2.22*	-3.88*	0.12*	-0.64	-10.36*	-0.04*	-1.02	-2.87*
30	LCA 443 × Surajmukhi	0.64	1.03	-0.22	-0.02	**0.07***	0.37*	19.29*	**115.34***	2.60*	-2.12	**0.28***	5.69*	-2.27	-0.02	8.90*	-0.46
31	LCA 206 × Pant C 1	0.53	-0.98	0.09	-0.03	**0.05***	**0.92***	-82.40*	-77.39*	-1.82*	-0.15	-0.24*	-2.27	-9.20*	-0.11*	2.42*	-3.89*
32	LCA 206 × Anugraha	-1.72	0.51	-0.20	**0.48***	-0.05*	-0.55*	**117.40***	**170.93***	-1.67*	1.49	**0.36***	**11.97***	-3.20*	**0.07***	5.58*	2.24*
33	LCA 206 × Surajmukhi	1.19	0.48	0.11	-0.46*	-0.000	-0.37*	-35.00*	-93.55*	**3.49***	-1.34	-0.11	-9.70*	**12.39***	0.04*	-8.00*	1.65
	SE (Sij) ±	1.08	0.84	0.22	0.14	0.02	0.01	3.37	10.45	0.53	1.91	0.06	1.96	1.20	0.01	1.03	1.10
	SE (Sij-Skl) ±	1.53	1.19	0.32	0.20	0.03	0.02	4.77	14.77	0.74	2.71	0.08	2.77	1.70	0.01	1.46	1.55
	CD 5 %	2.16	1.68	0.45	0.28	0.04	0.03	6.73	20.87	1.05	3.82	0.12	3.91	2.40	0.02	2.06	2.19

* Significant at $P \leq 0.05$ Bold digits means top five

Table 4.23: Estimates of specific combining ability (SCA) effects for yield and related traits in chilli at Bajaura during 2010

S. No.	Traits/ Crosses	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	-1.84*	-0.55	-0.22	-1.05*	-0.02	**0.66***	8.25*	**91.61***	-1.84*	-8.05*	-0.03	**7.63***	8.29*	-0.06*	-4.32*	-5.63*
2	Jawahar Mirch 283 × Anugraha	-0.48	-0.64	0.51*	0.20	0.01	-0.23*	15.47*	28.05*	1.40*	**6.78***	-0.08	5.57*	-5.39*	**0.04***	6.27*	5.32*
3	Jawahar Mirch 283 × Surajmukhi	2.31*	1.18	-0.29	**0.85***	0.01	-0.43*	-23.72*	-119.66*	0.43	1.27	0.11*	-13.20*	-2.90*	0.02*	-1.95	0.31
4	Chilli Sonal × Pant C 1	-0.95	**-4.32***	-0.44*	-0.65*	0.05*	-0.10*	-15.39*	-53.08*	0.61	-3.97	0.03	-4.78*	8.63*	-0.08*	-1.70	-0.41
5	Chilli Sonal × Anugraha	0.08	-1.75*	**0.55***	-0.55*	-0.00	0.49*	-49.18*	-45.04*	-6.49*	0.00	-0.02	-7.48*	5.44*	0.01	-2.04	-5.29*
6	Chilli Sonal × Surajmukhi	0.87	6.07*	-0.12	**1.20***	-0.05*	-0.39*	**64.57***	**98.12***	**5.88***	3.97	-0.01	**12.26***	-14.07*	**0.07***	3.74*	5.70*
7	PAU Sel Long × Pant C 1	-0.62	**-2.77***	-0.64*	0.29*	-0.13*	-0.14*	5.62	-29.95*	-1.73*	-5.04*	-0.24*	-1.40	-14.65*	-0.07*	-5.03*	-3.58*
8	PAU Sel Long × Anugraha	0.75	1.14	0.22	-0.00	0.00	-0.15*	21.16*	51.89*	0.52	0.39	-0.08	-0.13	2.17	**0.04***	-2.04	2.71*
9	PAU Sel Long × Surajmukhi	-0.13	1.63	0.42*	-0.29*	**0.13***	0.30*	-26.78*	-21.95	1.21*	4.65*	**0.32***	1.54	**12.49***	0.03*	7.07*	0.86
10	Arka Lohit × Pant C 1	0.94	4.57*	**0.94***	0.60*	-0.20*	-1.53*	21.20*	-58.48*	-0.28	-4.49*	0.15*	-3.53*	**9.18***	-0.01	**9.75***	-3.35*
11	Arka Lohit × Anugraha	1.64*	0.14	-1.34*	-0.61*	**0.15***	**1.75***	-24.84*	-17.78	**3.29***	-1.29	0.10*	1.94	8.50*	0.02	0.57	**8.27***
12	Arka Lohit × Surajmukhi	**-2.58***	**-4.71***	0.40	0.01	0.05*	-0.22*	3.64	**76.26***	-3.01*	**5.78***	-0.25*	1.58	-17.68*	-0.00	-10.32*	-4.91*
13	LCA 436 × Pant C 1	-1.95*	-0.43	**0.65***	0.54*	**0.15***	0.03	**44.26***	**154.88***	1.38*	5.59*	0.02	**12.17***	-5.21*	**0.04***	2.32	**5.87***
14	LCA 436 × Anugraha	-0.59	1.14	-0.49*	-0.19	-0.06*	-0.54*	17.50*	9.38	**3.63***	-1.35	-0.12*	-2.69*	-3.22*	-0.03*	-2.03	-5.51*
15	LCA 436 × Surajmukhi	2.54*	-0.71	-0.16	-0.35*	-0.10*	**0.52***	-61.76*	-164.26*	-5.01*	-4.24*	0.10*	-9.48*	8.43*	-0.01	-0.28	-0.36
16	Pusa Jwala × Pant C 1	1.39*	1.57	**0.74***	-0.05	0.04	-0.31*	4.63	-41.41*	**3.72***	3.15	-0.13*	0.07	-3.65*	**0.06***	-3.92*	3.81*
17	Pusa Jwala × Anugraha	0.08	-0.19	0.40	-0.05	**0.06***	-0.42*	10.66*	-7.51	-1.04*	-0.62	0.09*	-4.46*	**9.83***	-0.05*	**11.07***	-3.73*
18	Pusa Jwala × Surajmukhi	-1.47*	-1.37	-1.14*	0.09	-0.09*	**0.73***	-15.29*	48.92*	-2.68*	-2.53	0.04	4.38*	-6.18*	-0.01	-7.15*	-0.08
19	Pusa Sadabahar × Pant C 1	1.83*	**-1.88***	0.21	**0.97***	-0.09*	0.47*	-53.86*	-68.97*	-2.06*	1.03	**0.41***	-12.22*	-3.43*	0.03*	-3.58*	-4.52*
20	Pusa Sadabahar × Anugraha	1.19	4.70*	0.13	-3.03*	-0.18*	-0.04	-52.39*	-87.40*	1.85*	-7.28*	-0.15*	4.79*	-2.61	0.03*	-0.10	4.10*
21	Pusa Sadabahar × Surajmukhi	**-3.02***	**-2.82***	-0.34	**2.06***	**0.27***	-0.43*	**106.24***	**156.37***	0.21	**6.25***	-0.26*	7.43*	6.04*	-0.06*	3.68*	0.42
22	Kashmir Long × Pant C 1	-0.84	-0.88	-0.95*	-0.40*	0.05*	0.47*	-1.53	16.30	-0.51	1.88	**0.39***	**7.60***	-5.87*	**0.19***	**16.19***	**9.37***
23	Kashmir Long × Anugraha	1.19	-0.97	-0.49*	1.82*	-0.01	-0.56*	**24.28***	30.74*	-0.60	**6.62***	-0.12*	2.53*	3.28*	-0.12*	-7.82*	-4.68*
24	Kashmir Long × Surajmukhi	-0.35	1.85*	**1.44***	-1.42*	-0.05*	0.09*	-22.75*	-47.03*	1.10*	-8.50*	-0.28*	-10.13*	2.60	-0.07*	-8.37*	-4.69*
25	Sel 352 × Pant C 1	0.94	3.01*	0.25	-0.11	**0.11***	-0.03	8.69*	6.12	1.05*	1.65	-0.22*	5.91*	5.68*	-0.04*	-3.94*	-0.52
26	Sel 352 × Anugraha	**-2.03***	-2.08*	-0.16	0.44*	-0.00	0.51*	-1.70	43.09*	0.96*	-1.93	0.04	-2.49*	-8.17*	-0.01	-4.22*	-1.73
27	Sel 352 × Surajmukhi	1.09	-0.93	-0.09	-0.33*	-0.11*	-0.48	-6.98	-49.21*	-2.01*	0.28	**0.18***	-3.42*	2.49	**0.04***	**8.16***	2.25*
28	LCA 443 × Pant C 1	-0.95	0.12	-0.20	-0.23	-0.00	-0.15*	13.36*	8.61	0.61	**6.12***	-0.2.00*	-7.49*	**12.35***	0.01	-9.47*	**6.04***
29	LCA 443 × Anugraha	3.41*	0.03	0.49*	0.33*	-0.02	-0.18*	-2.34	-35.62*	-2.15*	1.15	0.13*	0.04	-10.17*	0.02*	-3.66*	-6.18*
30	LCA 443 × Surajmukhi	**-2.47***	-0.15	-0.28	-0.11	0.03	0.33*	-11.02*	27.01*	1.55*	-7.28*	0.07	**7.45***	-2.18	-0.04*	**13.13***	0.14
31	LCA 206 × Pant C 1	2.05*	1.57	-0.35	0.08	0.04	**0.63***	-35.22*	-25.63*	-0.95	2.14	-0.19*	-3.96*	-11.32*	-0.08*	3.69*	-7.08*
32	LCA 206 × Anugraha	**-5.25***	-1.53	0.18	**1.63***	0.05*	-0.62*	**41.38***	30.20*	-1.37*	-2.48	**0.20***	2.38*	0.33	**0.05***	4.01*	**6.71***
33	LCA 206 × Surajmukhi	3.20*	-0.04	0.17	-1.71*	-0.09*	-0.01	-6.16	-4.57	**2.32***	0.34	-0.01	1.58	**10.99***	0.03*	-7.71*	0.36
	SE (Sij) ±	0.66	0.85	0.20	0.12	0.02	0.02	3.97	11.55	0.48	2.04	0.04	1.15	1.42	0.01	1.18	0.87
	SE (Sij-Skl) ±	0.93	1.20	0.29	0.17	0.03	0.04	5.61	16.34	0.68	2.88	0.06	1.63	2.01	0.01	1.66	1.23
	CD 5 %	1.31	1.70	0.41	0.24	0.04	0.05	7.93	23.08	0.96	4.07	0.08	2.30	2.84	0.02	2.35	1.74

* Significant at P ≤ 0.05 Bold digits means top five

Table 4.24: Estimates of specific combining ability (SCA) effects for yield and related traits in chilli at Bajaura during 2011

S. No.	Traits/ Crosses	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketabl e fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Averag e dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	-0.63	-0.60	-0.35	-0.58*	-0.05*	**0.77***	-10.29*	24.51*	-1.14*	-0.82	-0.03	2.03	8.27*	-0.08*	0.22	-1.46
2	Jawahar Mirch 283 × Anugraha	0.71	**-5.23***	0.38	-0.02	0.04	-0.40*	**28.59***	**57.20***	0.04	2.36*	-0.05	2.40	-4.51*	0.001	1.90*	**6.59***
3	Jawahar Mirch 283 × Surajmukhi	-0.08	5.83*	-0.03	0.60*	0.01	-0.37*	-18.31*	-81.71*	1.10*	-1.54	0.08	-4.44*	-3.76*	**0.07***	-2.13*	-5.13*
4	Chilli Sonal × Pant C 1	-1.52*	**-5.26***	0.47	-0.56*	0.04*	-0.09*	-21.64*	-59.38*	0.08	-2.30*	-0.04	-8.63*	**10.16***	-0.05*	-0.22	-3.40*
5	Chilli Sonal × Anugraha	2.49*	-0.57	0.27	-0.57*	-0.04	0.56*	-59.01*	-80.02*	-6.74*	3.62*	0.03	-5.43*	1.55	0.01	-2.87*	-3.53*
6	Chilli Sonal × Surajmukhi	-0.97	5.83*	-0.74*	**1.13***	-0.00	-0.47*	**80.65***	**139.40***	**6.66***	-1.32	0.10	**14.07***	-11.71*	0.04*	3.10*	**6.93***
7	PAU Sel Long × Pant C 1	-0.74	0.29	0.36	0.05	-0.12*	-0.26*	3.12	-54.50*	-1.59*	0.08	-0.23*	-6.24*	-7.01*	-0.11*	-4.22*	0.60
8	PAU Sel Long × Anugraha	2.93*	2.99*	-0.64*	-0.10	0.02	-0.07*	1.35	7.54	0.26	-5.57*	-0.06	1.62	-2.28	**0.05***	-3.21*	2.64*
9	PAU Sel Long × Surajmukhi	**-2.19***	**-3.28***	0.28	0.04	**0.10***	0.33*	-4.47	46.96*	1.32*	**5.49***	**0.29***	**4.62***	9.29*	**0.06***	**7.43***	-3.24*
10	Arka Lohit × Pant C 1	**-2.74***	-0.26	0.34	0.37*	-0.16*	-1.52*	**24.74***	-17.94	0.53	-7.50*	**0.25***	-3.24	**9.71***	-0.02	**9.11***	-5.40*
11	Arka Lohit × Anugraha	1.93*	0.43	-0.86*	-0.81*	**0.09***	**1.72***	-21.76*	-21.91*	**2.71***	2.29*	0.05	-0.38	5.27*	-0.001	-0.37	**11.98***
12	Arka Lohit × Surajmukhi	0.81	-0.17	0.53	0.44*	0.07*	-0.20*	-2.98	39.85*	-3.23*	**5.22***	-0.30*	3.62*	-14.99*	0.02	-8.74*	-6.57*
13	LCA 436 × Pant C 1	-0.74	2.29*	-0.17	0.47*	**0.17***	-0.07*	**30.57***	**98.28***	**2.64***	5.04*	-0.25*	**9.77***	-2.79	**0.07***	2.00*	5.60*
14	LCA 436 × Anugraha	-0.40	0.32	0.29	-0.38*	-0.05*	-0.54*	22.79*	33.65*	2.15*	-2.60*	-0.04	-0.40	-7.73*	-0.05	-4.49*	-8.36*
15	LCA 436 × Surajmukhi	1.14	-2.62*	-0.12	-0.09	-0.12*	**0.61***	-53.35*	-131.93*	-4.79*	-2.44*	**0.29***	-9.37*	**10.52***	-0.06*	2.49*	2.76*
16	Pusa Jwala × Pant C 1	0.93	2.18*	**0.83***	0.03	0.07*	-0.41*	6.26*	-37.16*	2.19*	-6.86*	-0.14*	-3.36	-7.90*	**0.07***	-6.17*	2.10
17	Pusa Jwala × Anugraha	0.60	-0.79	0.09	-0.25*	0.04	-0.25*	14.19*	27.20*	1.37*	4.36*	0.07	3.51	9.50*	-0.01	**15.52***	-3.19*
18	Pusa Jwala × Surajmukhi	-1.53*	-1.39	-0.92*	0.22	-0.11*	**0.66***	-20.45*	9.96	-3.57*	2.50*	0.07	-0.16	-1.60	-0.06*	-9.35*	1.10
19	Pusa Sadabahar × Pant C 1	3.93*	-2.93*	-0.33	**0.97***	-0.04*	0.50*	-39.32*	-52.83*	-0.81	**6.34***	**0.42***	-0.97	-4.90*	**0.04***	-2.17*	-6.07*
20	Pusa Sadabahar × Anugraha	-1.74*	7.43*	-0.06	-2.24*	-0.03	-0.08*	-7.78*	0.20	1.71*	-4.81*	-0.14*	-2.27	2.17	0.01	-0.82	3.14*
21	Pusa Sadabahar × Surajmukhi	-2.19*	**-4.51***	0.39	**1.26***	0.07*	-0.42*	**47.10***	**52.63***	-0.90	-1.53	-0.28*	3.23	2.74	-0.05*	2.99*	2.93*
22	Kashmir Long × Pant C 1	-1.52*	-1.82*	-1.17*	-0.62*	-0.03	0.57*	9.80*	**73.51***	0.08	4.45*	**0.29***	**10.87***	-2.90	**0.16***	**12.61***	**11.65***
23	Kashmir Long × Anugraha	-0.18	-1.79*	-0.24	**1.34***	-0.05*	-0.69*	13.45*	-18.13	0.26	**5.69***	-0.05	-2.60	8.00*	-0.11*	-3.71*	-5.14*
24	Kashmir Long × Surajmukhi	1.70*	3.61*	**1.41***	-0.72*	**0.08***	0.12*	-23.25*	-55.37*	-0.34	-10.14*	-0.24*	-8.27*	-5.10*	-0.05*	-8.90*	-6.52*
25	Sel 352 × Pant C 1	4.60*	6.07*	**0.65***	-0.27*	**0.11***	-0.03	5.17	2.73	1.53*	2.57*	-0.11*	1.65	1.00	-0.04*	-7.17*	2.76*
26	Sel 352 × Anugraha	**-4.07***	**-4.57***	-0.22	0.28*	-0.02	0.45*	-7.02*	1.76	2.37*	-8.59*	0.04	-1.82	-5.28*	0.02	-4.82*	-1.86
27	Sel 352 × Surajmukhi	-0.53	-1.51*	-0.43	-0.02	-0.08*	-0.42*	1.85	-4..49	-3.90*	**6.02***	0.07	0.18	4.29*	0.02	**11.99***	-0.90
28	LCA 443 × Pant C 1	**-5.18***	-1.93*	-0.44	0.16	0.02	-0.22*	10.05*	6.95	-1.03*	4.68*	-0.15*	2.15	**9.93***	-0.00	-5.17*	3.49*
29	LCA 443 × Anugraha	5.15*	1.10	**0.63***	0.80*	-0.05*	-0.20*	7.39*	6.65	-2.85*	1.36	0.09	**5.85***	-8.01*	0.02*	-1.15	-5.64*
30	LCA 443 × Surajmukhi	0.03	0.83	-0.19	-0.96*	0.04	0.43*	-17.44*	-13.60	**3.88***	-6.04*	0.07	-8.00*	-1.93	-0.02*	6.32*	2.15
31	LCA 206 × Pant C 1	3.60*	1.96*	-0.17	-0.03	-0.01	**0.77***	-18.46*	15.84	-2.48*	-5.68*	-0.01	-4.02*	-13.57*	-0.05*	1.17	-9.85*
32	LCA 206 × Anugraha	**-7.40***	0.66	0.36	**1.94***	0.06*	-0.49*	7.82*	-14.13	-1.29*	1.88*	0.06	-0.49	1.33	0.01	4.02*	3.36*
33	LCA 206 × Surajmukhi	3.81*	-2.62*	-0.19	-1.92*	-0.05*	-0.28*	10.64*	-1.71	**3.77***	3.80*	-0.05	4.51*	**12.24***	0.04*	-5.18*	**6.49***
	SE (Sij) ±	0.62	0.67	0.27	0.12	0.02	0.03	3.11	10.12	0.46	0.93	0.05	1.78	1.48	0.01	0.94	1.00
	SE (Sij-Skl) ±	0.88	0.95	0.39	0.17	0.03	0.04	4.39	14.31	0.66	1.31	0.07	2.51	2.09	0.02	1.33	1.55
	CD 5 %	1.25	1.35	0.55	0.25	0.04	0.06	6.20	20.22	0.93	1.85	0.10	3.55	2.96	0.02	1.89	2.19

* Significant at $P \leq 0.05$ Bold digits means top five

Table 4.25: Pooled over environments estimates of specific combining ability (SCA) effects for yield and related traits in chilli

S. No.	Traits/ Crosses	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	-0.96*	-0.04	-0.11	-0.56*	-0.01	**0.65***	-19.08*	5.58	-1.83*	-8.66*	-0.07*	3.07*	**9.12***	-0.06*	-2.86*	-5.01*
2	Jawahar Mirch 283 × Anugraha	0.58*	-1.97*	**0.46***	0.12*	0.02*	-0.24*	30.00*	**79.14***	0.78*	**6.93***	-0.05*	**6.14***	-6.75*	0.02*	7.09*	**5.36***
3	Jawahar Mirch 283 × Surajmukhi	0.38	2.01*	-0.35*	0.44*	-0.01	-0.41*	-10.91*	-84.71*	1.06*	1.73*	0.12*	-9.21*	-2.36*	**0.05***	-4.23*	-0.36
4	Chilli Sonal × Pant C 1	-0.71*	**-5.04***	0.18*	-0.20*	0.03*	-0.10*	-13.37*	-42.91*	0.36*	-1.79*	0.06*	-3.34*	8.79*	-0.06*	-3.11*	-1.30*
5	Chilli Sonal × Anugraha	1.33*	**-2.38***	0.19*	-0.55*	0.03*	**0.48***	-40.61*	-34.59*	-6.78*	0.46	-0.08*	-7.36*	2.75*	0.000	-4.67*	-5.89*
6	Chilli Sonal × Surajmukhi	-0.62*	7.43*	-0.37*	**0.75***	-0.06*	-0.37*	**53.98***	**77.51***	**6.42***	1.34*	0.03	**10.70***	-11.53*	**0.06***	7.78*	**7.19***
7	PAU Sel Long × Pant C 1	-0.12	-1.46*	-0.12*	0.49*	-0.05*	-0.13*	6.31*	-21.17*	-2.00*	**10.54***	-0.26*	-2.00*	-10.23*	-0.07*	-4.08*	-1.80*
8	PAU Sel Long × Anugraha	1.41*	1.78*	0.09	-0.67*	0.000	-0.13*	-4.13*	-16.13*	0.53*	-3.37*	-0.04*	-2.36*	-0.89*	**0.04***	-2.42*	1.78*
9	PAU Sel Long × Surajmukhi	-1.29*	-0.32	0.03	0.18*	**0.06***	0.26*	-2.18	37.30*	1.47*	2.84*	**0.30***	4.36*	**11.12***	**0.03***	6.50*	0.02
10	Arka Lohit × Pant C 1	0.21	2.71*	**0.30***	0.40*	-0.13*	-1.58*	**34.41***	-10.61*	0.45*	-0.16	**0.24***	-3.06*	**9.07***	-0.02*	**9.67***	-4.02*
11	Arka Lohit × Anugraha	1.00*	1.95*	-0.71*	-0.36*	**0.09***	**1.70***	-30.91*	-23.38*	**2.97***	1.97*	0.02	1.37*	**9.02***	0.02*	0.09	**9.26***
12	Arka Lohit × Surajmukhi	-1.21*	**-4.66***	**0.41***	-0.04	0.05*	-0.13*	-3.51*	33.98*	-3.42*	-1.80*	-0.26*	1.69*	-18.09*	0.01*	-9.76*	-5.24*
13	LCA 436 × Pant C 1	**-1.54***	0.29	-0.01	-0.12*	**0.08***	0.12*	**31.65***	**122.03***	2.31*	**4.06***	-0.06*	**12.61***	-6.53*	**0.04***	2.34*	**6.92***
14	LCA 436 × Anugraha	-0.75*	0.20	-0.19*	0.40*	-0.06*	-0.52*	20.09*	24.25*	**3.08***	-0.43	-0.11*	-0.21	-2.03*	-0.02*	-0.69*	-7.71*
15	LCA 436 × Surajmukhi	2.29*	-0.49*	0.20*	-0.28*	-0.02	0.40*	-51.74*	-146.29*	-5.39*	-3.63*	0.17*	-12.40*	8.57*	-0.02*	-1.65*	0.78*
16	Pusa Jwala × Pant C 1	0.54*	1.15*	0.08	-0.22*	**0.06***	-0.44*	13.31*	-33.87*	**2.78***	-1.37*	-0.05*	-3.82*	-5.37*	0.05*	-4.74*	2.62*
17	Pusa Jwala × Anugraha	0.33	0.31	**0.34***	-0.06	0.02	-0.30*	5.44*	-7.55*	0.30*	-0.32	0.09*	0.24	8.93*	-0.03*	**10.00***	-0.68*
18	Pusa Jwala × Surajmukhi	-0.87*	-1.46*	-0.42*	0.27*	-0.08*	**0.74***	-18.75*	41.41*	-3.08*	1.69*	-0.04*	3.57*	-3.56*	-0.02*	-5.25*	-1.94*
19	Pusa Sadabahar × Pant C 1	1.32*	-2.21*	-0.07	**0.64***	-0.09*	0.46*	-33.94*	-33.28*	-1.66*	0.83	**0.41***	-3.69*	-3.80*	0.02*	-1.45*	-5.18*
20	Pusa Sadabahar × Anugraha	0.78*	4.70*	0.17*	-1.49*	-0.03*	0.00	-27.06*	-35.82*	1.69*	-2.61*	-0.14*	-2.09*	0.04	**0.04***	-1.10*	4.61*
21	Pusa Sadabahar × Surajmukhi	**-2.10***	**-2.49***	-0.10	**0.85***	**0.12***	-0.45*	**61.00***	**69.10***	-0.03	1.78*	-0.27*	**5.78***	3.76*	-0.06*	2.55*	0.57
22	Kashmir Long × Pant C 1	-0.79*	-1.15*	-0.21*	-0.23*	0.02*	0.29*	4.62*	23.89*	0.11	1.19*	**0.33***	**5.88***	-2.85*	**0.18***	**15.27***	**11.82***
23	Kashmir Long × Anugraha	0.41	-0.24	-0.50*	**0.62***	0.000	-0.65*	10.15*	-22.80*	-0.36*	**3.98***	-0.07*	-3.10*	5.11*	-0.11*	-4.69*	-6.70*
24	Kashmir Long × Surajmukhi	0.38	1.40*	**0.72***	-0.39*	-0.02*	0.36*	-14.78*	-1.10	0.25	-5.17*	-0.26*	-2.78*	-2.25*	-0.06*	-10.58*	-5.12*
25	Sel 352 × Pant C 1	2.54*	5.65*	0.08	-0.06	**0.07***	0.11*	6.42*	12.88*	1.28*	1.58*	-0.19*	1.01	2.63*	-0.02*	-5.41*	-1.23*
26	Sel 352 × Anugraha	**-3.09***	**-4.27***	-0.13	0.27*	-0.04*	0.42*	-8.92*	12.61*	1.64*	-4.87*	0.09*	1.14*	-6.37*	0.01*	-4.94*	0.01
27	Sel 352 × Surajmukhi	0.54*	-1.38*	0.05	-0.21*	-0.03*	-0.52*	2.50*	-25.49*	-2.92*	3.30*	0.10*	-2.16*	3.73*	0.01*	**10.35***	1.21*
28	LCA 443 × Pant C 1	**-2.07***	-0.82*	0.06	-0.10*	0.000	-0.17*	7.75*	-13.65*	-0.11	**4.77***	-0.26*	-4.62*	**11.12***	0.03*	-8.55*	4.05*
29	LCA 443 × Anugraha	2.89*	0.42	0.19*	0.47*	-0.04*	-0.18*	-3.24*	-25.46*	-2.42*	-1.75*	0.09*	2.10*	-9.13*	0.000	-2.71*	-4.3*
30	LCA 443 × Surajmukhi	-0.82*	0.40	-0.25*	-0.37*	0.04*	0.35*	-4.51*	39.11*	2.53*	-3.02*	0.17*	2.52*	-1.99*	-0.03*	**11.26***	0.32
31	LCA 206 × Pant C 1	1.57*	0.93*	-0.16*	-0.05	0.03*	**0.79***	-38.09*	-8.90*	-1.69*	-0.98	-0.15*	-2.04*	-11.95*	-0.08*	2.92*	-6.88*
32	LCA 206 × Anugraha	**-4.89***	-0.49*	0.07	**1.25***	0.01	-0.56*	**49.19***	**49.72***	-1.42*	0.02	**0.20***	4.12*	-0.66	**0.05***	4.03*	4.32*
33	LCA 206 × Surajmukhi	3.32*	-0.43	0.09	-1.20*	-0.04*	-0.23*	-11.10*	-40.82*	**3.11***	0.95	-0.05*	-2.08*	**12.61***	**0.04***	-6.96*	2.56*
	SE (Sij) ±	0.24	0.25	0.08	0.05	0.01	0.01	1.20	3.72	0.15	0.58	0.02	0.58	0.43	0.000	0.33	0.33
	SE (Sij-Skl) ±	0.34	0.35	0.11	0.07	0.01	0.01	1.69	5.25	0.21	0.82	0.03	0.82	0.60	0.000	0.47	0.47
	CD 5 %	0.48	0.50	0.16	0.10	0.02	0.02	2.40	7.44	0.30	1.16	0.04	1.16	0.86	0.00	0.66	0.66

* Significant at P ≤ 0.05 Bold digits means top five

ability (Table 4.21, 4.22, 4.23, 4.24 and 4.25). The top five cross combinations with desirable negative SCA effects for early harvest were ‘Chilli Sonal × Pant C 1’, ‘Arka Lohit × Surajmukhi’, ‘Selection 352 × Anugraha’, ‘Pusa Sadabahar × Surajmukhi’ and ‘Chilli Sonal × Anugraha’ in pooled over environments. These crosses also exhibited significant negative SCA effects at Palampur and Bajaura during both the years except cross ‘Pusa Sadabahar × Surajmukhi’ at Palampur during 2010 and ‘Arka Lohit × Surajmukhi’ and ‘Chilli Sonal × Anugraha’ during 2011 at Bajaura. The parents ‘Chilli Sonal’ and ‘Anugraha’ with good GCA effects for early harvest were involved in three crosses out of top five.

Primary branches/plant

Majority of cross combinations showed average specific combining ability effects for primary branches/plant. The significant SCA effects were observed for only ‘Chilli Sonal × Pant C1’ during 2010 whereas, five crosses showed good SCA effects during 2011 at Palampur. On the other hand, eight crosses during 2010 and four crosses during 2011 exhibited significant positive SCA effects at Bajaura. Pooled data over environments revealed ten crosses with positive SCA effects which were found to be good specific combiners (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

The top cross combination in order of ranking was ‘Kashmir Long × Surajmukhi’ at Bajaura during both the years and also in pooled environments which involved ‘Surajmukhi’ with good GCA effect. The other top five crosses with good SCA effects in pooled over environments were ‘Jawahar Mirch 283 × Anugraha’, ‘Arka Lohit × Surajmukhi’, ‘Pusa Jwala × Anugraha’ and ‘Arka Lohit × Pant C1’. Besides, cross ‘Pusa Jwala × Pant C1’ and ‘LCA 443 × Anugraha’ also showed consistency at Bajaura by exhibiting good SCA effects during both the years.

Fruit length (cm)

Out of 33 cross combinations, only four in 2010 and 12 in 2011 at Palampur, 11 each in respective years at Bajaura and 14 in pooled environment (Table 4.21, 4.22, 4.23, 4.24 and 4.25) exhibited significant positive SCA effects indicating their good specific combining ability. The crosses *viz*., 'LCA 206 × Anugraha' (Good × Good), 'LCA 436 × Anugraha'(Good × Good), 'PAU Selection Long × Pant C1' (Average × Poor) and 'PAU Selection Long × Surajmukhi' (Average × Average/Poor) at Palampur, and 'Pusa Sadabahar × Surajmukhi' (Poor × Good), 'Kashmir Long × Anugraha' (Good × Good), 'LCA 206 × Anugraha' (Good × Good), 'Chilli Sonal × Surajmukhi' (Poor × Good) and 'Pusa Sadabahar × Pant C1' (Poor × Poor) during both the years at Bajaura were noticed to have good specific combining ability. These top five crosses at Bajaura also exhibited significant positive SCA effects in pooled over environments.

Fruit girth (cm)

For this trait, out of the seven and 11 cross combinations in the respective years at Palampur, the top five crosses namely, 'Chilli Sonal × Anugraha', 'Pusa sadabahar × Surajmukhi', 'Pusa Jwala × Pant C1', 'LCA 436 × Surajmukhi' and 'LCA 206 × Pant C1' were observed to be good specific combiners during both the years. Similarly, 10 crosses in each year at Bajaura revealed significant positive SCA effects, of which 'Arka Lohit × Anugraha', 'LCA 436 × Pant C1', 'PAU Selection Long × Surajmukhi', 'Selection 352 × Pant C1' and 'Pusa Sadabahar × Surajmukhi' were the top five good specific combiners during both the years with one exception as cross 'Pusa Sadabahar × Surajmukhi' ranked sixth during 2011(Table 4.21, 4.22, 4.23, 4.24 and 4.25). These crosses with good specific combining ability at Bajaura were also ranked among top five in pooled environments out of 13 cross combinations.

Average fruit weight (g)

The cross combinations, *viz*., 'Arka Lohit × Anugraha' (Good × Good), 'LCA 206 × Pant C1' (Poor × Poor), 'Pusa Jwala × Surajmukhi' (Poor × Good) and 'Jawahar Mirch 283 × Pant C1' (Poor × Poor) expressed significant desirable SCA effects during both the years at both the locations and also in pooled over environments and were placed at top four positions out of the fourteen cross combinations each in the respective years at Palampur and pooled over environment and 12 crosses at Bajaura in each year (Table 4.21, 4.22, 4.23, 4.24 and 4.25). However, the parents ‘Anugraha’ and ‘Surajmukhi’ showed poor and average GCA effects at Palampur and Bajaura during 2011, respectively.

Marketable fruits/plant

A total of 11 and 13 cross combinations at Palampur and 13 and 12 crosses at Bajaura in the respective years along with 15 cross combinations in pooled environments exhibited positive SCA effects and thus, were good cross combinations (Table 4.21, 4.22, 4.23, 4.24 and 4.25). The crosses ‘ Jawahar Mirch 283 × Anugraha’ , ‘Chilli Sonal × Surajmukhi’, ‘Arka Lohit × Pant C1’ and ‘LCA 206 × Anugraha’ during 2010 and 2011 ranked among top five at Palampur, while at Bajaura, ‘Pusa Sadabahar × Surajmukhi’, ‘Chilli Sonal × Surajmukhi’ and ‘LCA 436 × Pant C1’ were placed at top three in the respective years. Also, cross ‘Pusa Sadabahar × Surajmukhi’ showed the maximum SCA effect during 2010 at Palampur. Similarly, five top ranked combinations in pooled environments with good SCA effects were ‘Pusa Sadabahar × Surajmukhi’ (Good × Good), ‘Chilli Sonal × Surajmukhi’ (Good × Good), ‘LCA 206 × Anugraha’ (Good × Good), ‘Arka Lohit × Pant C1’ (Poor × Poor) and ‘LCA 436 × Pant C1’ (Good × Poor).

Marketable fruit yield/plant

Significant positive SCA effects were noticed for 12 crosses each during 2010 and 2011 at Palampur, 12 and 10 cross combinations in the respective years at Bajaura and 13 crosses in pooled environments, which predicted these cross combinations with good specific combining ability for marketable green fruit yield. ‘Jawahar Mirch 283 × Anugraha’ (Good × Poor), ‘LCA 436 × Pant C1’ (Good × Poor), ‘Pusa Sadabahar × Surajmukhi’ (Poor × Good), ‘Selection 352 × Surajmukhi’ (Good × Poor), and ‘Pusa Jwala × Surajmukhi’ (Average × Poor) during 2010 and ‘LCA 206 × Anugraha’ (Poor × Average), ‘LCA 436 × Pant C1’ (Good × Poor), ‘LCA 443 × Surajmukhi’ (Good × Good), ‘Jawahar Mirch 283 × Anugraha’ (Good × Average) and ‘Arka Lohit × Pant C1’ (Poor × Poor) during 2011 were the top five cross combination in order of ranking at Palampur. On the other hand, ‘Pusa Sadabahar × Surajmukhi’ (Poor × Good), ‘LCA 436 × Pant C1’ (Good × Poor), ‘Chilli Sonal × Surajmukhi’ (Poor × Good), ‘Jawahar Mirch 283 × Pant C1’ (Good × Poor) and ‘Arka Lohit × Surajmukhi’ (Good × Good) during 2010 and ‘Chilli Sonal × Surajmukhi’ (Poor × Good), ‘LCA 436 × Pant C1’ (Good × Average), ‘Kashmir Long × Pant C1’ (Poor × Average), ‘Jawahar Mirch 283 × Anugraha’ (Average × Poor) and ‘Pusa Sadabahar × Surajmukhi’ (Poor × Good) during 2011 were the best five specific combiners at Bajaura (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Out of thirteen cross combinations in pooled environments, ‘LCA 436 × Pant C1’, ‘Jawahar Mirch 283 × Anugraha’, ‘Chilli Sonal × Surajmukhi’, ‘Pusa Sadabahar × Surajmukhi’ and ‘LCA 206 × Anugraha’ were the top five promising combinations with good specific combining ability and had ‘Good × Poor’, ‘Good × Poor’, ‘Poor × Good’, ‘Poor × Good’ and ‘Poor × Poor’ general combiners as their parents.

Harvest duration (days)

A total of 15 and 12 cross combinations in the respective years at Palampur, 13 each in the respective years at Bajaura and 17 combinations in the pooled environments (Table 4.21, 4.22, 4.23, 4.24 and 4.25) found to have significant positive SCA effects, indicating their good specific combining ability. The cross ‘Chilli Sonal × Surajmukhi’ (Poor × Good) was the top specific combiner in both the environments in both the years and pooled over environments. The other crosses namely ‘LCA 436 × Anugraha’, ‘Arka Lohit × Anugraha’ and ‘LCA 436 × Pant C1’ retained their positions among top five as good specific combiners in both the locations in the respective years and pooled over environments except ‘LCA 436 × Pant C1’ ranked at 9th position in 2010 at Bajaura.

Plant height (cm)

The four cross combinations to express significant desirable SCA effect during 2010 at Palampur were ‘Jawahar Mirch 283 × Anugraha’, ‘Arka Lohit × Pant C1’, ‘Pusa Sadabahar × Anugraha’ and ‘ Chilli Sonal × Surajmukhi’. On the other hand, out of the 10 cross combinations, 'Jawahar Mirch 283 × Surajmukhi', 'PAU Selection Long × Pant C1' and 'Jawahar Mirch 283 × Anugraha' were the three best crosses during 2011 at Palampur. At Bajaura, seven and 16 cross combinations exhibited significant desirable SCA effects during 2010 and 2011, respectively. The crosses 'Jawahar Mirch 283 × Anugraha', 'Kashmir Long × Anugraha' and 'Pusa Sadabahar × Surajmukhi' during 2010 and 'Pusa Sadabahar × Pant C1', 'Selection 352 × Surajmukhi' and 'Kashmir Long × Anugraha' during 2011 were the top three specific cross combiners at Bajaura. In pooled environments, out of 14 cross combinations, the five best crosses were 'PAU Selection Long × Pant C1', 'Jawahar Mirch 283 × Anugraha', 'LCA 443 × Pant C1', 'LCA 436 × Pant C1' and 'Kashmir Long × Anugraha' (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Average dry fruit weight (g)

Out of the 13 cross combinations in pooled environments which exhibited significant SCA effects, 'Pusa Sadabahar × Pant C1', 'Kashmir Long × Pant C1', 'PAU Selection Long × Surajmukhi', 'Arka Lohit × Pant C1' and 'LCA 206 × Anugraha' were ranked as top five cross combinations. These cross combinations had also retained their position among the top five cross combinations with one exception each *i.e.*, 'LCA 206 × Anugraha' and 'PAU Selection Long × Surajmukhi' at Palampur and 'Arka Lohit × Pant C 1' and 'LCA 206 × Anugraha' at Bajaura during 2010 and 2011, respectively (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Dry fruit yield/plant

Significant positive SCA effects were observed for 10 and nine crosses at Palampur and 12 and seven crosses at Bajaura in the respective years of 2010 and 2011, whereas 14 cross combinations revealed significant SCA effects in pooled environments (Table 4.21, 4.22, 4.23, 4.24 and 4.25). The five best specific combiners namely, 'LCA 436 × Pant C1' (Good × Average/Poor), 'Chilli

Sonal × Surajmukhi' (Poor × Good), 'Jawahar Mirch 283 × Anugraha' (Good × Average/Poor), 'Kashmir Long × Pant C1' (Average × Average/Poor) and 'Pusa Sadabahar × Surajmukhi' (Poor × Good) during 2010 at Palampur also maintained their position among top five in pooled over environments. Similarly, of these five crosses, 'LCA 436 × Pant C1' (Good × Average/Poor) and 'Chilli Sonal × Surajmukhi' (Poor × Good) retained their position among the top three during 2011 at Palampur and also at Bajaura in both the years. Other crosses among the best five with 'Good' SCA effects were 'LCA 206 × Anugraha', 'PAU Selection Long × Surajmukhi' and 'Jawahar Mirch 283 × Anugraha' during 2011 at Palampur, 'Jawahar Mirch 283 × Pant C1', 'Kashmir Long × Pant C1' and 'LCA 443 × Surajmukhi' during 2010 and 'Kashmir Long × Pant C1', 'LCA 443 × Anugraha' and 'PAU Selection Long × Surajmukhi' during 2011 at Bajaura.

Ascorbic acid (mg/100g)

Among the top five crosses having significant positive SCA effects, were 'LCA 206 × Surajmukhi', 'LCA 443 × Pant C1', 'Arka Lohit × Anugraha' and 'PAU Selection Long × Surajmukhi' out of 14 and 12 combinations, respectively during 2010 and 2011 at Palampur. These crosses also showed 'Good' SCA effects in pooled over environments along with 'Jawahar Mirch 283 × Pant C1' and 'Arka Lohit × Pant C1' among the top five. Similarly, 'LCA 206 × Surajmukhi', 'LCA 443 × Pant C1' and 'Arka Lohit × Pant C1' also maintained the same position amongst top five at Bajaura during 2010 and 2011with 'PAU Selection Long × Surajmukhi' as the top specific combiner during 2010 (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Capsaicin content (%)

Out of the 12 and 11 cross combinations with good specific combining ability effects during the respective years of 2010 and 2011 at Palampur, 'Kashmir Long × Pant C1' (Good × Average/Poor), 'Chilli Sonal × Surajmukhi' (Poor × Good), 'LCA 443 × Pant C1' (Good × Average/Poor) and 'Jawahar Mirch 283 × Surajmukhi' (Poor × Good) were ranked among the top five. On the other hand, ‘Kashmir Long × Pant C1’ was the best specific combiner out of 14 and nine crosses during 2010 and 2011, respectively at Bajaura. In addition, ‘Pusa Jwala × Pant C1’ (Good × Good/Average), ‘LCA 436 × Pant C1’ (Poor × Good/Average) and ‘PAU Selection Long × Anugraha’ (Poor × Poor) also showed promise by finding their position among the top five in both the years at Bajaura. In pooled environments, eight crosses out of 14 namely ‘Kashmir Long × Pant C1’(good × average), ‘Chilli Sonal × Surajmukhi’ (Poor × Good), ‘Jawahar Mirch 283 × Surajmukhi’ (Poor × Good)‘, ‘PAU Selection Long × Anugraha’ (Poor × Poor), ‘LCA 436 × Pant C1’(Poor × Average), ‘Pusa Sadabahar × Anugraha’ (Good × Poor), ‘LCA 206 × Surajmukhi’ (Good × Good) and ‘PAU Selection Long × Surajmukhi’ (Poor × Good) were the best specific combiners having their ranking among top five (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

Capsanthin (ASTA units)

The crosses ‘Kashmir Long × Pant C1’ and ‘Selection 352 × Surajmukhi’ had obtained position among the best five during both the years at Palampur and Bajaura and also in pooled environments out of the 13 and 11 cross at Palampur, and 11 and 12 cross at Bajaura in the respective years along with 12 crosses in pooled environments having desirable specific combining ability effects (Table 4.21, 4.22, 4.23, 4.24 and 4.25). The parents of these two crosses were in general, ‘Poor × Poor’ and ‘Good × Good’, respectively except ‘Kashmir Long’ during both the years and ‘Selection 352’ during 2010 with average GCA at Bajaura. ‘Chilli Sonal × Surajmukhi’ and ‘Jawahar Mirch 283 × Anugraha’ at Palampur and ‘Pusa Jwala × Anugraha’ and ‘Arka Lohit × Pant C1’ at Bajaura in both the years and in pooled environments were the other best specific combiners.

Oleoresin (ASTA units)

The crosses ‘Kashmir Long × Pant C1’(Good × Good), ‘Arka Lohit × Anugraha’ (Good × Poor), ‘Chilli Sonal × Surajmukhi’ (Poor × Good), ‘LCA 436 × Pant C1’ (Poor × Good) and ‘Jawahar Mirch 283 × Anugraha’ (Poor × Poor) had secured their rankings among the top five in pooled environments out of 13 combinations and also in both the years at Palampur out of 12 and 10 crosses during 2010 and 2011, respectively except ‘Jawahar Mirch 283 × Anugraha’ ranked 8th in 2011. Similarly, ‘Kashmir Long × Pant C1’ and ‘Arka Lohit × Pant C1’ were the top two crosses out of 12 and 13 in the respective years at Bajaura. In addition to these, ‘LCA 206 × Anugraha’, ‘LCA 443 × Pant C1’ and ‘LCA 443 × Surajmukhi’ during 2010 and ‘Chilli Sonal × Surajmukhi’, ‘Jawahar Mirch 283 × Anugraha’ and ‘LCA 206 × Surajmukhi’ during 2011 were the other best crosses at Bajaura (Table 4.21, 4.22, 4.23, 4.24 and 4.25).

The trait-wise good cross combinations over the locations and pooled environments have been summarized in (Table 4.26). It was observed that no single cross could reveal significant SCA for all the traits. Earlier workers have also reported significant SCA effects in their respective studies under different environmental conditions for days to 50% flowering (Pandey *et al*. 1981; Pandian and Shanmugavelu 1992; Khereba *et al*. 2008; Reddy *et al*. 2008), primary branches/plant and marketable fruits/plant (Sahoo *et al*. 1989; Bhagyalakshmi *et al*. 1991; Saritha *et al*. 2005; Reddy *et al*. 2008), fruit length, fruit girth and average fruit weight (Khereba *et al*. 2008; Reddy *et al*. 2008), marketable fruit yield/plant (Pandey *et al*. 2003; Patel *et al*. 2004; Patil *et al*. 2005; Venkataramana *et al*. 2005; Khereba *et al*. 2008; Prasath and Ponnuswami 2008; Reddy *et al*. 2008), plant height (Linganagouda *et al*. 2003; Saritha *et al*. 2005; Khereba *et al*. 2008; Reddy *et al*. 2008), average dry fruit weight (Gandhi *et al*. 2000), and dry fruit yield/plant (Mishra *et al*. 1989; Saritha *et al*. 2005; Srivastava *et al*. 2005; Shekhawat *et al*. 2007; Prasath and Ponnuswami 2008).

Similarly, for quality traits, different cross combinations with significant and positive SCA effects have been reported for ascorbic acid (Bhagyalakshmi *et al*. 1991; Saritha *et al*. 2005), capsaicin (Prasath and Ponnuswami 2008; Singh and Hundal 2001), Capsanthin (Singh and Hundal 2001; Saritha *et al*. 2005; Prasath and Ponnuswami 2008) and oleoresin (Singh and Hundal 2001; Saritha *et al*. 2005)

Table 4.26: Trait wise list of five promising hybrids exhibiting significant desirable SCA effects

Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Days to 50% flowering	LCA 206 × Anugraha Arka Lohit x Surajmukhi Sel 352 × Anugraha Pusa Jwala x Surajmukhi LCA 436 x Pant C1	Sel 352 × Anugraha Chilli Sonal x Surajmukhi PAU Sel Long ×Surajmukhi Pusa Sadabahar ×Surajmukhi	LCA206 × Anugraha Pusa Sadabahar × Surajmukhi Sel 352 × Anugraha Arka Lohit × Surajmukhi LCA 443 x Surajmukhi	LCA 206 x Anugraha LCA 443 x Anugraha Sel 352 x Anugraha Arka Lohit x Pant C 1 PAU Sel Long x Surajmukhi	LCA 206 x Anugraha Sel 352 x Anugraha Pusa Sadabahar x Surajmukhi LCA 443 x Pant C 1 LCA 436 x Pant C1
Days to first harvest	Arka Lohit × Surajmukhi Sel 352 x Anugraha Chilli Sonal x Pant C 1 Chilli Sonal x Anugraha Kashmir Long x Pant C 1	Chilli Sonal ×Pant C 1 Arka Lohit × Surajmukhi Sel 352 × Anugraha Chilli Sonal × Anugraha PAU Sel Long × Pant C 1	Arka Lohit x Surajmukhi Chilli Sonal x Pant C 1 Pusa Sadabahar x Surajmukhi PAU Sel Long x Pant C 1 Pusa Sadabahar x Pant C 1	Chilli Sonal x Pant C 1 Jawahar Mirch 283 x Anugraha Sel 352 x Anugraha Pusa Sadabahar x Surajmukhi PAU Sel Long x Surajmukhi	Chilli Sonal x Pant C 1 Arka Lohit x Surajmukhi Sel 352 x Anugraha Pusa Sadabahar x Surajmukhi Chilli Sonal x Anugraha
Primary branches/plant	Chilli Sonal x Pant C 1	LCA 436 x Surajmukhi Kashmir Long x Pant C 1 Pusa Jwala x Anugraha Jawahar Mirch 283 x Anugraha LCA 443 x Pant C 1	Kashmir Long x Surajmukhi Arka Lohit × Pant C 1 Pusa Jwala x Pant C 1 LCA 436 x Pant C 1 Chilli Sonal x Anugraha	Kashmir Long × Surajmukhi Pusa Jwala × Pant C 1 Sel 352 × Pant C 1 LCA 443 × Anugraha	Kashmir Long × Surajmukhi Jawahar Mirch 283 × Anugraha Arka Lohit x Surajmukhi Pusa Jwala × Anugraha Arka Lohit × Pant C 1
Fruit length (cm)	LCA 206 × Anugraha PAU Sel Long × Pant C 1 LCA 436 × Anugraha PAU Sel Long × Surajmukhi	LCA 436 × Anugraha PAU Sel Long × Pant C 1 PAU Sel Long × Surajmukhi Pusa Jwala × Surajmukhi LCA 206 × Anugraha	Pusa Sadabahar × Surajmukhi Kasmir Long × Anugraha LCA 206 × Anugraha Chilli Sonal × Surajmukhi Pusa Sadabahar × Pant C 1	LCA 206 × Anugraha Kashmir Long × Anugraha Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi Pusa Sadabahar × Pant C 1	LCA 206 × Anugraha Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi Pusa Sadabahar × Pant C 1 Kashmir Long × Anugraha
Fruit girth (cm)	Chilli Sonal × Anugraha LCA 436 × Surajmukhi Pusa Jwala × Pant C 1 Sel 352 × Pant C 1 LCA 443 × Surajmukhi	Pusa Sadabahar × Surajmukhi Chilli Sonal × Anugraha Pusa Jwala × Pant C 1 LCA 443 × Surajmukhi LCA 436 × Surajmukhi	Pusa Sadabahar × Surajmukhi Arka Lohit × Anugraha LCA 436 × Pant C 1 PAU Sel Long × Surajmukhi Sel 352 × Pant C 1	LCA 436 × Pant C 1 Sel 352 × Pant C 1 PAU Sel Long × Surajmukhi Arka Lohit × Anugraha Kasmir Long × Surajmukhi	Pusa Sadabahar × Surajmukhi Arka Lohit × Anugraha LCA 436 × Pant C 1, Sel 352 × Pant C 1 PAU Sel Long × Surajmukhi
Average fruit weight (g)	Arka Lohit × Anugraha LCA 206 × Pant C 1 Pusa Jwala × Surajmukhi Jawahar Mirch 283 × Pant C 1 Kashmir Long × Surajmukhi	Arka Lohit × Anugraha LCA 206 × Pant C 1 Pusa Jwala × Surajmukhi Jawahar Mirch 283 × Pant C 1 Kashmir Long × Surajmukhi	Arka Lohit × Anugraha Pusa Jwala × Surajmukhi Jawahar Mirch 283 × Pant C 1 LCA 206 × Pant C 1 LCA 436 × Surajmukhi	Arka Lohit × Anugraha LCA 206 × Pant C 1 Jawahar Mirch 283 × Pant C 1 Pusa Jwala × Surajmukhi LCA 436 × Surajmukhi	Arka Lohit × Anugraha LCA 206 × Pant C 1 Pusa Jwala × Surajmukhi Jawahar Mirch 283 × Pant C 1 Chilli Sonal × Anugraha
Marketable fruits/plant	Pusa Sadabahar × Surajmukhi Jawahar Mirch 283 × Anugraha Chilli Sonal × Surajmukhi Arka Lohit × Pant C 1 LCA 206 × Anugraha	LCA 206 × Anugraha Arka Lohit × Pant C 1 Jawahar Mirch 283 × Anugraha Chilli Sonal × Surajmukhi LCA 436 × Pant C 1	Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi LCA 436 × Pant C 1 LCA 206 × Anugraha Kashmir Long × Anugraha	Chilli Sonal × Surajmukhi Pusa Sadabahar × Surajmukhi LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha Arka Lohit × Pant C 1	Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi LCA 206 × Anugraha Arka Lohit × Pant C 1 LCA 436 × Pant C 1
Marketable fruit yield/plant (g)	Jawahar Mirch 283 × Anugraha LCA 436 × Pant C 1 Pusa Sadabahar × Surajmukhi Sel 352 × Pant C 1 Pusa Jwala × Surajmukhi	LCA 206 × Anugraha LCA 436 × Pant C 1 LCA 443 × Surajmukhi Jawahar Mirch 283 × Anugraha Arka Lohit × Pant C 1	Pusa Sadabahar × Surajmukhi LCA 436 × Pant C 1 Chilli Sonal x Surajmukhi, Jawahar Mirch 283 × Pant C 1 Arka Lohit x Surajmukhi	Chilli Sonal × Surajmukhi LCA 436 × Pant C 1 Kashmir Long × Pant C 1 Jawahar Mirch 283 × Anugraha Pusa Sadabahar × Surajmukhi	LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha Chilli Sonal × Surajmukhi Pusa Sadabahar × Surajmukhi LCA 206 × Anugraha

Contd../-

Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Harvest duration (days)	Chilli Sonal × Surajmukhi Pusa Jwala × Pant C 1 LCA 436 × Anugraha Arka Lohit × Anugraha LCA 206 × Surajmukhi	Chilli Sonal × Surajmukhi LCA 206 × Surajmukhi Arka Lohit x Surajmukhi LCA 436 × Anugraha Arka Lohit × Anugraha	Chilli Sonal × Surajmukhi Pusa Jwala × Pant C 1 LCA 436 × Anugraha Arka Lohit × Anugraha LCA 206 x suraj	Chilli Sonal × Surajmukhi LCA 443 × Surajmukhi LCA 206 × Surajmukhi Arka Lohit × Anugraha LCA 436 × Pant C 1	Chilli Sonal × Surajmukhi LCA 206 × Surajmukhi LCA 436 × Anugraha Arka Lohit × Anugraha Pusa Jwala × Pant C 1
Plant height (cm)	Jawahar Mirch 283 × Anugraha Arka Lohit × Pant C 1 Pusa Sadabahar × Anugraha Chilli Sonal × Surajmukhi	Jawahar Mirch 283 × Surajmukhi PAU Sel Long × Pant C 1 Jawahar Mirch 283 × Anugraha LCA 443 × Pant C 1 Pusa Jwala × Surajmukhi	Jawahar Mirch 283 × Anugraha Kashmir Long × Anugraha Pusa Sadabahar × Surajmukhi LCA 443× Pant C 1 Arka Lohit x Surajmukhi	Pusa Sadabahar × Pant C 1 Sel 352 × Surajmukhi Kashmir Long × Anugraha PAU Sel Long × Surajmukhi Arka Lohit x Surajmukhi	PAU Sel Long × Pant C 1 Jawahar Mirch 283 × Anugraha LCA 443 × Pant C 1 LCA 436 × Pant C 1 Kashmir Long × Anugraha
Average dry fruit weight (g)	Pusa Sadabahar × Pant C 1 PAU Sel Long × Surajmukhi Kashmir Long × Pant C 1 LCA 443 × Surajmukhi Arka Lohit × Pant C 1	Arka Lohit × Pant C 1 LCA 206 × Anugraha Pusa Sadabahar × Pant C 1 Kashmir Long × Pant C 1 LCA 443 × Surajmukhi	Pusa Sadabahar × Pant C 1 Kashmir Long × Pant C 1 PAU Sel Long × Surajmukhi LCA 206 × Anugraha Sel 352 × Surajmukhi	Pusa Sadabahar × Pant C 1 PAU Sel Long × Surajmukhi LCA 436 × Surajmukhi Kashmir Long × Pant C 1 Arka Lohit × Pant C 1	Pusa Sadabahar × Pant C 1 Kashmir Long × Pant C 1 PAU Sel Long × Surajmukhi Arka Lohit × Pant C 1 LCA 206 × Anugraha
Dry fruit yield/plant (g)	Pusa Sadabahar × Surajmukhi LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha Chilli Sonal × Surajmukhi Kashmir Long × Pant C 1	LCA 436 × Pant C 1 LCA 206 × Anugraha Chilli Sonal × Surajmukhi PAU Sel Long × Surajmukhi Jawahar Mirch 283 × Anugraha	Chilli Sonal × Surajmukhi LCA 436 × Pant C 1 Jawahar Mirch 283 × Pant C 1 Kashmir Long × Pant C 1 LCA 443 × Surajmukhi	Chilli Sonal × Surajmukhi Kashmir Long × Pant C 1 LCA 436 x Pant C1 LCA 443 × Anugraha PAU Sel Long × Surajmukhi	LCA 436 × Pant C 1 Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Anugraha Kashmir Long × Pant C 1 Pusa Sadabahar × Surajmukhi
Ascorbic acid (mg/100g)	LCA 206 × Surajmukhi Jawahar Mirch 283 × Pant C 1 PAU Sel Long × Surajmukhi Arka Lohit × Anugraha LCA 443 × Pant C 1	LCA 443 × Pant C 1 LCA 206 × Surajmukhi Arka Lohit × Anugraha PAU Sel Long × Surajmukhi Arka Lohit × Pant C 1	PAU Sel Long × Surajmukhi LCA 443 × Pant C 1 LCA 206 × Surajmukhi Pusa Jwala × Anugraha Arka Lohit × Pant C 1	LCA 206 × Surajmukhi LCA 436 × Surajmukhi Chilli Sonal × Pant C 1 LCA 443 × Pant C 1 Arka Lohit × Pant C 1	LCA 206 × Surajmukhi LCA 443 × Pant C 1 PAU Sel Long × Surajmukhi Jawahar Mirch 283 × Pant C 1 Arka Lohit × Pant C 1 Arka Lohit × Anugraha
Capsaicin content (%)	Kashmir Long × Pant C 1 Pusa Sadabahar × Anugraha Chilli Sonal × Surajmukhi LCA 443 × Pant C 1 Jawahar Mirch 283 × Surajmukhi	Chilli Sonal × Surajmukhi Kashmir Long × Pant C 1 LCA 206 × Anugraha LCA 443 × Pant C 1 Jawahar Mirch 283 × Surajmukhi	Kashmir Long × Pant C 1 Chilli Sonal × Surajmukhi Pusa Jwala × Pant C 1 LCA 206 × Anugraha PAU Sel Long × Anugraha	Kashmir Long × Pant C 1 Pusa Jwala × Pant C 1 LCA 436 × Pant C 1 Jawahar Mirch 283 × Surajmukhi PAU Sel Long × Surajmukhi	Kashmir Long × Pant C 1 Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Surajmukhi PAU Sel Long × Anugraha LCA 436 × Pant C 1
Capsanthin (ASTA units)	Kashmir Long × Pant C 1 LCA 443 × Surajmukhi Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Anugraha Sel 352 × Surajmukhi	Kashmir Long × Pant C 1 Chilli Sonal × Surajmukhi Sel 352 × Surajmukhi Arka Lohit × Pant C 1 Jawahar Mirch 283 × Anugraha	Chilli Sonal × Surajmukhi LCA 443 × Surajmukhi Pusa Jwala × Anugraha Arka Lohit × Pant C 1 Sel 352 × Surajmukhi	Pusa Jwala × Anugraha Kashmir Long × Pant C 1 352 × Surajmukhi Arka Lohit × Pant C 1 PAU Sel Long × Surajmukhi	Kashmir Long × Pant C 1 LCA 443 × Surajmukhi Sel 352 × Surajmukhi Pusa Jwala × Anugraha Arka Lohit × Pant C 1
Oleoresin (ASTA units)	Kashmir Long × Pant C 1 Arka Lohit × Anugraha LCA 436 × Pant C 1, Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Anugraha	Kashmir Long × Pant C 1 LCA 436 × Pant C 1 Chilli Sonal × Surajmukhi Arka Lohit × Anugraha Pusa Sadabahar × Anugraha	Kashmir Long × Pant C 1 Arka Lohit × Anugraha LCA 206 × Anugraha , LCA 443 × Pant C 1 LCA 436 × Pant C 1	Arka Lohit × Anugraha Kashmir Long × Pant C 1 Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Anugraha LCA 206 × Surajmukhi	Kashmir Long × Pant C 1 Arka Lohit × Anugraha Chilli Sonal × Surajmukhi LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha

On the basis of specific combining ability effects, it can be concluded that desirable SCA effects was not revealed by any of the cross for all the traits. However, ‘PAU Selection Long × Surajmukhi’, ‘LCA 436 × Pant C 1’, ‘Chilli Sonal × Surajmukhi’, ‘LCA 206 × Anugraha’, ‘Kashmir Long × Pant C 1’ and ‘Jawahar Mirch 283 × Anugraha’ exhibited significant and desirable SCA effects for seven to 12 traits out of 16 traits studied with consistency over the years in each location and also pooled over environments. In addition, cross combination ‘LCA 443 × Surajmukhi’ at Palampur and ‘Pusa Sadabahar × Surajmukhi’ at Bajaura showed desirable SCA effects for eight to 10 traits and also in pooled environments.

For fresh fruit yield/plant, ‘LCA 436 × Pant C 1’, ‘Chilli Sonal × Surajmukhi’, ‘Jawahar Mirch 283 × Anugraha’, ‘Pusa Sadabahar × Surajmukhi’, and ‘PAU Selection Long × Surajmukhi’ were the best specific combiners as they retained their position among the top ten crosses over the years and environments. The consistency of these good specific combiners appeared to be the result of the contributing traits like marketable fruits/plant, harvest duration, plant height and average fruit weight/plant for which these crosses also in general showed good specific combining ability effects. These crosses were also observed to be the good specific combiners for dry fruit yield/plant. The majority of these cross combinations with desirable SCA effects represent one parent at least as good or average general combiner. However, certain crosses had also revealed high SCA effects with ‘Poor × Poor’ or ‘Average × Poor’ GCA effects. This might be due to parental lines used in the present study had origin from the diverse genetic background and hence, exhibited high SCA effects. The specific interaction effects most likely complementary of ‘Poor × Poor’ crosses may perform better than ‘Good × Good’ and ‘Good × Poor’ combinations because of the prevalence of high magnitude of non-additive component for the superiority of the pertinent cross combinations. Prasad and Singh (1994) were also of the view that the parents having high estimates of GCA would not necessarily give high estimates of SCA effects.

Chilli Sonal (Poor) × Surajmukhi (Good)

Jawahar Mirch 283 (Good) × Anugraha (Poor)

LCA 436 (Good) × Pant C 1 (Poor)

Pusa Sadabahar (Poor) × Surajmukhi (Good)

PAU Selection Long (Poor/average) × Surajmukhi (Good)

Plate 6: Promising cross combinations on the basis of SCA effects

The combinations exhibiting high SCA effects derived from good or average general combiners will be of main interest as they certainly perform better for a particular character. The cross combinations ‘Selection 352 × Anugraha’ and ‘Chilli Sonal × Anugraha’ can be exploited to isolate transgressive segregants in early generations as they involve both parents with high GCA effects for early harvest. Similarly, cross combinations involving one good or other poor or average combiner may give transgressive segregants in the later generations if the additive effect of one parent and complementary epistatic effects (if present in the cross) act in the same direction and maximize the desirable plant character (Sharma *et al.* 2007). However, Singh *et al*. (1985) was of the view that the best crosses involving atleast one parent with good combining ability may produce transgressive segregants which are also possible in many of the crosses of the present study.

4.3 Gene action

In a breeding programme, once the appropriate parents and potential crosses are identified, the next important step is to adopt a suitable breeding strategy for the purposeful management of generated variability which largely depends upon type of gene action in the population for the traits under genetic improvement (Cockerham 1961; Sprauge 1966). Various mating designs have been developed for this purpose and among them, line × tester method not only evaluates parents and crosses for combining ability but also provides information on the nature of gene action controlling the traits under consideration. The nature of gene action has been inferred from the estimates of GCA and SCA variances. The estimates of σ_{SCA}^2 were higher than σ_{GCA}^2 (average) for majority of the traits except marketable fruit yield/plant and fruit girth in 2010 at Palampur and Bajaura, respectively along with primary branches/plant in pooled environments (Table 4.27 and 4.29). However, the magnitude of these estimates is proportionately equal for oleoresin and capsaicin content in 2010 and 2011, respectively at Palampur. The preponderence of σ_{SCA}^2 revealed the predominant role of non- additive gene action governing these traits.

Table 4.27: Estimates of genetic components of variance in chilli at Palampur during 2010 and 2011

Genetic Components/ Traits	σ_{GCA}^2 (Average)		σ_{SCA}^2		σ_A^2		σ_D^2		Heritability % (Narrow sense)		Genetic advance	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Days to 50% flowering	1.75	0.69	7.40	2.77	3.50	1.38	7.40	2.77	31.48	25.93	2.16	1.23
Days to first harvest	4.32	3.25	14.85	16.18	8.64	6.51	14.85	16.18	36.01	27.82	3.63	2.77
Primary branches/plant	0.08	0.05	0.15	0.22	0.16	0.09	0.15	0.22	40.16	25.15	0.53	0.31
Fruit length (cm)	0.22	0.18	0.29	0.47	0.45	0.37	0.29	0.47	57.67	43.14	1.05	0.82
Fruit girth (cm)	0.003	0.002	0.004	0.004	0.006	0.005	0.004	0.004	57.74	51.33	0.12	0.11
Average fruit weight (g)	0.14	0.13	0.53	0.56	0.29	0.25	0.53	0.56	35.03	31.05	0.65	0.58
Marketable fruits/ plant	417.81	47.90	1335.26	1873.00	835.61	95.80	1335.26	1873.00	38.33	4.84	36.87	4.43
Marketable fruit yield/ plant (g)	7513.42	838.19	6714.97	8098.40	15026.84	1676.37	6714.97	8098.40	68.79	16.96	209.44	34.74
Harvest duration (days)	6.43	8.11	12.52	11.76	12.86	16.21	12.52	11.76	50.25	57.38	5.24	6.28
Plant height (cm)	20.46	0.33	32.61	36.88	40.92	0.65	32.61	36.88	53.37	1.58	9.63	0.21
Average dry fruit weight (g)	0.006	0.007	0.06	0.07	0.01	0.02	0.06	0.07	17.18	17.14	0.10	0.11
Dry fruit yield/ plant(g)	55.83	35.63	76.28	69.23	111.66	71.26	76.28	69.23	58.49	49.37	16.65	12.22
Ascorbic acid (mg/100g)	6.94	1.12	111.04	100.15	13.88	2.23	111.04	100.15	11.05	2.15	2.55	0.45
Capsaicin content (%)	0.004	0.004	0.005	0.004	0.008	0.008	0.005	0.004	61.64	61.57	0.15	0.14
Capsanthin (ASTA units)	25.76	26.39	95.19	75.61	51.52	52.77	95.19	75.61	34.94	40.77	8.74	9.56
Oleoresin (ASTA units)	42.15	44.06	40.39	51.35	84.30	88.12	40.39	51.35	67.31	62.64	15.52	15.30

Table 4.28: Estimates of contribution of lines, testers and their interactions to genetic variance at Palampur during 2010 and 2011

Traits	% contribution of Lines		% contribution of Testers		% contribution of Interaction	
	2010	2011	2010	2011	2010	2011
Days to 50% flowering	67.84	66.70	2.11	1.02	30.05	32.28
Days to first harvest	74.07	68.38	0.37	0.80	25.56	30.82
Primary branches/plant	54.22	26.44	11.87	18.62	33.91	54.94
Fruit length (cm)	66.69	43.02	11.65	19.10	21.66	37.89
Fruit girth (cm)	74.37	70.88	6.85	6.78	18.78	22.34
Average fruit weight (g)	72.55	70.62	0.85	0.67	26.60	28.71
Marketable fruits/ plant	46.78	41.45	14.95	4.45	38.27	54.09
Marketable fruit yield/plant (g)	67.56	40.59	15.69	9.13	16.76	50.28
Harvest duration (days)	60.12	63.39	12.66	13.61	27.22	23.00
Plant height (cm)	50.17	44.43	19.91	2.36	29.91	53.22
Average dry fruit weight (g)	53.58	32.91	3.94	12.31	42.47	54.78
Dry fruit yield/ plant (g)	62.31	53.46	14.75	16.14	22.94	30.40
Ascorbic acid (mg/100g)	53.99	45.97	1.87	2.01	44.14	52.02
Capsaicin content (%)	82.84	81.31	2.65	3.63	14.51	15.05
Capsanthin (ASTA units)	55.69	59.34	9.13	9.43	35.19	31.23
Oleoresin (ASTA units)	83.45	78.65	3.96	5.73	12.59	15.62

Table 4.29: Estimates of genetic components of variance in chilli at Bajaura during 2010 and 2011

Genetic Components/ Traits	σ_{GCA}^2 (Average)		σ_{SCA}^2		σ_A^2		σ_D^2		Heritability % (Narrow sense)		Genetic advance	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Days to 50% flowering	2.35	-0.22	5.54	11.80	4.70	-0.43	5.54	11.80	44.02	-3.68	2.96	-0.26
Days to first harvest	1.38	0.95	8.25	16.73	2.75	1.91	8.25	16.73	23.49	9.99	1.66	0.90
Primary branches/plant	0.02	-0.01	0.51	0.41	0.04	-0.02	0.51	0.41	6.27	-4.45	0.10	-0.06
Fruit length (cm)	0.20	0.23	1.55	1.16	0.41	0.46	1.55	1.16	20.57	28.17	0.59	0.74
Fruit girth (cm)	0.002	0.002	0.01	0.008	0.004	0.004	0.01	0.008	21.18	32.29	0.06	0.08
Average fruit weight (g)	0.13	0.12	0.52	0.55	0.26	0.24	0.52	0.55	32.98	30.63	0.60	0.56
Marketable fruits/ plant	105.04	66.37	1878.39	1165.07	210.07	132.75	1878.39	1165.07	9.98	10.15	9.43	7.56
Marketable fruit yield/plant (g)	1552.54	697.93	7619.49	4551.05	3105.09	1395.86	7619.49	4551.05	28.60	23.07	61.39	36.97
Harvest duration (days)	7.02	7.76	9.80	11.91	14.04	15.52	9.80	11.91	58.33	56.15	5.90	6.08
Plant height (cm)	15.53	28.30	27.64	35.99	31.05	56.60	27.64	35.99	49.41	60.57	8.07	12.06
Average dry fruit weight (g)	0.006	0.002	0.05	0.05	0.01	0.004	0.05	0.05	19.95	8.88	0.11	0.04
Dry fruit yield/ plant (g)	20.76	10.30	67.78	45.85	41.52	20.60	67.78	45.85	37.53	29.59	8.13	5.09
Ascorbic acid (mg/100g)	2.94	5.51	109.53	90.30	5.89	11.03	109.53	90.30	5.01	10.65	1.12	2.23
Capsaicin content (%)	0.004	0.004	0.005	0.005	0.009	0.008	0.005	0.005	62.93	62.08	0.15	0.15
Capsanthin (ASTA units)	19.48	14.19	70.97	62.22	38.96	28.37	70.97	62.22	35.00	31.01	7.61	6.11
Oleoresin (ASTA units)	33.56	20.99	33.54	47.43	67.11	41.98	33.54	47.43	66.18	46.33	13.73	9.09

Table 4.30: Estimates of contribution of lines, testers and their interactions to genetic variance at Bajaura during 2010 and 2011

Traits	% contribution of Lines		% contribution of Testers		% contribution of Interaction	
	2010	2011	2010	2011	2010	2011
Days to 50% flowering	71.66	46.25	3.96	0.14	24.38	53.61
Days to first harvest	60.56	52.63	3.00	2.06	36.43	45.31
Primary branches/plant	48.40	34.48	2.45	3.64	49.15	61.88
Fruit length (cm)	48.33	48.46	7.27	10.02	44.40	41.53
Fruit girth (cm)	57.35	68.93	3.66	1.82	38.99	29.24
Average fruit weight (g)	71.14	69.35	0.96	1.15	27.90	29.50
Marketable fruits/ plant	30.50	38.70	10.33	7.33	59.17	53.98
Marketable fruit yield/plant (g)	39.00	51.35	14.52	6.86	46.47	41.79
Harvest duration (days)	63.01	65.31	14.24	11.91	22.75	22.78
Plant height (cm)	39.42	42.75	24.23	28.33	36.34	28.92
Average dry fruit weight (g)	59.81	51.18	2.25	2.25	37.94	46.57
Dry fruit yield/ plant (g)	46.71	62.38	14.64	4.09	38.65	33.53
Ascorbic acid (mg/100g)	46.18	51.96	2.84	2.51	50.98	45.52
Capsaicin content (%)	82.38	80.34	3.34	4.43	14.28	15.23
Capsanthin (ASTA units)	56.39	60.93	8.80	5.23	34.80	33.84
Oleoresin (ASTA units)	82.45	77.44	4.30	1.47	13.25	21.09

Table 4.31: Pooled over environments estimates of genetic components of variance in chilli and proportionate (%) contribution of lines, testers and their interactions to genetic variance

Genetic Components/ Traits	σ^2_{GCA} (Average)	σ^2_{GCA} lines × env	σ^2_{GCA} tester × env	σ^2_{SCA}	σ^2_{SCA} × env	σ^2_A	σ^2_D	Heritability % (Narrow sense)	Genetic advance	% contribution of		
										Lines	Testers	Interaction
Days to 50% flowering	-15.18	26.19	-0.08	15.24	3.11	1.74	15.24	28.56	1.51	67.63	1.36	31.02
Days to first harvest	8.64	2.80	-0.23	41.14	3.72	4.10	41.14	27.53	2.25	67.50	1.12	31.38
Primary branches/plant	29.27	-0.02	-0.01	0.21	0.36	0.10	0.21	39.72	0.39	55.55	11.00	33.45
Fruit length (cm)	0.74	0.23	-0.02	1.54	0.48	0.36	1.54	42.01	0.81	49.39	15.20	35.41
Fruit girth (cm)	0.01	0.001	0.002	0.02	0.000	0.002	0.02	47.50	0.09	72.39	4.73	23.08
Average fruit weight (g)	0.52	0.000	0.000	2.08	0.02	0.26	2.08	32.90	0.60	71.56	0.74	27.70
Marketable fruits/ plant	346.83	212.11	65.31	4071.24	543.12	125.04	4071.24	13.04	9.80	36.53	9.23	5.42
Marketable fruit yield/plant (g)	8333.04	1852.60	457.41	12732.58	3544.79	3788.34	12732.58	50.39	94.39	56.66	14.73	28.61
Harvest duration (days)	39.87	0.23	-0.04	44.67	23.68	14.62	44.67	56.41	5.92	63.25	13.29	23.45
Plant height (cm)	0.18	6.79	2.54	37.42	0.27	25.40	37.42	62.81	8.50	46.12	27.38	26.50
Average dry fruit weight (g)	0.02	0.001	0.000	0.2	0.01	0.01	0.20	17.87	0.09	51.57	4.93	43.51
Dry fruit yield/ plant (g)	108.21	9.76	3.41	139.86	29.51	51.72	139.86	55.65	11.30	60.89	14.43	24.68
Ascorbic acid (mg/100g)	16.31	2.53	-0.60	382.45	7.01	8.12	382.45	7.70	1.63	49.89	2.36	47.75
Capsaicin content (%)	0.02	0.001	0.001	0.022	0.00	0.01	0.02	64.11	0.15	82.78	3.35	13.76
Capsanthin (ASTA units)	84.58	1.25	0.18	270.26	8.45	42.08	270.26	37.68	8.22	59.07	8.44	32.49
Oleoresin (ASTA units)	136.13	2.22	1.36	145.77	6.66	67.30	145.77	63.96	13.59	82.42	3.63	13.95

The results of analysis of variance were also confirmed from the study of additive (σ_A^2) and dominant (σ_D^2) component of variances. The differences in variances due to σ_{SCA}^2 and dominance variance (σ_D^2) for some of the traits might be attributed to the fact that statistically GCA variance is the additive portion of variability but, it also includes additive × additive and higher order of epistatic interactions (Matzinger and Kempthorne, 1956). Hayman (1960) also pointed out that GCA was a component of dominance or epistasis or both with additive genetic effects in the presence of SCA.

The magnitude of dominance variance (σ_D^2) was higher than additive variance (σ_A^2) for majority of the traits over the locations and pooled environments which indicated the involvement of non- additive gene action. Similar non-additive gene actions have also been reported by earlier workers in different studies with different genetic materials for days to 50% flowering (Shukla *et al*. 1999; Anandanayaki and Natarajan 2000; Venkataramana *et al*. 2005; Reddy *et al*. 2008), days to first harvest and fruit length (Lohithaswa *et al*. 2001; Khereba *et al*. 2008; Marame *et al*. 2008), primary branches/plant (Srivastava *et al*. 2005; Kamboj *et al*. 2007; Reddy *et al*. 2008), fruit girth (Bhagyalakshmi *et al*. 1991; Srivastava *et al*. 2005; Khereba *et al*. 2008), average fruit weight (Jadhav *et al*. 2002; Khereba *et al*. 2008; Reddy *et al*. 2008), Marketable fruits/plant (Jadhav and Dhumal 1994; Jadhav *et al*. 2002; Srivastava *et al*. 2005; Reddy *et al*. 2008), marketable fruit yield/plant (Shukla *et al*. 1999; Jadhav *et al*. 2002; Venkataramana *et al*. 2005; Khereba *et al*. 2008; Reddy *et al*. 2008), plant height (Anandanayaki and Natarajan 2000; Jadhav *et al*. 2002; Venkataramana *et al*. 2005; Khereba *et al*. 2008; Reddy *et al*. 2008), average dry fruit weight (Lohithaswa *et al*. 2001), dry fruit yield/plant (Anandnayaki and Natarajan 2000; Marame *et al*. 2008), ascorbic acid (Srivastava *et al*. 2005) and capsaicin (Lohithaswa *et al*. 2001; Srivastava *et al*. 2005)

However, additive genetic variance (σ_A^2), with higher magnitude, was noticed for fruit length, primary branches/plant, plant height and dry fruit yield/plant in 2010, harvest duration in 2011 and capsaicin content and oleoresin in both the years at Palampur whereas, at Bajaura the same effect was observed for harvest duration, plant height and capsaicin content in both the years and oleoresin in 2010 (Table 4.27, 4.29 and 4.31). Similarly, predominance of additive gene action have also been reported for primary branches (Devi and Arumugam 1999; Kumar *et al.* 2004; Prasath and Ponnuswami 2008), fruit length (Kumar *et al.* 2004; Srivastava *et al*. 2005; Venkataramana *et al*. 2005; Kamboj *et al*. 2006, Kamboj *et al.* 2011), plant height (Devi and Arumugam 1999; Doshi 2003; Kumar *et al.* 2004; Kamboj *et al*. 2007), dry fruit yield/plant (Devi and Arumugam 1999; Kamboj *et al*. 2007), capsaicin content (Doshi 2003; Kumar *et al.* 2004) and oleoresin (Prasath and Ponnuswami 2008). In contrary, earlier research workers have also reported additive genetic variance for other than these traits *viz*., days to 50% flowering (Devi and Arumugam 1999; Kumar *et al.* 2004; Patel *et al.* 2004; Prasath and Ponnuswami 2008), fruit girth (Devi and Arumugam 1999; Shukla *et al.* 1999), average fruit weight (Doshi 2003; Kumar *et al.* 2004; Ajith and Anju 2005; Kamboj *et al.* 2006), marketable fruits/plant (Kumar *et al.* 2004; Patel *et al.* 2004; Kamboj *et al.* 2007), marketable fruit yield/plant (Devi and Arumugam 1999; Patel *et al.* 2004), average dry fruit weight (Prasath and Ponnuswami 2008) and capsanthin (Prasath and Ponnuswami 2008).

In addition, the magnitude of both these components was almost the same for harvest duration and primary branches/plant in 2010, dry fruit yield/plant in 2011 and fruit girth in both the years at Palampur which have also been reported for primary branches (Gopalakrishnan *et al*. 1987; Sahoo *et al*. 1989; Anandnayaki and Natarajan 2000; Marame *et al*. 2008), fruit girth (Jadhav and Dhumal 1994; Patel *et al*. 2004) and harvest duration (Marame *et al*. 2008).

The estimates of σ_{GCA}^2 (lines × environment) were higher than the σ_{GCA}^2 (tester × environment) for most of the traits studied which suggested that the testers were more stable than the lines for these traits. Fruit girth and average fruit weight had these estimates in equal proportion indicating similar performance of lines and testers across environments for these traits. The interaction value of σ_{SCA}^2 × environment were higher than the σ_{GCA}^2 (lines × environment) for majority of the traits except for days to 50% flowering, fruit girth and plant height. Similarly, σ_{SCA}^2 × environment showed higher magnitude than σ_{GCA}^2 (tester × environment) for all the traits except fruit girth. This leads to the conclusion that the hybrids were less stable than the lines and testers and are required to be evaluated over locations to ensure a higher level of homeostasis.

The type of gene action observed in the present investigation can be best utilized by developing hybrids which seems a difficult task because of absence of genetic mechanism in the parents involved in the present study. So, development of hybrids through crossing between the two parents by hand is not feasible on account of small flower size and low seed yield per an act of pollination. Moreover, hand emasculation and pollination are very labour extensive and expensive process.

Therefore, it may be worthwhile to effect improvement in chilli by developing superior open pollinated varieties by deferring selection to the later generations thereby advancing segregating material through single seed descent or bulk pedigree method (Sharma and Vidyasagar 2005) or single fruit descent method with one or two intermating like recurrent selection. During the process, non-additive gene action would have diminished and may constantly be converted into additive gene action due to frequent opportunity for recombination. This may also be achieved by adopting reciprocal recurrent selection and diallel selective mating design (Sharma *et al*. 2008). Though, in these approaches, a large number of crosses are required to be attempted, which is again a difficult proposition in self pollinated crops.

The role of selection is to guide evolution by promoting additive gene action that meet the demand of either natural or improved environment. In the present material, the whole philosophy is to defer selection to the later generations according to the above concept and genetic theory of gene action evolution by Fasoulas (1978; 1981). This theory presents a dynamic approach that tries to explain in biological and consistent manner that how the evolution of gene action takes place through combined action of recombination and selection. According to the theory, the role of various recombinational mechanisms is not merely to reshuffle the genes into random recombinations to recognize the structure of genetic material and change its function. The most important outcome of this theory is that all the non-additive effects are constantly converted through recombination into additive and fixable effects and vice-versa.

Proportionate contribution of lines, testers and their interactions to genetic variance

The proportional contribution of lines (Table 4.28, 4.30 and 4.31) ranged from 46.78 (marketable fruits/plant) to 83.45 per cent (oleoresin) during 2010 and from 26.44 (primary branches/plant) to 81.31 per cent (capsaicin content) during 2011 at Palampur. While, at Bajaura, it was in the range of 30.50 (marketable fruits/plant) to 82.45 per cent (oleoresin) and 34.48 (primary branches/plant) to 80.34 per cent (capsaicin content) in the respective years. In pooled environments, the range varied from 36.53 (marketable fruits/plant) to 82.78 per cent (capsaicin content).

The proportional contribution of testers in the respective years ranged from 0.37 (days to first harvest) to 19.91 per cent (plant height) and from 0.67 (average fruit weight) to 19.10 per cent (fruit length) at Palampur, and that from 0.96 (average fruit weight) to 24.23 per cent (plant height) and 0.14 (days to 50% flowering) to 28.33 per cent (plant height) at Bajaura, while it ranged from 5.42 (marketable fruits/plant) to 47.75 per cent (ascorbic acid) in pooled environment (Table 4.28, 4.30 and 4.31).

The proportional contribution of line × tester interactions ranged from 12.59 (oleoresin) to 44.14 per cent (ascorbic acid) and 15.05 (capsaicin content) to 54.94 (primary branches/plant) at Palampur and 13.25 (oleoresin) to 59.17 (marketable fruits/plant) and 15.23 (capsaicin content) to 61.88 (primary branches/plant) at Bajaura in the respective years. On the other hand, it ranged from 5.42 (marketable fruits/plant) to 47.75 (ascorbic acid) in pooled environments. The proportional contribution of these interactions for marketable fruit yield/ plant was 16.76 and 50.28 per cent at Palampur and 46.47 and 41.79 per cent at Bajaura in the respective years of 2010 and 2011 along with 28.61 per cent in pooled environments (Table 4.28, 4.30 and 4.31).

Further, it was observed that the per cent contribution of lines was higher than the corresponding testers and their interactions for all the traits in 2010 at Palampur and also in pooled environments. Similarly, the contribution of lines was higher than the corresponding testers and their interactions for majority of the traits in 2011 at Palampur with few exceptions for primary branches/plant, marketable fruits/plant, marketable fruit yield/plant, plant height, average dry fruit weight and ascorbic acid where interaction comparatively contributed more than the corresponding lines.

Similarly, at Bajaura the contribution of lines was greater than that of testers and interactions for most of the traits except marketable fruits/plant and marketable fruit yield/plant in 2010, days to 50% flowering, primary branches/plant and marketable fruits/plant in 2011, whereas for primary branches/plant in 2010 and ascorbic acid during both the years, the contribution of lines and interaction was almost equal.

Therefore, it can be concluded that lines played a significant role in the expression of different characters in different cross combinations.

4.4 Estimation of Heterosis

The discovery of hybrid vigour by Shull (1908) opened a new era in genetic improvement of crop plants which is now referred as “heterosis breeding”. Genetically diverse varieties are the main necessity to observe heterosis in F_1 hybrids (Mole *et al*. 1962). It is an effective tool in improving the yield and component traits of different crop species. Commercial exploitation of heterosis in self (Rick 1945; Bishop 1954) and cross (Hutchins 1939) pollinated species suggest that irrespective of the breeding system, these crops are essentially similar in their heterotic response and therefore, use of heterosis should carefully be considered in all the crop plants. The first report of hybrid vigour in chilli appeared in 1933 at IARI. In chilli, per cent share of hybrid variety is low, *i.e.,* approximately 5-10 per cent. The probable reason may be the small flower size and low seed yield per pollination. The identification of potential cross combination on the basis of heterosis with respect to various horticultural traits in chilli is of paramount importance for future breeding strategies. An attempt has been made to gather information on nature and magnitude of heterosis for yield and other traits in 33 cross combinations over the better parent (BP) and standard check (SC) 'CH-1'. In general, heterosis over BP and SC was observed for majority of the traits in both the locations during 2010 and 2011 and also pooled over environments and is discussed character wise as under:

Days to 50% flowering

Earliness is economically desirable in vegetables as the market prices are invariably high early in the season and results in remunerative returns. The magnitude of heterosis (Table 4.32) over better parent (BP) and standard check (SC) ranged from 0.00 (Arka Lohit × Anugraha) to -38.42 per cent (Kashmir Long × Pant C 1) and 18.00 (LCA 206 × Surajmukhi) to -16.67 per cent (Kashmir Long × Pant C 1; Kashmir Long × Anugraha) in 2011, 0.60 (Pusa Sadabahar × Anugraha) to -24.86 per cent (LCA 436 × Pant C1; Kashmir Long × Pant C 1) and 9.15 (Pusa Sadabahar × Anugraha) to -13.73 per cent (Chilli Sonal × Surajmukhi) in 2011 at Palampur, 0.57 (LCA 206 × Pant C 1) to -35.35 per cent (Kashmir Long × Surajmukhi) and 23.45 (LCA 206 × Surajmukhi) to -12.41 per cent (Kashmir Long × Pant C 1) in 2010 and -1.60 (LCA 206 × Pant C 1) to -38.74 per cent (Pusa Jwala × Surajmukhi) and 19.38 (LCA 206 × Pant C 1) to -13.95 per cent (Kashmir Long × Pant C 1) in 2011 at Bajaura and -5.58 (Arka Lohit × Anugraha) to -31.05 per cent (Kashmir Long × Surajmukhi) and 15.42 (LCA 206 × Surajmukhi) to -13.52 per cent (Kashmir Long × Pant C 1) in pooled environments, respectively. All the crosses showed significant negative heterosis over the BP except 'LCA 206 × Pant C1' at Bajaura during both the years and

Table 4.32: Estimates of heterosis (%) for days to 50% flowering over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-31.53*	-7.33*	-17.68*	-2.61	-21.71*	-5.52*	-23.32*	-6.98*	-23.83*	-5.55*
2	Jawahar Mirch 283 × Anugraha	-15.15*	-6.67*	0.00	1.31	-17.58*	-6.21*	-18.54*	-4.65*	-10.65*	-3.99*
3	Jawahar Mirch 283 × Surajmukhi	-25.93*	-6.67*	-8.81*	-1.96	-24.75*	2.76	-36.65*	-6.20*	-24.58*	-2.95*
4	Chilli Sonal × Pant C 1	**-37.44***	**-15.33***	-20.99*	-6.54*	-24.57*	-8.97*	-23.32*	-6.98*	-27.05*	-9.53*
5	Chilli Sonal × Anugraha	-16.34*	**-14.67***	-4.52	-3.27	-21.21*	**-10.34***	-5.07*	1.55	-11.82*	-6.93*
6	Chilli Sonal × Surajmukhi	-30.16*	-12.00*	-19.76*	**-13.73***	**-30.81***	-5.52*	-36.65*	-6.20*	**-29.70***	-9.53*
7	PAU Sel Long × Pant C 1	-26.60*	-0.67	-18.23*	-3.27	-16.29*	2.76	-21.41*	-4.65*	-20.48*	-1.39
8	PAU Sel Long × Anugraha	-8.48*	0.67	-5.81	-4.58	-16.85*	2.07	-11.33*	3.10	-10.25*	0.17
9	PAU Sel Long × Surajmukhi	-20.11*	0.67	-17.93*	**-11.76***	-24.24*	3.45	**-38.22***	-8.53*	-25.39*	-3.99*
10	Arka Lohit × Pant C 1	-23.65*	3.33*	-16.57*	-1.31	-13.14*	4.83*	-25.24*	**-9.30***	-19.64*	-0.35
11	Arka Lohit × Anugraha	0.00	3.33*	-9.62*	-7.84*	-9.70*	2.76	-5.11*	0.78	-5.58*	-0.35
12	Arka Lohit × Surajmukhi	-26.46*	-7.33*	-8.81*	-1.96	-28.79*	-2.76	-33.51*	-1.55	-24.99*	-3.47*
13	LCA 436 × Pant C 1	**-34.98***	-12.00*	**-24.86***	-11.11*	-23.30*	-6.90*	-20.77*	-3.88	-26.35*	-8.67*
14	LCA 436 × Anugraha	-18.40*	-11.33*	-12.26*	-11.11*	-23.86*	-7.59*	-18.42*	-3.88	-18.04*	-8.67*
15	LCA 436 × Surajmukhi	-18.52*	2.67*	-14.29*	-7.84*	-25.25*	2.07	-32.46*	0.00	-22.97*	-0.87
16	Pusa Jwala × Pant C 1	-30.05*	-5.33*	**-22.65***	-8.50*	-14.86*	2.76	-20.13*	-3.10	-22.29*	-3.64*
17	Pusa Jwala × Anugraha	-5.23*	-3.33*	-12.26*	-11.11*	-15.15*	-3.45	-19.08*	-4.65*	-10.67*	-5.72*
18	Pusa Jwala × Surajmukhi	-29.63*	-11.33*	-10.03*	-3.27	-29.29*	-3.45	**-38.74***	**-9.30***	-27.54*	-6.76*
19	Pusa Sadabahar × Pant C 1	-23.65*	3.33*	-12.71*	3.27	-21.72*	6.90*	-22.03*	6.98*	-17.10*	5.03*
20	Pusa Sadabahar × Anugraha	-18.42*	3.33*	0.60	9.15*	-25.25*	2.07	-32.20*	-6.98*	-19.29*	2.25*
21	Pusa Sadabahar × Surajmukhi	-18.95*	2.67*	-9.04*	-1.31	-29.29*	-3.45	**-37.70***	-7.75*	-24.04*	-2.25*
22	Kashmir Long × Pant C 1	**-38.42***	**-16.67***	**-24.86***	-11.11*	-27.43*	**-12.41***	-29.07*	**-13.95***	**-30.26***	**-13.52***
23	Kashmir Long × Anugraha	-18.30*	**-16.67***	-11.61*	-10.46*	-22.42*	**-11.72***	-16.18*	**-11.63***	-17.24*	**-12.65***
24	Kashmir Long × Surajmukhi	-30.69*	-12.67*	-19.15*	**-13.07***	**-35.35***	**-11.72***	-37.17*	-6.98*	**-31.05***	-11.27*
25	Sel 352 × Pant C 1	-23.65*	3.33*	-14.36*	1.31	-14.29*	3.45	-3.51*	17.05*	-14.61*	5.89*
26	Sel 352 × Anugraha	-11.76*	-10.00*	-10.90*	-9.15*	-17.58*	-6.21*	-20.00*	-3.88	-13.17*	**-7.45***
27	Sel 352 × Surajmukhi	-20.11*	0.67	-8.81*	-1.96	-24.24*	3.45	-29.32*	4.65*	-21.08*	1.56
28	LCA 443 × Pant C 1	-33.00*	-9.33*	-22.10*	-7.84*	-27.92*	-2.07	-29.82*	-6.98*	-26.37*	-6.59*
29	LCA 443 × Anugraha	-22.28*	-4.67*	-18.89*	-4.58	-23.86*	3.45	-12.28*	16.28*	-19.54*	2.08
30	LCA 443 × Surajmukhi	-28.04*	-9.33*	-19.44*	-5.23	**-30.81***	-5.52*	-29.32*	4.65*	-25.52*	-4.16*
31	LCA 206 × Pant C 1	-21.18*	6.67*	-13.81*	1.96	0.57	21.38*	-1.60	19.38*	-9.72*	11.96*
32	LCA 206 × Anugraha	-13.94*	-5.33*	-11.38*	-3.27	-14.37*	2.76	-21.05*	-6.98*	-15.05*	-3.12*
33	LCA 206 × Surajmukhi	-6.35*	18.00*	-6.59*	1.96	-9.60*	23.45*	-19.37*	19.38*	-10.31*	15.42*
	Range	-38.42 to 0.00	-16.67 to 18.00	-24.86 to 0.60	-13.73 to 9.15	-35.35 to 0.57	-12.41 to 23.45	-38.74 to -1.60	-13.95 to 19.38	-31.05 to -5.58	-13.52 to 15.42
	No. of significant genotypes	32	20	29	14	32	12	32	17	33	21

* Significant at P ≤ 0.05 Bold digits means top three

'Arka Lohit × Anugraha' in 2010 at Palampur while four crosses did not express the same in 2011 at Palampur. A total of 20 and 14 hybrids at Palampur and 12 and 17 hybrids at Bajaura in the respective years and 21 hybrids in pooled environments revealed significantly negative heterosis over the standard check out of which three hybrids were common namely, 'Kashmir Long × Pant C1', 'Kashmir Long × Anugraha' and 'Kashmir Long × Surajmukhi'. The early flowering cross combinations may be of great significance for exploitation in some specific pockets where the growing season is short especially in high hills. Heterosis with variable magnitude have also been observed earlier by Gopalakrishnan *et al.* (1987), Thomas and Peter (1988), Burli *et al.* (2001), Prasad *et al.* (2003), Gondane and Deshmukh (2004), Adapawar *et al*. (2006), Shankarnag and Madalageri (2006), Satish and Lad (2007) and Kamble *et al.* (2009) for days to flowering.

Days to first harvest

Like days to 50% flowering, early maturing strains are also of great value in catching the market early in the season. The range of heterosis over the BP varied from 8.57 (Arka Lohit × Anugraha) to -30.86 per cent (Kashmir Long × Pant C1) and 8.85 (Arka Lohit × Anugraha) to -28.15 per cent (Kashmir Long × Pant C1) at Palampur and -0.92 (Arka Lohit × Anugraha) to -22.62 per cent (Chilli Sonal × Pant C1) and 4.41 (Arka Lohit × Anugraha) to -30.08 per cent (Kashmir Long × Pant C1) at Bajaura during 2010 and 2011, respectively along with -5.58 (Arka Lohit × Anugraha) to -31.05 per cent (Kashmir Long × Surajmukhi) in the pooled environments. On the other hand, the heterosis over standard check observed for 10 and eight crosses at Palampur and eight and four crosses at Bajaura in the respective years while nine crosses exhibited the same in pooled environments. 'Pusa Jwala × Anugraha', 'Kashmir Long × Pant C1', 'Kashmir Long × Anugraha' and 'Selection 352 × Anugraha' had desirable negative heterosis in common in the respective locations and years along with pooled environments (Table 4.33). Similarly, Gopalakrishnan *et al.* (1987), Thomas and Peter (1988), Kumar and Lal (2001) and Kamble *et al.* (2009) have also revealed desirable heterosis for days to first harvest for different cross combinations.

Table 4.33: Estimates of heterosis (%) for days to first harvest over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-16.80*	2.90	-13.87*	6.77*	-10.71*	6.64*	-15.85*	8.38*	-14.31*	6.12*
2	Jawahar Mirch 283 × Anugraha	0.00	2.90	-5.94*	-1.04	-7.17*	4.27*	-17.24*	0.52	-7.81*	1.75
3	Jawahar Mirch 283 × Surajmukhi	-10.25*	5.80*	-12.78*	3.13	-6.53*	8.53*	-4.96*	20.42*	-8.56*	9.36*
4	Chilli Sonal × Pant C 1	**-25.00***	-7.25*	**-23.11***	-4.69*	**-22.62***	**-7.58***	**-24.39***	-2.62	**-23.79***	-5.62*
5	Chilli Sonal × Anugraha	-8.10*	-6.76*	-2.62	-3.13	-8.76*	-6.16*	-2.45	4.19*	-5.60*	-3.12*
6	Chilli Sonal × Surajmukhi	-6.56*	10.14*	1.76	20.31*	-8.16*	6.64*	-7.85*	16.75*	-5.32*	13.23*
7	PAU Sel Long × Pant C 1	-10.94*	10.14*	-13.03*	7.81*	-13.89*	2.84	-13.41*	11.52*	-12.80*	7.99*
8	PAU Sel Long × Anugraha	4.11*	10.14*	4.27*	14.58*	-7.05*	6.16*	-7.17*	15.18*	-1.76*	11.36*
9	PAU Sel Long × Surajmukhi	-6.56*	10.14*	-4.41*	13.02*	-6.53*	8.53*	-14.88*	7.85*	-8.14*	9.86*
10	Arka Lohit × Pant C 1	-10.94*	10.14*	-10.50*	10.94*	-7.54*	10.43*	-13.82*	10.99*	-10.69*	10.61*
11	Arka Lohit × Anugraha	8.57*	10.14*	8.85*	8.85*	-0.92	1.90	4.41*	11.52*	5.23*	7.99*
12	Arka Lohit × Surajmukhi	-21.31*	-7.25*	-17.62*	-2.60	-16.73*	-3.32	-10.74*	13.09*	-16.60*	-0.25
13	LCA 436 × Pant C 1	-21.09*	-2.42	-15.97*	4.17*	-18.25*	-2.37	-17.89*	5.76*	-18.35*	1.12
14	LCA 436 × Anugraha	-5.63*	-2.90	-2.99	1.56	-5.50*	-2.37	-12.56*	2.09	-6.78*	-0.50
15	LCA 436 × Surajmukhi	-15.16*	0.00	-11.89*	4.17*	-16.73*	-3.32	-21.07*	0.00	-16.28*	0.12
16	Pusa Jwala × Pant C 1	**-24.61***	-6.76*	**-23.11***	-4.69*	-17.86*	-1.90	-20.73*	2.09	-21.57*	-2.87*
17	Pusa Jwala × Anugraha	-5.71*	-4.35*	-13.73*	**-8.33***	-9.22*	**-6.64***	-15.53*	-3.14*	-10.00*	-5.62*
18	Pusa Jwala × Surajmukhi	-23.36*	**-9.66***	-22.47*	**-8.33***	**-19.59***	**-6.64***	**-22.31***	-1.57	**-21.92***	-6.62*
19	Pusa Sadabahar × Pant C 1	-7.42*	14.49*	-10.74*	12.50*	-14.68*	1.90	-20.73*	2.09	-13.00*	7.74*
20	Pusa Sadabahar × Anugraha	-2.79*	17.87*	-2.89	22.40*	-8.73*	9.00*	-5.06*	17.80*	-4.89*	16.60*
21	Pusa Sadabahar × Surajmukhi	-5.58*	14.49*	-9.50*	14.06*	-16.27*	0.00	-19.83*	1.57	-12.32*	7.49*
22	Kashmir Long × Pant C 1	**-30.86***	**-14.49***	**-28.15***	**-10.94***	**-21.83***	**-6.64***	**-30.08***	**-9.95***	**-27.72***	**-10.49***
23	Kashmir Long × Anugraha	-11.43*	**-10.14***	-12.57*	**-13.02***	-11.52*	**-9.00***	-16.81*	**-10.47***	-12.90*	**-10.61***
24	Kashmir Long × Surajmukhi	-23.77*	**-10.14***	**-26.43***	**-13.02***	-16.73*	-3.32	-20.66*	0.52	-21.82*	-6.49*
25	Sel 352 × Pant C 1	-10.94*	10.14*	-7.14*	15.10*	-14.68*	1.90	-15.45*	8.90*	-12.10*	8.86*
26	Sel 352 × Anugraha	-10.95*	**-9.66***	-9.80*	-4.17*	-10.14*	**-7.58***	-20.09*	**-8.38***	-12.41*	**-7.49***
27	Sel 352 × Surajmukhi	-15.16*	0.00	-15.86*	-0.52	-17.55*	-4.27*	-21.90*	-1.05	-17.64*	-1.50
28	LCA 443 × Pant C 1	-12.89*	7.73*	-14.71*	5.73*	-13.89*	2.84	-19.11*	4.19*	-15.12*	5.12*
29	LCA 443 × Anugraha	-6.25*	8.70*	-13.73*	4.69*	-14.86*	0.47	-14.81*	8.38*	-12.44*	5.49*
30	LCA 443 × Surajmukhi	-8.20*	8.21*	-10.73*	8.33*	-13.65*	1.90	-13.17*	10.47*	-11.09*	7.12*
31	LCA 206 × Pant C 1	-10.94*	10.14*	-17.57*	2.60	-10.71*	6.64*	-15.85*	8.38*	-13.61*	6.99*
32	LCA 206 × Anugraha	-12.85*	4.83*	-17.15*	3.13	-14.23*	0.00	-14.77*	5.76*	-14.73*	3.37*
33	LCA 206 × Surajmukhi	-9.64*	8.70*	-15.90*	4.69*	-10.98*	3.79*	-18.60*	3.14*	-13.29*	5.12*
	Range	-30.86 to 8.57	-14.49 to 17.87	-28.15 to 8.85	-13.02 to 22.40	-22.62 to 0.92	-9.00 to 10.43	-30.08 to 4.41	-10.47 to 20.42	-27.72 to 5.23	-10.61 to 16.60
	No of significant genotypes	30	10	27	8	32	8	31	4	32	9

* Significant at P ≤ 0.05 Bold digits means top three

Primary branches/plant

Primary branches/plant have a great bearing on the total productivity. Perusal of the data (Table 4.34) revealed that the magnitude of heterosis in the respective years over BP ranged from -35.54 (Kashmir Long × Anugraha) to 19.78 per cent (Chilli Sonal × Pant C1) and -25.23 (Kashmir Long × Anugraha) to 17.05 per cent (LCA 443 × Pant C1) at Palampur and -36.00 (Kashmir Long × Anugraha) to 22.22 per cent (Pusa Jwala × Pant C1) and -34.41 (Kashmir Long × Pant C1) to 8.60 per cent (PAU Selection Long × Pant C1) at Bajaura and that of -19.57 (Arka Lohit × Anugraha) to 14.02 per cent (Pusa Sadabahar × Pant C1) in pooled environments. Hybrid 'LCA 443 × Pant C 1' during both the years and 'Chilli Sonal × PAU Selection Long' during 2011 at Palampur, 'Arka Lohit × Pant C 1', 'LCA 436 × Pant C 1', 'Pusa Jwala × Pant C 1' and Pusa Sadabahar × Pant C 1' during 2010 at Bajaura and 'Jawahar Mirch 283 × Pant C 1', 'Pusa Jwala × Pant C 1', 'Pusa Sadabahar × Pant C 1' and 'LCA 443 × Pant C 1' in pooled environments could surpass the BP for this trait. On the other hand, majority of the crosses exhibited economic heterosis for this trait e.g. 25 and 31 crosses in the respective years at Palampur, 23 crosses during 2010 at Bajaura and 30 crosses in pooled environments while, only five crosses showed hybrid vigour during 2011 at Bajaura. Of these 'Chilli Sonal × Pant C1', 'Arka Lohit × Surajmukhi, 'Pusa Sadabahar × Surajmukhi' and 'LCA 443 × Anugraha' were observed consistent in all sets of environments. The present findings related to heterobeltiosis for primary branches/plant are in agreement with those of Thiruvelavan *et al.* (2002), Linganagouda *et al.* (2003), Gondane and Deshmukh (2004), Zate *et al.* (2005) and Adapawar *et al*. (2006) who had also reported hybrid vigour in a good number of cross combinations in their respective studies.

Fruit length (cm)

Fruit length is one of the most important traits which contributes towards yield and heterosis in positive direction is desirable for this trait. The heterobeltiosis and economic heterosis in the respective years was observed for eight and 26 and seven and 24 crosses at Palampur and that of 14 and 26, and

Table 4.34: Estimates of heterosis (%) for primary branches/plant over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	2.02	23.17*	-4.90	32.88*	2.78	8.82*	-1.08	-2.13	8.09*	14.25*
2	Jawahar Mirch 283 × Anugraha	-8.26	35.37*	0.90	**53.42***	-2.40	19.61*	0.00	9.57	-2.61	**27.64***
3	Jawahar Mirch 283 × Surajmukhi	-19.51*	20.73*	-11.82*	32.88*	-14.29*	11.76*	-9.01	7.45	-13.84*	17.09*
4	Chilli Sonal × Pant C 1	**19.78***	32.93*	1.15	20.55*	-1.71	12.75*	1.89	**14.89***	5.53	19.66*
5	Chilli Sonal × Anugraha	-19.01*	19.51*	-9.91*	36.99*	4.00	**27.45***	-0.94	11.70	-5.87*	23.36*
6	Chilli Sonal × Surajmukhi	-17.89*	23.17*	-16.36*	26.03*	-6.77*	21.57*	-15.32*	0.00	-13.84*	17.09*
7	PAU Sel Long × Pant C 1	-3.74	25.61*	-11.83*	12.33	-5.56	0.00	8.60	7.45	-0.51	10.54*
8	PAU Sel Long × Anugraha	-9.09	34.15*	-8.11	39.73*	-8.00*	12.75*	-16.50*	-8.51	-10.22*	17.66*
9	PAU Sel Long × Surajmukhi	-21.14*	18.29*	-10.91*	34.25*	-8.27*	19.61*	-6.31	10.64	-11.74*	19.94*
10	Arka Lohit × Pant C 1	6.19	25.61*	-8.82	27.40*	**13.89***	20.59*	6.45	5.32	5.82	19.09*
11	Arka Lohit × Anugraha	-9.92	32.93*	-18.02*	24.66*	-28.80*	-12.75*	-21.36*	-13.83*	-19.57*	5.41
12	Arka Lohit × Surajmukhi	-4.07	**43.90***	-3.64	45.21*	-10.53*	16.67*	-4.50	**12.77***	-5.87*	**27.92***
13	LCA 436 × Pant C 1	-4.26	9.76	-14.95*	24.66*	**12.96***	19.61*	-1.08	-2.13	3.40	12.54*
14	LCA 436 × Anugraha	-17.36*	21.95*	-16.22*	27.40*	-16.00*	2.94	-3.88	5.32	-13.70*	13.11*
15	LCA 436 × Surajmukhi	-12.20*	31.71*	2.73	**54.79***	-14.29*	11.76*	-12.61*	3.19	-9.43*	23.08*
16	Pusa Jwala × Pant C 1	-3.33	6.10	-1.11	21.92*	**22.22***	**29.41***	7.53	6.38	**9.97***	16.24*
17	Pusa Jwala × Anugraha	-10.74*	31.71*	0.90	**53.42***	1.60	**24.51***	-13.59*	-5.32	-5.22	24.22*
18	Pusa Jwala × Surajmukhi	-7.32	39.02*	-7.27	39.73*	-18.80*	5.88	-29.73*	-17.02*	-15.72*	14.53*
19	Pusa Sadabahar × Pant C 1	-1.87	28.05*	0.49	41.10*	10.19*	16.67*	3.23	2.13	**14.02***	20.51*
20	Pusa Sadabahar × Anugraha	0.00	**47.56***	0.00	**52.05***	-5.60	15.69*	-2.91	6.38	-2.17	**28.21***
21	Pusa Sadabahar × Surajmukhi	0.00	**50.00***	-11.82*	32.88*	-13.53*	12.75*	0.00	**18.09***	-6.50*	27.07*
22	Kashmir Long × Pant C 1	2.25	10.98	10.34	31.51*	-32.41*	-28.43*	-34.41*	-35.11*	-13.48*	-8.55*
23	Kashmir Long × Anugraha	-35.54*	-4.88	-25.23*	13.70*	-36.00*	-21.57*	-27.18*	-20.21*	-31.26*	-9.91*
24	Kashmir Long × Surajmukhi	-25.20*	12.20	-16.36*	26.03*	-15.04*	10.78*	-6.31	10.64	-15.93*	14.25*
25	Sel 352 × Pant C 1	2.33	7.32	-13.98*	9.59	6.48	12.75*	6.00	**12.77***	1.30	10.83*
26	Sel 352 × Anugraha	-24.79*	10.98	-13.51*	31.51*	-12.80*	6.86	-9.71	-1.06	-15.43*	10.83*
27	Sel 352 × Surajmukhi	-16.26*	25.61*	-8.18	38.36*	-14.29*	11.76*	-15.32*	0.00	-13.63*	17.38*
28	LCA 443 × Pant C 1	15.91*	24.39*	**17.05***	41.10*	-0.46	5.39	-3.23	-4.26	**8.52***	14.70*
29	LCA 443 × Anugraha	-17.36*	21.95*	-10.81*	35.62*	-5.60	15.69*	2.91	**12.77***	-8.00*	20.57*
30	LCA 443 × Surajmukhi	-18.70*	21.95*	-9.09*	36.99*	-16.92*	8.33	-11.71*	4.26	-14.34*	16.41*
31	LCA 206 × Pant C 1	-3.16	12.20	5.75	26.03*	-6.31	1.96	-8.25	-5.32	-3.33	7.41*
32	LCA 206 × Anugraha	-18.18*	20.73*	-14.41*	30.14*	-10.40*	9.80*	-5.83	3.19	-12.39*	14.81*
33	LCA 206 × Surajmukhi	-13.01*	30.49*	-9.09*	36.99*	-12.78*	13.73*	-16.22*	-1.06	-12.79*	18.52*
	Range	-35.54 to 19.78	18.29 to 50.00	-25.23 to 17.05	13.70 to 54.79	-36.00 to 22.22	-12.75 to 29.41	-34.41 to -11.71	-35.11 to 18.09	-19.57 to 14.02	-9.91 to 28.21
	No of significant genotypes	2	25	1	31	4	23	-	5	4	30

* Significant at P ≤ 0.05   Bold digits means top three

13 and 22 crosses at Bajaura in 2010 and 2011, respectively while 13 and 28 crosses in pooled environments showed heterosis over BP and SC, respectively (Table 4.35). The magnitude of heterosis over BP varied from -18.18 (Arka Lohit × Surajmukhi) to 27.57 per cent (LCA 436 × Anugraha) and -29.10 (Kashmir Long × Pant C1) to 28.18 per cent (LCA 436 × Anugraha) at Palampur, and -42.13 (Pusa Sadabahar × Anugraha) to 58.05 per cent (Pusa Sadabahar × Pant C1) and -34.37 (Pusa Sadabahar × Anugraha) to 47.68 per cent (Pusa Sadabahar × Pant C1) at Bajaura in 2010 and 2011, respectively while, it ranged from -26.30 (Pusa Sadabahar × Anugraha) to 36.40 per cent (Pusa Sadabahar × Pant C1) in pooled environments. On the other hand, the significant economic heterosis was in the range of -4.53 (Selection 352 × Pant C 1) to 59.79 per cent (LCA 436 × Anugraha) and -3.62 (Selection 352 × Surajmukhi) to 54.13 per cent (LCA 436 × Anugraha) at Palampur, and -26.69 (Pusa Sadabahar × Anugraha) to 88.75 per cent (Kashmir Long × Anugraha) and -20.55 (Chilli Sonal × Pant C1) to 65.85 per cent (Kashmir Long × Anugraha) at Bajaura in the respective years, while it was -9.06 (Pusa Sadabahar × Anugraha) to 54.13 per cent (LCA 206 × Anugraha) in pooled environments.

Out of the 33 crosses, 16 crosses showed consistency for economic heterosis over the locations in respective years and pooled environments. The top ranking combinations were ‘LCA 436 × Anugraha’ and ‘LCA 206 × Anugraha’ at Palampur and ‘Kashmir Long × Anugraha’ and ‘LCA 206 × Anugraha’ at Bajaura in both the years and were also ranked among top three in pooled environments. The results are in line with those of Thomas and Peter (1988), Burli *et al.* (2001), Singh and Hundal (2001), Thiruvelavan *et al.* (2002), Prasad *et al.* (2003), Seneviratne and Kannangara (2004), Singh and Chaudhary (2005), Zate *et al.* (2005), Adapawar *et al*. (2006) and Shankarnag and Madalageri (2006), who have also observed heterosis in variable number of hybrids developed and studied by them.

Table 4.35: Estimates of heterosis (%) for fruit length (cm) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-12.83*	14.40*	-15.55*	3.91	-16.89*	7.61*	-13.14*	5.42*	-14.56*	7.85*
2	Jawahar Mirch 283 × Anugraha	-1.03	29.90*	2.59	26.24*	9.85*	42.23*	6.05*	29.04*	4.29*	31.65*
3	Jawahar Mirch 283 × Surajmukhi	-7.33*	21.62*	-5.07*	16.82*	16.06*	50.27*	10.78*	34.46*	3.21*	30.28*
4	Chilli Sonal × Pant C 1	3.72	7.08	5.20	7.54*	-37.61*	-17.68*	-30.56*	-20.55*	-15.98*	-5.47*
5	Chilli Sonal × Anugraha	-10.18*	12.51*	-12.74*	4.93	-25.35*	-1.50	-22.44*	-5.62*	-16.78*	2.68
6	Chilli Sonal × Surajmukhi	10.33*	13.90*	9.13*	11.55*	-5.93*	24.12*	1.61	16.26*	3.38*	16.30*
7	PAU Sel Long × Pant C 1	1.49	28.55*	3.37	20.06*	21.73*	24.87*	17.04*	11.66*	9.81*	21.27*
8	PAU Sel Long × Anugraha	-13.49*	9.57*	-15.31*	1.84	6.26*	34.62*	2.27	24.44*	-5.05*	17.16*
9	PAU Sel Long × Surajmukhi	-1.81	24.36*	4.62	21.51*	11.83*	27.65*	12.08*	22.39*	12.20*	23.90*
10	Arka Lohit × Pant C 1	-11.18*	20.73*	-16.83*	16.29*	-8.61*	6.97*	12.14*	-0.82	-8.10*	10.94*
11	Arka Lohit × Anugraha	-4.77	29.45*	-12.13*	22.86*	-19.54*	1.93	-21.01*	-3.89	-8.45*	12.96*
12	Arka Lohit × Surajmukhi	-18.18*	11.21*	-18.15*	14.45*	-6.50*	9.43*	1.78	11.15*	-7.51*	11.65*
13	LCA 436 × Pant C 1	6.85	27.45*	-9.19*	7.88*	-19.18*	22.40*	-20.08*	15.54*	-11.12*	18.23*
14	LCA 436 × Anugraha	**27.57***	**59.79***	**28.18***	**54.13***	-17.41*	25.08*	-18.56*	17.74*	5.02*	**39.70***
15	LCA 436 × Surajmukhi	**19.80***	42.90*	-5.82*	11.89*	-20.67*	20.15*	-18.46*	17.89*	-7.38*	23.19*
16	Pusa Jwala × Pant C 1	-14.98*	24.96*	-19.90*	17.69*	-27.46*	-2.89	-25.06*	-5.83*	-21.45*	8.86*
17	Pusa Jwala × Anugraha	-1.93	**44.15***	-6.81*	36.93*	-16.65*	11.58*	-16.44*	5.01	-9.90*	24.86*
18	Pusa Jwala × Surajmukhi	-7.12*	36.52*	-6.74*	**37.02***	-16.73*	11.47*	-14.16*	7.87*	-10.78*	23.65*
19	Pusa Sadabahar × Pant C 1	**22.33***	1.54	**21.80***	1.26	**58.05***	23.15*	**47.68***	14.01*	**36.40***	9.67*
20	Pusa Sadabahar × Anugraha	-17.34*	3.54	-12.58*	5.12	-42.13*	-26.69*	-34.37*	-20.14*	-26.30*	-9.06*
21	Pusa Sadabahar × Surajmukhi	16.60*	2.89	14.34*	-0.97	**33.80***	**52.73***	18.45*	29.35*	**21.25***	20.20*
22	Kashmir Long × Pant C 1	-13.13*	23.57*	-29.10*	6.33*	24.71*	38.48*	1.11	20.76*	-7.17*	21.87*
23	Kashmir Long × Anugraha	-13.45*	23.12*	-20.34*	19.48*	**48.98***	**88.75***	**36.30***	**65.85***	12.92*	**48.25***
24	Kashmir Long × Surajmukhi	-13.03*	23.72*	-20.01*	19.96*	17.56*	34.19*	8.90*	30.06*	-3.47*	26.73*
25	Sel 352 × Pant C 1	12.71*	-4.53	**20.33***	3.00	-11.42*	-11.04*	-25.75*	-18.92*	-2.51	-7.65*
26	Sel 352 × Anugraha	-9.71*	13.10*	-5.59*	13.53*	-11.42*	12.22*	-14.03*	4.60	-10.14*	10.89*
27	Sel 352 × Surajmukhi	13.04*	-0.25	11.27*	-3.62	-14.55*	-2.47	-12.27*	-4.19	-1.79	-2.63
28	LCA 443 × Pant C 1	5.56	13.60*	-20.33*	-1.69	12.45*	14.26*	**26.35***	22.09*	3.95*	11.85*
29	LCA 443 × Anugraha	1.51	27.15*	1.45	25.18*	8.71*	37.73*	20.92*	**47.14***	8.62*	34.03*
30	LCA 443 × Surajmukhi	0.42	8.07	-11.20*	9.57*	12.39*	28.30*	6.09*	15.85*	7.01*	15.14*
31	LCA 206 × Pant C 1	-10.58*	16.64*	-6.55*	17.30*	-1.21	31.62*	-6.22*	18.61*	-6.17*	20.86*
32	LCA 206 × Anugraha	11.27*	**45.14***	10.09*	**38.18***	28.40*	**71.06***	29.59*	**63.91***	**19.65***	**54.13***
33	LCA 206 × Surajmukhi	-14.78*	11.16*	-7.59*	16.00*	-13.76*	14.90*	-20.53*	0.51	-14.07*	10.68*
	Range	-18.18 to 27.54	-4.53 to 59.79	-29.10 to 28.18	-3.62 to 54.13	-42.13 to 58.05	-26.69 to 88.75	-34.37 to 47.68	-20.55 to 65.85	-26.30 to 36.40	-9.06 to 54.13
	No of significant genotypes	8	26	7	24	14	26	13	22	13	28

* Significant at P ≤ 0.05 Bold digits means top three

Fruit girth (cm)

Only one hybrid each *i.e*., 'Chilli Sonal × Anugraha' (6.29%) over BP and 'Pusa Jwala × Pant C1' (22.93%) over SC showed heterosis during 2010 at Palampur whereas, 'Pusa Sadabahar × Surajmukhi' (4.79%) in 2010 and 'LCA 443 × Pant C1' (6.67%) and 'LCA 443 × Surajmukhi' (6.09%) in 2011 revealed economic heterosis at Bajaura. 'Pusa Sadabahar × Surajmukhi' (54.07% and 8.21%) and 'Jawahar Mirch 283 × Surajmukhi' (12.20 % and 16.56 %) were the common hybrids out of the four and five combinations which exhibited heterobeltiosis in the respective years of 2010 and 2011 at Bajaura. These two crosses along with 'Jawahar Mirch 283 × Anugraha' and 'Jawahar Mirch 283 × Pant C1' showed heterosis over BP in pooled environments. However, none of the cross could surpass 'CH-1' (SC) in pooled environments (Table 4.36). Results are in close proximity to those of Singh and Hundal (2001), Thiruvelavan *et al.* (2002), Prasad *et al.* (2003) and Seneviratne and Kannangara (2004).

Average fruit weight (g)

Average fruit weight is one of the most important component trait which contributes for yield. Consumers prefer long and medium sized fruits. Keeping in the view, the negative correlation between average fruit weight and number of fruits/plant it is important for breeders to keep a balance to meet increased productivity and consumer's preference. The range of heterosis (Table 4.37) for average fruit weight over BP and SC in the respective years was -54.41 (LCA 206 × Surajmukhi) to 45.42 per cent (LCA 206 × Pant C1) and -66.78 (LCA 206 × Anugraha) to 37.47 per cent (Arka Lohit × Anugraha) and -54.76 (LCA 206 × Surajmukhi) to 39.19 per cent (LCA 206 × Pant C1) and -65.23 (LCA 206 × Anugraha) to 38.52 per cent (Arka Lohit × Anugraha) at Palampur and -57.18 (Pusa Sadabahar × Surajmukhi) to 40.53 per cent (Arka Lohit × Anugraha) and -64.41 (LCA 206 × Pant C1) to 38.38 per cent (Arka Lohit × Anugraha), and -55.81(Pusa Sadabahar × Surajmukhi) to 43.80 per cent (LCA 206 × Pant C1) and -58.28 (Pusa Sadabahar × Surajmukhi) to 42.06 per cent (Arka Lohit × Anugraha) at Bajaura. On the other hand, it was in the range of -54.05 (Pusa

Table 4.36: Estimates of heterosis (%) for fruit girth (cm) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	1.32	-17.87*	1.31	-17.33*	4.88	-13.35*	**8.86***	-0.29	5.83*	-12.33*
2	Jawahar Mirch 283 × Anugraha	0.70	-22.93*	4.64	-21.87*	5.79*	-12.59*	17.88*	3.19	7.36*	-13.94*
3	Jawahar Mirch 283 × Surajmukhi	-4.52	-21.07*	-6.82*	-23.47*	**12.20***	-7.30*	**16.56***	2.03	**9.03***	-12.60*
4	Chilli Sonal × Pant C 1	-2.63	-21.07*	-3.59	-21.33*	-5.16	-25.94*	-4.43	-12.46*	-3.88*	-20.38*
5	Chilli Sonal × Anugraha	**6.29***	-18.93*	-1.37	-23.47*	5.47	-31.99*	3.13	-23.48*	3.30	-24.40*
6	Chilli Sonal × Surajmukhi	-14.84*	-29.60*	-18.51*	-33.07*	6.11	-29.97*	0.00	-18.84*	-7.56*	-27.88*
7	PAU Sel Long × Pant C 1	-4.28	-22.40*	-3.92	-21.60*	-34.84*	-49.12*	-30.38*	-36.23*	-18.45*	-32.44*
8	PAU Sel Long × Anugraha	-1.13	-29.87*	-11.27*	-32.80*	-18.18*	-41.06*	-13.89*	-28.12*	-11.39*	-33.24*
9	PAU Sel Long × Surajmukhi	-8.71*	-24.53*	-11.69*	-27.47*	2.80	-25.94*	-3.47	-19.42*	-3.09	-24.40*
10	Arka Lohit × Pant C 1	-33.67*	-29.07*	-34.80*	-29.07*	-31.67*	-38.04*	-26.37*	-22.32*	-31.77*	-29.76*
11	Arka Lohit × Anugraha	-28.68*	-21.60*	-30.88*	-24.80*	-5.28*	-14.11*	-9.34*	-4.35	-18.75*	-16.35*
12	Arka Lohit × Surajmukhi	-26.93*	-21.87*	-36.96*	-20.53*	-7.78*	-16.37*	-9.34*	-4.35	-18.49*	-16.09*
13	LCA 436 × Pant C 1	-20.05*	-10.67*	-18.49*	-10.67*	-8.70*	-10.08*	-3.23	4.35	-12.78*	-6.70*
14	LCA 436 × Anugraha	-29.36*	-21.07*	-27.98*	-21.07*	-26.85*	-27.96*	-24.19*	-18.26*	-27.32*	-22.25*
15	LCA 436 × Surajmukhi	-14.80*	-4.80*	-15.33*	-7.20*	-24.30*	-25.44*	-29.03*	-23.48*	-20.55*	-15.01*
16	Pusa Jwala × Pant C 1	-4.93	**22.93***	-4.58	-22.13*	-14.52*	-33.25*	-12.66*	-20.00*	-9.06*	-24.66*
17	Pusa Jwala × Anugraha	-5.36	-34.13*	-5.43	-34.93*	**20.64***	-33.75*	3.25	-26.38*	2.44	-32.44*
18	Pusa Jwala × Surajmukhi	-26.13*	-38.93*	-17.21*	-32.00*	-8.40*	-39.55*	-23.57*	-37.97*	-19.24*	-37.00*
19	Pusa Sadabahar × Pant C 1	-23.73*	-35.73*	-29.97*	-40.80*	-5.16	-25.94*	-12.66*	-20.00*	-16.18*	-30.56*
20	Pusa Sadabahar × Anugraha	-18.99*	-31.73*	-20.19*	-32.53*	-3.70	-34.51*	1.14	-22.90*	-11.30*	-30.56*
21	Pusa Sadabahar × Surajmukhi	-14.87*	-28.27*	-11.36*	-25.07*	**54.07***	**4.79***	8.21*	-12.17*	**8.90***	-14.75*
22	Kashmir Long × Pant C 1	-17.49*	-15.73*	-15.56*	-11.73*	-9.03*	-28.97*	-12.66*	-20.00*	-10.91*	-19.03*
23	Kashmir Long × Anugraha	-22.98*	-21.33*	-21.17*	-17.60*	-14.09*	-35.52*	-9.29*	-26.38*	-17.70*	-25.20*
24	Kashmir Long × Surajmukhi	-22.72*	-21.07*	-25.51*	-22.13*	-10.74*	-33.00*	6.79*	-13.33*	-14.75*	-22.52*
25	Sel 352 × Pant C 1	-11.28*	-7.73*	-18.50*	-13.07*	-0.88	-14.86*	4.35	-2.61	-7.42*	-9.65*
26	Sel 352 × Anugraha	-25.90*	-22.93*	-28.75*	-24.00*	-13.49*	-25.69*	-11.80*	-17.68*	-20.60*	-22.52*
27	Sel 352 × Surajmukhi	-17.18*	-13.87*	-14.75*	-9.07*	-16.72*	-28.46*	-15.53*	-21.16*	-16.21*	-18.23*
28	LCA 443 × Pant C 1	-13.90*	2.40	-17.56*	-9.87*	-25.11*	-15.11*	-11.54*	**6.67***	-17.36*	-4.29*
29	LCA 443 × Anugraha	-27.13*	-13.33*	-19.51*	-12.00*	-28.44*	-18.89*	-19.71*	-3.19	-23.84*	-11.80*
30	LCA 443 × Surajmukhi	-15.25*	0.80	-9.51*	-1.07	-20.44*	-9.82*	-12.02*	**6.09***	-14.58*	-1.07
31	LCA 206 × Pant C 1	-4.61	-22.67*	-9.48*	-26.13*	-15.16*	-33.75*	-13.92*	-21.16*	-10.68*	-26.01*
32	LCA 206 × Anugraha	-4.63	-34.13*	1.35	-39.73*	-4.09	-35.01*	-6.42*	-19.71*	0.40	-32.17*
33	LCA 206 × Surajmukhi	-17.42*	-31.73*	-16.56*	-31.47*	-11.90*	-40.30*	-15.20*	-27.25*	-14.09*	-32.98*
	Range	-33.67 to 6.29	-38.93 to 22.93	-36.96 to 4.64	-40.80 to -1.07	-34.84 to 54.07	-49.12 to 4.79	-30.38 to 17.88	-37.97 to 6.67	-31.77 to 9.03	-37.00 to -1.07
	No of significant genotypes	1	1	-	-	4	1	5	2	4	-

* Significant at P ≤ 0.05 Bold digits means top three

Table 4.37: Estimates of heterosis (%) for average fruit weight (g) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	14.04*	-26.72*	12.01*	-27.39*	15.30*	-23.44*	20.97*	-17.70*	15.56*	-23.81*
2	Jawahar Mirch 283 × Anugraha	-5.68*	-39.39*	-7.17*	-39.82*	-4.20*	-36.39*	-5.54*	-35.73*	-5.60*	-37.76*
3	Jawahar Mirch 283 × Surajmukhi	-37.94*	-44.03*	-36.16*	-41.87*	-36.39*	-41.50*	-34.43*	-38.09*	-36.18*	-41.31*
4	Chilli Sonal × Pant C 1	1.98	-52.19*	7.11*	-50.61*	4.34*	-53.72*	16.13*	-51.08*	8.16*	-51.98*
5	Chilli Sonal × Anugraha	**27.86***	-40.05*	**38.96***	-35.93*	**36.01***	-37.05*	**32.89***	-32.30*	**36.35***	-36.35*
6	Chilli Sonal × Surajmukhi	-46.18*	-51.46*	-46.06*	-50.89*	-51.99*	-55.84*	-53.24*	-55.85*	-49.38*	-53.45*
7	PAU Sel Long × Pant C 1	-24.78*	-49.27*	-29.73*	-49.32*	-27.65*	-51.00*	-26.20*	-49.39*	-27.11*	-49.70*
8	PAU Sel Long × Anugraha	-23.11*	-48.14*	-29.55*	-49.18*	-20.78*	-46.35*	-12.27*	-39.84*	-21.57*	-45.88*
9	PAU Sel Long × Surajmukhi	-34.56*	-40.98*	-31.13*	-37.30*	-33.21*	-38.58*	-30.93*	-34.79*	-32.46*	-37.89*
10	Arka Lohit × Pant C 1	-32.01*	-31.70*	-33.79*	-30.18*	-30.75*	-31.81*	-31.85*	-29.00*	-32.17*	-30.85*
11	Arka Lohit × Anugraha	**36.83***	**37.47***	**32.55***	**38.52***	**40.53***	38.38*	**36.37***	**42.06***	**36.51***	**39.17***
12	Arka Lohit × Surajmukhi	2.05	**2.52***	3.40*	**8.06***	-0.40	-1.93*	-3.49*	0.54	0.39	**2.35***
13	LCA 436 × Pant C 1	-37.27*	-19.63*	-33.75*	-13.39*	-37.26*	-21.85*	-37.12*	-21.13*	-36.34*	-19.05*
14	LCA 436 × Anugraha	-44.41*	-28.78*	-46.66*	-30.26*	-42.48*	-28.35*	-40.13*	-24.90*	-43.41*	-28.03*
15	LCA 436 × Surajmukhi	-31.00*	-11.60*	-34.06*	-13.80*	-26.44*	-8.37*	-23.98*	-4.64*	-28.85*	-9.52*
16	Pusa Jwala × Pant C 1	-4.79*	-55.17*	-5.22*	-52.87*	6.96*	-52.06*	11.32*	-48.38*	2.00*	-52.05*
17	Pusa Jwala × Anugraha	13.24*	-46.68*	8.65*	-45.97*	9.04*	-49.54*	18.49*	-39.64*	16.12*	-45.41*
18	Pusa Jwala × Surajmukhi	-16.91*	-25.07*	-13.20*	-20.97*	-21.44*	-27.76*	-19.60*	-24.09*	-17.87*	-24.48*
19	Pusa Sadabahar × Pant C 1	-23.70*	-44.69*	-19.71*	-39.89*	-23.51*	-46.41*	-20.50*	-42.33*	-21.67*	-43.26*
20	Pusa Sadabahar × Anugraha	-28.09*	-47.88*	-28.28*	-46.31*	-31.09*	-51.73*	-28.94*	-48.45*	-28.98*	-48.56*
21	Pusa Sadabahar × Surajmukhi	-53.38*	-57.96*	-49.44*	-53.96*	-57.18*	-60.62*	-55.81*	-58.28*	-54.05*	-57.75*
22	Kashmir Long × Pant C 1	-28.88*	-25.20*	-24.87*	-21.17*	-22.83*	-22.11*	-18.78*	-15.88*	-23.87*	-21.06*
23	Kashmir Long × Anugraha	-39.85*	-36.74*	-37.24*	-34.15*	-38.22*	-37.65*	-37.82*	-35.60*	-38.29*	-36.02*
24	Kashmir Long × Surajmukhi	-14.50*	-10.08*	-9.44*	-4.99*	-26.51*	-25.83*	-24.76*	-22.07*	-18.76*	-15.76*
25	Sel 352 × Pant C 1	-1.64	-16.31*	4.84*	-9.70*	-7.81*	-21.65*	-1.37	-17.77*	-1.50*	-16.36*
26	Sel 352 × Anugraha	7.25*	-8.75*	7.22*	-7.65*	10.47*	-6.11*	17.11*	-2.36*	10.43*	-6.24*
27	Sel 352 × Surajmukhi	-17.94*	-25.99*	-17.55*	-24.93*	-20.65*	-27.03*	-18.18*	-22.75*	-18.60*	-25.15*
28	LCA 443 × Pant C 1	-16.17*	-10.61*	-1.19*	-9.56*	-18.69*	-15.07*	-17.86*	-12.11*	-14.01*	-11.87*
29	LCA 443 × Anugraha	-13.93*	-8.22*	1.72*	-6.90*	-14.49*	-10.69*	-12.20*	-6.06*	-10.21*	-7.98*
30	LCA 443 × Surajmukhi	-4.42*	1.92	16.64*	**6.76***	-5.91*	-1.73*	-3.02*	**3.77***	0.20	**2.68***
31	LCA 206 × Pant C 1	**45.42***	-42.04*	**39.19***	-36.68*	**37.99***	-44.29*	**43.80***	-38.36*	**43.16***	-40.38*
32	LCA 206 × Anugraha	-26.00*	-66.78*	-22.17*	-65.23*	-23.10*	-64.41*	-17.83*	-58.14*	-22.13*	-63.65*
33	LCA 206 × Surajmukhi	-54.41*	-58.89*	-54.76*	-58.81*	-49.24*	-53.32*	-54.10*	-56.66*	-53.10*	-56.87*
	Range	-54.41 to 45.42	-66.78 to 37.47	-54.76 to 39.19	-65.23 to 38.52	-57.18 to 40.53	-64.41 to 38.38	-55.81 to 43.80	-58.28 to 42.06	-54.05 to 43.16	-63.65 to 39.17
	No of significant genotypes	6	2	11	3	8	1	8	2	8	3

* Significant at P ≤ 0.05 Bold digits means top three

Sadabahar × Surajmukhi) to 43.16 per cent (LCA 206 × Pant C1) and -63.65 (LCA 206 × Anugraha) to 39.17 per cent (Arka Lohit × Anugraha) over BP and SC in pooled environments, respectively. 'Arka Lohit × Anugraha' showed consistency for economic heterosis irrespective of the environments while, 'LCA 443 × Surajmukhi' and 'Arka Lohit × Surajmukhi' in pooled environments and 2011 at Palampur, 'Arka Lohit × Surajmukhi' in 2010 at Palampur and 'LCA 443 × Surajmukhi' in 2011 at Bajaura also revealed economic heterosis for this trait. Eight crosses showed heteobeltiosis at Bajaura in the respective years and pooled environments whereas, six crosses in 2010 and 11 crosses in 2011 revealed the same at Palampur. Of these, 'LCA 206 × Pant C1', 'Arka Lohit × Anugraha' and 'Chilli Sonal × Anugraha' were the three top ranked hybrids. The results are in consonance with those of Thomas and Peter (1988), Mishra *et al.* (1989), Subashri and Natarajan (1999), Burli *et al.* (2001), Singh and Hundal (2001) and Sitaresmi *et al.* (2010), who have also reported heterosis in different cross combinations of their respective studies.

Marketable fruits/plant

Majority of the crosses showed heterobeltiosis and economic heterosis and respective magnitude of which varied from -34.22 (Chilli Sonal × Pant C1) to 205.84 per cent (Pusa Sadabahar × Surajmukhi) and -25.71 (Chilli Sonal × Pant C1) to 167.96 per cent (Jawahar Mirch 283 × Anugraha), -66.62 (Arka Lohit × Anugraha) to 163.97 per cent (LCA 206 × Anugraha) and -48.53 (Arka Lohit × Anugraha) to 307.08 per cent (LCA 206 × Anugraha) at Palampur, and -45.85 (Arka Lohit × Anugraha) to 305.10 per cent (Pusa Sadabahar × Surajmukhi) and -53.47 (Arka Lohit × Anugraha) to 276.04 per cent (Pusa Sadabahar × Surajmukhi), and -26.66 (Arka Lohit × Anugraha) to 268.03 per cent (Chilli Sonal × Surajmukhi) at Bajaura during 2010 and 2011, respectively (Table 4.38).

In pooled environments, the range of heterosis over BP and SC was -44.65 (Arka Lohit × Anugraha) to 236.29 per cent (Pusa Sadabahar × Surajmukhi) and -21.46 (Arka Lohit × Anugraha) to 184.75 per cent (Pusa Sadabahar × Surajmukhi), respectively. Of the 17 crosses which showed

Table 4.38: Estimates of heterosis (%) for marketable fruits/plant over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	37.26*	55.01*	2.99	39.65*	50.60*	103.43*	11.91*	52.32*	34.83*	62.05*
2	Jawahar Mirch 283 × Anugraha	130.27*	**167.96***	74.52*	**169.14***	43.46*	112.60*	27.70*	101.27*	69.63*	**140.72***
3	Jawahar Mirch 283 × Surajmukhi	**139.24***	125.64*	111.81*	136.33*	48.00*	99.92*	58.80*	64.91*	89.91*	108.92*
4	Chilli Sonal × Pant C 1	-34.22*	-25.71*	7.23	88.45*	90.20*	92.30*	34.91*	83.62*	23.55*	53.20*
5	Chilli Sonal × Anugraha	-16.43*	-2.75	-5.07	66.83*	-4.33	41.79*	-27.79*	13.81*	-9.80*	28.00*
6	Chilli Sonal × Surajmukhi	104.39*	98.45*	35.00*	**137.24***	**236.68***	**251.71***	**184.39***	**268.03***	**126.33***	**180.64***
7	PAU Sel Long × Pant C 1	63.02*	84.10*	53.38*	107.99*	122.21*	120.04*	68.01*	128.68*	73.04*	107.98*
8	PAU Sel Long × Anugraha	73.01*	101.33*	9.31*	68.57*	62.85*	**141.33***	35.97*	114.30*	44.90*	105.63*
9	PAU Sel Long × Surajmukhi	**174.78***	**150.70***	**115.79***	115.50*	106.67*	115.90*	**155.67***	**141.92***	**162.25***	132.17*
10	Arka Lohit × Pant C 1	35.26*	52.75*	21.19*	64.34*	50.06*	48.59*	15.64*	57.39*	29.44*	55.57*
11	Arka Lohit × Anugraha	-12.24*	2.12	-66.62*	-48.53*	-45.85*	-19.75*	-53.47*	-26.66*	-44.65*	-21.46*
12	Arka Lohit × Surajmukhi	61.24*	40.59*	70.88*	13.41	58.96*	66.06*	71.17*	39.29*	65.01*	39.72*
13	LCA 436 × Pant C 1	63.40*	84.53*	39.38*	89.00*	**139.01***	136.68*	71.47*	133.37*	73.45*	108.47*
14	LCA 436 × Anugraha	77.27*	106.29*	33.50*	105.88*	32.52*	96.39*	33.01*	109.64*	44.18*	104.60*
15	LCA 436 × Surajmukhi	65.68*	42.95*	85.27*	22.97*	20.03*	25.39*	56.96*	27.73*	54.37*	30.71*
16	Pusa Jwala × Pant C 1	34.09*	70.01*	37.80*	121.05*	-7.52	58.54*	-3.57	54.34*	15.47*	76.18*
17	Pusa Jwala × Anugraha	33.60*	69.39*	36.38*	118.78*	-3.19	65.98*	-3.12	55.07*	16.22*	77.33*
18	Pusa Jwala × Surajmukhi	39.94*	77.43*	12.31*	80.16*	0.65	72.56*	-13.90*	37.81*	10.30*	68.29*
19	Pusa Sadabahar × Pant C 1	-30.99*	-22.07*	-9.64	22.54*	48.56*	47.11*	7.50	46.32*	-0.35	19.76*
20	Pusa Sadabahar × Anugraha	-3.40	12.41*	-14.46*	31.92*	-0.18	47.92*	16.63*	83.83*	-0.64	41.00*
21	Pusa Sadabahar × Surajmukhi	**205.84***	**163.88***	93.19*	57.52*	**305.10***	**323.18***	**276.04***	**206.00***	**236.29***	**184.75***
22	Kashmir Long × Pant C 1	1.87	15.04*	-2.87	31.71*	33.16*	31.86*	16.64*	58.75*	10.26*	32.53*
23	Kashmir Long × Anugraha	14.00*	32.66*	3.79	60.06*	13.43*	68.10*	-3.03	52.83*	7.06*	51.93*
24	Kashmir Long × Surajmukhi	59.55*	37.66*	**124.56***	53.92*	37.84*	44.00*	62.65*	32.36*	67.58*	41.89*
25	Sel 352 × Pant C 1	15.60*	30.55*	-44.82*	-25.18*	56.56*	55.03*	10.98*	51.05*	5.96*	27.35*
26	Sel 352 × Anugraha	-13.50*	0.66	-22.57*	19.41*	-6.49	38.58*	-23.58*	20.45*	-16.60*	18.35*
27	Sel 352 × Surajmukhi	77.20*	52.89*	87.33*	35.12*	67.77*	75.25*	110.09*	70.96*	86.35*	57.79*
28	LCA 443 × Pant C 1	-12.14*	-0.78	-20.92*	7.24	54.24*	52.73*	2.09	38.95*	1.78	22.33*
29	LCA 443 × Anugraha	6.22	23.60*	-34.42*	1.13	-13.26*	28.54*	-21.84*	23.19*	-15.96*	19.26*
30	LCA 443 × Surajmukhi	55.21*	33.92*	50.40*	51.02*	53.43*	60.28*	48.96*	21.21*	67.01*	41.41*
31	LCA 206 × Pant C 1	-32.47*	-23.74*	-36.76*	-8.69	3.59	24.75*	3.95	41.48*	-12.48*	5.46
32	LCA 206 × Anugraha	28.76*	49.84*	**163.97***	**307.08***	58.51*	134.91*	8.36	70.78*	66.40*	136.14*
33	LCA 206 × Surajmukhi	27.35*	27.22*	25.19*	80.76*	74.45*	110.08*	71.91*	11.87*	47.69*	77.95*
	Range	-34.22 to 205.84	-25.71 to 167.96	-66.62 to 163.97	-48.53 to 307.08	-45.85 to 305.10	-19.75 to 323.18	-53.47 to 276.04	-26.66 to 268.03	-44.65 to 236.29	-21.46 to 184.75
	No of significant genotypes	23	26	20	27	24	32	21	32	25	31

* Significant at P ≤ 0.05 Bold digits means top three

heterobeltiosis commonly in both the locations and years along with pooled environments, ‘Pusa Sadabahar × Surajmukhi’, ‘PAU Selection Long × Surajmukhi’ and ‘Jawahar Mirch 283 × Surajmukhi’ in 2010 and ‘LCA 206 × Anugraha’ and ‘Kashmir Long × Surajmukhi’ and ‘PAU Selection Long × Surajmukhi’ in 2011 at Palampur were the top three crosses. ‘Pusa Sadabahar × Surajmukhi’ and ‘Chilli Sonal × Surajmukhi’ in both the years at Bajaura whereas ‘Pusa Sadabahar × Surajmukhi’, ‘PAU Selection Long × Surajmukhi’ and ‘Chilli Sonal × Surajmukhi’ were placed amongst the top three in pooled environments.

On the other hand, 24 crosses observed to have consistency for economic heterosis over the locations and years. ‘Jawahar Mirch 283 × Anugraha’ (167.96%), ‘Pusa Sadabahar × Surajmukhi’ (163.88%) and ‘PAU Selection Long × Surajmukhi’ (150.70 %) in 2010 and ‘LCA 206 × Anugraha’ (307.08%), ‘Jawahar Mirch 283 × Anugraha’ (169.14%) and ‘Chilli Sonal × Surajmukhi’ (137.24%) in 2011 were ranked among the top three at Palampur while, crosses ‘Pusa Sadabahar × Surajmukhi’ and ‘Chilli Sonal × Surajmukhi’ had obtained top two positions in both the years at Bajaura and pooled over environments. Subashri and Natarajan (1999), Burli *et al.* (2001), Kumar and Lal (2001), Singh and Hundal (2001), Gondane and Deshmukh (2004), Seneviratne and Kannangara (2004), Adapawar *et al.* (2006), Kamble *et al.* (2009) and Sitaresmi *et al.* (2010) also reported hybrid vigour in variable number of hybrids for marketable fruits/plant by using different genetic materials in varied environments.

Marketable fruit yield/plant

High marketable yield is the basic objective of all the crop improvement programs and is of relevance to the farmers from economic view point. A new genotype/hybrid will achieve little or no success, unless it exceeds the current cultivars in performance. Out of the 27 crosses each in the respective years at Palampur, and 29 and 30 crosses in the respective years at Bajaura (Table 4.39). The range of heterobeltiosis varied from -32.78 (LCA 206 × Surajmukhi) to 168.12 per cent (Jawahar Mirch 283 × Anugraha) and -6.27 (LCA 206 × Pant C1)

Table 4.39: Estimates of heterosis (%) for marketable fruit yield/plant over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	87.52*	13.58*	40.21*	1.40	73.64*	55.75*	77.45*	25.37*	70.18*	23.22*
2	Jawahar Mirch 283 × Anugraha	**168.12***	**62.41***	**123.93***	**61.95***	50.78*	35.24*	61.10*	29.35*	**105.36***	**48.70***
3	Jawahar Mirch 283 × Surajmukhi	62.29*	26.28*	89.94*	37.37*	21.73*	16.95*	32.88*	2.10	56.07*	21.43*
4	Chilli Sonal × Pant C 1	-21.14*	-64.51*	14.86*	-6.94	98.45*	-11.00*	56.67*	-10.17*	34.66*	-26.48*
5	Chilli Sonal × Anugraha	11.67	-41.70*	31.92*	6.89	30.13*	-10.75*	-4.05	-22.96*	22.73*	-18.86*
6	Chilli Sonal × Surajmukhi	23.80*	-3.67	43.79*	16.51*	61.65*	55.31*	**111.46***	**62.47***	66.30*	29.40*
7	PAU Sel Long × Pant C 1	51.79*	-6.61*	46.34*	5.41	**135.36***	7.83	78.35*	15.72*	71.22*	4.49*
8	PAU Sel Long × Anugraha	69.57*	4.33	18.93*	-14.33*	88.78*	29.48*	60.57*	28.93*	68.21*	11.21*
9	PAU Sel Long × Surajmukhi	90.04*	**47.87***	87.58*	35.12*	38.03*	32.61*	105.32*	**57.76***	84.32*	43.41*
10	Arka Lohit × Pant C 1	19.11*	4.33	68.00*	13.71*	43.26*	1.33	88.67*	11.74*	47.70*	7.45*
11	Arka Lohit × Anugraha	60.27*	40.38*	3.51	-28.69*	57.01*	11.06*	29.77*	4.19	50.24*	9.30*
12	Arka Lohit × Surajmukhi	64.54*	44.13*	81.07*	22.55*	69.52*	**62.86***	82.26*	40.04*	83.23*	42.57*
13	LCA 436 × Pant C 1	98.23*	**48.31***	**165.36***	**63.69***	**227.59***	**84.98***	**146.28***	**84.07***	**150.65***	**68.37***
14	LCA 436 × Anugraha	96.37*	46.92*	**108.42***	43.58*	**105.16***	40.71*	96.08*	57.44*	**118.77***	**46.96***
15	LCA 436 × Surajmukhi	62.39*	26.36*	74.22*	5.99	19.60*	14.90*	58.53*	21.80*	51.47*	17.86*
16	Pusa Jwala × Pant C 1	27.68*	-23.79*	30.61*	4.18	-1.08	-23.99*	7.34	-20.34*	16.58*	-16.49*
17	Pusa Jwala × Anugraha	51.29*	-9.69*	48.18*	18.20*	9.01	-16.24*	16.58*	-6.39	34.10*	-3.94
18	Pusa Jwala × Surajmukhi	70.79*	32.89*	78.48*	42.37*	29.76*	24.67*	36.15*	4.61	63.26*	27.03*
19	Pusa Sadabahar × Pant C 1	-4.24	-56.90*	19.40*	-26.35*	71.20*	-21.17*	47.17*	-15.62*	33.09*	-32.28*
20	Pusa Sadabahar × Anugraha	12.24*	-41.41*	2.81	-29.18*	4.11	-28.59*	18.02*	-5.24	9.46*	-27.63*
21	Pusa Sadabahar × Surajmukhi	42.57*	10.94*	18.81*	-27.48*	73.44*	**66.63***	66.17*	27.67*	52.50*	18.66*
22	Kashmir Long × Pant C 1	15.58*	-13.95*	44.37*	3.82	15.05*	2.71	**109.54***	33.54*	39.31*	4.50*
23	Kashmir Long × Anugraha	12.72*	-16.08*	46.55*	5.39	17.41*	4.81	22.58*	-1.57	29.40*	-2.93
24	Kashmir Long × Surajmukhi	59.09*	23.79*	103.36*	46.24*	11.17*	6.80	34.24*	3.14	54.98*	20.59*
25	Sel 352 × Pant C 1	**113.67***	9.25*	8.75	-32.44*	47.34*	21.48*	106.09*	24.21*	67.28*	5.56*
26	Sel 352 × Anugraha	75.95*	-8.15*	60.07*	10.27*	57.82*	30.12*	46.48*	17.61*	67.63*	10.83*
27	Sel 352 × Surajmukhi	45.40*	13.14*	63.27*	1.43	33.12*	27.89*	71.90*	32.08*	51.62*	17.98*
28	LCA 443 × Pant C 1	63.69*	-11.31*	5.52	-3.02	51.47*	29.71*	43.65*	22.12*	39.36*	7.60*
29	LCA 443 × Anugraha	**109.35***	13.44*	2.45	-5.85	34.06*	14.81*	36.13*	15.72*	42.09*	9.71*
30	LCA 443 × Surajmukhi	75.41*	36.49*	75.43*	**61.23***	63.94*	57.51*	47.97*	25.79*	86.30*	44.96*
31	LCA 206 × Pant C 1	-1.79	-55.80*	-6.27	-42.18*	42.94*	-30.50*	52.10*	-12.79*	25.16*	-37.26*
32	LCA 206 × Anugraha	-4.64	-50.22*	105.44*	41.53*	21.90*	-16.39*	-10.97	-28.51*	27.24*	-15.88*
33	LCA 206 × Surajmukhi	-32.78*	-47.69*	20.78*	-25.55*	2.07	-1.93	19.51*	-8.18	-1.14	-23.08*
	Range	-32.78 to 168.12	-64.51 to 62.41	-6.27 to 165.36	-42.18 to 63.69	-1.08 to 227.59	-30.50 to 84.98	-10.97 to 146.28	-28.51 to 84.07	-1.14 to 150.65	-37.26 to 68.37
	No of significant genotypes	27	16	27	14	29	19	30	19	32	23

* Significant at P ≤ 0.05 Bold digits means top three

to 165.36 per cent (LCA 436 × Pant C1) at Palampur and -1.08 (Pusa Jwala × Pant C 1) to 227.59 per cent (LCA 436 × Pant C1) and -10.97 (LCA 206 × Anugraha) to 146.28 per cent (LCA 436 × Pant C1) at Bajaura in 2010 and 2011, respectively.

On the other hand, all the crosses except 'LCA 206 × Surajmukhi' showed heterobeltiosis in pooled environments and out of which 'LCA 436 × Pant C1' (150.65%), 'LCA 436 × Anugraha' (118.77%), 'Jawahar Mirch 283 × Anugraha' (105.36%), 'LCA 443 × Surajmukhi' (86.30%) and 'PAU Selection Long × Surajmukhi' (84.32%) were the top five crosses. These crosses were also found among top ten at Palampur in both the years whereas, at Bajaura, they showed significant heterosis along with 'LCA 436 × Pant C1' and 'LCA 436 × Anugraha' among the top ten.

The range of economic heterosis varied from -64.51 (Chilli Sonal × Pant C1) to 62.41 per cent (Jawahar Mirch 283 × Anugraha) during 2010 and -42.18 (LCA 206 × Pant C1) to 63.69 per cent (LCA 436 × Pant C1) during 2011 at Palampur, -30.50 (LCA 206 × Pant C1) to 84.98 per cent (LCA 436 × Pant C1) during 2010 and -28.51 (LCA 206 × Anugraha) to 84.07 per cent (LCA 436 × Pant C1) during 2011 at Bajaura, and -37.26 (LCA 206 × Pant C1) to 68.37 per cent (LCA 436 × Pant C1) in pooled environments. A total of 16 and 14 crosses at Palampur and 19 crosses each at Bajaura during 2010 and 2011, respectively and 23 crosses in pooled environments showed significant positive economic heterotic effects. For economic heterosis, hybrids'Jawahar Mirch 283 × Anugraha', 'PAU Selection Long × Surajmukhi', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C1', 'LCA 436 × Anugraha', 'LCA 436 × Surajmukhi' and 'LCA 443 × Surajmukhi' showed consistent performance by attaining positions among top ten crosses at Palampur and Bajaura in both the years and also in pooled environments. In respective studies, Patel *et al.* (2001), Singh and Hundal (2001), Seneviratne and Kannangara (2004), Adapawar *et al*. (2006), Shankarnag and Madalageri (2006) and Kamble *et al.* (2009) have also reported hybrid vigour for marketable fruit yield/plant with variable magnitude in good number of cross combinations. The variation for heterosis in different studies may be attributed to the differences in the genotypes involved in cross combinations and growing conditions.

Arka Lohit × Surajmukhi

Jawahar Mirch 283 × Anugraha

LCA 436 × Pant C1

LCA 436 × Anugraha

PAU Sel Long × Surajmukhi

LCA 443 × Surajmukhi

Plate 7: Promising heterotic cross combinations for fruit yield and related traits

Harvest duration (days)

Longer harvest duration results in the higher marketable fruit yield in Chilli. The magnitude of heterosis varied from the -32.26 (Chilli Sonal × Anugraha) to 1.07 per cent (Pusa Sadabahar × Surajmukhi) and -17.65 (Chilli Sonal × Anugraha) to 23.53 per cent (Pusa Sadabahar × Surajmukhi) in 2010, and -34.39 (Chilli Sonal × Anugraha) to 2.11 per cent (Pusa Sadabahar × Surajmukhi) and -21.02 (Chilli Sonal × Anugraha) to 23.57 per cent (Pusa Sadabahar × Surajmukhi) in 2011 at Palampur over BP and SC, respectively while, it ranged from -32.46 (Chilli Sonal × Anugraha) to 5.52 per cent (Pusa Sadabahar × Surajmukhi) and -17.31 (Chilli Sonal × Anugraha) to 22.44 per cent (Pusa Sadabahar × Surajmukhi) in 2010, and -33.85 (Chilli Sonal × Anugraha) to 2.63 per cent (Pusa Sadabahar × Surajmukhi) and -16.77 (Chilli Sonal × Anugraha) to 25.81 per cent (Pusa Sadabahar × Surajmukhi) in 2011 at Bajaura over BP and SC, respectively (Table 4.40).

On the other hand, the range in pooled over environments was -33.25 (Chilli Sonal × Anugraha) to 2.81 per cent (Pusa Sadabahar × Surajmukhi) for heterobeltiosis and -18.20 (Chilli Sonal × Anugraha) to 23.83 per cent (Pusa Sadabahar × Surajmukhi) for economic heterosis. Cross 'Pusa Sadabahar × Surajmukhi' during both the years at Bajaura and pooled environments was found to have significant desirable heterosis over BP, while 'PAU Selection Long × Surajmukhi' had the same heterosis in 2011 at Bajaura only. On the other hand, as many as 16 crosses in each location in 2010, 15 and 18 crosses in the respective locations in 2011, and 17 crosses in pooled environments exhibited significant desirable heterosis over standard check. Out of these crosses, 'Pusa Sadabahar × Surajmukhi', 'Pusa Sadabahar × Anugraha' and 'LCA 436 × Anugraha' were the top three economic heterotic combinations over the years in both the locations, and pooled environments. The present findings are in conformity with those of Adapawar *et al.* (2006) and Satish and Lad (2007).

Table 4.40: Estimates of heterosis (%) for harvest duration (days) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-27.37*	-9.80*	-24.06*	-9.55*	-24.*47*	-8.97*	-23.66*	-8.39*	-24.90*	-9.18*
2	Jawahar Mirch 283 × Anugraha	-17.20*	0.65	-17.99*	-1.27	-17.*80*	0.64	-22.56*	-2.58*	-18.92*	-0.64
3	Jawahar Mirch 283 × Surajmukhi	-12.83*	6.54*	-12.11*	6.37*	-9.*94*	4.49*	-14.21*	5.16*	-12.30*	5.64*
4	Chilli Sonal × Pant C 1	-26.83*	-8.50*	-23.53*	-8.92*	-22.87*	-7.05*	-22.58*	-7.10*	-23.83*	-7.89*
5	Chilli Sonal × Anugraha	-32.26*	-17.65*	-34.39*	-21.02*	-32.46*	-17.31*	-33.85*	-16.77*	-33.25*	-18.20*
6	Chilli Sonal × Surajmukhi	-6.95*	13.73*	-7.89*	11.46*	-3.31*	12.18*	-6.32*	14.84*	-6.15*	13.04*
7	PAU Sel Long × Pant C 1	-16.32*	3.92*	-16.04*	0.00	-13.30*	4.49*	-14.52*	2.58*	-15.05*	2.74*
8	PAU Sel Long × Anugraha	-5.91*	14.38*	-10.05*	8.28*	-8.38*	12.18*	-12.82*	9.68*	-9.33*	11.11*
9	PAU Sel Long × Surajmukhi	-1.07	**20.92***	-3.16*	17.20*	**2.76***	**19.23***	-4.21*	17.42*	-1.47*	18.68*
10	Arka Lohit × Pant C 1	-12.63*	8.50*	-10.16*	7.01*	-12.77*	5.13*	-8.06*	10.32*	-10.92*	7.73*
11	Arka Lohit × Anugraha	-4.30*	16.34*	-4.76*	14.65*	-5.76*	15.38*	-6.15*	18.06*	-5.26*	16.10*
12	Arka Lohit × Surajmukhi	-11.76*	7.84*	-10.00*	8.92*	-6.08*	8.97*	-8.42*	12.26*	-9.09*	9.50*
13	LCA 436 × Pant C 1	-6.32*	16.34*	-3.74*	14.65*	-6.91*	12.18*	-1.61	18.06*	-4.66*	15.30*
14	LCA 436 × Anugraha	-0.54	**20.92***	-0.53	**19.75***	-2.09	**19.87***	-4.10*	**20.65***	-1.84*	**20.29***
15	LCA 436 × Surajmukhi	-11.76*	7.84*	-10.00*	8.92*	-6.08*	8.97*	-7.89*	12.90*	-8.96*	9.66*
16	Pusa Jwala × Pant C 1	-17.89*	1.96	-18.72*	-3.18*	-16.49*	0.64	-17.20*	-0.65	-17.58*	-0.32
17	Pusa Jwala × Anugraha	-18.82*	-1.31	-17.99*	-1.27	-22.51*	-5.13*	-19.49*	1.29	-19.71*	-1.61*
18	Pusa Jwala × Surajmukhi	-19.79*	-1.96	-19.47*	-2.55	-16.02*	-2.56	-20.53*	-2.58*	-18.98*	-2.42*
19	Pusa Sadabahar × Pant C 1	-12.63*	8.50*	-6.42*	11.46*	-9.57*	8.97*	-2.69*	16.77*	-7.86*	11.43*
20	Pusa Sadabahar × Anugraha	-1.61	**19.61***	0.53	**21.02***	-2.09	**19.87***	-0.51	**25.16***	-0.92	**21.42***
21	Pusa Sadabahar × Surajmukhi	1.07	**23.53***	2.11	**23.57***	**5.52***	**22.44***	**2.63***	**25.81***	**2.81***	**23.83***
22	Kashmir Long × Pant C 1	-27.89*	-10.46*	-25.13*	-10.83*	-26.60*	-11.54*	-23.66*	-8.39*	-25.83*	-10.31*
23	Kashmir Long × Anugraha	-25.27*	-9.15*	-24.34*	-8.92*	-25.13*	-8.33*	-24.10*	-4.52*	-24.70*	-7.73*
24	Kashmir Long × Surajmukhi	-18.18*	0.00	-20.53*	-3.82*	-13.26*	0.64	-18.42*	0.00	-17.65*	-0.81
25	Sel 352 × Pant C 1	-21.58*	-2.61*	-19.79*	-4.46*	-19.15*	-2.56	-17.74*	-1.29	-19.57*	-2.74*
26	Sel 352 × Anugraha	-16.67*	1.31	-16.93*	0.00	-17.80*	0.64	-17.44*	3.87*	-17.21*	1.45*
27	Sel 352 × Surajmukhi	-19.25*	-1.31	-20.00*	-3.18*	-13.26*	0.64	-20.53*	-2.58*	-18.32*	-1.61*
28	LCA 443 × Pant C 1	-24.74*	-6.54*	-24.60*	-10.19*	-22.87*	-7.05*	-23.66*	-8.39*	-23.97*	-8.05*
29	LCA 443 × Anugraha	-24.73*	-8.50*	-25.40*	-10.19*	-25.65*	-8.97*	-27.18*	-8.39*	-25.76*	-9.02*
30	LCA 443 × Surajmukhi	-13.37*	5.88*	-13.16*	5.10*	-10.50*	3.85*	-10.00*	10.32*	-11.76*	6.28*
31	LCA 206 × Pant C 1	-22.63*	-3.92*	-18.72*	-3.18*	-19.15*	-2.56	-17.74*	-1.29	-19.57*	-2.74*
32	LCA 206 × Anugraha	-17.74*	0.00	-16.40*	0.64	-18.32*	0.00	-16.92*	4.52*	-17.35*	1.29
33	LCA 206 × Surajmukhi	-6.95*	13.73*	-3.68*	16.56*	-2.76*	12.82*	-2.11*	20.00*	-3.88*	15.78*
	Range	-32.26 to 1.07	-17.65 to 23.53	-34.39 to 2.11	-21.02 to 23.57	-32.46 to 5.52	-17.31 to 22.44	-33.85 to 2.63	-16.77 to 25.81	-33.25 to 2.81	-18.20 to 23.83
	No of significant genotypes	-	16	-	15	2	16	1	18	1	17

* Significant at P ≤ 0.05   Bold digits means top three

Plant height (cm)

Plant height plays an important role in areas with high rainfall as tall plants result in less incidence of fruit rot. The respective range of heterobeltiosis and economic heterosis (Table 4.41) varied from -28.94 (Arka Lohit × Surajmukhi) to 32.72 per cent (Jawahar Mirch 283 × Anugraha) and -7.34 (Pusa Sadabahar × Pant C1) to 54.99 per cent (Jawahar Mirch 283 × Anugraha) during 2010 and -16.61 (LCA 443 × Anugraha) to 31.80 per cent (Jawahar Mirch 283 × Anugraha) and -11.48 (Pusa Jwala × Pant C1) to 37.08 per cent (Pusa Sadabahar × Surajmukhi) during 2011 at Palampur , -7.74 (LCA 206 × Anugraha) to 47.44 per cent (LCA 443 × Pant C1) and -3.77 (Pusa Jwala × Anugraha) to 38.28 per cent (Pusa Sadabahar × Surajmukhi) in 2010 and -11.66 (LCA 206 × Pant C1) to 35.60 per cent (LCA 443 × Pant C1) and -21.76 (Pusa Jwala × Pant C1) to 45.31 per cent (Selection 352 × Surajmukhi) in 2011 at Bajaura, and -11.06 (LCA 206 × Pant C1) to 23.21 per cent (LCA 443 × Pant C1) and -4.71 (Pusa Jwala × Anugraha) to 34.62 per cent (Jawahar Mirch 283 × Surajmukhi) in pooled environments.

A total of seven and eight crosses at Palampur and 24 and 21 crosses at Bajaura in the respective years along with 17 crosses in pooled environments showed heterobeltiosis. Out of these, ‘Jawahar Mirch 283 × Anugraha’, ‘LCA 443 × Pant C1’ and ‘LCA 443 × Surajmukhi’ in 2010 and ‘Jawahar Mirch 283 × Anugraha’, ‘Pusa Sadabahar × Pant C1’ and ‘PAU Selection Long × Pant C1’ in 2011 at Palampur, ‘LCA 443 × Pant C1’ and ‘Arka Lohit × Surajmukhi’ in each year along with ‘Pusa Sadabahar × Surajmukhi’ and ‘LCA 443 × Surajmukhi’ in the respective years at Bajaura, and ‘LCA 443 × Pant C1’, ‘Jawahar Mirch 283 × Surajmukhi’ and ‘Jawahar Mirch 283 × Anugraha’ in pooled environments were the top three heterotic combinations over BP. Similarly, 24 crosses in 2010 at both the locations, 28 and 21 crosses in the respective locations in 2011 and 31 crosses in pooled environments exhibited economic heterosis and out of which ‘Jawahar Mirch 283 × Anugraha’ and ‘Jawahar Mirch 283 × Surajmukhi’ in each year along with ‘LCA 443 × Surajmukhi’ and ‘Jawahar Mirch 283 × Surajmukhi’ in

Table 4.41: Estimates of heterosis (%) for plant height (cm) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur 2010 % increase/decrease over BP	SC	Palampur 2011 BP	SC	Bajaura 2010 % increase/decrease over BP	SC	Bajaura 2011 BP	SC	Pooled 2010 % increase/ decrease over BP	Pooled 2011 SC
1	Jawahar Mirch 283 × Pant C 1	-10.12*	4.96	-6.99	-7.66	-7.22	3.15	7.88*	18.38*	-3.75*	5.22*
2	Jawahar Mirch 283 × Anugraha	**32.72***	**54.99***	**31.80***	**31.64***	13.40*	26.07*	12.44*	23.37*	**21.96***	**33.33***
3	Jawahar Mirch 283 × Surajmukhi	7.27*	**41.85***	16.67*	**35.65***	16.58*	29.61*	20.70*	32.44*	**23.14***	**34.62***
4	Chilli Sonal × Pant C 1	-6.27	3.52	13.95*	20.22*	2.36	11.04*	6.94*	13.91*	4.17*	12.20*
5	Chilli Sonal × Anugraha	8.97*	20.36*	5.78	11.60*	7.68	16.81*	15.55*	23.08*	9.68*	18.13*
6	Chilli Sonal × Surajmukhi	2.26	35.22*	-0.21	16.03*	24.73*	**35.32***	22.57*	30.55*	19.10*	29.52*
7	PAU Sel Long × Pant C 1	-1.18	20.48*	**22.56***	16.99*	-1.52	4.52	2.95	9.14*	5.17*	12.37*
8	PAU Sel Long × Anugraha	3.43	26.09*	-6.35	-6.46	6.09	12.59*	-4.99*	0.72	1.15	8.06*
9	PAU Sel Long × Surajmukhi	5.73	39.82*	-7.00	8.13	23.97*	31.57*	25.00*	**32.51***	17.99*	28.32*
10	Arka Lohit × Pant C 1	-4.46	9.97*	1.49	18.42*	13.81*	9.03	-0.90	1.35	2.29	9.32*
11	Arka Lohit × Anugraha	-3.01	11.64*	1.59	18.54*	10.81*	13.60*	13.81*	16.39*	7.64*	15.05*
12	Arka Lohit × Surajmukhi	-28.94*	-6.03	-12.15*	2.51	**29.35***	**37.00***	**32.82***	**35.84***	9.16*	18.71*
13	LCA 436 × Pant C 1	-12.19*	14.39*	4.32	22.67*	5.66	17.48*	1.64	15.99*	-0.29	17.55*
14	LCA 436 × Anugraha	-5.96	22.51*	0.61	18.30*	-4.63	6.04	-8.39*	4.54*	-4.75*	12.29*
15	LCA 436 × Surajmukhi	-1.04	30.87*	-12.31*	3.11	2.28	13.73*	4.96*	19.78*	-0.85	16.89*
16	Pusa Jwala × Pant C 1	-3.97	-3.28	-14.15*	-11.48*	14.90*	2.68	-7.60*	-21.76*	-0.48	-8.66*
17	Pusa Jwala × Anugraha	-10.00*	-3.28	-10.21*	-7.42	-6.13	-3.77	-2.76	-4.54*	-6.45*	-4.71*
18	Pusa Jwala × Surajmukhi	-15.76*	11.40*	-5.14	10.29*	-0.43	5.46	26.33*	7.63*	-0.19	8.55*
19	Pusa Sadabahar × Pant C 1	-8.00	-7.34	**29.82***	23.92*	11.90*	18.28*	19.67*	20.97*	14.56*	14.38*
20	Pusa Sadabahar × Anugraha	9.00*	17.13*	19.58*	19.44*	-0.99	4.66	3.08	4.19*	8.82*	10.85*
21	Pusa Sadabahar × Surajmukhi	-15.21*	12.12*	17.90*	**37.08***	**30.56***	**38.28***	22.84*	24.17*	17.77*	28.08*
22	Kashmir Long × Pant C 1	-12.38*	4.84	-5.13	-0.36	0.77	10.55*	1.26	14.93*	-3.64*	7.89*
23	Kashmir Long × Anugraha	-9.18*	8.66	9.45*	14.95*	7.13	17.53*	3.06	16.98*	2.46	14.72*
24	Kashmir Long × Surajmukhi	-11.42*	17.13*	-7.51	7.54	-3.46	5.91	-4.93*	7.91*	-2.26	9.44*
25	Sel 352 × Pant C 1	3.52	19.28*	-4.97	2.99	9.52*	25.45*	10.95*	24.91*	5.27*	18.67*
26	Sel 352 × Anugraha	-11.19*	2.33	1.43	9.93*	4.16	19.32*	-3.96*	8.12*	-2.30	10.14*
27	Sel 352 × Surajmukhi	-1.58	30.15*	4.73	21.77*	17.90*	35.05*	29.07*	**45.31***	18.55*	**33.64***
28	LCA 443 × Pant C 1	**14.53***	28.00*	-2.18	12.68*	**47.44***	35.04*	**35.60***	27.76*	**23.21***	26.24*
29	LCA 443 × Anugraha	9.72*	22.63*	-16.61*	-3.95	23.60*	26.71*	25.17*	22.88*	14.80*	17.61*
30	LCA 443 × Surajmukhi	**10.88***	**46.63***	-11.83*	2.51	18.62*	25.64*	**34.40***	26.62*	15.33*	25.42*
31	LCA 206 × Pant C 1	-18.75*	17.97*	-12.12*	18.78*	-1.28	18.86*	-11.66*	-0.83	-11.06*	13.25*
32	LCA 206 × Anugraha	-13.49*	25.61*	-9.12*	22.85*	-7.74*	11.08*	-1.28	10.82*	-8.04*	17.10*
33	LCA 206 × Surajmukhi	-5.76	36.84*	-10.44*	21.05*	6.13	27.78*	14.66*	28.72*	0.97	28.58*
	Range	-28.94 to 32.72	-7.34 to 54.99	-16.61 to 31.80	-11.48 to 37.08	-7.74 to 47.44	-3.77 to 38.28	-11.66 to 35.60	-21.76 to 45.31	-11.06 to 23.21	-4.71 to 34.62
	No of significant genotypes	7	24	8	21	15	24	19	28	17	31

* Significant at P ≤ 0.05 Bold digits means top three

the respective years at Palampur, ‘Pusa Sadabahar × Surajmukhi’, ‘Arka Lohit × Surajmukhi’ and ‘Chilli Sonal × Surajmukhi’ in 2010 and ‘Selection 352 × Surajmukhi’, ‘Arka Lohit × Surajmukhi’ and ‘PAU Selection Long × Surajmukhi’ in 2011 at Bajaura, ‘Jawahar Mirch 283 × Surajmukhi’, ‘Selection 352 × Surajmukhi’ and ‘Jawahar Mirch 283 × Anugraha’ in pooled environments were the three best combinations. These results are in broad conformity to the findings of Thomas and Peter (1988), Linganagouda *et al.* (2003), Gondane and Deshmukh (2004), Adapawar *et al.* (2006), Shankarnag and Madalageri (2006), Satish and Lad (2007) and Kamble *et al.* (2009), who have also reported positive heterosis for variable number of hybrids evaluated by them.

Average dry fruit weight (g)

It is an important component trait for obtaining high dry fruit yield/plant. It was observed that the magnitude of heterosis over better parent and standard check ranged (Table 4.42) from -58.24 (LCA 443 × Pant C1) to 105.56 per cent (Arka Lohit × Anugraha) and -68.19 (Pusa Sadabahar × Surajmukhi) to -3.43 per cent (LCA 436 × Surajmukhi) during 2010, and -56.67 (LCA 443 × Pant C1) to 115.02 per cent (Arka Lohit × Pant C1) and -63.05 (Pusa Sadabahar × Anugraha) to -4.19 per cent (LCA 443 × Surajmukhi) during 2011 at Palampur, -45.85 (LCA 443 × Pant C1) to 119.68 per cent (Arka Lohit × Anugraha) and -63.00 (Pusa Sadabahar × Surajmukhi) to 1.40 per cent (LCA 436 × Surajmukhi) during 2010 and -47.70 (LCA 443 × Pant C1) to 108.77 per cent (Arka Lohit × Pant C1) and -60.36 (Kashmir Long × Surajmukhi) to 5.33 per cent (LCA 436 × Surajmukhi) during 2011 at Bajaura, and -52.67 (LCA 443 × Pant C1) to 107.39 per cent (Arka Lohit × Pant C1) and -61.87 (Pusa Sadabahar × Surajmukhi) to -0.39 per cent (LCA 436 × Surajmukhi) in pooled environments, respectively. Cross combinations namely ‘Arka Lohit × Anugraha’, ‘Arka Lohit × Pant C1’ and ‘Pusa Sadabahar × Pant C1’ in 2010 at Palampur and 2011 at Bajaura, ‘Arka Lohit × Pant C1’, ‘Chilli Sonal × Pant C1’ and ‘Pusa Sadabahar × Pant C1’ in 2011 at Palampur and ‘Arka Lohit × Pant C1’, ‘Arka Lohit × Anugraha’ and ‘Kashmir Long × Pant C1’ in 2010 at Bajaura and pooled environments had got

Table 4.42: Estimates of heterosis (%) for average dry fruit weight (g) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur 2010 % increase/decrease over BP	SC	Palampur 2011 BP	SC	Bajaura 2010 % increase/decrease over BP	SC	Bajaura 2011 BP	SC	Pooled % increase/ decrease over BP	SC
1	Jawahar Mirch 283 × Pant C 1	12.39	-49.90*	-3.43	-57.14*	11.16	-50.20*	15.35	-48.13*	8.70	-51.36*
2	Jawahar Mirch 283 × Anugraha	-8.81	-60.57*	4.11	-56.57*	-5.12	-59.20*	5.02	-54.64*	-0.91	-57.78*
3	Jawahar Mirch 283 × Surajmukhi	34.36*	-41.90*	52.05*	-36.57*	31.16*	-43.60*	33.79*	-42.21*	38.36*	-41.05*
4	Chilli Sonal × Pant C 1	21.18*	-41.14*	**80.26***	-20.00*	25.21*	-41.40*	19.31*	-45.17*	38.30*	-36.77*
5	Chilli Sonal × Anugraha	-4.71	-53.71*	-5.00	-60.19*	5.98	-50.40*	16.74	-46.35*	3.40	-52.72*
6	Chilli Sonal × Surajmukhi	35.29*	-34.29*	53.64*	-35.62*	16.67*	-45.40*	24.46*	-42.80*	32.77*	-39.30*
7	PAU Sel Long × Pant C 1	-40.29*	-52.57*	-38.75*	-49.71*	-33.68*	-49.20*	-18.97*	-50.30*	-33.77*	-50.39*
8	PAU Sel Long × Anugraha	-33.33*	-47.05*	-33.87*	-45.71*	-29.50*	-46.00*	-9.65	-44.58*	-27.79*	-45.91*
9	PAU Sel Long × Surajmukhi	12.95*	-10.29*	-11.14	-27.05*	7.83	-17.40*	31.19*	-19.53*	8.83*	-18.48*
10	Arka Lohit × Pant C 1	**102.14***	-9.90*	**115.02***	-4.57	**104.91***	-8.20*	**108.77***	-6.11	**107.39***	-7.20*
11	Arka Lohit × Anugraha	**105.56***	-22.48*	30.95*	-47.62*	**119.68***	-17.40*	**82.33***	-22.68*	**84.16***	-27.63*
12	Arka Lohit × Surajmukhi	69.19*	-36.19*	45.75*	-41.14*	75.53*	-34.00*	45.12*	-38.46*	59.41*	-37.35*
13	LCA 436 × Pant C 1	-26.06*	-7.05	-28.69*	-17.14*	-10.40*	-1.80	-33.86*	-26.04*	-24.83*	-12.84*
14	LCA 436 × Anugraha	-35.91*	-19.43*	-48.85*	-40.57*	-23.54*	-16.20*	-26.98*	-18.34*	-34.23*	-23.74*
15	LCA 436 × Surajmukhi	-23.18*	-3.43	-18.36*	-5.14	-7.48	1.40	-5.82	5.33	-14.09*	-0.39
16	Pusa Jwala × Pant C 1	17.44	-42.29*	36.82*	-32.76*	11.11	-46.00*	4.94	-45.56*	17.58*	-41.44*
17	Pusa Jwala × Anugraha	22.87*	-39.62*	7.75	-47.05*	24.69*	-39.40*	19.39*	-38.07*	18.36*	-41.05*
18	Pusa Jwala × Surajmukhi	11.24	-45.33*	4.65	-48.57*	28.40*	-37.60*	28.52*	-33.33*	17.97*	-41.25*
19	Pusa Sadabahar × Pant C 1	**70.09***	-24.19*	**77.25***	-21.33*	76.34*	-21.00*	**82.46***	-17.95*	76.09*	-21.21*
20	Pusa Sadabahar × Anugraha	-6.15	-65.14*	-7.62	-63.05*	10.00	-60.40*	1.37	-56.21*	-1.00	-61.28*
21	Pusa Sadabahar × Surajmukhi	-15.66	-68.19*	8.96	-56.00*	2.78	-63.00*	-7.31	-59.96*	-2.49	-61.87*
22	Kashmir Long × Pant C 1	62.39*	-27.62*	64.38*	-27.05*	**81.70***	-18.60*	58.77*	-28.60*	**66.52***	-25.49*
23	Kashmir Long × Anugraha	9.64	-58.86*	0.00	-59.43*	10.34	-55.20*	15.05	-53.25*	8.29	-56.81*
24	Kashmir Long × Surajmukhi	-2.02	-63.05*	-2.82	-60.57*	-2.46	-60.40*	-2.43	-60.36*	-2.44	-61.09*
25	Sel 352 × Pant C 1	-37.37*	-42.86*	-36.38*	-39.05*	-35.37*	-36.40*	-31.73*	-35.50*	-35.38*	-38.52*
26	Sel 352 × Anugraha	-22.34*	-29.14*	-29.22*	-32.19*	-25.81*	-27.00*	-26.93*	-30.97*	-26.38*	-29.96*
27	Sel 352 × Surajmukhi	-15.03*	-22.48*	-23.86*	-27.05*	-13.01*	-14.40*	-20.46*	-24.85*	-18.40*	-22.37*
28	LCA 443 × Pant C 1	-58.24*	-40.19*	-56.67*	-40.57*	-45.85*	-33.40*	-47.70*	-37.28*	-52.67*	-37.94*
29	LCA 443 × Anugraha	-49.34*	-27.43*	-44.72*	-24.19*	-34.80*	-19.80*	-39.80*	-27.81*	-42.58*	-24.71*
30	LCA 443 × Surajmukhi	-34.71*	-6.48	-30.14*	-4.19	-34.15*	-19.00*	-37.01*	-24.46*	-33.98*	-13.42*
31	LCA 206 × Pant C 1	-8.73	-52.19*	6.45	-49.71*	-2.20	-46.60*	12.01	-31.95*	2.17	-45.14*
32	LCA 206 × Anugraha	15.64	-39.43*	51.21*	-28.57*	29.30*	-29.40*	10.71	-32.74*	25.72*	-32.49*
33	LCA 206 × Surajmukhi	9.09	-42.86*	16.94	-44.76*	15.38*	-37.00*	8.12	-34.32*	11.96*	-39.88
	Range	-58.24 to 105.56	-68.19 to -3.43	-56.67 to 115.02	-63.05 to -4.19	-45.85 to 119.68	-63.00 to 1.40	-47.70 to 108.77	-60.36 to 5.33	-52.67 to 107.39	-61.87 to -0.39
	No of significant genotypes	10	-	10	-	12	-	11	-	14	-

* Significant at P ≤ 0.05 Bold digits means top three

their position amongst top three heterotic combinations over BP. Out of 10 crosses in each year at Palampur, 12 and 11 crosses in respective years at Bajaura and 14 crosses in pooled environments, none of the hybrid exhibited economic heterosis for this trait. Similar findings have also been reported by Gandhi *et al.* (2000) and Thiruvelavan *et al.* (2002).

Dry fruit yield/plant

Dry chillies are used as spice and higher dry fruit yield is of the prime objective in chilli breeding. Hybrids in chilli have great significance to the farmer on account of their high export potential. The magnitude of heterosis (Table 4.43) for this trait over BP ranged from -24.72 (Pusa Sadabahar × Pant C1) to 133.33 per cent (Arka Lohit × Anugraha) and -23.40 (Chilli Sonal × Anugraha) to 130.51 per cent (Arka Lohit × Surajmukhi) in the respective years at Palampur, 15.65 (Pusa Jwala × Anugraha) to 137.33 per cent (Selection 352 × Pant C1) and -8.96 (Pusa Jwala × Pant C1) to 103.90 per cent (LCA 436 × Pant C1) in the respective years at Bajaura, and 5.35 (Chilli Sonal × Anugraha) to 110.43 per cent (LCA 436 × Pant C1) in pooled environments. On the other hand, range for economic heterosis varied from -57.76 (Pusa Sadabahar × Pant C1) to 39.79 per cent (Arka Lohit × Surajmukhi) and -42.67 (LCA 206 × Pant C1) to 32.25 per cent (LCA 436 × Pant C1) in the respective years at Palampur, -33.91 (LCA 206 × Pant C1) to 49.07 per cent (LCA 436 × Pant C1) and -20.76 (LCA 206 × Pant C1) to 77.12 per cent (LCA 436 × Pant C1) in the respective years at Bajaura and -35.93 (LCA 206 × Pant C1) to 47.26 per cent (LCA 436 × Pant C1) in pooled environments.

As many as 29 and 26 at Palampur and 33 and 25 at Bajaura in the respective years of 2010 and 2011 and 32 hybrids in pooled environments revealed heterobeltiosis whereas, 13 and 11 at Palampur and 16 and 18 at Bajaura in the respective years along with 19 crosses in pooled environments showed economic heterosis. ‘Arka Lohit × Surajmukhi’, ‘Arka Lohit × Anugraha’ and ‘Jawahar Mirch 283 × Anugraha’ in both the years at Palampur and ‘LCA 436 × Pant C1’, ‘Jawahar Mirch 283 × Anugraha’, ‘Arka Lohit × Surajmukhi’ and ‘PAU

Table 4.43: Estimates of heterosis (%) for dry fruit yield/plant (g) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	91.73*	18.47*	51.90*	1.43	**120.57***	33.01*	60.41*	33.90*	**100.46***	20.76*
2	Jawahar Mirch 283 × Anugraha	**123.37***	**38.02***	**126.84***	24.43*	94.78*	23.50*	52.45*	31.78*	**105.55***	29.44*
3	Jawahar Mirch 283 × Surajmukhi	70.75*	14.12*	96.57*	12.05*	49.70*	4.20	44.17*	25.85*	64.20*	13.47*
4	Chilli Sonal × Pant C 1	30.82*	-34.43*	-22.98*	-41.04*	58.53*	-10.96*	11.05	-19.07*	15.01*	-27.12*
5	Chilli Sonal × Anugraha	-5.95	-50.19*	-23.40*	-41.37*	23.37*	-21.78*	-0.49	-13.98*	5.35	-33.24*
6	Chilli Sonal × Surajmukhi	51.98*	1.58	34.04*	2.61	99.01*	**38.53***	68.45*	47.03*	74.36*	20.49*
7	PAU Sel Long × Pant C 1	53.95*	-2.84	25.75*	-9.32	71.36*	3.93	64.81*	13.14*	52.69*	0.42
8	PAU Sel Long × Anugraha	72.83*	9.08	2.08	-26.38*	59.78*	1.31	50.49*	30.08*	55.03*	1.96
9	PAU Sel Long × Surajmukhi	102.92*	35.62*	69.83*	22.48*	78.51*	24.26*	**70.87***	**49.15***	91.03*	**32.01***
10	Arka Lohit × Pant C 1	**126.49***	7.82	52.68*	1.95	102.00*	4.41	61.73*	11.02	82.62*	6.05*
11	Arka Lohit × Anugraha	**133.33***	23.58*	118.53*	19.87*	74.24*	10.48*	33.33*	15.25*	86.70*	17.57*
12	Arka Lohit × Surajmukhi	109.15*	**39.79***	**130.51***	**31.40***	85.64*	29.22*	56.80*	36.86*	94.31*	**34.28***
13	LCA 436 × Pant C 1	77.89*	**37.96***	98.05*	**32.25***	**126.49***	**49.07***	**103.90***	**77.12***	**110.43***	**47.26***
14	LCA 436 × Anugraha	70.49*	32.22*	87.29*	2.74	71.83*	13.09*	70.63*	**48.22***	75.49*	22.81*
15	LCA 436 × Surajmukhi	42.28*	10.34*	64.57*	-6.19	70.30*	18.54*	56.80*	36.86*	62.09*	13.43*
16	Pusa Jwala × Pant C 1	18.04*	-24.91*	20.49*	-19.54*	42.73*	-12.06*	-8.96	-18.22*	17.50*	-18.86*
17	Pusa Jwala × Anugraha	53.72*	-2.21	52.13*	0.00	15.65**	-26.67*	7.08	-3.81	33.05*	-8.12*
18	Pusa Jwala × Surajmukhi	74.62*	16.71*	96.73*	29.32*	59.60*	11.10*	9.43	-1.69	66.23*	14.87*
19	Pusa Sadabahar × Pant C 1	-24.72*	-57.76*	2.44	-31.60*	32.13*	-31.70*	25.61*	-12.71	12.01*	-34.96*
20	Pusa Sadabahar × Anugraha	-10.22	-49.62*	5.11	-42.35*	54.89*	-1.79	-6.37	-19.07*	12.20*	-29.34*
21	Pusa Sadabahar × Surajmukhi	65.00*	10.28*	30.29*	-25.73*	76.93*	23.16*	21.84*	6.36	49.21*	3.11
22	Kashmir Long × Pant C 1	81.08*	-2.84	20.52*	-8.93	82.15*	11.85*	**102.98***	44.49*	67.48*	8.95*
23	Kashmir Long × Anugraha	42.19*	-23.71*	25.00*	-5.54	51.63*	-3.86	24.02*	7.20	42.17*	-7.52*
24	Kashmir Long × Surajmukhi	77.74*	18.79*	61.21*	21.82*	28.51*	-10.54*	19.42*	4.24	58.04*	9.21*
25	Sel 352 × Pant C 1	102.65*	-3.53	29.76*	-13.36*	**137.33***	34.94*	85.19*	27.12*	89.14*	9.83*
26	Sel 352 × Anugraha	91.07*	1.20	122.09*	21.82*	77.17*	12.34*	33.33*	15.25*	78.48*	12.39*
27	Sel 352 × Surajmukhi	54.91*	3.53	118.29*	24.43*	86.63*	29.91*	50.97*	31.78*	75.90*	21.56*
28	LCA 443 × Pant C 1	44.47*	-26.67*	29.27*	-13.68*	75.32*	-4.55	46.53*	25.42*	54.18*	-6.93*
29	LCA 443 × Anugraha	91.79*	1.58	83.39*	3.58	66.85*	5.79	52.45*	31.78*	73.67*	9.37*
30	LCA 443 × Surajmukhi	83.96*	22.95*	**128.57***	**30.29***	101.98*	**40.59***	23.79*	8.05	82.76*	26.30*
31	LCA 206 × Pant C 1	20.66*	-42.56*	-14.15	-42.67*	27.87*	-33.91*	15.43	-20.76*	10.33*	-35.93*
32	LCA 206 × Anugraha	23.57*	-34.55*	71.02*	-6.19	16.63*	-26.05*	-1.47	-14.83*	25.78*	-20.79*
33	LCA 206 × Surajmukhi	3.96	-30.52*	15.43	-34.20*	31.88*	-8.20*	25.24*	9.32	19.10*	-17.70*
	Range	-24.72 to 133.33	-57.76 to 39.79	-23.40 to 130.51	-42.67 to 32.25	15.65 to 137.33	-33.91 to 49.07	-8.96 to 103.90	-20.76 to 77.12	5.35 to 110.43	-35.93 to 47.26
	No of significant genotypes	29	13	26	11	33	16	25	18	32	19

* Significant at P ≤ 0.05 Bold digits means top three

Selection Long × Surajmukhi' in pooled environments showed consistency in ranking amongst top five for heterosis over BP and SC except 'Arka Lohit × Anugraha' in 2011 at Palampur over SC though had significant heterosis. On the other hand, at Bajaura, 'Selection 352 × Pant C1', 'LCA 436 × Pant C1' and 'Jawahar Mirch 283 × Pant C1' in 2010 and 'LCA 436 × Pant C1', 'Kashmir Long × Pant C1' and 'PAU Selection Long × Surajmukhi' in 2011 over BP, and 'LCA 436 × Pant C1', 'LCA 443 × Surajmukhi' and 'Chilli Sonal × Surajmukhi' in 2010 and 'LCA 436 × Pant C1', 'PAU Selection Long × Surajmukhi' and 'LCA 436 × Anugraha' in 2011 over SC were the top three heterotic combinations. Results are in close proximity with those of Burli *et al.* (2001), Kumar and Lal (2001), Prasad *et al.* (2003) and Prasath and Ponnuswami (2008) who have also observed hybrid vigour for variable number of crosses in different studies.

Ascorbic acid (mg/100g)

Ascorbic acid has unique anti-oxidant properties and also strengthens the immune system of the body against diseases. Chilli is quite rich source of ascorbic acid and thus, has enormous potential. The respective heterobeltiosis and economic heterosis range for this trait (Table 4.44) varied from -31.71 (Pusa Jwala × Pant C1) to 23.17 per cent (Kashmir Long × Anugraha) and -14.51 (Selection 352 × Anugraha) to 26.05 per cent (Kashmir Long × Anugraha) during 2010 and -28.44 (LCA 436 × Pant C1) to 14.16 per cent (PAU Selection Long × Surajmukhi) and -14.06 (LCA 436 × Pant C1) to 19.63 per cent (PAU Selection Long × Surajmukhi) during 2011 at Palampur, -28.11 (LCA 206 × Pant C1) to 23.70 per cent (Kashmir Long × Anugraha) and -19.10 (LCA 206 × Pant C1) to 15.01 per cent (Pusa Sadabahar × Surajmukhi) during 2010 and -27.12 (LCA 206 × Pant C1) to 22.85 per cent (Pusa Sadabahar × Anugraha) and -20.60 (LCA 206 × Pant C1) to 18.06 per cent (Kashmir Long × Anugraha) during 2011 at Bajaura, and -27.65 (LCA 206 × Pant C1) to 20.70 per cent (Kashmir Long × Anugraha) and -15.20 (LCA 206 × Pant C1) to 18.42 per cent (Kashmir Long × Anugraha) in pooled environments. Out of the 10 crosses exhibiting heterobeltiosis in 2010 in each location and 2011 at Bajaura along with nine crosses in 2011 at Palampur, 'Kashmir Long × Anugraha', 'PAU Selection Long ×

Table 4.44: Estimates of heterosis (%) for ascorbic acid (mg/100g) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur 2010		Palampur 2011		Bajaura 2010		Bajaura 2011		Pooled	
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-14.63*	9.20*	-13.64*	3.71*	-15.03*	-4.37*	-13.97*	-6.27*	-14.33*	0.41
2	Jawahar Mirch 283 × Anugraha	-9.72*	-10.14*	-7.87*	-5.87*	2.59	-13.27*	-2.23	-15.07*	-4.55*	-11.16*
3	Jawahar Mirch 283 × Surajmukhi	-2.30*	-0.47	-5.60*	-1.08	-10.33*	-10.20*	-13.41*	-13.28*	-7.96*	-6.39*
4	Chilli Sonal × Pant C 1	-15.73*	7.80*	-11.45*	6.34*	-9.33*	2.04	-3.56*	5.07*	-10.20*	5.26*
5	Chilli Sonal × Anugraha	7.05*	6.55*	-0.45	1.70	**21.03***	2.33	15.12*	0.00	10.24*	2.61*
6	Chilli Sonal × Surajmukhi	-10.87*	-9.20*	-8.55*	-4.17*	-13.97*	-13.85*	-10.88*	-10.75*	-11.08*	-9.57*
7	PAU Sel Long × Pant C 1	-21.46*	0.47	-19.95*	-3.86*	-23.06*	-13.41*	-11.92*	-4.03*	-19.23*	-5.33*
8	PAU Sel Long × Anugraha	11.60*	11.08*	3.63*	5.87*	6.23*	4.37*	5.67*	2.84	9.15*	5.97*
9	PAU Sel Long × Surajmukhi	**20.52***	**22.78***	**14.16***	**19.63***	14.12*	**14.29***	14.16*	**14.33***	**15.69***	**17.66***
10	Arka Lohit × Pant C 1	-14.59*	9.27*	-5.79*	13.14*	-7.51*	4.08*	-2.74	5.97*	-7.83*	8.03*
11	Arka Lohit × Anugraha	-0.81	14.82*	7.02*	**17.77***	9.10*	6.56*	1.45	4.63*	4.08*	10.81*
12	Arka Lohit × Surajmukhi	-24.80*	-12.95*	-19.24*	-11.13*	-15.57*	-15.45*	-15.05*	-12.39*	-18.29*	-13.01*
13	LCA 436 × Pant C 1	-29.27*	-9.52*	-28.44*	-14.06*	-27.20*	-18.08*	-17.67*	-10.30*	-25.81*	-13.05*
14	LCA 436 × Anugraha	-2.34*	-2.18	1.51	3.71*	-1.16	-13.27*	1.20	-12.09*	0.85	-6.13*
15	LCA 436 × Surajmukhi	3.98*	5.93*	3.39*	8.35*	-2.33	-2.19	5.22*	5.37*	2.53*	4.27*
16	Pusa Jwala × Pant C 1	-31.71*	-12.64*	-25.35*	-10.36*	-24.74*	-15.31*	-23.15*	-16.27*	-23.36*	-13.69*
17	Pusa Jwala × Anugraha	-1.92	3.59*	1.36	3.55*	10.16*	-0.44	**17.35***	1.94	7.70*	2.11*
18	Pusa Jwala × Surajmukhi	-13.74*	-8.89*	-8.55*	-4.17*	-13.68*	-13.56*	-7.00*	-6.87*	-9.97*	-8.44*
19	Pusa Sadabahar × Pant C 1	-15.37*	8.27*	-7.34*	11.28*	-8.68*	2.77	-4.38*	4.18*	-9.10*	6.54*
20	Pusa Sadabahar × Anugraha	**19.12***	18.56*	11.20*	13.60*	**23.48***	6.56*	**22.85***	13.13*	**19.12***	12.86*
21	Pusa Sadabahar × Surajmukhi	18.68*	**20.90***	**12.24***	17.62*	14.85*	**15.01***	14.61*	**14.78***	15.06*	**17.02***
22	Kashmir Long × Pant C 1	-10.49*	14.51*	-5.15*	13.91*	-11.14*	0.00	-3.01	5.67*	-7.55*	8.36*
23	Kashmir Long × Anugraha	**23.17***	**26.05***	**13.91***	**19.01***	**23.70**	11.08*	**22.45***	**18.06***	**20.70***	**18.42***
24	Kashmir Long × Surajmukhi	15.85*	18.56*	7.82*	12.98*	11.21*	**11.37***	7.30*	7.46*	10.64*	12.52*
25	Sel 352 × Pant C 1	-29.15*	-9.36*	-24.32*	-9.12*	-19.95*	-9.91*	-16.99*	-9.55*	-22.78*	-9.49*
26	Sel 352 × Anugraha	-14.11*	-14.51*	-14.98*	-13.14*	-12.99*	-18.95*	-1.84	-12.54*	-8.49*	-14.83*
27	Sel 352 × Surajmukhi	-7.50*	-5.77*	-6.94*	-2.01	-8.88*	-8.75*	-2.98	-2.84	-6.47*	-4.88*
28	LCA 443 × Pant C 1	-14.88*	8.89*	-7.59*	10.97*	-4.92*	7.00*	0.82	9.85*	-6.87*	9.15*
29	LCA 443 × Anugraha	-6.53*	-4.06*	-10.14*	-8.19*	-7.46*	-9.62*	2.87	-3.58	-3.54*	-6.39*
30	LCA 443 × Surajmukhi	-0.91	1.72	-3.98*	0.62	-1.89	-1.75	2.83	2.99	-0.82	0.87
31	LCA 206 × Pant C 1	-30.61*	-11.23*	-24.58*	-9.43*	-28.11*	-19.10*	-27.12*	-20.60*	-27.65*	-15.20*
32	LCA 206 × Anugraha	4.55*	4.06*	-3.78*	-1.70	6.25*	-5.83*	0.00	-4.63*	5.16*	-2.12*
33	LCA 206 × Surajmukhi	16.54*	18.72*	8.85*	14.06*	4.22*	4.37*	6.11*	6.27*	8.85*	10.70*
	Range	-31.71 to 23.17	-14.51 to 26.05	-28.44 to 14.16	-14.06 to 19.63	-28.11 to 23.70	-19.10 to 15.01	-27.12 to 22.85	-20.60 to 18.06	-27.65 to 20.70	-15.20 to 18.42
	No of significant genotypes	10	18	9	17	10	10	10	13	12	16

* Significant at P ≤ 0.05 Bold digits means top three

Surajmukhi', 'Pusa Sadabahar × Anugraha' and 'Pusa Sadabahar × Surajmukhi' showed consistency in ranking among top five in each location except 'PAU Selection Long × Surajmukhi' which ranked 6th in 2011 at Bajaura. All these crosses also got position with consistency among top six for economic heterosis out of 18 and 17 crosses in the respective years at Palampur, 10 and 13 crosses in the respective years at Bajaura, and 16 crosses in pooled environments. Heterosis for ascorbic acid has also been reported earlier by Rao and Chhonkar (1982), Gondane and Deshmukh (2004) and Adapawar *et al.* (2006).

Capsaicin content (%)

Capsaicin is produced by glands in the pepper's placenta which has many health benefits and primarily used as pain killer and carry anti-carcinogenic properties. Relatively high capsaicin is desirable in chilli, since it is associated with more pungency and spicy flavour. The range for heterosis over BP and SC varied from -56.98 (Chilli Sonal × Pant C1) to 42.14 per cent (Selection 352 × Anugraha) and -67.65 (Chilli Sonal × Pant C1) to 5.46 per cent (Pusa Jwala × Surajmukhi) during 2010 and -50.75 (Chilli Sonal × Pant C1) to 40.82 per cent (Selection 352 × Anugraha) and -58.40 (Chilli Sonal × Pant C1) to 12.18 per cent (Pusa Jwala × Surajmukhi) during 2011, respectively at Palampur. Only nine and seven crosses showed significant positive heterosis for this trait on BP and two and three crosses on SC in 2010 and 2011, respectively at Palampur.

On the other hand, seven and nine crosses on BP and three each on SC at Bajaura during 2010 and 2011, respectively showed desirable significant positive heterosis and the range varied from -55.72 (Chilli Sonal × Pant C1) to 42.25 per cent (Selection 352 × Anugraha) and -61.80 (Chilli Sonal × Pant C1) to 14.59 per cent (Pusa Jwala × Pant C1) during 2010 and -49.81 (LCA 436 × Surajmukhi) to 41.83 per cent (Sel 352 × Anugraha) and -53.19 (Chilli Sonal × Pant C1) to 15.74 per cent (Pusa Jwala × Pant C1) during 2011 on BP and SC, respectively. In pooled over environments, -51.04 (Chilli Sonal × Pant C1) to 42.76 per cent (Selection 352 × Anugraha) and -60.34 (Chilli Sonal × Pant C1) to 10.97 per cent (Pusa Jwala × Pant C1) were the ranges for heterosis over BP and SC, respectively (Table 4.45).

Table 4.45: Estimates of heterosis (%) for capsaicin content (%) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-37.43*	-52.94*	-40.80*	-50.00*	-42.29*	-50.21*	-40.64*	-52.77*	-40.10*	-51.48*
2	Jawahar Mirch 283 × Anugraha	-9.29*	-46.64*	-6.12*	-42.02*	-12.75*	-44.21*	-22.01*	-47.23*	-12.75*	-45.15*
3	Jawahar Mirch 283 × Surajmukhi	-42.12*	-33.61*	-36.40*	-30.25*	-45.93*	-37.34*	-35.52*	-28.94*	-40.45*	-32.91*
4	Chilli Sonal × Pant C 1	-56.98*	-67.65*	-50.75*	-58.40*	-55.72*	-61.80*	-41.18*	-53.19*	-51.04*	-60.34*
5	Chilli Sonal × Anugraha	-35.71*	-62.18*	-31.29*	-57.56*	-29.58*	-57.08*	-21.48*	-50.21*	-29.66*	-56.96*
6	Chilli Sonal × Surajmukhi	-52.38*	-45.38*	-46.74*	-41.60*	-48.89*	-40.77*	-43.24*	-37.45*	-47.94*	-41.35*
7	PAU Sel Long × Pant C 1	-20.67*	-40.34*	-23.88*	-35.71*	-23.88*	-34.33*	-22.99*	-38.72*	-22.40*	-37.13*
8	PAU Sel Long × Anugraha	5.96*	-32.77*	4.73	-25.63*	21.13*	-26.18*	21.48*	-22.98*	14.57*	-27.00*
9	PAU Sel Long × Surajmukhi	-33.70*	-23.95*	-28.35*	-21.43*	-30.37*	-19.31*	-20.08*	-11.91*	-28.09*	-18.99*
10	Arka Lohit × Pant C 1	14.53*	-13.87*	3.98	-18.91*	9.45*	-5.58*	14.44*	-8.94*	8.85*	-11.81*
11	Arka Lohit × Anugraha	25.44*	-10.92*	**37.91***	-11.34*	**39.87***	-8.15*	**38.00***	-11.91*	**35.26***	-10.97*
12	Arka Lohit × Surajmukhi	-17.95*	-5.88*	-13.03*	-4.62*	-15.56*	-2.15	-9.27*	0.00	-14.23*	-3.38*
13	LCA 436 × Pant C 1	-22.35*	-41.60*	-27.36*	-38.66*	-27.86*	-37.77*	-14.97*	-32.34*	-22.92*	-37.55*
14	LCA 436 × Anugraha	-24.16*	-52.52*	-23.67*	-45.80*	-29.30*	-52.36*	-16.11*	-46.81*	-23.08*	-49.37*
15	LCA 436 × Surajmukhi	-49.45*	-42.02*	-41.76*	-36.13*	-49.26*	-41.20*	-49.81*	-44.68*	-47.94*	-41.35*
16	Pusa Jwala × Pant C 1	-8.76*	**5.04***	-0.76	**9.24***	0.75	**14.59***	11.48*	**15.74***	0.77	**10.97***
17	Pusa Jwala × Anugraha	-16.42*	-3.78*	-9.92*	-0.84	-16.98*	-5.58*	-3.28	0.43	-11.88*	-2.95*
18	Pusa Jwala × Surajmukhi	-8.39*	**5.46***	1.91	**12.18***	-7.41*	**7.30***	-5.41*	**4.26***	-5.24*	**6.75***
19	Pusa Sadabahar × Pant C 1	-15.35*	-9.66*	-14.75*	-12.61*	-10.13*	-8.58*	-11.02*	-7.23*	-12.65*	-9.70*
20	Pusa Sadabahar × Anugraha	-10.63*	-4.62*	-12.30*	-10.08*	-16.03*	-14.59*	-18.78*	-15.32*	-14.29*	-11.39*
21	Pusa Sadabahar × Surajmukhi	-28.57*	-18.07*	-21.46*	-13.87*	-28.15*	-16.74*	-22.01*	-14.04*	-25.47*	-16.03*
22	Kashmir Long × Pant C 1	**34.64***	1.26	**23.88***	**4.62***	27.36*	**9.87***	**33.69***	**6.38***	**30.21***	**5.49***
23	Kashmir Long × Anugraha	1.43	-40.34*	8.84*	-32.77*	6.34	-35.19*	5.37	-33.19*	5.52*	-35.44*
24	Kashmir Long × Surajmukhi	-32.97*	-23.11*	-28.35*	-21.43*	-32.22*	-21.46*	-24.32*	-16.60*	-29.59*	-20.68*
25	Sel 352 × Pant C 1	13.41*	-14.71*	3.98	-12.18*	2.99	-11.16*	13.90*	-9.36*	8.85*	-11.81*
26	Sel 352 × Anugraha	**42.14***	-16.39*	**40.82***	-13.03*	**42.25***	-13.30*	**41.83***	-7.66*	**42.76***	-12.66*
27	Sel 352 × Surajmukhi	-21.98*	-10.50*	-17.24*	-9.24*	-12.22*	1.72	-6.95*	2.55	-14.61*	-3.80*
28	LCA 443 × Pant C 1	12.85*	-15.13*	4.48*	-11.76*	-1.00	-14.59*	4.81*	-16.60*	5.21*	-14.77*
29	LCA 443 × Anugraha	22.86*	-27.73*	21.09*	-25.21*	**32.39***	-19.31*	28.86*	-18.30*	26.21*	-22.78*
30	LCA 443 × Surajmukhi	-33.33*	-23.53*	-22.61*	-15.13*	-30.00*	-18.88*	-22.39*	-14.47*	-27.34*	-18.14*
31	LCA 206 × Pant C 1	-7.26*	-30.25*	-22.39*	-34.45*	-11.94*	-24.03*	1.60	-19.15*	-9.90*	-27.00*
32	LCA 206 × Anugraha	**36.49***	-15.13*	16.85*	-12.61*	32.03*	-13.30*	15.70*	-15.32*	23.78*	-14.35*
33	LCA 206 × Surajmukhi	-20.88*	-9.24*	-16.48*	-8.40*	-20.74*	-8.15*	-11.58*	-2.55	-17.98*	-7.59*
	Range	-56.98 to 42.14	-67.65 to 5.46	-50.75 to 37.91	-58.40 to 12.18	-55.72 to 42.25	-61.80 to 14.59	-49.81 to 41.83	-53.19 to 15.74	-51.04 to 42.76	-60.34 to 10.97
	No of significant genotypes	9	2	7	3	7	3	9	3	10	3

* Significant at P ≤ 0.05 Bold digits means top three

‘Selection 352 × Anugraha’, ‘Arka Lohit × Anugraha’, ‘Kashmir Long × Pant C1’, ‘LCA 443 × Anugraha’ and ‘LCA 206 × Anugraha’ were the top best five crosses exhibiting heterosis over BP over the locations in respective years and pooled environments. On the other hand, only three crosses namely, ‘Pusa Jwala × Pant C1’, ‘Pusa Jwala × Surajmukhi’ and ‘Kashmir Long × Pant C1’ revealed economic heterosis over the environments, years and pooled over environments except ‘Kashmir Long × Pant C1’ in 2010 at Palampur. The results are in close proximity with those of Milerue and Nikornpun (2000) and Prasath and Ponnuswami (2008).

Capsanthin (ASTA units)

Capsanthin is a kind of natural pigment with deep red colour and have industrial importance as natural dye. For this trait, the range of heterosis over BP and SC varied from -26.74 (Pusa Sadabahar × Pant C1) to 33.64 per cent (LCA 436 × Pant C1) and -17.57 (Pusa Sadabahar × Pant C1) to 31.59 per cent (Jawahar Mirch 283 × Anugraha) during 2010 and -23.84 (Pusa Sadabahar × Anugraha) to 36.70 per cent (Arka Lohit × Pant C1) and -21.37 (Pusa Sadabahar × Anugraha) to 25.41 per cent (Jawahar Mirch 283 × Anugraha) during 2011 at Palampur, -26.54 (LCA 206 × Surajmukhi) to 28.63 per cent (LCA 436 × Pant C1) and -9.09 (Chilli Sonal × Anugraha) to 34.39 per cent (LCA 443 × Surajmukhi) during 2010 and -25.00 (LCA 206 × Surajmukhi) to 31.08 per cent (LCA 436 × Pant C1) and -17.50 (Chilli Sonal × Anugraha) to 22.53 per cent (Selection 352 × Surajmukhi) during 2011 at Bajaura, and -23.86 (LCA 206 × Surajmukhi) to 33.46 per cent (LCA 436 × Pant C1) and -15.02 (Chilli Sonal × Anugraha) to 25.41 per cent (Jawahar Mirch 283 × Anugraha) in pooled environments, respectively. Cross combinations ‘LCA 436 × Pant C1’, ‘Jawahar Mirch 283 × Pant C1’, ‘Arka Lohit × Pant C1’ and ‘Jawahar Mirch 283 × Anugraha’ were the top four heterotic combinations over BP in range of environments and pooled environments (Table 4.46).

On the other hand, ‘Jawahar Mirch 283 × Anugraha’, ‘LCA 443 × Surajmukhi’, ‘PAU Selection Long × Surajmukhi’, ‘Selection 352 × Surajmukhi’ and ‘LCA 436 × Surajmukhi’ secured top five positions for economic heterosis in

Table 4.46: Estimates of heterosis (%) for capsanthin (ASTA units) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	**32.46***	11.96*	33.41*	11.53*	**19.44***	17.08*	**30.23***	14.71*	**29.33***	13.76*
2	Jawahar Mirch 283 × Anugraha	29.65*	**31.59***	**34.62***	**25.41***	**18.48***	29.25*	20.35*	15.64*	25.71*	**25.41***
3	Jawahar Mirch 283 × Surajmukhi	7.97*	19.48*	13.84*	17.12*	0.00	28.06*	0.96	17.32*	5.43*	20.35*
4	Chilli Sonal × Pant C 1	-1.48	-15.48*	-1.71	-17.12*	-6.45*	-8.30*	-1.90	-13.59*	-1.92*	-13.73*
5	Chilli Sonal × Anugraha	-17.38*	-16.15*	-10.83*	-16.94*	-16.67*	-9.09*	-14.15*	-17.50*	-14.82*	-15.02*
6	Chilli Sonal × Surajmukhi	1.52	12.34*	9.28*	12.43*	-16.98*	6.32*	-17.95*	-4.66*	-6.57*	6.66*
7	PAU Sel Long × Pant C 1	15.57*	2.13	17.19*	0.72	13.48*	11.46*	16.28*	2.42	16.03*	4.05*
8	PAU Sel Long × Anugraha	3.68*	5.23*	11.22*	3.60*	5.07*	14.62*	6.78*	2.61	6.63*	6.38*
9	PAU Sel Long × Surajmukhi	8.78*	20.37*	18.56*	**21.98***	4.63*	**33.99***	3.85*	**20.67***	8.71*	**24.10***
10	Arka Lohit × Pant C 1	**30.92***	10.65*	**36.70***	12.07*	17.74*	15.42*	**26.85***	11.73*	**27.81***	12.43*
11	Arka Lohit × Anugraha	0.37	1.87	9.86*	2.34	-4.53*	4.15*	4.26*	0.19	2.35*	2.11*
12	Arka Lohit × Surajmukhi	-10.78*	-1.27	-3.50	-0.72	-22.07*	-0.20	-16.51*	-2.98*	-13.54*	-1.30
13	LCA 436 × Pant C 1	**33.64***	18.50*	**34.51***	10.27*	**28.63***	26.09*	**31.08***	15.46*	**33.46***	17.39*
14	LCA 436 × Anugraha	19.93*	21.72*	16.83*	8.83*	10.51*	20.55*	11.63*	7.26*	14.72*	14.45*
15	LCA 436 × Surajmukhi	8.95*	20.56*	8.93*	12.07*	2.44	**31.19***	4.33*	**21.23***	6.03*	21.04*
16	Pusa Jwala × Pant C 1	0.26	-12.45*	2.72	-11.53*	-1.21	-3.16	-0.63	-11.92*	2.46*	-9.87*
17	Pusa Jwala × Anugraha	2.58	4.11*	6.96*	-0.36	4.71*	14.23*	15.89*	11.36*	7.43*	7.17*
18	Pusa Jwala × Surajmukhi	-11.18*	-1.72	-1.23	1.62	-20.99*	1.19	-22.76*	-10.24*	-14.42*	-2.31*
19	Pusa Sadabahar × Pant C 1	-26.74*	-17.57*	-20.94*	-18.38*	-15.30*	-8.10*	-14.39*	-13.59*	-19.55*	-14.53*
20	Pusa Sadabahar × Anugraha	-24.58*	-15.14*	-23.84*	-21.37*	-12.32*	-4.35*	-13.84*	-13.04*	-18.74*	-13.67*
21	Pusa Sadabahar × Surajmukhi	-14.35*	-3.63*	-12.04*	-9.19*	-12.12*	8.70*	-16.19*	-2.61	-14.06*	-1.89*
22	Kashmir Long × Pant C 1	8.52*	16.64*	14.44*	11.35*	9.31*	25.30*	18.87*	13.78*	12.58*	16.60*
23	Kashmir Long × Anugraha	-11.13*	-4.49*	-5.37*	-7.93*	-15.86*	-3.56	-1.55	-5.40*	-8.64*	-5.39*
24	Kashmir Long × Surajmukhi	-15.84*	-6.88*	-11.73*	-9.19*	-18.52*	4.35*	-18.27*	-5.03*	-16.21*	-4.35*
25	Sel 352 × Pant C 1	11.35*	-4.67*	15.82*	-5.05*	4.03*	1.98	8.88*	-4.10*	10.22*	-3.05*
26	Sel 352 × Anugraha	-4.24*	-2.80*	3.09	-3.96*	-7.17*	1.26	1.55	-2.42	-1.81*	-2.04*
27	Sel 352 × Surajmukhi	11.32*	**23.18***	17.86*	**21.26***	-2.78	24.51*	5.45*	**22.53***	7.60*	22.83*
28	LCA 443 × Pant C 1	4.87*	-11.36*	9.52*	-9.23*	1.41	-0.59	11.21*	-2.05	6.97*	-5.91*
29	LCA 443 × Anugraha	-2.95*	-1.50	6.19*	-1.08	-2.90	5.93*	5.62*	1.49	1.37	1.13
30	LCA 443 × Surajmukhi	18.07*	**30.65***	14.54*	17.84*	4.94*	**34.39***	-0.16	16.01*	9.07*	**24.52***
31	LCA 206 × Pant C 1	4.47*	-11.70*	1.98	-16.40*	1.41	-0.59	1.06	-10.99*	2.20*	-10.11*
32	LCA 206 × Anugraha	-12.71*	-11.40*	-5.80*	-12.25*	-8.88*	-0.59	-5.04*	-8.75*	-8.17*	-8.39*
33	LCA 206 × Surajmukhi	-22.47*	-14.21*	-21.02*	-18.74*	-26.54*	-5.93*	-25.00*	-12.85*	-23.86*	-13.08*
	Range	-26.74 to 33.64	-17.57 to 31.59	-23.84 to 36.70	-21.37 to 25.41	-26.54 to 28.63	-9.09 to 34.39	-25.00 to 31.08	-17.50 to 22.53	-23.86 to 33.46	-15.02 to 25.41
	No of significant genotypes	16	14	19	13	12	19	16	12	19	16

* Significant at P ≤ 0.05 Bold digits means top three

pooled environments and also showed consistency by remaining among top seven over the locations and years. Prasath and Ponnuswami (2008) also observed hybrid vigour in 1/3rd of cross combinations studied.

Oleoresin (ASTA units)

It is an oil soluble extract from the fruits of red chilli and have importance primarily in cosmetics and pharmaceutical industries. On BP and SC, respectively the heterosis ranged from -50.77 (Chilli Sonal × Anugraha) to 32.92 per cent (Kashmir Long × Pant C1) and -62.62 (Chilli Sonal × Anugraha) to 3.52 per cent (Pusa Jwala × Pant C1) during 2010 and -59.75 (Chilli Sonal × Anugraha) to 32.88 per cent (Kashmir Long × Pant C1) and -67.28 (Chilli Sonal × Anugraha) to 0.62 per cent (Kashmir Long × Pant C1) during 2011 at Palampur, -33.61 (LCA 436 × Anugraha) to 19.95 per cent (Arka Lohit × Anugraha) and -53.16 (LCA 436 × Anugraha) to 0.79 per cent (Pusa Jwala × Pant C1) during 2010 and -33.33 (LCA 436 × Anugraha) to 26.83 per cent (Arka Lohit × Anugraha) and -48.80 (LCA 436 × Anugraha) to 4.60 per cent (Pusa Jwala × Surajmukhi) during 2011 at Bajaura, -41.84 (Chilli Sonal × Anugraha) to 26.89 per cent (Kashmir Long × Pant C1) and -56.97 (Chilli Sonal × Anugraha) to 1.80 per cent (Pusa Jwala × Pant C 1) in pooled environments. The heterobeltiosis revealed 15 and 10 crosses in the respective years at Palampur, 14 crosses in each year at Bajaura and 16 crosses in pooled environments and out of which ‘Kashmir Long × Pant C1’, ‘Arka Lohit × Anugraha’, ‘LCA 443 × Pant C1’, ‘Selection 352 × Pant C1’ and ‘Selection 352 × Surajmukhi’ were the top five crosses in pooled environments and were also ranked among top ten over the locations and years. Only ‘Pusa Jwala × Pant C1’ in 2010 at Palampur and ‘Pusa Jwala × Surajmukhi’ and ‘Arka Lohit × Anugraha’ in 2011 at Bajaura exhibited economic heterosis for this trait (Table 4.47). Prasath and Ponnuswami (2008) also observed hybrid vigour for oleoresin.

Fruit yield, itself, a complex character, is the sum total of the contributions made by individual components. Grafius (1959) has doubted the individuality of yield. To breed for higher yield, the breeder has to simplify the complex situation

Table 4.47: Estimates of heterosis (%) for oleoresin (ASTA units) over better parent (BP) and standard check (SC) in chilli at Palampur and Bajaura during both the years and pooled over environments

Sr No	Hybrids	Palampur				Bajaura				Pooled	
		2010		2011		2010		2011			
		% increase/decrease over				% increase/decrease over				% increase/ decrease over	
		BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-26.12*	-48.53*	-37.50*	-52.67*	-31.30*	-48.81*	-18.28*	-39.20*	-28.31*	-47.28*
2	Jawahar Mirch 283 × Anugraha	-24.74*	-42.86*	-32.66*	-45.27*	-10.47*	-39.13*	-1.41	-30.00*	-17.95*	-39.29*
3	Jawahar Mirch 283 × Surajmukhi	-22.22*	-43.84*	-18.99*	-34.16*	-23.75*	-37.55*	-25.44*	-40.20*	-22.63*	-38.99*
4	Chilli Sonal × Pant C 1	-32.02*	-52.64*	-29.89*	-46.91*	-24.67*	-43.87*	-25.54*	-44.60*	-27.96*	-47.02*
5	Chilli Sonal × Anugraha	-50.77*	-62.62*	-59.75*	-67.28*	-30.81*	-52.96*	-22.82*	-45.20*	-41.84*	-56.97*
6	Chilli Sonal × Surajmukhi	-17.89*	-40.70*	-19.49*	-34.57*	-17.47*	-32.41*	-11.22*	-28.80*	-16.49*	-34.15*
7	PAU Sel Long × Pant C 1	7.30*	-25.24*	1.36	-23.25*	-2.39	-27.27*	9.14*	-18.80*	3.80*	-23.66*
8	PAU Sel Long × Anugraha	-7.99*	-30.14*	-7.85*	-25.10*	13.08*	-23.12*	17.18*	-16.80*	2.96*	-23.82*
9	PAU Sel Long × Surajmukhi	8.67*	-21.53*	3.80	-15.64*	0.39	-17.79*	-0.25	-20.00*	3.01*	-18.77*
10	Arka Lohit × Pant C 1	11.78*	-16.44*	19.70*	-8.23*	7.21*	-11.86*	1.95	-16.40*	9.89*	-13.28*
11	Arka Lohit × Anugraha	**22.68***	-6.85*	19.49*	-2.88	**19.95***	-1.38	**26.83***	**4.00***	**24.45***	-1.80
12	Arka Lohit × Surajmukhi	16.75*	-12.72*	8.86*	-11.52*	10.10*	-9.49*	4.39	-14.40*	11.47*	-12.03*
13	LCA 436 × Pant C 1	-7.30*	-35.42*	-2.99	-26.54*	-14.59*	-36.36*	-10.94*	-31.60*	-8.28*	-32.55*
14	LCA 436 × Anugraha	-45.62*	-58.71*	-47.59*	-57.41*	-33.61*	-53.16*	-33.33*	-48.80*	-38.53*	-54.52*
15	LCA 436 × Surajmukhi	-20.33*	-42.47*	-20.00*	-34.98*	-26.16*	-39.53*	-14.71*	-31.60*	-20.36*	-37.20*
16	Pusa Jwala × Pant C 1	1.73	**3.52***	0.83	0.41	4.51*	0.79	7.56*	2.40	3.61*	1.80
17	Pusa Jwala × Anugraha	-10.19*	-8.61*	-1.24	-1.65	-8.20*	-11.46*	0.42	-4.40*	-4.93*	-6.59*
18	Pusa Jwala × Surajmukhi	-5.38*	-3.72*	-4.75*	-5.14*	4.10*	0.40	9.87*	**4.60***	0.82	-0.95
19	Pusa Sadabahar × Pant C 1	-0.89	-12.52*	-7.33*	-11.52*	-4.46*	-15.42*	-12.39*	-16.60*	-6.36*	-14.03*
20	Pusa Sadabahar × Anugraha	1.77	-10.18*	2.59	-2.06	3.35*	-8.50*	-1.26	-6.00*	1.58	-6.74*
21	Pusa Sadabahar × Surajmukhi	6.52*	-5.99*	0.65	-3.91*	6.92*	-5.34*	2.52	-2.40	4.10*	-4.42*
22	Kashmir Long × Pant C 1	**32.92***	-7.40*	**32.88***	0.62	**17.77***	-12.25*	**24.46***	-7.40*	**26.89***	-6.68*
23	Kashmir Long × Anugraha	-20.10*	-39.33*	-18.23*	-33.54*	-0.29	-32.21*	1.41	-28.00*	-9.86*	-33.30*
24	Kashmir Long × Surajmukhi	-1.36	-28.77*	1.52	-17.49*	-8.06*	-24.70*	-7.48*	-25.80*	-3.96*	-24.26*
25	Sel 352 × Pant C 1	10.39*	-23.09*	**20.11***	-9.05*	10.34*	-17.79*	16.67*	-13.20*	14.39*	-15.88*
26	Sel 352 × Anugraha	3.61*	-21.33*	8.35*	-11.93*	13.95*	-22.53*	13.80*	-19.20*	9.71*	-18.82*
27	Sel 352 × Surajmukhi	**21.41***	-12.33*	18.23*	-3.91*	9.56*	-10.28*	6.98*	-14.20*	13.83*	-10.24*
28	LCA 443 × Pant C 1	17.13*	-18.40*	**20.65***	-8.64*	14.59*	-14.62*	**20.70***	-10.20*	**18.26***	-13.03*
29	LCA 443 × Anugraha	-10.31*	-31.90*	-6.58*	-24.07*	-0.58	-32.41*	10.42*	-21.60*	-2.09	-27.56*
30	LCA 443 × Surajmukhi	8.40*	-21.72*	9.11*	-11.32*	0.87	-17.39*	14.21*	-8.40*	8.07*	-14.78*
31	LCA 206 × Pant C 1	4.21*	-27.40*	4.08	-21.19*	-5.04*	-29.25*	-13.87*	-34.20*	-2.17	-28.06*
32	LCA 206 × Anugraha	5.41*	-19.96*	-3.29	-21.40*	**15.22***	-16.21*	6.28*	-18.80*	9.38*	-19.07*
33	LCA 206 × Surajmukhi	15.99*	-16.24*	7.85*	-12.35*	2.32	-16.21*	10.72*	-11.20*	9.02*	-14.03*
	Range	-50.77 to 32.92	-62.62 to 3.52	-59.75 to 32.88	-67.28 to 0.62	-33.61 to 19.95	-53.16 to 0.79	-33.33 to 26.83	-48.80 to 4.60	-41.84 to 26.89	-56.97 to 1.80
	No of significant genotypes	15	1	10	-	14	-	14	2	16	-

* Significant at P ≤ 0.05 Bold digits means top three

and handle a number of related traits simultaneously. The extent of these component traits is not fully understood for efficient use in selection for increased yield. In the present study, heterosis was displayed for almost all the characters and in few crosses it reached to the level obtained for yield. On the basis of economic heterosis calculated over 'CH-1', it can, therefore, be concluded that a good number of crosses showed the presence of desirable heterotic response for different characters. For marketable fruit yield/plant, 'Jawahar Mirch 283 × Anugraha', 'PAU Selection Long × Surajmukhi', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C1', 'LCA 436 × Anugraha' and 'LCA 443 × Surajmukhi' were the best hybrid combinations with consistency and were ranked among top ten crosses across the environments. These crosses also showed heterosis for component traits like marketable fruits/plant, harvest duration, average fruit weight and fruit length with few exceptions which might have resulted into better economic heterosis. Further, evaluation of hybrids based on combination of *per se*, SCA and heterosis parameters would be more meaningful than on individual parameters. In the present context based on these parameters, these crosses were found superior in respect of yield and majority of economic traits. These crosses exhibited significant SCA effects coupled with high GCA of female parent for fresh yield and component traits. Therefore, additive component seemed to influence the fruit yield in these crosses and better selection advance can be expected in the subsequent generations. Therefore, it may be possible to take advantage of such heterotic effects to be fixed in the later generations to facilitate further selection (Ghosh *et al*. 2002). These results for heterosis are in wider proximity with those of Burli *et al*. (2001), Singh and Hundal (2001), Prasad *et al.* (2003), Seneviratne and Kannangara (2004), Adapawar *et al.* (2006), Shankarnag and Madalageri (2006) and Kamble *et al.* (2009). However, Sharma *et al*. (2007) were of the view that selection of crosses based on SCA effects would be more reliable than heterosis.

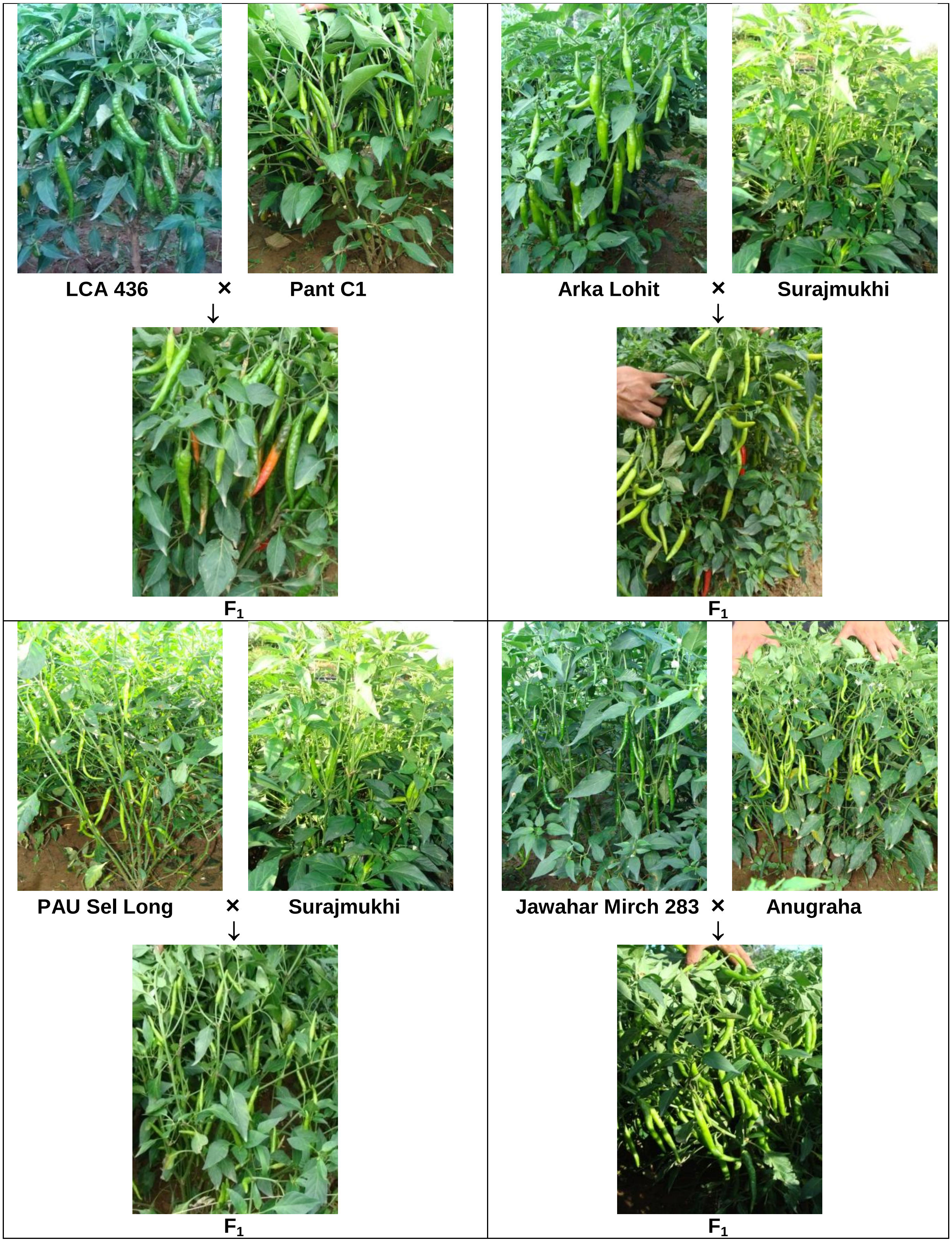


Plate 8: Superior cross combinations based on *per se* performance, SCA and heterosis

Table 4.48: Trait-wise list of promising three cross combinations having significant desirable heterosis over better parent and standard check (CH-1)

Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Days to 50% flowering	**BP** Kasmir Long x Pant C 1 Chilli Sonal × Pant C 1 LCA 436 × Pant C 1 **SC** Kashmir Long × Pant C 1 Kashmir Long × Anugraha Chilli Sonal × Pant C 1	**BP** LCA 436 × Pant C 1 Kashmir Long × Pant C 1 Pusa Jwala × Pant C 1 **SC** Chilli Sonal × Surajmukhi, Kashmir Long × Surajmukhi PAU Sel Long × SurajmukhI	**BP** Kashmir Long × Surajmukhi, LCA 443 × Surajmukhi Chilli Sonal × Surajmukhi **SC** Kashmir Long × Pant C 1, Kashmir Long × Anugraha Kashmir Long × Surajmukhi	**BP** Pusa Jwala × Surajmukhi, PAU Sel Long × Surajmukhi Pusa Sadabahar × Surajmukhi **SC** Kashmir Long × Pant C 1 Kashmir Long × Anugraha Arka Lohit × Pant C 1	**BP** Kashmir Long × Surajmukhi, Kashmir Long × Pant C 1 Chilli Sonal × Surajmukhi **SC** Kashmir Long × Anugraha, Kashmir Long × Pant C 1 Sel 352 × Anugraha
Days to first harvest	**BP** Kashmir Long × Pant C 1 Chilli Sonal × Pant C 1 Pusa Jwala × Pant C 1 **SC** Pusa Sadabahar × Surajmukhi Kashmir Long × Pant C 1 Kashmir Long × Anugraha	**BP** Kashmir Long × Pant C 1 Kashmir Long × Surajmukhi Pusa Jwala × Pant C 1 **SC** Kashmir Long × Anugraha, Kashmir Long × Surajmukhi Pusa Jwala × Anugraha	**BP** Chilli Sonal × Pant C 1 Kashmir Long × Pant C 1 Pusa Jwala × Surajmukhi **SC** Kashmir Long × Anugraha Chilli Sonal × Pant C 1 Sel 352 × Anugraha	**BP** Kashmir Long × Pant C 1 Chilli Sonal × Pant C 1 Pusa Jwala × Surajmukhi **SC** Kashmir Long × Anugraha, Kashmir Long × Pant C 1 Sel 352 × Anugraha	**BP** Kashmir Long × Pant C 1 Chilli Sonal × Pant C 1 Pusa Jwala × Surajmukhi **SC** Kashmir Long × Anugraha Kashmir Long × Pant C 1 Sel 352 × Anugraha
Primary branches/plant	**BP** Chilli Sonal × Pant C 1 **SC** Pusa Sadabahar × Surajmukhi Pusa Sadabahar × Anugraha Arka Lohit × Surajmukhi	**BP** LCA 443 × Pant C 1 **SC** LCA 436 × Surajmukhi Jawahar Mirch 283 × Anugraha Pusa Jwala × Anugraha	**BP** Pusa Jwala × Pant C 1 Arka Lohit × Pant C 1 LCA 436 × Pant C 1 **SC** Pusa Jwala × Pant C 1 Chilli Sonal × Anugraha Pusa Jwala × Anugraha	**BP** Pusa Sadabahar × Surajmukhi Chilli Sonal × Pant C 1 Arka Lohit × Surajmukhi **SC** Pusa Jwala × Surajmukhi Chilli Sonal × Pant C 1 Arka Lohit × Surajmukhi	**BP** Pusa Sadabahar × Pant C 1 Pusa Jwala × Pant C 1 LCA 443 × Pant C 1 **SC** Pusa Sadabahar × Anugraha Arka Lohit × Surajmukhi Jawahar Mirch 283 × Anugraha
Fruit length (cm)	**BP** LCA 436 × Anugraha Pusa Sadabahar × Pant C 1 LCA 436 × Anugraha **SC** LCA 436 × Anugraha LCA 206 × Anugraha Pusa Jwala x Anugraha	**BP** LCA 436 × Anugraha Pusa Sadabahar x Pant C 1 Sel 352 x Pant C 1 **SC** LCA 436 × Anugraha LCA 206 × Anugraha Pusa Jwala x Surajmukhi	**BP** Pusa Sadabahar x Pant C 1 Kashmir Long × Anugraha, Pusa Sadabahar x Surajmukhi **SC** Kashmir Long × Anugraha LCA 206 × Anugraha Pusa Sadabahar x Surajmukhi	**BP** Pusa Sadabahar x Pant C 1 Kashmir Long × Anugraha LCA 443 × Pant C 1 **SC** Kashmir Long × Anugraha LCA 206 × Anugraha LCA 443 x Anugraha	**BP** Pusa Sadabahar x Pant C 1 Pusa Sadabahar x Surajmukhi LCA 206 × Anugraha **SC** LCA 206 × Anugraha Kashmir Long × Anugraha LCA 436 × Anugraha
Fruit girth (cm)	**BP** Chilli Sonal × Anugraha Jawahar Mirch 283 x Pant C 1 Jawahar Mirch 283 × Anugraha **SC** Pusa Sadabahar x Pant C 1	**BP** Jawahar Mirch 283 × Anugraha, LCA 206 × Anugraha Jawahar Mirch 283 x Pant C 1 **SC** -	**BP** Pusa Sadabahar × Surajmukhi, Pusa Jwala x Anugraha Jawahar Mirch 283 x Pant C 1 **SC** Pusa Sadabahar × Surajmukhi	**BP** Jawahar Mirch 283 × Anugraha Jawahar Mirch 283 x Surajmukhi Jawahar Mirch 283 x Pant C 1 **SC** LCA 443 × Pant C 1 LCA 443 x Surajmukhi	**BP** Jawahar Mirch 283 x Surajmukhi, Pusa Sadabahar × Surajmukhi Jawahar Mirch 283 × Anugraha **SC** -

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Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Average fruit weight (g)	**BP** LCA 206 × Pant C 1 Arka Lohit x Anugraha Chilli Sonal × Anugraha **SC** Arka Lohit x Anugraha Arka Lohit x Surajmukhi	**BP** LCA 206 × Pant C 1 Chilli Sonal × Anugraha Arka Lohit x Anugraha **SC** Arka Lohit x Anugraha Arka Lohit x Surajmukhi LCA 443 × Surajmukhi	**BP** Arka Lohit x Anugraha LCA 206 × Pant C 1 Chilli Sonal × Anugraha **SC** -	**BP** LCA 206 × Pant C 1 Arka Lohit x Anugraha Chilli Sonal × Anugraha **SC** Arka Lohit x Anugraha LCA 443 × Surajmukhi	**BP** LCA 206 × Pant C 1 Arka Lohit x Anugraha Chilli Sonal × Anugraha **SC** Arka Lohit x Anugraha LCA 443 × Surajmukhi Arka Lohit x Surajmukhi
Marketable fruits/plant	**BP** Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi Jawahar Mirch 283 x Surajmukhi **SC** Jawahar Mirch 283 × Anugraha Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi	**BP** LCA 206 × Anugraha Kashmir Long x Surajmukhi PAU Sel Long × Surajmukhi **SC** LCA 206 × Anugraha Jawahar Mirch 283 × Anugraha Chilli Sonal × Surajmukhi	**BP** Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi LCA 436 x Pant C 1 **SC** Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi PAU Sel Long x Anugraha	**BP** Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi PAU Sel Long × Surajmukhi **SC** Chilli Sonal × Surajmukhi Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi	**BP** Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi Chilli Sonal × Surajmukhi **SC** Pusa Sadabahar × Surajmukhi Chilli Sonal × Surajmukhi Jawahar Mirch 283 × Anugraha
Marketable fruit yield/plant (g)	**BP** Jawahar Mirch 283 × Anugraha Sel 352 x Pant C 1 LCA 443 × Anugraha **SC** Jawahar Mirch 283 × Anugraha LCA 436 x Pant C 1 PAU Sel Long × Surajmukhi	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha LCA 436 × Anugraha **SC** LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha LCA 443 x Surajmukhi	**BP** LCA 436 × Pant C 1 PAU Sel Long × Pant C 1 LCA 436 × Anugraha **SC** LCA 436 × Pant C 1 Pusa Sadabahar × Surajmukhi Arka Lohit x Surajmukhi	**BP** LCA 436 × Pant C 1 Chilli Sonal × Surajmukhi, Kashmir Long × Pant C 1 **SC** LCA 436 × Pant C 1 Chilli Sonal × Surajmukhi PAU Sel Long x Surajmukhi	**BP** LCA 436 × Pant C 1, LCA 436 × Anugraha Jawahar Mirch 283 × Anugraha **SC** LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha LCA 443 × Surajmukhi
Harvest duration (days)	**BP** - **SC** Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi LCA 436 × Anugraha	**BP** - **SC** Pusa Sadabahar × Surajmukhi Pusa Sadabahar x Anugraha LCA 436 × Anugraha	**BP** Pusa Sadabahar × Surajmukhi PAU Sel Long × Surajmukhi **SC** Pusa Sadabahar × Surajmukhi Pusa Sadabahar x Anugraha LCA 436 × Anugraha	**BP** Pusa Sadabahar × Surajmukhi **SC** Pusa Sadabahar × Surajmukhi Pusa Sadabahar x Anugraha LCA 436 × Anugraha	**BP** Pusa Sadabahar × Surajmukhi **SC** Pusa Sadabahar × Surajmukhi Pusa Sadabahar x Anugraha LCA 436 × Anugraha
Plant height (cm)	**BP** Jawahar Mirch 283 × Anugraha LCA 443 × Pant C 1 LCA 443 × Surajmukhi **SC** Jawahar Mirch 283 × Anugraha LCA 443 × Surajmukhi Jawahar Mirch 283 x Surajmukhi	**BP** Jawahar Mirch 283 × Anugraha Pusa Sadabahar x Pant C 1 PAU Sel Long × Pant C 1 **SC** Pusa Sadabahar × Surajmukhi Jawahar Mirch 283 x Surajmukhi Jawahar Mirch 283 × Anugraha	**BP** LCA 443 × Pant C 1 Pusa Sadabahar × Surajmukhi Arka Lohit x Surajmukhi **SC** Pusa Sadabahar × Surajmukhi Arka Lohit x Surajmukhi Chilli Sonal × Surajmukhi	**BP** LCA 443 × Pant C 1 LCA 443 x Surajmukhi Arka Lohit x Surajmukhi **SC** Sel 352 x Suraj Arka Lohit x Surajmukhi PAU Sel Long × Surajmukhi	**BP** LCA 443 × Pant C 1 Jawahar Mirch 283 x Surajmukhi Jawahar Mirch 283 × Anugraha **SC** Jawahar Mirch 283 x Surajmukhi Sel 352 x Surajmukhi ,

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Traits	Palampur 2010	Palampur 2011	Bajaura 2010	Bajaura 2011	Pool
Average dry fruit weight (g)	**BP** Arka Lohit x Anugraha Arka Lohit × Pant C 1 Pusa Sadabahar x Pant C 1 **SC** -	**BP** Arka Lohit × Pant C 1 Chilli Sonal x Pant C 1 Pusa Sadabahar x Pant C 1 **SC** -	**BP** Arka Lohit x Anugraha Arka Lohit × Pant C 1 Kashmir Long x Pant C 1 **SC** -	**BP** Arka Lohit × Pant C 1 Pusa Sadabahar x Pant C 1 Arka Lohit x Anugraha **SC** -	**BP** Arka Lohit × Pant C 1 Arka Lohit x Anugraha Kashmir Long × Pant C 1 **SC** -
Dry fruit yield/plant (g)	**BP** Arka Lohit x Anugraha Arka Lohit × Pant C 1 Jawahar Mirch 283 × Anugraha **SC** Arka Lohit x Surajmukhi Jawahar Mirch 283 × Anugraha LCA 436 × Pant C 1	**BP** Arka Lohit x Surajmukhi LCA 443 × Surajmukhi Jawahar Mirch 283 × Anugraha **SC** LCA 436 × Pant C 1 Arka Lohit x Surajmukhi LCA 443 × Surajmukhi	**BP** Sel 352 x Pant C 1 LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 **SC** LCA 436 × Pant C 1 LCA 443 × Surajmukhi Chilli Sonal × Surajmukhi	**BP** LCA 436 × Pant C 1 Kashmir Long × Pant C 1 PAU Sel Long x Surajmukhi **SC** LCA 436 × Pant C 1 PAU Sel Long × Surajmukhi LCA 436 x Anugraha	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 × Anugraha Jawahar Mirch 283 x Pant C 1 **SC** LCA 436 × Pant C 1 Arka Lohit x Surajmukhi PAU Sel Long × Surajmukhi
Ascorbic acid (mg/100g)	**BP** Kashmir Long × Anugraha, PAU Sel Long × Surajmukhi Pusa Sadabahar × Anugraha **SC** Kashmir Long × Anugraha, PAU Sel Long × Surajmukhi, Pusa Sadabahar x Surajmukhi	**BP** PAU Sel Long × Surajmukhi Kashmir Long × Anugraha Pusa Sadabahar x Surajmukhi **SC** PAU Sel Long × Surajmukhi Kashmir Long × Anugraha Arka Lohit x Anugraha	**BP** Kashmir Long × Anugraha Pusa Sadabahar × Anugraha Pusa Sadabahar x Surajmukhi **SC** Pusa Sadabahar x Surajmukhi PAU Sel Long × Surajmukhi Kashmir longl x Surajmukhi	**BP** Pusa Sadabahar × Anugraha Kashmir Long × Anugraha Pusa Jwala x Anugraha **SC** Kashmir Long × Anugraha Pusa Sadabahar x Surajmukhi PAU Sel Long × Surajmukhi	**BP** Kashmir Long × Anugraha Pusa Sadabahar × Anugraha PAU Sel Long × Surajmukhi **SC** Kashmir Long × Anugraha PAU Sel Long × Surajmukhi Pusa Sadabahar × Surajmukhi
Capsaicin content (%)	**BP** Sel 352 x Anugraha LCA 206 x Anugraha Kashmir Long x Pant C 1 **SC** Pusa Jwala x Surajmukhi Pusa Jwala × Pant C 1	**BP** Sel 352 x Anugraha Arka Lohit x Anugraha Kashmir Long × Pant C 1 **SC** Pusa Jwala x Surajmukhi Pusa Jwala × Pant C 1 Kashmir Long × Pant C 1	**BP** Sel 352 x Anugraha Arka Lohit x Anugraha LCA 443 x Anugraha **SC** Pusa Jwala × Pant C 1 Kashmir Long × Pant C 1 Pusa Jwala x Surajmukhi	**BP** Sel 352 x Anugraha Arka Lohit x Anugraha Kashmir Long × Pant C 1 **SC** Pusa Jwala × Pant C 1 Kashmir Long × Pant C 1 Pusa Jwala x Surajmukhi	**BP** Sel 352 x Anugraha Arka Lohit x Anugraha Kashmir Long × Pant C 1 **SC** Pusa Jwala × Pant C 1 Pusa Jwala x Surajmukhi Kashmir Long × Pant C 1
Capsanthin (ASTA units)	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 Arka Lohit x Pant C 1 **SC** Jawahar Mirch 283 × Anugraha LCA 443 x Surajmukhi Sel 352 x Surajmukhi	**BP** Arka Lohit x Pant C1 LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 **SC** Jawahar Mirch 283 × Anugraha PAU Sel Long × Surajmukhi Sel 352 x Surajmukhi	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 Jawahar Mirch 283 × Anugraha **SC** LCA 443 x Surajmukhi PAU Sel Long × Surajmukhi Jawahar Mirch 283 × Anugraha	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 Arka Lohit x Pant C **SC** Sel 352 x Surajmukhi LCA 436 x Surajmukhi PAU Sel Long × Surajmukhi	**BP** LCA 436 × Pant C 1 Jawahar Mirch 283 x Pant C 1 Arka Lohit x Pant C 1 **SC** Jawahar Mirch 283 × Anugraha LCA 443 × Surajmukhi PAU Sel Long × Surajmukhi
Oleoresin (ASTA units)	**BP** Kashmir Long × Pant C 1 Arka Lohit x Anugraha Sel 352 x Surajmukhi **SC** Pusa Jwala × Pant C 1	**BP** Kashmir Long × Pant C 1 LCA 443 × Pant C 1 Sel 352 x Pant C 1 **SC** -	**BP** Arka Lohit x Anugraha Kashmir Long × Pant C 1 LCA 206 x Anugraha **SC** -	**BP** Arka Lohit x Anugraha Kashmir Long × Pant C 1 LCA 443 × Pant C 1 **SC** Pusa Jwala x Surajmukhi, Arka Lohit x Anugraha	**BP** Kashmir Long × Pant C 1 Kashmir Long × Pant C 1 LCA 443 × Pant C 1 **SC** -

On the other hand, many heterotic combinations for fresh yield exhibited average and low SCA effects which indicated the role of non-additive gene action thereby revealing the importance of breeding methods like reciprocal recurrent selection, diallel selective mating system and single seed descent method in the improvement of yield in chilli. Besides fresh fruit yield, 'Jawahar Mirch 283 × Anugraha' and 'Arka Lohit × Surajmukhi' also had desirable negative heterosis for early fruit harvest. For dry fruit yield/plant, 'LCA 436 × Pant C1', 'Arka Lohit × Surajmukhi', 'PAU Selection Long × Surajmukhi' and 'Jawahar Mirch 283 × Anugraha' were the best hybrids with consistency for heterosis across the environments and also had significant SCA effects except, 'Arka Lohit × Surajmukhi' at Palampur during both the years and 'PAU Selection Long × Surajmukhi' and 'Jawahar Mirch 283 × Anugraha' in the respective years at Bajaura with average SCA. These crosses also had high GCA for female/male parent across environments. This indicated the role of both additive and non-additive type of gene action in influencing dry fruit yield/plant in these crosses.

4.5 Genotype environment interactions and stability analysis

In plant breeding, the effects of G × E interaction on the stability and adaptability are very important as every genotype has an inherent capacity to respond to variable environments. Statistically, these effects are non-additive because the difference in crop yield between the genotypes depends upon the environment (Scapim *et al.* 2010). The selection of genotypes on the basis of mean crop yield is inefficient and, therefore, strategy should be based on selection of genotypes with high stability and adaptability in a wide range of environmental conditions (Eberhart and Russell 1966).

The analysis of variance (Table 4.49) indicated significant differences among genotypes and diversity in environment for all the traits revealing thereby the presence of high variability among the tested genotypes and environments. Genotypes also interacted significantly with environment for all the traits

Table 4.49: Analysis of variance (mean squares) of multi-environment data for different horticultural traits in chilli

Sources of variation	Traits df	Days to 50% flowering	Days to first harvest	Primary branches/ plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
Replications within environments	8	1.89*	1.43*	0.42*	0.03	0.01*	0.003*	54.33*	573.92*	1.84*	7.50*	0.01*	9.28*	4.66*	0.000*	6.47*	10.69*
Genotypes	46	103.15*	135.41*	1.31*	4.41*	0.09*	5.56*	8584.56*	49941.89*	128.11*	172.23*	0.54*	694.45*	470.38*	0.10*	573.87*	686.13*
Env + (G x E)	141	13.41*	11.41*	0.54*	0.78*	0.01*	0.02*	688.53*	5862.68*	1.15*	64.07*	0.01*	40.50*	14.12*	0.001*	10.98*	13.60*
Environments	3	293.90*	223.86*	8.72*	4.59*	0.01*	0.09*	4433.29*	60909.28*	12.70*	1437.84*	0.01*	178.43*	22.36*	0.01*	20.16*	86.48*
Genotype x Environment	138	7.31*	6.79*	0.36*	0.70*	0.01*	0.02*	607.12*	4666.01*	0.90*	34.20*	0.01*	37.50*	13.94*	0.001*	10.78*	12.02*
Environmets (Linear)	1	881.70*	671.59*	26.16*	13.78*	0.02*	0.28*	13299.86*	182727.83*	38.10*	4313.53*	0.03*	535.28*	67.07*	0.02*	60.48*	259.44*
G x E (Linear)	46	7.94*	4.34*	0.30*	1.81*	0.01*	0.01*	516.56*	6688.73*	1.51*	55.73*	0.01*	36.48*	22.58*	0.001*	7.09*	16.65*
Pooled Deviation	94	6.84*	7.84*	0.39*	0.14*	0.004*	0.03*	638.52*	3576.89*	0.58*	22.94*	0.01*	37.20*	9.41*	0.001*	12.36*	9.50*
Pooled Error	368	0.55	0.60	0.06	0.02	0.000	0.001	11.49	112.18	0.23	2.95	0.003	2.82	1.60	0.000	1.02	0.93
Total	187	35.48	41.91	0.73	1.67	0.03	1.39	2138.89	16705.69	32.38	90.68	0.14	201.36	126.35	0.03	149.45	179.04

* Significant at $P \leq 0.05$

indicating differential response of genotypes to different environments. The results corroborate the findings of Singh *et al*. (1989) and Roy *et al*. (1997). High and significant mean squares of environments (linear) showed considerable differences prevailed over two locations over the years due to variation in environmental conditions. Genotype × environment interaction (linear) component against pooled deviation was significant for fruit length, fruit girth, marketable fruit yield/plant, harvest duration, plant height, ascorbic acid and oleoresin which revealed that linear regression was the major component responsible for differences in stability whereby, the performance can be predicted for these traits with some reliance under different environments. However, prediction for the unpredictable traits *viz*., days to 50% flowering, days to frist harvest, primary branches/plant, average fruit weight, marketable fruits/plant, average dry fruit weight, dry fruit yield/plant, capsaicin content and capsanthin can be made by considering the stability parameters of individual genotypes (Singh *et al.* 1991).

Hybrids 'LCA 436 × Pant C 1' and 'LCA 436 × Anugraha' were highly adapted under unfavourable conditions for both early flowering and getting early harvest (Table 4.50). On the other hand, 'Chilli Sonal × Surajmukhi', 'Kashmir Long × Surajmukhi' and 'Selection 352 × Anugraha' for days to 50% flowering and 'Chilli Sonal × Pant C 1' for fruit harvest had mean values on the desirable direction with regression coefficient (βi) less than one and deviation from regression (S^2di) equal to zero and accordingly suited to unfavourable environments with predictable performance for these traits. On the other hand, the hybrids 'Pusa Jwala × Pant C 1', 'LCA 443 × Pant C 1', LCA 206 × Anugraha' for days to 50% flowering and 'Pusa Jwala × Anugraha' and 'Kashmir Long × Anugraha' for days to first harvest were suited for favourable environmental conditions as these have regression coefficient more than unity and deviation from regression equal to zero.

Hybrid 'Arka Lohit × Surajmukhi' and 'LCA 443 × Anugraha' for primary branches/plant (Table 4.50), 'Chilli Sonal × Surajmukhi' for harvest duration (4.53), 'Arka Lohit × Surajmukhi' and 'Selection 352 × Pant C 1' for capsaicin (Table 4.54), 'LCA 206 × Surajmukhi' for oleoresin (Table 4.54) and 'Selection

Table 4.50: Estimates of mean and stability parameters for different traits in chilli

Crosses/Genotypes	Days to 50% flowering			Days to first harvest			Primary branches/plant		
	mean	β_i	S^2 di	mean	β_i	S^2 di	Mean	β_i	S^2 di
Jawahar Mirch 283 × Pant C1	45.42	1.39	5.41*	70.83	1.19	2.83*	6.68	1.24	-0.07
Jawahar Mirch 283 × Anugraha	46.17	1.30	12.61*	67.92	2.21	2.08*	7.47	1.13	-0.02
Jawahar Mirch 283 × Surajmukhi	46.67	1.70	2.55*	73.00	1.48	20.45*	6.85	1.02	0.03
Chilli Sonal × Pant C 1	43.50	0.90	7.43*	63.00	0.83	-0.48	7.00	1.04	0.54*
Chilli Sonal × Anugraha	44.75	0.23	13.20*	64.67	0.52	3.36*	7.22	1.89	0.40*
Chilli Sonal × Surajmukhi	43.50	0.87	-0.05	75.58	-0.21	1.13	6.85	2.20	0.01
PAU Sel Long × Pant C 1	47.42	1.71*	-0.44	72.08	1.11	3.68*	6.47	0.59	0.50*
PAU Sel Long × Anugraha	48.17	1.02	0.18	74.33	0.48	0.16	6.88	1.70	0.20*
PAU Sel Long × Surajmukhi	46.17	1.87	6.82*	73.33	1.23	8.09*	7.02	1.42	0.26*
Arka Lohit × Pant C 1	47.92	2.37*	0.43	73.83	1.52	1.70*	6.97	1.88	0.07
Arka Lohit × Anugraha	47.92	1.23	4.63*	72.08	0.89	4.97*	6.17	0.38	0.82*
Arka Lohit × Surajmukhi	46.42	1.06	3.89*	66.58	0.30	26.77*	7.48	0.96	0.02
LCA 436 × Pant C 1	43.92	0.69	-0.10	67.50	0.31	-0.24	6.58	2.15	0.25*
LCA 436 × Anugraha	43.92	0.68	-0.22	66.42	0.74	0.21	6.62	0.59	-0.01
LCA 436 × Surajmukhi	47.67	1.25	3.94*	66.83	0.66	4.36*	7.20	0.81	0.15*
Pusa Jwala × Pant C 1	46.33	1.29	0.93	64.83	1.21	5.02*	6.80	2.53	1.03*
Pusa Jwala × Anugraha	45.33	1.15	1.69*	63.00	1.59	-0.31	7.27	2.13	0.29*
Pusa Jwala × Surajmukhi	44.83	1.53	6.28*	62.33	1.11	2.90*	6.70	1.59	0.88*
Pusa Sadabahar × Pant C 1	50.50	1.18	0.10	71.92	1.22	37.77*	7.05	1.47	-0.05
Pusa Sadabahar × Anugraha	49.17	2.35	13.80*	77.83	0.33	9.54*	7.50	1.04	0.20*
Pusa Sadabahar × Surajmukhi	47.00	1.88	8.16*	71.75	0.88	47.06*	7.43	0.70	0.58*
Kashmir Long × Pant C 1	41.58	1.19	3.98*	59.75	1.42	9.54*	5.35	0.00	1.68*
Kashmir Long × Anugraha	42.00	1.04	4.35*	59.67	1.78	0.39	5.27	0.15	-0.003
Kashmir Long × Surajmukhi	42.67	0.68	0.47	62.42	1.85	14.56*	6.68	0.93	0.38*

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	Days to 50% flowering			Days to first harvest			Primary branches/plant		
Crosses/Genotypes	mean	β_i	S^2 di	mean	β_i	S^2 di	Mean	β_i	S^2 di
Sel 352 × Pant C 1	50.92	0.13	0.42	72.67	0.28	10.93*	6.48	1.29	1.19*
Sel 352 × Anugraha	44.50	0.83	0.09	61.75	0.84	5.77*	6.48	1.05	0.06
Sel 352 × Surajmukhi	48.83	1.02	-0.43	65.75	1.15	2.35*	6.87	1.26	-0.05
LCA 443 × Pant C 1	44.92	1.32	0.31	70.17	1.49	5.03*	6.71	0.93	0.06
LCA 443 × Anugraha	49.08	-0.22	0.92	70.42	1.26	5.34*	7.05	1.02	0.15
LCA 443 × Surajmukhi	46.08	0.26	2.27*	71.50	0.85	2.27*	6.81	0.84	-0.05
LCA 206 × Pant C 1	53.83	0.77	10.51*	71.42	2.23*	0.35	6.28	0.99	-0.05
LCA 206 × Anugraha	46.58	1.77	0.67	69.00	1.22	1.10	6.72	1.12	-0.03
LCA 206 × Surajmukhi	55.50	1.19	15.69*	70.17	1.83	6.41*	6.93	1.49	-0.04
Jawahar Mirch 283	51.67	0.32	6.02*	73.67	1.35	30.99*	5.90	-0.80	1.05*
Chilli Sonal	47.58	0.44	14.52*	64.17	0.17	2.12*	6.63	1.33	0.90*
Pau Sel Long	53.67	1.10	17.38*	75.67	1.09	25.05*	6.50	0.33	0.19*
Arka Lohit	49.50	0.96	3.87*	66.00	0.77	2.19*	6.58	0.71	0.04
LCA 436	53.58	0.89	13.76*	71.25	0.73	10.43*	6.37	0.33	0.50*
Pusa Jwala	48.42	-0.55	5.24*	70.00	0.04	6.37*	6.10	0.31*	-0.06
Pusa Sadabahar	60.92	0.64	28.85*	81.83	0.92	2.08*	6.06	0.58	2.01*
Kashmir Long	42.25	0.37	3.43*	63.25	0.45	3.40*	5.70	0.03	-0.01
Sel 352	51.25	-0.13*	0.07	70.50	0.29	5.27*	6.40	0.50	0.32*
LCA 443	61.00	1.15	6.49*	80.42	0.78	2.47*	5.58	-1.32*	0.001
LCA 206	54.83	1.15	1.08	80.92	0.74	0.80	6.50	1.26	0.15*
Pant C 1	59.63	1.90	26.68*	82.67	1.14	0.39	6.18	1.20	0.33*
Anugraha	50.75	1.50	2.53*	68.50	1.62	0.96	7.67	1.40	0.04
Surajmukhi	61.88	-0.34	33.88*	79.83	1.12	2.21*	7.95	1.63	-0.02
Population mean	48.64	1.00		70.06	1.00		6.68	1.00	
SE	1.51	0.60		1.62	0.74		0.36	0.83	

* Significant at $P \leq 0.05$

Table 4.51: Estimates of mean and stability parameters for different traits in chilli

	Fruit length (cm)			Fruit girth (cm)			Average fruit weight (g)		
Crosses/Genotypes	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di
Jawahar Mirch 283 × Pant C 1	7.10	1.13	0.05*	1.09	-5.17	0.000	3.79	3.12	0.05*
Jawahar Mirch 283 × Anugraha	8.66	0.18	0.02	1.07	-9.21	0.002*	3.09	0.53	0.02*
Jawahar Mirch 283 × Surajmukhi	8.58	-1.68	0.11*	1.09	-9.13	0.01*	2.91	1.57	0.01*
Chilli Sonal × Pant C 1	6.22	3.92	0.03	0.99	-0.54	-0.000	2.39	0.81	0.000
Chilli Sonal × Anugraha	6.76	2.28	0.01	0.94	5.04*	-0.000	3.16	2.06	0.02*
Chilli Sonal × Surajmukhi	7.65	0.03*	-0.02	0.89	-2.62	0.001*	2.31	-0.75	0.02*
PAU Sel Long × Pant C 1	7.98	1.75	0.03	0.84	11.23	0.01*	2.50	0.44	0.001
PAU Sel Long × Anugraha	7.71	-1.92*	0.05*	0.83	2.49	0.000	2.69	3.45	0.03*
PAU Sel Long × Surajmukhi	8.16	0.71	-0.02	0.94	-0.33	0.001*	3.09	1.56	0.01*
Arka Lohit × Pant C 1	7.30	2.76*	-0.02	0.87	0.71	0.001*	3.44	1.07	0.001
Arka Lohit × Anugraha	7.44	4.17*	0.002	1.04	-6.09	0.01*	6.91	1.38	0.01*
Arka Lohit × Surajmukhi	7.35	1.11	0.10*	1.04	-5.32	0.000	5.08	-0.28	0.04*
LCA 436 × Pant C 1	7.78	0.77	0.27*	1.16	-3.50	0.000	4.02	-0.91	0.03*
LCA 436 × Anugraha	9.19	5.40*	0.00	0.97	1.85	0.000	3.58	1.73	0.02*
LCA 436 × Surajmukhi	8.11	1.93	0.85*	1.05	11.80	0.003*	4.49	2.23	0.06*
Pusa Jwala × Pant C 1	7.16	3.93*	0.03	0.94	2.48	0.000	2.38	1.80	0.02*
Pusa Jwala × Anugraha	8.22	4.88*	0.01	0.84	-1.51	0.000	2.71	4.41*	0.000
Pusa Jwala × Surajmukhi	8.14	4.22*	0.05*	0.78	1.77	0.004*	3.75	0.80	0.01*
Pusa Sadabahar × Pant C 1	7.22	-1.18*	0.01	0.86	-6.47	0.01*	2.82	1.11	0.01*
Pusa Sadabahar × Anugraha	5.99	3.96	0.24*	0.86	-1.27	-0.000	2.55	0.85	0.01*
Pusa Sadabahar × Surajmukhi	7.91	-3.73	0.45*	1.06	-9.73	0.06*	2.10	0.26	0.02*
Kashmir Long × Pant C 1	8.02	-0.71	0.36*	1.00	5.99	0.004*	3.92	2.78	0.02*
Kashmir Long × Anugraha	9.76	-5.46*	0.44*	0.93	6.28	0.004*	3.18	0.41	0.000
Kashmir Long × Surajmukhi	8.34	-0.27*	-0.02	0.96	0.95	0.003*	4.19	-0.84	0.31*

Contd../-

Crosses/Genotypes	Fruit length (cm)			Fruit girth (cm)			Average fruit weight (g)		
	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di
Sel 352 × Pant C 1	6.08	2.48	0.11*	1.12	0.77	0.000	4.16	0.27	0.06*
Sel 352 × Anugraha	7.30	1.49	-0.003	0.96	0.11	0.000	4.66	1.77	0.02*
Sel 352 × Surajmukhi	6.41	0.90	-0.01	1.02	7.40	0.01*	3.72	1.67	-0.000
LCA 443 × Pant C 1	7.36	-0.74	0.31*	1.19	2.38	0.01*	4.38	0.55	0.01*
LCA 443 × Anugraha	8.83	-1.08	0.21*	1.09	-0.61	0.000	4.57	1.59	0.000
LCA 443 × Surajmukhi	7.58	-0.63	0.06*	1.23	1.90	0.000	5.10	1.43	0.01*
LCA 206 × Pant C 1	7.95	0.03	0.05*	0.92	2.64	0.000	2.96	1.90	0.02*
LCA 206 × Anugraha	10.14	-1.92*	-0.01	0.84	-4.12	0.004*	1.81	3.15	0.02*
LCA 206 × Surajmukhi	7.28	1.67	0.11*	0.83	1.39	0.000	2.14	-1.19	0.03*
Jawahar Mirch 283	8.31	1.22	-0.001	0.99	-3.57	0.004*	3.27	0.79	0.01*
Chilli Sonal	7.41	-1.47	0.17*	0.91	4.51	0.001*	2.21	-2.48	0.02*
Pau Sel Long	7.27	3.59*	0.03	0.94	-2.57	0.000	3.43	-0.33	0.00*
Arka Lohit	7.95	5.43	0.36*	1.28	5.77	0.003*	5.06	1.83	0.00*
LCA 436	8.76	-2.46*	-0.003	1.33	5.73*	0.000	6.32	-0.72	0.01*
Pusa Jwala	9.12	3.18*	0.01	0.82	3.37	0.004*	2.34	0.04	0.01*
Pusa Sadabahar	5.29	1.27	0.01	0.97	7.42	0.002*	3.60	0.45	0.00*
Kashmir Long	8.64	4.62	0.55*	1.13	14.42	0.01*	5.15	0.52	0.01*
Sel 352	6.23	-1.77	0.13*	1.21	9.32	0.005*	4.22	-1.24	0.002
LCA 443	7.08	2.83	0.43*	1.44	1.75	0.01*	5.09	2.48	0.25*
LCA 206	8.48	0.79	-0.02	0.84	-10.31*	0.002*	2.03	0.85	0.01*
Pant C 1	5.13	0.76	0.003	1.03	-1.41*	-0.000	2.07	0.66	0.02*
Anugraha	8.12	0.78	-0.02	0.74	5.93	0.002*	2.32	2.40	0.01*
Surajmukhi	6.52	-2.16*	-0.02	0.97	5.12	0.003*	4.57	1.04	0.01*
Population mean	7.66	1.00		1.00	1.00		3.54	1.00	
SE	0.22	0.69		0.04	3.12		0.10	2.19	

* Significant at $P \leq 0.05$

Table 4.52: Estimates of mean and stability parameters for different traits in chilli

	Marketable fruits/plant			Marketable fruit yield/plant			Harvest duration (days)		
Crosses/Genotypes	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di
Jawahar Mirch 283 × Pant C 1	119.05	2.03	273.35*	450.26	1.73	6388.77*	47.00	1.03	-0.03
Jawahar Mirch 283 × Anugraha	176.85	4.43	1027.10*	543.35	3.55	6033.38*	51.42	-0.84	0.49
Jawahar Mirch 283 × Surajmukhi	153.49	3.86	502.09*	443.73	2.54	4096.10*	54.67	0.07	0.40
Chilli Sonal × Pant C 1	112.55	-2.27	708.91*	268.64	-1.77	1834.55*	47.67	0.99	0.11
Chilli Sonal × Anugraha	94.04	0.36	497.78*	296.49	-0.30	4188.75*	42.33	0.68	0.54*
Chilli Sonal × Surajmukhi	206.18	-1.84	1698.69*	472.82	-0.51	5469.67*	58.50	1.05	-0.21
PAU Sel Long × Pant C 1	152.80	0.86	9.10	381.82	0.74	7.80	53.17	-0.13	0.78*
PAU Sel Long × Anugraha	151.07	2.22	472.90*	406.38	1.34	5649.91*	57.50	-1.41	0.32
PAU Sel Long × Surajmukhi	170.57	3.08	738.40*	524.04	2.35	4140.12*	61.42	-0.83	-0.06
Arka Lohit × Pant C 1	114.30	1.47	124.77*	392.62	1.36	1178.12*	55.75	1.40	0.43
Arka Lohit × Anugraha	57.70	2.09	251.01*	399.38	4.33	5934.08*	60.08	1.31	-0.25
Arka Lohit × Surajmukhi	102.65	1.83	215.03*	520.96	2.80	2093.94*	56.67	2.36*	-0.20
LCA 436 × Pant C 1	153.15	0.94	197.29*	615.23	1.23	629.75*	59.67	1.42	0.81*
LCA 436 × Anugraha	150.32	2.15	236.15*	536.98	2.17	2030.29*	62.25	0.54	-0.12
LCA 436 × Surajmukhi	96.03	2.02	146.28*	430.62	2.50	1578.83*	56.75	2.63*	-0.24
Pusa Jwala × Pant C 1	129.43	1.90	794.44*	305.16	0.72	3429.98*	51.58	-0.62	0.40
Pusa Jwala × Anugraha	130.28	1.90	634.08*	351.01	0.96	4787.68*	50.92	1.72	1.24*
Pusa Jwala × Surajmukhi	123.64	2.91	93.43*	464.19	2.78	4117.12*	50.50	0.27	-0.02
Pusa Sadabahar × Pant C 1	87.99	-0.92	126.68*	247.45	-0.87*	273.29*	57.67	4.02	0.18
Pusa Sadabahar × Anugraha	103.59	-0.57	103.13*	264.44	-0.20	854.27*	62.83	2.93*	-0.14
Pusa Sadabahar × Surajmukhi	209.20	3.04	307.11*	433.58	1.96	22069.37*	64.08	1.62	-0.07
Kashmir Long × Pant C 1	97.37	0.11	49.91*	381.86	-0.14	1465.53*	46.42	1.35	-0.18
Kashmir Long × Anugraha	111.62	0.89	8.09	354.70	0.65	331.03*	47.75	2.35*	-0.24
Kashmir Long × Surajmukhi	104.24	1.56	53.21*	440.63	2.23	8568.13*	51.33	0.40	0.78*

Contd../-

Crosses/Genotypes	Marketable fruits/plant			Marketable fruit yield/plant			Harvest duration (days)		
	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di
Sel 352 × Pant C 1	93.56	1.35	944.98*	385.71	2.03	10206.65*	50.33	1.00	-0.12
Sel 352 × Anugraha	86.95	0.61	25.85*	404.98	0.53	1158.26*	52.50	1.57	-0.21
Sel 352 × Surajmukhi	115.92	1.41	191.10*	431.10	1.52	2195.52*	50.92	-0.12	1.10*
LCA 443 × Pant C 1	89.88	0.21	194.30*	393.17	0.43	2779.39*	47.58	-0.35	0.17
LCA 443 × Anugraha	87.62	1.53	114.30*	400.88	2.09	1346.65*	47.08	0.50	-0.21
LCA 443 × Surajmukhi	103.89	1.77	52.21*	529.68	2.13	3933.70*	55.00	2.42	0.36
LCA 206 × Pant C 1	77.48	-0.74	153.57*	229.25	-0.64	1152.34*	50.33	1.56	-0.03
LCA 206 × Anugraha	173.48	-0.22	327.94*	307.40	-1.19	20121.11*	52.42	2.39*	-0.21
LCA 206 × Surajmukhi	130.74	-0.80	132.92*	281.08	-0.55	2237.91*	59.92	3.28	0.76*
Jawahar Mirch 283	80.87	0.82	75.30*	264.58	0.54	1286.26*	51.17	2.92	0.11
Chilli Sonal	91.10	-0.23	798.08*	199.50	-0.08	4640.76*	41.42	2.39*	-0.21
Pau Sel Long	65.04	0.78	248.45*	223.00	0.75	2929.62*	52.17	-0.98	2.73*
Arka Lohit	52.59	1.81	22.66	265.82	2.50*	203.56	52.67	1.53	0.11
LCA 436	38.76	0.64	73.63*	245.45	1.44	2221.84*	53.08	-0.26*	-0.25
Pusa Jwala	112.09	0.49	17.19	261.75	0.28	197.44	47.00	1.28	-0.15
Pusa Sadabahar	51.55	0.27	34.29*	185.92	0.25	701.07*	60.67	-0.42	1.11*
Kashmir Long	53.16	1.08	12.67	274.11	1.54	767.38*	52.08	0.22	-0.13
Sel 352	54.57	0.40	77.73*	230.58	0.42	1874.43*	53.25	-1.14	0.36
LCA 443	56.04	-0.37	142.84*	282.13	-0.52	756.63*	52.58	3.37	2.85*
LCA 206	88.52	0.30	128.47*	179.41	-0.18	545.28*	51.83	-0.72	0.02
Pant C 1	88.30	0.46	284.76*	183.17	0.15	1736.08*	62.58	-1.06*	-0.24
Anugraha	104.26	0.10	5.12	241.59	-0.16*	-43.23	63.42	2.31	-0.05
Surajmukhi	62.21	1.26	100.20*	284.32	1.57	2280.73*	62.33	0.98	2.35*
Population mean	107.80	1.00		353.40	1.00		53.84	1.00	
SE	14.60	1.50		34.50	1.00		0.44	0.85	

* Significant at $P \leq 0.05$

Table 4.53: Estimates of mean and stability parameters for different traits in chilli

Crosses/Genotypes	Plant height (cm)			Average dry fruit weight (g)			Dry fruit yield/plant (g)		
	Mean	β_i	S^2 di	mean	β_i	S^2 di	Mean	β_i	S^2 di
Jawahar Mirch 283 × Pant C 1	63.32	1.91	19.33*	0.83	-0.18	0.003	57.88	2.41	27.46*
Jawahar Mirch 283 × Anugraha	80.23	0.35	35.42*	0.72	-0.13	0.000	62.05	3.89	26.63*
Jawahar Mirch 283 × Surajmukhi	81.01	0.84	0.43	1.01	3.07	0.002	54.39	1.75	21.46*
Chilli Sonal × Pant C 1	67.52	0.86	41.62*	1.08	5.99	0.05*	34.93	1.34	36.11*
Chilli Sonal × Anugraha	71.09	1.44	2.40	0.81	-2.70	0.01*	32.00	-0.79	30.20*
Chilli Sonal × Surajmukhi	77.95	1.79	2.87	1.04	7.40*	-0.001	57.76	0.11	61.75*
PAU Sel Long × Pant C 1	67.62	0.37	3.50	0.85	-0.02	-0.002	48.13	1.51	-0.28
PAU Sel Long × Anugraha	65.03	1.09	60.93*	0.93	0.67	-0.002	48.88	0.54	99.49*
PAU Sel Long × Surajmukhi	77.22	2.01	24.63*	1.40	4.20	0.01*	63.28	2.05	24.34*
Arka Lohit × Pant C 1	65.79	0.30	8.32*	1.59	1.76	0.001	50.83	2.63	3.35
Arka Lohit × Anugraha	69.24	0.96	13.99*	1.24	-3.91	0.06*	56.36	3.81	32.12*
Arka Lohit × Surajmukhi	71.44	3.23	79.81*	1.07	0.55	-0.000	64.37	3.83	20.42*
LCA 436 × Pant C 1	70.74	0.84	13.29*	1.49	3.06	0.04*	70.59	0.65	3.26
LCA 436 × Anugraha	67.57	0.15*	-1.53	1.31	-2.79	0.04*	58.87	1.27	77.43*
LCA 436 × Surajmukhi	70.35	1.40	31.25*	1.71	-1.46	0.000	54.38	0.85	25.57*
Pusa Jwala × Pant C 1	54.96	0.63	51.83*	1.00	5.14	0.01*	38.89	2.10	3.97
Pusa Jwala × Anugraha	57.34	0.97	-2.55	1.01	-0.08	0.002	44.04	2.00	85.13*
Pusa Jwala × Surajmukhi	65.32	0.74	0.06	1.01	-4.57	0.004	55.07	5.02	72.68*
Pusa Sadabahar × Pant C 1	68.83	1.35	135.98*	1.35	-0.10	-0.001	31.18	-1.82	31.24*
Pusa Sadabahar × Anugraha	66.71	0.14*	-1.26	0.66	-2.45	-0.001	33.87	0.55	126.00*
Pusa Sadabahar × Surajmukhi	77.07	1.16	106.21*	0.66	-0.87	0.01*	49.43	3.82	99.00*
Kashmir Long × Pant C 1	64.93	1.68	2.10	1.28	-1.08	0.002	52.23	-1.18	17.73*
Kashmir Long × Anugraha	69.04	1.28	15.82*	0.74	-1.59	-0.002	44.33	0.20	17.51*
Kashmir Long × Surajmukhi	65.86	0.78	0.46	0.67	-0.19	-0.002	52.35	3.65	131.16*

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Crosses/Genotypes	Plant height (cm)			Average dry fruit weight (g)			Dry fruit yield/plant (g)		
	Mean	β_i	$S^2 di$	mean	β_i	$S^2 di$	Mean	β_i	$S^2 di$
Sel 352 × Pant C 1	71.41	2.09*	-2.58	1.05	-1.86	-0.002	52.65	1.36	105.59*
Sel 352 × Anugraha	66.28	1.28	31.40*	1.20	0.97	-0.002	53.88	2.20	41.83*
Sel 352 × Surajmukhi	80.42	2.21	10.73*	1.33	-1.14	0.002	58.27	1.54	35.52*
LCA 443 × Pant C 1	75.97	1.92	2.77	1.06	-1.61	-0.002	44.61	-1.87	6.74*
LCA 443 × Anugraha	70.78	2.26	9.58*	1.29	-0.26	0.002	52.43	0.23	-1.31
LCA 443 × Surajmukhi	75.48	1.74	85.82*	1.49	11.33	0.01*	60.54	5.78	26.14*
LCA 206 × Pant C 1	68.15	0.32	26.28*	0.94	-4.86	0.02*	30.71	-0.07	-1.08
LCA 206 × Anugraha	70.47	0.29*	-1.84	1.16	-1.76	0.006	37.97	0.58	63.55*
LCA 206 × Surajmukhi	77.38	1.30	1.88	1.03	-2.84	0.000	39.45	-0.92	31.14*
Jawahar Mirch 283	65.79	1.32	3.15	0.73	0.97	0.003	28.88	-0.52	42.89*
Chilli Sonal	64.82	0.98	-2.80	0.79	1.39	0.000	30.38	-0.28	49.37*
Pau Sel Long	64.29	1.19	32.16*	1.29	7.53	0.02*	31.53	1.39	17.24*
Arka Lohit	64.32	-0.02	8.27*	0.67	0.26	0.001	21.29	0.50	-2.70
LCA 436	70.95	0.55	7.87*	1.99	10.61*	0.002	33.54	0.67	44.19*
Pusa Jwala	54.30	-0.09	8.97*	0.85	0.87	0.002	33.10	-0.74	2.13
Pusa Sadabahar	60.08	1.36	1.51	0.67	0.51	0.002	26.83	0.04	5.32
Kashmir Long	67.38	1.16	3.87	0.68	-0.33	0.002	31.18	0.36	34.43*
Sel 352	67.84	1.18*	-2.89	1.63	-0.19	0.001	24.92	0.35	6.71*
LCA 443	61.65	-0.33*	2.22	2.25	15.21*	0.002	28.93	-1.68*	-2.24
LCA 206	76.63	-0.21	9.44*	0.92	-2.14	0.001	23.63	-0.53*	-2.42
Pant C 1	55.23	0.15*	-0.51	0.77	0.95	0.002	27.83	-0.32	24.43*
Anugraha	61.30	0.78	-1.94	0.64	1.66	0.001	30.18	-1.24	0.35
Surajmukhi	65.45	-0.68	56.54*	0.65	2.00	0.001	33.13	0.01	8.20*
Population mean	68.35	1.00		1.07	1.00		43.66	1.00	
SE	2.77	0.50		0.06	3.57		3.52	1.81	

* Significant at $P \leq 0.05$

Table 4.54: Estimates of mean and stability parameters for different traits in chilli

	Ascorbic acid (mg/100g)			Capsaicin content (%)			Capsanthin (ASTA units)			Oleoresin (ASTA units)		
Crosses/Genotypes	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di	mean	β_i	S^2 di
Jawahar Mirch 283 × Pant C 1	110.63	6.84	2.53	0.38	0.17	0.000	101.10	-1.66	4.06*	44.00	2.57	19.33*
Jawahar Mirch 283 × Anugraha	97.88	1.45	10.61*	0.43	0.30	0.001*	111.46	5.34	42.81*	50.67	3.39	18.81*
Jawahar Mirch 283 × Surajmukhi	103.13	6.13	2.86	0.53	1.92	0.001*	106.97	2.22	-0.81	50.92	0.29	8.42*
Chilli Sonal × Pant C 1	115.96	-1.73*	-1.45	0.31	3.76	0.000	76.68	-0.11	0.15	44.21	1.68	6.11*
Chilli Sonal × Anugraha	113.04	-1.13	12.22*	0.34	2.62	0.001*	75.53	2.08	-0.68	35.92	4.74	44.01*
Chilli Sonal × Surajmukhi	99.63	0.21	9.26*	0.46	1.70	0.000	94.79	6.31	88.02*	54.96	2.69	2.41*
PAU Sel Long × Pant C 1	104.29	1.33	20.02*	0.49	0.34	0.001*	92.48	1.51	0.12	63.71	1.44	4.99*
PAU Sel Long × Anugraha	116.75	0.36	8.59*	0.58	2.37	0.000	94.54	3.25*	-0.91	63.58	3.11	2.08
PAU Sel Long × Surajmukhi	129.63	1.28	1.02	0.64	2.35	0.001*	110.29	3.62	4.33*	67.79	-0.17	1.21
Arka Lohit × Pant C 1	119.02	0.20	5.60*	0.69	-0.73	0.002*	99.92	-0.30	9.96*	72.38	-0.71	5.69*
Arka Lohit × Anugraha	122.08	4.68	8.81*	0.70	-0.61	0.000	90.75	0.35	11.30*	81.96	2.40	3.60*
Arka Lohit × Surajmukhi	95.83	-2.68	-0.42	0.76	0.97	0.000	87.72	-0.05	14.08*	73.42	-0.88	5.10*
LCA 436 × Pant C 1	95.79	-2.24	11.86*	0.49	1.93	0.001*	104.33	1.02	4.31*	56.29	0.44	8.01*
LCA 436 × Anugraha	103.42	7.21	20.11*	0.40	2.21	0.000	101.72	3.48	31.19*	37.96	2.45	4.43*
LCA 436 × Surajmukhi	114.88	-0.78	9.79*	0.46	0.25	0.001*	107.58	-0.17	11.59*	52.42	2.42	0.08
Pusa Jwala × Pant C 1	95.08	-0.03	3.90*	0.87	1.75	0.001*	80.10	2.13	1.55	84.96	-0.52	9.90*
Pusa Jwala × Anugraha	112.50	-2.25*	-1.48	0.77	1.53	0.001*	95.25	-3.26	10.03*	77.96	0.56	6.35*
Pusa Jwala × Surajmukhi	100.88	-1.99	11.77*	0.84	0.56	0.001*	86.83	5.60	26.96*	82.67	1.95	17.77*
Pusa Sadabahar × Pant C 1	117.38	0.51	3.60*	0.71	-0.09	0.000	75.96	-0.26	4.08*	71.75	-1.45*	-0.56
Pusa Sadabahar × Anugraha	124.33	0.24	7.82*	0.70	-1.93	0.002*	76.73	0.13	15.77*	77.83	0.44	0.68
Pusa Sadabahar × Surajmukhi	128.92	-0.90	3.57*	0.66	1.32	0.000	87.19	1.39	13.53*	79.77	0.54	1.19
Kashmir Long × Pant C 1	119.38	4.74	6.28*	0.83	0.57	0.001*	103.63	2.05	0.11	77.88	-0.63	12.59*
Kashmir Long × Anugraha	130.46	1.67	14.37*	0.51	2.05	0.000	84.08	-1.48	2.59*	55.67	2.56	1.01
Kashmir Long × Surajmukhi	123.96	1.73	15.65*	0.62	1.42	0.000	85.01	1.24	4.81*	63.21	0.01	9.65*
Sel 352 × Pant C 1	99.71	-3.59	0.98	0.69	1.08	0.000	86.17	0.61	0.77	70.21	1.76	9.98*

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	Ascorbic acid (mg/100g)			Capsaicin content (%)			Capsanthin (ASTA units)			Oleoresin (ASTA units)		
Crosses/Genotypes	mean	β_i	$S^2 di$	mean	β_i	$S^2 di$	mean	β_i	$S^2 di$	mean	β_i	$S^2 di$
Sel 352 × Anugraha	93.83	-2.94	3.32	0.69	1.97	0.000	87.06	-0.52	1.76	67.75	-0.10	8.55*
Sel 352 × Surajmukhi	104.79	-3.55	5.23*	0.76	1.48	0.003*	109.17	-1.60	10.75*	74.92	-1.23	5.08*
LCA 443 × Pant C 1	120.25	-3.98*	-0.02	0.67	0.14	0.001*	83.63	-2.49	13.68*	72.58	1.49	1.24
LCA 443 × Anugraha	103.13	-4.06	5.61*	0.61	1.37	0.001*	89.88	-0.45	2.75*	60.46	2.25	6.27*
LCA 443 × Surajmukhi	111.13	-4.42*	-0.91	0.65	2.64*	-0.000	110.67	5.43	25.20*	71.13	2.88	0.86
LCA 206 × Pant C 1	93.42	4.80	3.61*	0.57	0.93	0.003*	79.89	1.43	9.29*	60.04	-2.39	5.53*
LCA 206 × Anugraha	107.83	1.79	4.18*	0.68	0.12	0.00	81.42	0.99	4.14*	67.54	0.04	11.45*
LCA 206 × Surajmukhi	121.96	5.21	0.26	0.73	1.39	0.001*	77.25	-0.03	3.77*	71.75	0.91	0.06
Jawahar Mirch 283	94.38	3.27	3.42*	0.50	1.69	0.001*	74.83	-1.54	6.37*	54.17	-0.93	31.00*
Chilli Sonal	93.38	-2.05	3.58*	0.28	3.94	0.001*	75.50	3.43	2.33*	30.63	1.91	0.07
Pau Sel Long	106.96	-4.92	15.37*	0.50	1.24	0.002*	79.70	2.89	0.90	53.33	-0.39	9.23*
Arka Lohit	117.29	6.32	9.22*	0.52	-1.93	0.001*	70.92	-0.88	2.44*	65.86	1.54	10.87*
LCA 436	100.88	5.76	7.18*	0.52	0.72	0.001*	77.06	-0.24	16.25*	54.53	5.76	20.81*
Pusa Jwala	104.46	8.68	10.79*	0.87	-3.00	0.001*	78.05	-1.78	2.68*	82.00	-2.02	3.13*
Pusa Sadabahar	104.38	5.12	13.01*	0.82	-0.60	0.001*	94.42	1.54	28.01*	76.63	1.27	1.31
Kashmir Long	108.08	3.88	13.66*	0.35	-0.94	0.001*	92.04	6.02	15.89*	53.25	-0.04	7.87*
Sel 352	101.55	-1.07	21.62*	0.45	1.33	0.001*	75.17	-2.72	-0.07	51.25	0.34	20.48*
LCA 443	106.92	-0.54	29.50*	0.45	2.54	0.003*	74.37	-0.55	3.68*	49.71	0.97	15.64*
LCA 206	100.50	-6.44*	1.78	0.54	3.84	0.000	73.90	-0.73	8.17*	59.01	3.30	5.58*
Pant C 1	129.13	7.85	10.81*	0.64	1.04	0.001*	78.18	1.18	14.96*	61.38	0.72	0.77
Anugraha	102.54	8.91	10.61*	0.48	1.16	-0.000	88.67	2.76	7.88*	61.75	-1.77	15.90*
Surajmukhi	112.04	-1.87	4.48*	0.89	-1.88*	-0.000	101.46	-0.15	47.17*	65.81	1.42	8.44*
Population mean	109.20	1.00		0.60	1.00		88.72	1.00		62.93	1.00	
SE	1.80	2.60		0.02	1.33		2.03	3.10		1.78	1.31	

* Significant at $P \leq 0.05$

352 × Anugraha' for average dry fruit weight (Table 4.53) had regression coefficient (βi) equal to one and variances of regression deviation (S^2di) equal to zero which revealed their average capacity of adaptation to all the environments with high predictability for these traits. These crosses are the most ideal because of their sensitiveness to favourable environment stimuli and the good performance under unfavourable environments (Eberhart and Russell 1966). This concept, however, was questioned by Hildebrand (1990) who was of the view that it is important to find genotypes capable of maintaining high crop yields under unfavourable environments or those with excellent performance in diverse environments, rather than selecting genotypes with a regression coefficient equal to one. These genotypes may have lower performance for these traits under unfavourable environments than those with low regression coefficients and poor performance for the same characters under favourable environments than those with high regression coefficients.

Hybrids 'Jawahar Mirch 283 × Anugraha', 'PAU Selection Long × Surajmukhi', 'Kashmir Long × Surajmukhi' and 'LCA 206 × Anugraha' along with lines 'LCA 436', 'LCA 206' and 'Anugraha' for fruit length (Table 4.51) and 'Jawahar Mirch 283 × Pant C 1', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C 1' and 'Selection 352 × Pant C 1' for fruit girth (Table 4.51) had a regression coefficient less than one which predicts these hybrids adapted to unfavourable conditions. Moreover, the variance level was less than zero which indicated the performance for these traits with high prediction. On the other hand, hybrids 'PAU Selection Long × Pant C 1', 'LCA 436 × Anugraha' and ' Pusa Jwala × Anugraha' and lines 'Jawahar Mirch 283' and 'Pusa Jwala' for fruit length and hybrid 'LCA 443 × Surajmukhi' along with line 'LCA 436' for fruit girth possessed regression coefficient greater than unity and non-significant deviation from regression which showed their stability and suitability to favourable environments.

Line 'Selection 352' and cross 'PAU Selection Long × Pant C 1' were observed to be stable and suitable to unfavourable environment for average fruit weight (Table 4.51) and marketable fruits/plant (Table 4.52), respectively while, hybrids ‘Selection 352 × Surajmukhi’ and ‘LCA 443 × Anugraha’ were found suitable for average fruit weight under favourable environments with high predictability.

‘Chilli Sonal × Surajmukhi’, ‘Selection 352 × Anugraha’, ‘LCA 443 × Pant C 1’ had regression coefficient less than one for marketable fruit yield/plant (Table 4.52) which means they are adapted to unfavourable growth conditions. However, the variance level (S^2di) was significant which means they had low predictability. Therefore, special attention is necessary before recommending these for general adaptability. The top ranking genotypes for marketable fruit yield/plant namely, ‘LCA 436 × Pant C 1’, ‘Jawahar Mirch 283 × Anugraha’, ‘LCA 436 × Anugraha’, ‘LCA 443 × Surajmukhi’ and ‘PAU Selection Long × Surajmukhi’ were adapted to favourable growth conditions with low predictability which revealed that performance of these crosses may not be taken for granted even under favourable condition and therefore, they require special attention. Similar findings have also been reported by Sharma *et al.* (2006).

The hybrid ‘Jawahar Mirch 283 × Surajmukhi’ for harvest duration and plant height while, ‘PAU Selection Long × Anugraha’, ‘PAU Selection Long × Surajmukhi’, ‘LCA 436 × Anugraha’ and ‘Pant C 1’ for harvest duration only had higher mean values with regression coeffiecient less than unity and non-significant deviation from regression, indicating their adaptability under unfavourable environments with predictable performance . On the other hand, crosses ‘Arka Lohit × Pant C 1’, ‘Arka Lohit × Anugraha’, ‘Arka Lohit × Surajmukhi’, ‘LCA 436 × Surajmukhi’, ‘Pusa Sadabahar × Pant C 1’, ‘Pusa Sadabahar × Anugraha’, ‘Pusa Sadabahar × Surajmukhi’, ‘LCA 443 × Surajmukhi’ and line ‘Anugraha’ for harvest duration and crosses ‘Chilli Sonal × Surajmukhi’, ‘Selection 352 × Pant C 1’, ‘LCA 443 × Pant C 1’ and ‘LCA 206 × Surajmukhi’ for plant height were stable under favourable environmental conditions as these have regression coefficient more than unity and non-significant deviation from regression.

For average dry fruit weight (Table 4.53), 'LCA 436 × Surajmukhi', 'Pusa Sadabahar × Pant C 1', 'Kashmir Long × Pant C 1', 'Selection 352 × Surajmukhi', 'LCA 443 × Anugraha', 'LCA 206 × Anugraha' and 'Selection 352' under unfavourable environments and 'Arka Lohit × Pant C 1', 'LCA 436' and 'LCA 443' under favourable environments were noticed to be stable.

For dry fruit yield/plant (Table 4.53), 'LCA 436 × Pant C 1' and 'LCA 443 × Anugraha' had the capacity to adapt under unfavourable environments with highly predictable performance. On the other hand, 'PAU Selection Long × Pant C 1' and 'Arka Lohit × Pant C 1' adapted to favourable growth conditions with high predictability.

Among quality traits (Table 4.54), 'Chilli Sonal × Pant C 1', 'Pusa Jwala × Anugraha', 'LCA 443 × Pant C 1' and 'LCA 443 × Surajmukhi' for ascorbic acid, 'Arka Lohit × Anugraha', 'Pusa Sadabahar × Pant C 1', 'LCA 206 × Anugraha' and 'Surajmukhi' for capsaicin, 'PAU Selection Long × Surajmukhi', 'Pusa Sadabahar × Pant C1', 'Pusa Sadabahar × Anugraha' and 'Pusa Sadabahar × Surajmukhi' for oleoresin were having regression coefficient less than one and deviation from regression equal to zero indicating their highly predictable performance under unfavourable environments. On the other hand, 'PAU Selection Long × Surajmukhi' and 'LCA × Surajmukhi' for ascorbic acid, 'Pusa Sadabahar × Surajmukhi', 'Kashmir Long × Surajmukhi', 'Selection 352 × Anugraha' and 'LCA 443 × Surajmukhi' for capsaicin, 'Jawahar Mirch 283 × Surajmukhi', 'PAU Selection Long × Pant C 1', 'PAU Selection Long × Anugraha' and 'Kashmir Long × Pant C 1' for capsanthin, and 'LCA 443 × Pant C 1', 'LCA 443 × Surajmukhi' and 'Pusa Sadabahar' for oleoresin were observed to be stable and suitable for favourable environments which was depicted from their regression coefficient equal to one and non-significant deviation from regression.

It can be concluded that the cross combination 'LCA 436 × Pant C 1' had high mean dry fruit yield/plant along with early flowering and fruit harvest with specific adaptability and high predictable performance under unfavourable environments. Therefore, this cross combination is the most suitable for obtaining early and high yield. Reddy and Sadashiva (2003) also observed genotype with high yield and earliness in their studies.

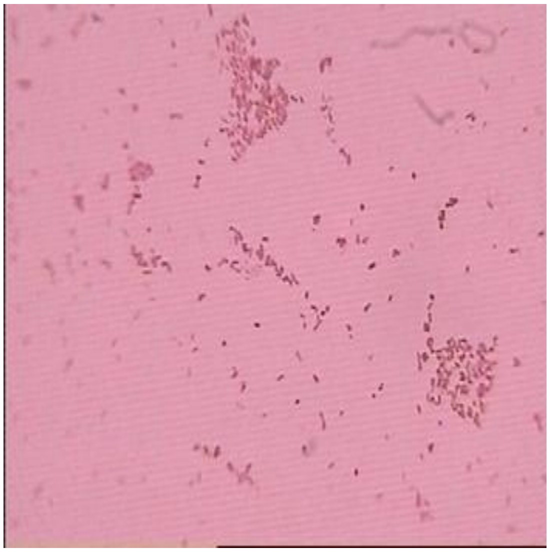
Bacterial wilt incidence (%)

Chilli is vulnerable to the attack of a number of fungal, bacterial and viral diseases of which bacterial wilt, caused by pathogen *Ralstonia solanacearum,* is most important. The disease is soil borne in nature. In Himachal Pradesh, the disease becomes a limiting factor for chilli cultivation in humid areas of mid and low hills. The disease assumes serious proportions when the season starts with high rainfall and warm weather conditions and results in complete failure of chilli crop.The identification of high yielding chilli lines combined with bacterial wilt resistance and acceptable quality is the present day need. The susceptible checks, namely, ‘Chilli Sonal’ and ‘Arka Lohit’ succumbed to bacterial wilt disease completely (100% plant mortality) which was confirmed through bacterial ooze test (Table 4.55).

In the present investigation, 13 and 11 cross combinations showed 100 per cent plant survival (resistant) during 2010 and 2011, respectively, while, 15 and 18 cross combinations revealed moderately resistant reaction to bacterial wilt disease. The rest of the crosses were moderately susceptible/susceptible during respective years as per the scale of Sinha *et al*. (1990). Among the 14 parents, seven were found resistant during 2010 and 8 parents during 2011.

Table 4.55: Bacterial wilt incidence (%) in chilli at Palampur

S.No	Genotypes/crosses	2010	2011
1	Jawahar Mirch 283	MR	MR
2	Chilli Sonal	S	S
3	PAU Sel Long	R	R
4	Arka Lohit	S	S
5	LCA 436	R	R
6	Pusa Jwala	MS	S
7	Pusa Sadabahar	R	R
8	Kashmir Long	S	S
9	Sel 352	MR	R
10	LCA 443	R	R
11	LCA 206	MR	S
12	Pant C 1	R	R
13	Anugraha	R	R
14	Surajmukhi	R	R
15	CH-1	R	R
16	Jawahar Mirch 283 × Pant C 1	MR	MR
17	Jawahar Mirch 283 × Anugraha	R	R
18	Jawahar Mirch 283 × Surajmukhi	R	MR
19	Chilli Sonal × Pant C 1	MR	MR
20	Chilli Sonal × Anugraha	MR	MR
21	Chilli Sonal × Surajmukhi	MR	MR
22	PAU Sel Long × Pant C 1	R	R
23	PAU Sel Long × Anugraha	R	MR
24	PAU Sel Long × Surajmukhi	MR	R
25	Arka Lohit × Pant C 1	MR	MR
26	Arka Lohit × Anugraha	R	R
27	Arka Lohit × Surajmukhi	MS	MS
28	LCA 436 × Pant C 1	R	R
29	LCA 436 × Anugraha	MR	MR
30	LCA 436 × Surajmukhi	R	R
31	Pusa Jwala × Pant C 1	MS	MS
32	Pusa Jwala × Anugraha	R	R
33	Pusa Jwala × Surajmukhi	MR	MR
34	Pusa Sadabahar × Pant C 1	R	R
35	Pusa Sadabahar × Anugraha	MS	MS
36	Pusa Sadabahar × Surajmukhi	MS	MR
37	Kashmir Long × Pant C 1	MR	MR
38	Kashmir Long × Anugraha	MR	MR
39	Kashmir Long × Surajmukhi	MR	MR
40	Sel 352 × Pant C 1	R	R
41	Sel 352 × Anugraha	R	R
42	Sel 352 × Surajmukhi	R	R
43	LCA 443 × Pant C 1	MR	MR
44	LCA 443 × Anugraha	MR	MR
45	LCA 443 × Surajmukhi	R	MR
46	LCA 206 × Pant C 1	MR	MR
47	LCA 206 × Anugraha	S	S
48	LCA 206 × Surajmukhi	MR	MR



***Ralstonia solanacearum*, the wilt causing bacteria**

Ooze test for bacterial wilt

Susceptible (Chilli Sonal) vs resistant cross in bacterial wilt sick plots at Palampur

Plate 9: Bacterial wilt (*Ralstonia solanacearum*) disease in Chilli

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5. SUMMARY AND CONCLUSIONS

The present investigation entitled “Heterosis and gene action studies for fruit yield and horticultural traits in chilli (*Capsicum annuum* var. *annuum* L.)” was undertaken to get information on gene action and identify potential parental lines and cross combinations on the basis of combining ability and magnitude of heterosis for different traits, *viz*., days to 50% flowering, days to first harvest, primary branches/plant fruit length (cm), fruit girth (cm), average fruit weight (g), marketable fruits/plant, marketable fruit yield/plant (g), harvest duration (days), plant height (cm), average dry fruit weight (g), dry fruit yield/plant (g), ascorbic acid (mg/100g), capsaicin content (%), capsanthin (ASTA units), oleoresin (ASTA units) and bacterial wilt incidence (%) by following ‘line × tester’ mating design. Eleven lines of chilli, *viz*., ‘LCA 206’ ,’Selection 352’, ‘LCA 436’, ‘LCA 443’, ‘Arka Lohit’, ‘Chilli Sonal’, ‘Jawahar Mirch 283’, ‘Kashmir Long’, ‘Pusa Sadabahar’, ‘Pusa Jwala’ and ‘PAU Selection Long’ and three testers, *viz*., ‘Pant C 1’, ‘Anugraha’ and ‘Surajmukhi’, along with 33 hybrids derived by following ‘line × tester’ mating design and the standard check (CH-1), were evaluated in Randomized Complete Block Design with three replications at two diverse locations namely, Palampur and Bajaura during summer-rainy seasons of 2010 and 2011. For recording the incidence of bacterial wilt disease, a separate trial was laid out at Palampur for two consecutive years in sick plots.

Analysis of variance revealed sufficient genetic variability among treatments for marketable fruit yield and dry fruit yield and all other characters studied in both the environments during both the years and pooled over environments. Also, significant G × E interaction for all the characters indicated a definite role of environment on the performance of genotypes/crosses. The ‘line × tester’ analysis revealed the significant differences due to lines, testers and line × tester interactions for majority of the traits in both the locations in the respective years and pooled environments indicating appreciable diversity in the experimental material. The interactions of line, tester and line vs tester with the environment revealed that the performance was influenced by environment. The estimation of GCA effects showed that the lines ‘Chilli Sonal’, ‘LCA 436’, ‘Kashmir Long’ and ‘Pusa Jwala’ were the most suitable general combiners for earliness in terms of days to 50% flowering and days to first harvest. Out of 11 lines, ‘LCA 436’ and ‘LCA 443’ were good general combiners for 11 traits out of 16 studied followed by ‘Selection 352’ and ‘Arka Lohit’ for 10 traits each and ‘Jawahar Mirch 283’ for nine traits on the basis of pooled analysis over environments. Lines ‘Jawahar Mirch 283’, ‘PAU Selection Long’, LCA 436’ and ‘LCA 443’ were good general combiners for marketable fruit yield/plant and dry fruit yield/plant. These lines, in general, also showed good general combining ability for fruit length, marketable fruits/plant and harvest duration. Amongst the testers, ‘Surajmukhi’ was the most promising as evident from its good GCA for 12 and 13 traits at Palampur and 13 and 11 traits at Bajaura out of 16 traits studied in the respective years and also showed good GCA for 14 traits in pooled over environments. Besides, ‘Anugraha’ also showed promise for earliness, fruit length and average fruit weight while, ‘Pant C 1’ was good general combiner for fruit girth. These parental lines showing consistency of GCA effects for various traits including yield, appear to have higher frequency of desirable additive genes which can be exploited for high yields in chilli.

On the basis of SCA effects, it was observed that no single cross could reveal significant SCA for all the traits. However, cross ‘PAU Selection Long × Surajmukhi’, ‘LCA 436 × Pant C1’, ‘Chilli Sonal × Surajmukhi’, ‘Jawahar Mirch 283 × Anugraha’ and ‘Pusa Sadabahar × Surajmukhi’ revealed significant SCA effects on the desirable direction for majority of the traits over the locations, years and pooled over environments including marketable fruit yield/plant and dry fruit yield/plant. These crosses also, retained their position among the top ten crosses for marketable fruit yield/plant over the environments and represent one parent atleast as Good or Average general combiner. The cross combinations ‘Selection 352 × Anugraha’ and ‘ Chilli Sonal × Anugraha’ which involved both parents with high GCA effects for early harvest, had desirable SCA effects and can be exploited to isolate transgressive segregants in early generations for early harvest. Certain crosses with significant and desirable SCA effects for various traits also involve parents with ‘Poor × Poor’ or ‘Average × Poor’ GCA effects which might be the result of complementary gene interactions.

The magnitude of dominance variance was higher than additive variance for majority of the traits over locations and pooled environments which indicated the involvement of non-additive gene action. However, additive genetic variance with higher magnitude was noticed for fruit length, primary branches/plant, plant height and dry fruit yield/plant in 2010, harvest duration in 2011 and capsaicin content and oleoresin in both the years at Palampur whereas, the same effect was observed for oleoresin in 2010 and harvest duration, plant height and capsaicin content in both the years and at Bajaura. In addition, harvest duration and primary branches/plant in 2010, dry fruit yield/plant in 2011 and fruit girth in both the years at Palampur had the same magnitude for both additive and dominance variance. Further, a complete correspondence between σ_{SCA}^2 and σ_D^2 and σ_{GCA}^2 and σ_A^2 was noticed with a few exceptions. The ‘σ_{SCA}^2 × environment’ showed higher magnitude than σ_{GCA}^2 (tester × environment) for all the traits except fruit girth indicating that the hybrids were less stable than the lines and testers.

It was observed that lines played a significant role in the expression of different characters in different cross combinations which was evident as the per cent contribution of lines in the expression of genetic variance was higher than tester and their interactions for all the traits in 2010 at Palampur and also in pooled environments along with few exceptions for primary branches/plant, marketable fruits/plant, plant height, average dry fruit weight and ascorbic acid in 2011 at Palampur. Similarly, at Bajaura also, the contribution of lines was greater than that of testers and line × tester interaction for most of the traits at Bajaura except marketable fruits/plant in 2010, days to 50% flowering, primary branches/plant and marketable fruits/plant in 2011 whereas, the contribution of lines and testers was almost equal for primary branches/plant in 2010 and ascorbic acid during both the years.

A wide variation in magnitude and direction of heterosis was found among all the crosses for all the traits. Appreciable economic heterosis and heterobeltiosis was noticed for majority of the traits. For marketable fruit yield/plant, 27 crosses during both the years at Palampur, 29 and 30 crosses in the respective years at Bajaura and 32 crosses in pooled environments showed heterobeltiosis. On the other hand, a total of 16 and 14 crosses at Palampur and 19 crosses each at Bajaura during 2010 and 2011, respectively and 23 crosses in pooled environments showed significant positive economic heterosis for marketable fruit yield/plant. Cross 'LCA 436 × Pant C 1' showed maximum magnitude of 227.59 per cent and 84.98 per cent over BP and SC during 2010 at Bajaura, respectively. Hybrids 'Jawahar Mirch 283 × Anugraha', 'PAU Selection Long × Surajmukhi', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C 1', 'LCA 436 × Anugraha' and 'LCA 443 × Surajmukhi' were the best hybrid combinations for marketable fruit yield/plant with maximum consistency and were ranked among top ten crosses across the environments. These crosses were also heterotic for marketable fruits/plant, harvest duration, average fruit weight and fruit length with few exceptions which might be resulted into better economic heterosis for marketable fruit yield/plant. These crosses were also found superior in respect of yield and majority of economic traits on the basis of *per se* performance, SCA and heterosis. For dry fruit yield/plant, 'LCA 436 × Pant C 1', 'Arka Lohit × Surajmukhi', 'PAU Selection Long × Surajmukhi' and 'Jawahar Mirch 283 × Anugraha' were the best hybrids with consistency for heterosis across the environments and also showed significant SCA effects with few exceptions.

Cross combination 'LCA 436 × Pant C 1' observed to be the most suitable for obtaining early and high yield as evident from its high mean dry fruit yield/plant along with early flowering and fruit harvest with specific adaptability and high predictable performance under unfavourable environments.

On the basis of gene action, combining ability effects and heterosis, it can be concluded that breeding methods like single seed descent method, reciprocal recurrent selection, bulk pedigree method and diallel selective mating system can be utilized to obtain transgressive segregants in the segregating generations with high yield and desirable component traits in chilli.

Conclusions:

From the present study, the following conclusions can be drawn:

- Sufficient quantum of genetic variability was generated for yield and component traits involving diverse genotypes of chilli by following line × tester mating design.
- The estimates of GCA effects revealed that lines ‘Chilli Sonal’, ‘LCA 436’, ‘Kashmir Long’ and ‘Pusa Jwala’ were the most promising general combiners for earliness in terms of days to 50% flowering and days to first harvest.
- Lines ‘Jawahar Mirch 283’, ‘PAU Selection Long’, LCA 436’ and ‘LCA 443’ were good general combiners for both marketable and dry fruit yield/plant. “Surajmukhi” was the most promising tester having good GCA effects for majority of the traits.
- On the basis of SCA effects over the environments,‘PAU Selection Long × Surajmukhi’, ‘LCA 436 × Pant C1’, ‘Chilli Sonal × Surajmukhi’, ‘Jawahar Mirch 283 × Anugraha’ and ‘Pusa Sadabahar × Surajmukhi’ were the most promising cross combinations for majority of traits including marketable fruit yield/plant and dry fruit yield/plant. In addition, desirable SCA effects of ‘Selection 352 × Anugraha’ and ‘Chilli Sonal × Anugraha’ for early harvest involving both parents with high GCA effects revealed the possibility of obtaining transgressive segregants with early generations.
- The magnitude of dominance variance was higher than additive variance for majority of the traits over the locations and pooled over environments which indicated the involvement of non-additive gene action. Lines played a significant role in the expression of genetic variance of different characters.

- Considerable heterosis was observed for most of the characters studied over better parent and standard check. The cross combinations, *viz.,* 'Pusa Jwala × Anugraha', 'Kashmir Long × Pant C1' and 'Kashmir Long × Anugraha' exhibited desirable heterosis for earliness.
- Hybrids 'Jawahar Mirch 283 × Anugraha', 'PAU Selection long × Surajmukhi', 'Arka Lohit × Surajmukhi', 'LCA 436 × Pant C1', 'LCA 436 × Anugraha' and 'LCA 443 × Surajmukhi' showed significant and positive heterobeltiosis and economic heterosis for marketable fruit yield/plant with maximum consistency and got ranking among top ten crosses across the environments. These crosses were also heterotic for marketable fruits/plant, harvest duration, average fruit weight and fruit length.

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Appendix I

Mean weekly weather data at Palampur

Standard Week	2010					2011				
	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)		Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	
	Max.	Min.		Morning	Evening	Max.	Min.		Morning	Evening
1	16.99	4.07	2.49	79.14	60.86	15.70	2.90	5.80	65.00	52.00
2	17.14	3.91	0.80	70.00	51.14	17.10	4.70	0.00	63.00	44.00
3	19.49	5.20	0.00	74.00	47.57	12.00	2.40	58.20	76.00	60.00
4	19.10	5.99	0.00	76.29	38.57	16.10	3.50	0.00	78.00	49.00
5	17.43	4.96	0.31	81.14	48.17	18.10	6.50	1.00	69.00	50.00
6	15.31	5.89	15.14	88.00	75.14	19.10	7.60	23.00	61.00	48.00
7	17.36	4.86	0.00	87.29	69.29	14.30	6.90	110.80	80.00	64.00
8	20.39	7.13	2.09	78.86	65.14	16.80	5.90	1.00	76.00	59.00
9	22.31	11.07	0.17	63.86	52.29	15.10	6.10	38.80	81.00	72.00
10	20.99	8.40	2.09	68.29	46.43	19.50	9.00	7.70	66.00	44.00
11	25.31	11.56	0.00	63.29	40.14	24.40	11.20	0.00	66.00	42.00
12	26.50	13.30	0.50	70.00	46.00	24.80	11.70	0.00	63.00	35.00
13	28.79	14.73	1.46	54.86	28.00	25.90	12.70	5.40	61.00	40.00
14	28.39	13.93	0.00	42.29	26.43	22.70	10.50	5.00	69.00	43.00
15	31.06	16.00	0.01	45.57	26.00	24.50	12.60	5.60	78.00	51.00
16	72.10	16.50	3.49	52.71	34.29	24.00	11.80	80.20	69.00	50.00
17	29.79	16.67	0.46	49.00	31.43	28.70	17.00	0.00	65.00	46.00
18	31.86	18.61	0.43	52.86	35.43	31.60	19.20	10.00	78.00	46.00
19	28.41	16.63	2.97	71.57	42.71	30.40	18.30	2.60	73.00	44.00
20	31.89	20.16	1.91	52.00	29.86	33.50	20.90	0.60	71.00	54.00
21	34.79	21.29	0.00	33.71	22.71	31.00	18.10	97.60	81.00	61.00
22	27.79	16.86	10.97	63.00	51.00	28.60	17.50	42.80	77.00	54.00
23	27.79	16.86	10.97	63.00	51.00	30.50	18.30	39.20	76.00	60.00
24	30.73	18.31	1.06	64.43	40.86	28.70	19.00	117.60	81.00	80.00
25	33.14	21.17	6.06	56.86	44.14	28.90	19.40	34.60	85.00	71.00
26	30.36	19.66	12.86	73.29	60.71	26.50	20.10	167.00	94.00	91.00
27	26.43	19.30	18.89	85.57	79.86	27.30	19.10	117.40	86.00	81.00
28	27.63	20.23	1.31	83.71	77.71	27.00	19.80	87.80	96.00	85.00

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Standard Week	2010					2011				
	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)		Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	
	Max.	Min.		Morning	Evening	Max.	Min.		Morning	Evening
29	26.71	20.87	21.89	92.14	92.43	26.80	20.60	61.80	92.00	85.00
30	25.86	19.97	25.70	90.71	85.29	24.50	20.10	196.80	97.00	90.00
31	26.96	19.84	35.26	94.29	88.50	26.50	20.00	106.00	94.00	88.00
32	25.93	20.27	27.23	95.86	88.00	25.90	20.40	191.40	96.00	90.00
33	25.84	20.30	38.91	93.14	88.00	24.00	17.70	335.00	95.00	91.00
34	25.21	19.19	46.63	93.00	90.43	25.10	19.70	209.20	97.00	90.00
35	26.69	19.84	13.99	93.57	84.00	26.70	19.50	68.80	92.00	83.00
36	25.96	19.09	28.94	94.14	88.43	27.20	18.90	103.00	96.00	88.00
37	25.14	17.74	13.14	92.57	86.29	25.50	18.80	83.60	94.00	89.00
38	24.43	17.19	1.69	93.86	84.57	26.00	16.10	12.20	92.00	78.00
39	25.87	14.84	1.77	84.71	73.71	26.20	15.40	32.40	89.00	80.00
40	27.23	14.97	0.26	87.14	67.57	25.50	15.80	32.20	92.00	81.00
41	26.50	14.27	0.36	77.29	57.71	27.10	14.40	0.00	85.00	60.00
42	26.67	14.97	0.00	83.57	61.57	25.90	12.50	0.00	76.00	53.00
43	23.13	10.03	4.09	72.14	54.71	24.20	11.70	2.60	72.00	55.00
44	23.73	10.56	0.00	75.43	51.00	23.40	12.60	1.80	82.00	66.00
45	24.51	10.59	0.00	73.29	50.29	23.60	11.50	0.00	84.00	75.00
46	23.94	9.76	0.17	68.57	37.14	23.00	10.10	0.00	78.00	80.00
47	21.17	8.40	0.57	74.14	50.57	22.80	9.70	0.00	86.00	76.00
48	20.26	7.17	0.00	86.29	57.57	20.70	7.10	0.00	85.00	68.00
49	19.60	5.77	0.00	70.57	40.57	21.90	8.70	6.00	90.00	86.00
50	17.70	4.74	0.00	77.14	55.00	18.50	6.60	0.00	88.00	83.00
51	18.91	4.14	0.00	66.86	37.57	17.90	3.60	0.00	88.00	88.00
52	16.80	4.64	13.03	65.71	52.57	18.10	3.80	0.00	81.00	54.00

Appendix II

Mean weekly weather data at Bajaura

Standard Week	2010					2011				
	Temperature (^oC)		Rainfall (mm)	Relative Humidity (%)	Temperature (^oC)	Temperature (^oC)		Rainfall (mm)	Relative Humidity (%)	Temperature (^oC)
	Max.	Min.		Morning	Evening	Max.	Min.		Morning	Evening
1	17.50	1.10	10.80	93.00	33.00	15.70	-1.10	0.00	94.00	35.00
2	18.40	-0.40	1.80	89.00	31.00	17.30	0.40	0.00	92.00	31.00
3	19.70	1.20	0.00	87.00	21.00	10.70	1.00	27.20	94.00	48.00
4	21.20	1.30	0.00	84.00	25.00	17.20	0.10	0.00	94.00	30.00
5	18.10	1.20	2.40	88.00	23.00	17.90	2.20	0.00	91.00	34.00
6	14.00	4.00	115.60	90.00	54.00	18.70	4.60	21.40	82.00	42.00
7	17.30	3.20	3.80	90.00	29.00	13.40	4.20	58.20	91.00	63.00
8	22.50	4.60	6.00	88.00	28.00	16.60	4.20	9.80	91.00	44.00
9	22.60	8.20	3.20	83.00	39.00	13.80	4.70	84.60	87.00	69.00
10	21.30	5.00	33.80	90.00	30.00	20.90	5.10	6.80	83.00	31.00
11	26.20	6.90	0.00	87.00	23.00	26.30	6.60	0.00	81.00	24.00
12	30.00	9.60	0.00	86.00	32.00	25.60	6.90	2.60	87.00	21.00
13	28.20	9.60	8.60	85.00	25.00	25.80	6.90	9.20	90.00	26.00
14	29.20	8.20	0.40	83.00	16.00	21.90	6.80	3.00	85.00	37.00
15	31.40	9.50	2.20	84.00	22.00	23.40	8.90	20.10	90.00	48.00
16	28.60	12.10	48.80	83.00	43.00	24.70	8.90	66.40	92.00	43.00
17	28.50	10.80	3.80	89.00	32.00	29.60	11.90	0.00	89.00	34.00
18	32.20	15.10	18.80	87.00	27.00	30.90	11.80	21.80	86.00	33.00
19	28.80	13.20	24.00	84.00	36.00	29.50	12.30	3.20	86.00	30.00
20	29.50	12.90	22.60	81.00	33.00	33.30	13.80	1.00	85.00	28.00
21	34.10	13.40	0.00	84.00	15.00	32.00	14.70	19.80	89.00	35.00
22	33.60	13.50	22.20	82.00	39.00	29.30	15.30	29.40	88.00	45.00
23	25.90	14.20	125.30	88.00	45.00	31.40	15.80	7.00	89.00	39.00
24	29.30	14.20	21.20	87.00	45.00	31.00	18.10	35.60	88.00	51.00
25	32.60	16.90	9.20	82.00	35.00	31.10	19.50	9.90	88.00	50.00

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Standard Week	2010					2011				
	Temperature (^oC)		Rainfall (mm)	Relative Humidity (%)	Temperature (^oC)	Temperature (^oC)		Rainfall (mm)	Relative Humidity (%)	Temperature (^oC)
	Max.	Min.		Morning	Evening	Max.	Min.		Morning	Evening
26	31.60	18.50	11.40	87.00	42.00	30.50	21.70	14.60	86.00	59.00
27	26.00	18.50	142.30	92.00	66.00	31.70	20.50	0.00	85.00	46.00
28	29.10	19.80	10.40	89.00	52.00	31.00	21.00	21.40	88.00	58.00
29	29.70	21.70	37.60	90.00	62.00	30.30	21.90	28.40	89.00	53.00
30	28.10	21.50	72.80	92.00	67.00	29.20	21.90	26.50	91.00	68.00
31	30.60	21.60	58.20	90.00	62.00	31.40	22.00	7.20	88.00	58.00
32	29.00	21.80	62.60	91.00	65.00	30.40	21.00	41.80	92.00	60.00
33	30.40	22.30	31.80	91.00	61.00	26.20	18.60	268.60	92.00	74.00
34	29.00	21.60	29.40	90.00	73.00	29.90	22.10	8.40	90.00	61.00
35	30.70	21.90	6.80	89.00	50.00	29.90	21.40	21.60	91.00	60.00
36	31.30	21.50	12.20	89.00	49.00	30.90	20.90	40.80	92.00	59.00
37	26.20	18.20	47.40	91.00	68.00	29.00	20.50	9.90	91.00	62.00
38	26.10	18.10	60.00	89.00	57.00	29.00	16.70	20.20	89.00	44.00
39	28.80	13.30	2.60	88.00	39.00	29.70	15.10	0.00	87.00	42.00
40	29.50	12.10	0.00	85.00	35.00	29.50	16.60	0.00	87.00	44.00
41	27.70	10.60	0.00	86.00	35.00	28.60	10.90	0.00	89.00	36.00
42	29.30	12.30	3.80	91.00	36.00	28.00	9.50	0.00	89.00	32.00
43	22.50	6.50	40.80	90.00	44.00	25.70	6.60	0.00	88.00	31.00
44	25.70	7.00	0.00	89.00	35.00	25.10	6.20	0.00	90.00	32.00
45	25.70	5.20	0.00	92.00	60.00	24.60	6.20	0.00	92.00	37.00
46	24.40	4.30	2.00	92.00	36.00	24.30	4.80	1.60	91.00	34.00
47	20.10	4.80	9.60	92.00	38.00	24.00	4.10	0.00	93.00	33.00
48	23.00	2.70	0.00	93.00	36.00	22.10	0.90	0.00	93.00	27.00
49	20.50	-0.10	0.00	97.00	24.00	22.20	2.50	29.80	91.00	34.00
50	18.70	0.30	0.00	94.00	29.00	18.00	-0.50	3.00	95.00	31.00
51	18.90	-2.00	0.00	91.00	22.00	18.20	-1.50	0.00	93.00	26.00
52	15.40	0.50	65.80	93.00	37.00	17.20	-2.50	0.00	92.00	26.00

Appendix-III Mean values of fourteen parents, thirty three F_1s and one check for the characters studied at Palampur during 2010

S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283	55.00	71.00	6.60	8.78	0.96	3.23	85.18	275.00	49.00	65.20	0.76	32.67	94.67	0.47	74.83	54.33
2	Chilli Sonal	43.67	62.67	6.07	6.91	0.95	2.36	87.69	198.67	40.00	61.67	0.85	26.50	92.33	0.23	76.50	27.50
3	PAU Sel Long	55.00	73.00	7.13	8.47	0.89	3.39	82.40	279.33	52.00	68.07	1.39	33.37	105.83	0.50	78.80	56.67
4	Arka Lohit	51.67	69.00	6.47	9.09	1.34	5.05	78.75	397.67	52.00	64.27	0.66	21.67	123.67	0.56	68.67	63.67
5	LCA 436	54.33	71.00	6.27	7.98	1.40	6.44	52.76	339.67	53.33	72.73	2.20	41.00	107.00	0.50	79.07	45.27
6	Pusa Jwala	49.00	69.00	6.00	9.83	0.87	2.37	114.51	271.00	46.00	50.93	0.86	33.63	112.83	0.91	77.87	86.67
7	Pusa Sadabahar	63.33	83.67	7.13	5.55	1.05	3.64	55.96	203.80	61.67	54.53	0.65	29.67	106.33	0.85	100.33	75.17
8	Kashmir Long	43.33	62.33	5.93	9.52	1.28	5.29	63.95	338.00	52.00	66.80	0.66	28.37	109.33	0.37	95.83	51.33
9	Sel 352	51.00	70.00	5.73	5.67	1.30	4.28	54.28	232.13	54.00	64.33	1.60	22.33	102.87	0.45	76.33	49.67
10	LCA 443	61.33	80.00	5.87	7.20	1.49	5.36	45.91	246.00	51.00	62.40	2.51	26.83	109.67	0.43	72.97	51.67
11	LCA 206	55.00	83.00	6.33	8.73	0.72	1.88	90.22	169.47	52.33	81.07	0.92	22.17	95.33	0.49	71.93	52.20
12	Pant C 1	67.67	85.33	5.53	5.31	1.01	2.00	102.00	204.33	63.33	56.23	0.78	25.17	136.67	0.60	75.37	59.33
13	Anugraha	51.00	70.00	8.07	8.38	0.86	2.26	105.10	237.00	62.00	60.00	0.63	28.00	106.33	0.47	90.50	64.67
14	Surajmukhi	63.00	81.33	8.20	5.90	1.03	4.53	77.93	353.27	62.33	73.83	0.66	35.33	108.83	0.91	98.67	61.50
15	Jawahar Mirch 283 × Pant C 1	46.33	71.00	6.73	7.65	1.03	3.68	140.00	515.67	46.00	58.60	0.88	**62.63**	116.67	0.37	99.83	43.83
16	Jawahar Mirch 283 × Anugraha	46.67	71.00	7.40	8.69	0.96	3.05	242.01	**737.33**	51.33	86.53	0.69	**72.97**	96.00	0.42	117.33	48.67
17	Jawahar Mirch 283 × Surajmukhi	46.67	73.00	6.60	8.14	0.99	2.81	203.79	**573.33**	54.33	79.20	1.02	**60.33**	106.33	0.53	106.53	47.83
18	Chilli Sonal × Pant C 1	42.33	64.00	7.27	7.16	0.99	2.40	67.09	161.13	46.67	57.80	1.03	34.67	115.17	0.26	75.37	40.33
19	Chilli Sonal × Anugraha	42.67	64.33	6.53	7.53	1.01	3.01	87.83	264.67	42.00	67.20	0.81	26.33	113.83	0.30	74.77	31.83
20	Chilli Sonal × Surajmukhi	44.00	76.00	6.73	7.62	0.88	2.44	179.23	437.33	58.00	75.50	1.15	53.70	97.00	0.43	100.17	50.50
21	PAU Sel Long × Pant C 1	49.67	76.00	6.87	8.60	0.97	2.55	166.27	424.00	53.00	67.27	0.83	51.37	107.33	0.47	91.07	63.67
22	PAU Sel Long × Anugraha	50.33	76.00	7.33	7.33	0.88	2.61	181.83	473.67	58.33	70.40	0.93	57.67	118.67	0.53	93.83	59.50
23	PAU Sel Long × Surajmukhi	50.33	76.00	6.47	8.32	0.94	2.97	226.42	**671.33**	61.67	78.07	1.57	**71.70**	131.17	0.60	107.33	66.83
24	Arka Lohit × Pant C 1	51.67	76.00	6.87	8.08	0.89	3.43	137.96	473.67	55.33	61.40	1.58	57.00	116.73	0.68	98.67	71.17
25	Arka Lohit × Anugraha	51.67	76.00	7.27	8.66	0.98	6.91	92.23	**637.33**	59.33	62.33	1.36	**65.33**	122.67	0.71	90.83	79.33

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S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
26	Arka Lohit × Surajmukhi	46.33	64.00	7.87	7.44	0.98	5.15	126.97	**654.33**	55.00	52.47	1.12	**73.90**	93.00	0.75	88.03	74.33
27	LCA 436 × Pant C 1	44.00	67.33	6.00	8.53	1.12	4.04	166.67	**673.33**	59.33	63.87	1.63	**72.93**	96.67	0.46	105.67	55.00
28	LCA 436 × Anugraha	44.33	67.00	6.67	10.69	0.99	3.58	186.31	**667.00**	61.67	68.40	1.41	**69.90**	104.50	0.38	108.53	35.17
29	LCA 436 × Surajmukhi	51.33	69.00	7.20	9.56	1.19	4.44	129.11	573.67	55.00	73.07	1.69	58.33	113.17	0.46	107.50	49.00
30	Pusa Jwala × Pant C 1	47.33	64.33	5.80	8.36	0.96	2.25	153.55	346.00	52.00	54.00	1.01	39.70	93.33	0.83	78.07	88.17
31	Pusa Jwala × Anugraha	48.33	66.00	7.20	9.64	0.82	2.68	152.99	410.00	50.33	54.00	1.06	51.70	110.67	0.76	92.83	77.83
32	Pusa Jwala × Surajmukhi	44.33	62.33	7.60	9.13	0.76	3.77	160.25	**603.33**	50.00	62.20	0.96	61.70	97.33	0.84	87.63	82.00
33	Pusa Sadabahar × Pant C 1	51.67	79.00	7.00	6.79	0.80	2.78	70.38	195.67	55.33	51.73	1.33	22.33	115.67	0.72	73.50	74.50
34	Pusa Sadabahar × Anugraha	51.67	81.33	8.07	6.93	0.85	2.62	101.53	266.00	61.00	65.40	0.61	26.63	126.67	0.76	75.67	76.50
35	Pusa Sadabahar × Surajmukhi	51.33	79.00	8.20	6.88	0.90	2.11	238.33	503.67	63.00	62.60	0.56	58.30	129.17	0.65	85.93	80.07
36	Kashmir Long × Pant C 1	41.67	59.00	6.07	8.27	1.05	3.76	103.90	390.67	45.67	58.53	1.27	51.37	122.33	0.80	104.00	78.87
37	Kashmir Long × Anugraha	41.67	62.00	5.20	8.24	0.98	3.18	119.81	381.00	46.33	60.67	0.72	40.33	134.67	0.47	85.17	51.67
38	Kashmir Long × Surajmukhi	43.67	62.00	6.13	8.28	0.99	4.52	124.34	**562.00**	51.00	65.40	0.65	**62.80**	126.67	0.61	83.03	60.67
39	Sel 352 × Pant C 1	51.67	76.00	5.87	6.39	1.15	4.21	117.91	496.00	49.67	66.60	1.00	51.00	96.83	0.68	85.00	65.50
40	Sel 352 × Anugraha	45.00	62.33	6.07	7.57	0.96	4.59	90.92	417.00	51.67	57.13	1.24	53.50	91.33	0.66	86.67	67.00
41	Sel 352 × Surajmukhi	50.33	69.00	6.87	6.67	1.08	3.72	138.08	513.67	50.33	72.67	1.36	54.73	100.67	0.71	109.83	74.67
42	LCA 443 × Pant C 1	45.33	74.33	6.80	7.60	1.28	4.49	89.61	402.67	47.67	71.47	1.05	38.77	116.33	0.67	79.03	69.50
43	LCA 443 × Anugraha	47.67	75.00	6.67	8.51	1.08	4.61	111.63	515.00	46.67	68.47	1.27	53.70	102.50	0.57	87.83	58.00
44	LCA 443 × Surajmukhi	45.33	74.67	6.67	7.23	1.26	5.12	120.95	**619.67**	54.00	81.87	1.64	**65.00**	108.67	0.61	116.50	66.67
45	LCA 206 × Pant C 1	53.33	76.00	6.13	7.80	0.97	2.91	68.88	200.67	49.00	65.87	0.84	30.37	94.83	0.55	78.73	61.83
46	LCA 206 × Anugraha	47.33	72.33	6.60	9.71	0.82	1.67	135.33	226.00	51.00	70.13	1.06	34.60	111.17	0.67	79.00	68.17
47	LCA 206 × Surajmukhi	59.00	75.00	7.13	7.44	0.85	2.07	114.90	237.47	58.00	76.40	1.00	36.73	126.83	0.72	76.50	71.33
48	CH-1	50.00	69.00	5.47	6.69	1.25	5.03	90.32	454.00	51.00	55.83	1.75	52.87	106.83	0.79	89.17	85.17
	Mean	49.78	71.60	6.68	7.90	1.02	3.57	119.46	404.66	53.16	65.52	1.11	45.45	109.86	0.59	88.69	61.97
	CV (%)	1.64	1.72	7.81	4.32	3.61	1.90	4.40	4.37	1.46	4.67	9.33	6.50	1.35	2.63	1.70	2.07
	CD at P ≤ 0.05	1.32	1.99	0.85	0.55	0.06	0.11	8.53	28.66	1.26	4.96	0.17	4.79	2.41	0.03	2.45	2.08

Appendix-IV Mean values of fourteen parents, thirty three F_1s and one check for the characters studied at Palampur during 2011

S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283	51.00	67.33	6.80	8.49	0.93	3.16	78.82	249.33	52.00	55.33	0.73	20.83	98.33	0.49	77.33	60.67
2	Chilli Sonal	51.00	63.67	5.60	7.05	0.97	2.25	124.15	279.33	41.67	58.80	0.73	39.17	92.67	0.34	78.00	31.33
3	PAU Sel Long	50.33	70.33	6.20	8.01	0.95	3.52	70.55	248.33	51.33	52.13	1.44	36.90	101.00	0.56	79.50	51.00
4	Arka Lohit	52.00	64.00	6.80	9.64	1.36	5.10	45.75	233.33	52.00	65.03	0.69	21.33	118.67	0.51	71.67	62.10
5	LCA 436	50.67	67.00	7.13	8.19	1.37	6.38	32.88	209.75	53.00	65.53	2.03	27.18	100.50	0.56	72.17	49.33
6	Pusa Jwala	45.00	68.00	6.00	10.13	0.86	2.43	113.32	275.00	47.00	57.47	0.86	33.63	105.00	0.87	79.67	80.67
7	Pusa Sadabahar	55.33	80.67	6.83	5.73	1.06	3.65	57.60	210.42	60.67	52.33	0.70	26.33	109.67	0.81	95.50	77.33
8	Kashmir Long	44.33	61.00	5.80	10.34	1.31	5.12	48.42	247.92	51.67	58.53	0.71	38.67	112.67	0.36	90.00	56.83
9	Sel 352	52.00	68.00	6.20	5.90	1.33	4.20	50.95	214.17	52.33	60.40	1.68	26.83	97.33	0.41	73.33	56.33
10	LCA 443	60.00	77.67	5.87	8.51	1.37	4.47	70.93	316.83	54.00	64.20	2.40	28.90	101.67	0.47	76.67	47.67
11	LCA 206	55.67	79.67	5.80	8.66	0.74	2.08	102.00	212.50	52.33	75.33	0.83	24.33	98.83	0.59	71.50	58.83
12	Pant C 1	60.33	79.33	5.80	5.37	1.02	2.22	95.80	212.67	62.33	53.20	0.78	34.17	129.50	0.67	75.83	61.33
13	Anugraha	51.67	63.67	7.40	8.29	0.72	2.18	108.94	237.50	63.00	55.67	0.70	28.07	110.17	0.49	86.17	65.83
14	Surajmukhi	54.83	75.67	7.33	5.97	1.03	4.44	46.89	208.33	63.33	64.80	0.71	29.17	113.00	0.87	95.17	65.83
15	Jawahar Mirch 283 × Pant C 1	49.67	68.33	6.47	7.17	1.03	3.54	98.66	349.58	47.33	51.47	0.75	51.90	111.83	0.40	103.17	38.33
16	Jawahar Mirch 283 × Anugraha	51.67	63.33	7.47	8.71	0.98	2.94	190.12	**558.33**	51.67	73.37	0.76	**63.67**	101.50	0.46	116.00	44.33
17	Jawahar Mirch 283 × Surajmukhi	50.00	66.00	6.47	8.06	0.96	2.84	166.95	**473.58**	55.67	75.60	1.11	57.33	106.67	0.55	108.33	53.33
18	Chilli Sonal × Pant C 1	47.67	61.00	5.87	7.42	0.98	2.41	133.13	320.83	47.67	67.00	1.40	30.17	114.67	0.33	76.67	43.00
19	Chilli Sonal × Anugraha	49.33	62.00	6.67	7.24	0.96	3.13	117.86	368.50	41.33	62.20	0.70	30.00	109.67	0.34	76.83	26.50
20	Chilli Sonal × Surajmukhi	44.00	77.00	6.13	7.69	0.84	2.40	167.59	401.67	58.33	64.67	1.13	52.50	103.33	0.46	104.00	53.00
21	PAU Sel Long × Pant C 1	49.33	69.00	5.47	8.28	0.98	2.47	146.93	363.42	52.33	65.20	0.88	46.40	103.67	0.51	93.17	62.17
22	PAU Sel Long × Anugraha	48.67	73.33	6.80	7.02	0.84	2.48	119.09	295.33	56.67	52.13	0.95	37.67	114.17	0.59	95.83	60.67
23	PAU Sel Long × Surajmukhi	45.00	72.33	6.53	8.38	0.91	3.06	152.23	**465.83**	61.33	60.27	1.28	**62.67**	129.00	0.62	112.83	68.33
24	Arka Lohit × Pant C 1	50.33	71.00	6.20	8.02	0.89	3.38	116.09	392.00	56.00	66.00	1.67	52.17	122.00	0.64	103.67	74.33
25	Arka Lohit × Anugraha	47.00	69.67	6.07	8.47	0.94	6.76	36.37	245.83	60.00	66.07	0.92	**61.33**	127.00	0.70	94.67	78.67

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S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
26	Arka Lohit × Surajmukhi	50.00	62.33	7.07	7.89	0.99	5.27	80.12	**422.50**	57.00	57.13	1.03	**67.23**	95.83	0.76	91.83	71.67
27	LCA 436 × Pant C 1	45.33	66.67	6.07	7.44	1.12	4.23	133.52	**564.33**	60.00	68.37	1.45	**67.67**	92.67	0.49	102.00	59.50
28	LCA 436 × Anugraha	45.33	65.00	6.20	10.63	0.99	3.40	145.45	**495.00**	62.67	65.93	1.04	52.57	111.83	0.43	100.67	34.50
29	LCA 436 × Surajmukhi	47.00	66.67	7.53	7.72	1.16	4.21	86.87	365.42	57.00	57.47	1.66	48.00	116.83	0.51	103.67	52.67
30	Pusa Jwala × Pant C 1	46.67	61.00	5.93	8.12	0.97	2.30	156.16	359.17	50.67	49.33	1.18	41.17	96.67	0.87	81.83	81.33
31	Pusa Jwala × Anugraha	45.33	58.67	7.47	9.44	0.81	2.64	154.55	407.50	51.67	51.60	0.93	51.17	111.67	0.79	92.17	79.67
32	Pusa Jwala × Surajmukhi	49.33	58.67	6.80	9.45	0.85	3.86	127.27	**490.83**	51.00	61.47	0.90	**66.17**	103.33	0.89	94.00	76.83
33	Pusa Sadabahar × Pant C 1	52.67	72.00	6.87	6.98	0.74	2.93	86.56	253.92	58.33	69.07	1.38	35.00	120.00	0.69	75.50	71.67
34	Pusa Sadabahar × Anugraha	55.67	78.33	7.40	7.25	0.84	2.62	93.19	244.17	63.33	66.57	0.65	29.50	122.50	0.71	72.73	79.33
35	Pusa Sadabahar × Surajmukhi	50.33	73.00	6.47	6.83	0.94	2.25	111.28	250.00	64.67	76.40	0.77	38.00	126.83	0.68	84.00	77.83
36	Kashmir Long × Pant C 1	45.33	57.00	6.40	7.33	1.10	3.85	93.05	357.92	46.67	55.53	1.28	46.60	122.83	0.83	103.00	81.50
37	Kashmir Long × Anugraha	45.67	55.67	5.53	8.24	1.03	3.21	113.07	363.33	47.67	64.07	0.71	48.33	128.33	0.53	85.17	53.83
38	Kashmir Long × Surajmukhi	44.33	55.67	6.13	8.27	0.97	4.64	108.73	**504.17**	50.33	59.93	0.69	**62.33**	121.83	0.62	84.00	66.83
39	Sel 352 × Pant C 1	51.67	73.67	5.33	7.10	1.09	4.41	52.86	232.92	50.00	57.40	1.07	44.33	98.00	0.70	87.83	73.67
40	Sel 352 × Anugraha	46.33	61.33	6.40	7.83	0.95	4.51	84.36	380.17	52.33	61.27	1.19	**62.33**	93.67	0.69	88.83	71.33
41	Sel 352 × Surajmukhi	50.00	63.67	6.73	6.65	1.14	3.66	95.45	349.67	50.67	67.87	1.28	**63.67**	105.67	0.72	112.17	77.83
42	LCA 443 × Pant C 1	47.00	67.67	6.87	6.78	1.13	4.41	75.76	334.33	47.00	62.80	1.04	44.17	119.67	0.70	83.97	74.00
43	LCA 443 × Anugraha	48.67	67.00	6.60	8.63	1.10	4.54	71.44	324.58	47.00	53.53	1.33	53.00	99.00	0.59	91.50	61.50
44	LCA 443 × Surajmukhi	48.33	69.33	6.67	7.56	1.24	5.21	106.69	**555.83**	55.00	57.13	1.68	**66.67**	108.50	0.67	109.00	71.83
45	LCA 206 × Pant C 1	52.00	65.67	6.13	8.09	0.92	3.09	64.51	199.33	50.67	66.20	0.88	29.33	97.67	0.52	77.33	63.83
46	LCA 206 × Anugraha	49.33	66.00	6.33	9.53	0.75	1.70	287.57	**487.92**	52.67	68.47	1.25	48.00	106.00	0.69	81.17	63.67
47	LCA 206 × Surajmukhi	52.00	67.00	6.67	8.00	0.86	2.01	127.69	256.67	61.00	67.47	0.97	33.67	123.00	0.73	75.17	71.00
48	CH-1	51.00	64.00	4.87	6.90	1.25	4.88	70.65	344.75	52.33	55.73	1.75	51.17	107.83	0.79	92.50	81.00
	Mean	49.71	67.40	6.42	7.90	1.01	3.55	104.56	336.14	53.85	61.74	1.10	43.99	109.64	0.61	89.12	63.01
	CV (%)	3.73	2.15	6.01	3.02	3.25	0.72	5.53	5.34	1.69	5.36	9.03	7.69	1.89	2.95	2.00	2.99
	CD at P ≤ 0.05	3.01	2.35	0.63	0.39	0.05	0.04	9.38	29.14	1.47	5.37	0.16	5.49	3.36	0.03	2.90	3.06

Appendix-V Mean values of fourteen parents, thirty three F_1s and one check for the characters studied at Bajaura during 2010

S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283	50.33	79.00	5.00	8.05	1.09	3.33	92.80	309.33	51.00	70.41	0.72	29.17	92.83	0.50	71.50	49.33
2	Chilli Sonal	49.67	66.00	7.80	8.21	0.85	2.23	69.46	154.67	41.00	68.71	0.78	27.17	91.67	0.23	75.83	29.67
3	PAU Sel Long	59.33	80.33	6.47	6.38	0.95	3.40	46.47	158.00	54.33	67.21	1.28	29.33	112.33	0.46	82.83	51.33
4	Arka Lohit	48.67	66.00	7.00	7.28	1.20	4.94	49.35	243.93	52.67	60.67	0.63	22.33	111.67	0.51	70.83	69.33
5	LCA 436	58.67	72.67	6.47	9.42	1.30	6.25	31.14	194.73	53.00	70.42	1.83	31.83	100.33	0.52	79.67	59.50
6	Pusa Jwala	49.00	70.00	6.33	8.33	0.73	2.25	117.78	265.00	47.33	53.09	0.81	29.80	103.33	0.88	75.33	81.33
7	Pusa Sadabahar	66.00	84.00	5.80	4.85	0.90	3.52	45.16	158.80	59.33	66.95	0.60	24.00	98.67	0.79	91.50	74.67
8	Kashmir Long	40.67	65.00	5.60	6.91	0.99	5.07	60.76	307.87	52.33	69.48	0.68	29.70	102.67	0.33	96.67	52.67
9	Sel 352	50.33	71.00	7.00	6.25	1.14	4.27	66.64	284.33	54.00	72.55	1.64	27.50	106.50	0.42	73.67	47.33
10	LCA 443	65.67	83.00	4.67	6.32	1.50	5.24	56.33	295.33	50.33	58.01	2.05	26.33	111.67	0.40	72.83	45.83
11	LCA 206	58.00	82.00	7.40	8.29	0.90	2.03	82.73	167.67	51.33	76.25	0.91	23.17	101.33	0.51	76.33	61.33
12	Pant C 1	58.33	84.00	7.20	4.79	1.03	1.96	68.03	133.33	62.67	56.60	0.75	25.00	128.67	0.67	82.67	62.83
13	Anugraha	55.00	72.33	8.33	7.88	0.68	2.32	101.81	236.53	63.67	64.93	0.59	30.67	96.67	0.47	92.00	57.33
14	Surajmukhi	66.00	81.67	8.87	7.10	0.87	4.62	71.77	331.33	60.33	67.08	0.59	33.67	114.50	0.90	108.00	69.07
15	Jawahar Mirch 283 × Pant C 1	45.67	75.00	7.40	6.69	1.15	3.84	139.76	**537.13**	47.33	65.33	0.83	**64.33**	109.33	0.39	98.73	43.17
16	Jawahar Mirch 283 × Anugraha	45.33	73.33	8.13	8.85	1.16	3.19	146.05	**466.40**	52.33	79.85	0.68	**59.73**	99.17	0.43	109.00	51.33
17	Jawahar Mirch 283 × Surajmukhi	49.67	76.33	7.60	9.35	1.23	2.94	137.34	403.33	54.33	82.09	0.94	50.40	102.67	0.49	108.00	52.67
18	Chilli Sonal × Pant C 1	44.00	65.00	7.67	5.12	0.98	2.32	132.11	306.93	48.33	70.33	0.98	43.07	116.67	0.30	77.33	47.33
19	Chilli Sonal × Anugraha	43.33	66.00	8.67	6.13	0.90	3.16	97.41	307.80	43.00	73.98	0.83	37.83	117.00	0.33	76.67	39.67
20	Chilli Sonal × Surajmukhi	45.67	75.00	8.27	7.72	0.93	2.22	241.62	**535.60**	58.33	85.70	0.91	**67.00**	98.50	0.46	89.67	57.00
21	PAU Sel Long × Pant C 1	49.67	72.33	6.80	7.77	0.67	2.46	151.17	371.87	54.33	66.19	0.85	50.27	99.00	0.51	94.00	61.33
22	PAU Sel Long × Anugraha	49.33	74.67	7.67	8.37	0.78	2.69	165.79	446.53	58.33	71.31	0.90	49.00	119.33	0.57	96.67	64.83
23	PAU Sel Long × Surajmukhi	50.00	76.33	8.13	7.94	0.98	3.08	148.32	457.33	62.00	83.33	1.38	**60.10**	130.67	0.63	113.00	69.33
24	Arka Lohit × Pant C 1	50.67	77.67	8.20	6.65	0.82	3.42	102.08	349.47	54.67	69.05	1.53	50.50	119.00	0.73	97.33	74.33
25	Arka Lohit × Anugraha	49.67	71.67	5.93	6.34	1.14	6.95	55.13	383.00	60.00	71.95	1.38	53.43	121.83	0.71	87.83	83.17

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S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaici n content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
26	Arka Lohit × Surajmukhi	47.00	68.00	7.93	6.81	1.11	4.92	114.08	**561.67**	56.67	86.77	1.10	**62.50**	96.67	0.76	84.17	76.33
27	LCA 436 × Pant C 1	45.00	68.67	8.13	7.61	1.19	3.92	162.60	**637.93**	58.33	74.41	1.64	**72.10**	93.67	0.48	106.33	53.67
28	LCA 436 × Anugraha	44.67	68.67	7.00	7.78	0.95	3.60	134.92	**485.27**	62.33	67.16	1.40	54.70	99.17	0.37	101.67	39.50
29	LCA 436 × Surajmukhi	49.33	68.00	7.60	7.47	0.99	4.60	86.14	396.27	56.67	72.03	1.69	57.33	111.83	0.46	110.63	51.00
30	Pusa Jwala × Pant C 1	49.67	69.00	8.80	6.04	0.88	2.41	108.92	262.13	52.33	65.03	0.90	42.53	96.83	0.89	81.67	85.00
31	Pusa Jwala × Anugraha	46.67	65.67	8.47	6.94	0.88	2.53	114.03	288.87	49.33	60.95	1.01	35.47	113.83	0.73	96.33	74.67
32	Pusa Jwala × Surajmukhi	46.67	65.67	7.20	6.93	0.80	3.63	118.55	429.93	50.67	66.79	1.04	53.73	98.83	0.83	85.33	84.67
33	Pusa Sadabahar × Pant C 1	51.67	71.67	7.93	7.66	0.98	2.69	101.07	271.87	56.67	74.91	1.32	33.03	117.50	0.71	77.50	71.33
34	Pusa Sadabahar × Anugraha	49.33	76.67	7.87	4.56	0.87	2.42	101.62	246.27	62.33	66.29	0.66	47.50	121.83	0.66	80.67	77.17
35	Pusa Sadabahar × Surajmukhi	46.67	70.33	7.67	9.50	1.39	1.98	290.73	**574.67**	63.67	87.58	0.62	**59.57**	131.50	0.65	91.67	79.83
36	Kashmir Long × Pant C 1	42.33	65.67	4.87	8.61	0.94	3.91	90.59	354.20	46.00	70.01	1.36	54.10	114.33	0.85	105.67	74.00
37	Kashmir Long × Anugraha	42.67	64.00	5.33	11.74	0.85	3.13	115.48	361.47	47.67	74.43	0.75	46.50	127.00	0.50	81.33	57.17
38	Kashmir Long × Surajmukhi	42.67	68.00	7.53	8.35	0.89	3.72	98.93	368.33	52.33	67.07	0.66	43.27	127.33	0.61	88.00	63.50
39	Sel 352 × Pant C 1	50.00	71.67	7.67	5.53	1.13	3.93	106.51	418.93	50.67	79.45	1.06	**65.27**	103.00	0.69	86.00	69.33
40	Sel 352 × Anugraha	45.33	65.00	7.27	6.98	0.98	4.71	95.21	**448.73**	52.33	75.57	1.22	54.33	92.67	0.67	85.40	65.33
41	Sel 352 × Surajmukhi	50.00	67.33	7.60	6.07	0.95	3.66	120.40	441.07	52.33	85.53	1.43	**62.83**	104.33	0.79	105.00	75.67
42	LCA 443 × Pant C 1	47.33	72.33	7.17	7.11	1.12	4.26	104.93	**447.33**	48.33	85.53	1.11	46.17	122.33	0.66	83.83	72.00
43	LCA 443 × Anugraha	50.00	70.67	7.87	8.57	1.07	4.48	88.31	395.93	47.33	80.25	1.34	51.17	103.33	0.63	89.33	57.00
44	LCA 443 × Surajmukhi	45.67	71.67	7.37	7.98	1.19	4.93	110.11	**543.20**	54.00	79.57	1.35	**68.00**	112.33	0.63	113.33	69.67
45	LCA 206 × Pant C 1	58.67	75.00	6.93	8.19	0.88	2.80	85.70	239.67	50.67	75.28	0.89	31.97	92.50	0.59	83.83	59.67
46	LCA 206 × Anugraha	49.67	70.33	7.47	10.64	0.86	1.79	161.38	288.33	52.00	70.35	1.18	35.77	107.67	0.67	83.83	70.67
47	LCA 206 × Surajmukhi	59.67	73.00	7.73	7.15	0.79	2.34	144.3243	338.20	58.67	80.93	1.05	44.40	119.33	0.71	79.33	70.67
48	CH-1	48.33	70.33	6.80	6.22	1.32	5.02	68.70	344.87	52.00	63.33	1.67	48.37	114.33	0.78	84.33	84.33
	Mean	50.16	72.03	7.26	7.40	1.00	3.52	108.34	353.15	53.74	71.89	1.07	44.71	108.92	0.60	89.23	63.29
	CV (%)	2.27	2.03	4.86	2.76	3.80	1.23	6.28	5.61	1.55	4.93	6.74	4.45	2.25	2.55	2.26	2.36
	CD at P ≤ 0.05	1.85	2.37	0.57	0.33	0.06	0.07	11.03	32.14	1.35	5.76	0.12	3.23	3.98	0.02	3.27	2.43

Appendix-VI Mean values of fourteen parents, thirty three F_1s and one check for the characters studied at Bajaura during 2011

S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283	50.33	77.33	5.20	7.91	1.01	3.37	66.67	224.67	52.67	72.21	0.73	32.83	91.67	0.53	75.67	52.33
2	Chilli Sonal	46.00	64.33	7.07	7.46	0.85	1.99	83.08	165.33	43.00	70.09	0.78	28.67	96.83	0.30	71.67	34.00
3	PAU Sel Long	50.00	79.00	6.20	6.22	0.96	3.40	60.75	206.33	51.00	69.76	1.04	26.50	108.67	0.48	77.67	54.33
4	Arka Lohit	45.67	65.00	6.07	5.77	1.21	5.16	36.50	188.33	54.00	67.30	0.72	19.83	115.17	0.50	72.50	68.33
5	LCA 436	50.67	74.33	5.60	9.43	1.24	6.21	38.25	237.67	53.00	75.09	1.89	34.17	95.67	0.49	77.33	64.00
6	Pusa Jwala	50.67	73.00	6.07	8.19	0.82	2.30	102.76	236.00	47.67	55.72	0.88	35.33	96.67	0.81	79.33	79.33
7	Pusa Sadabahar	59.00	79.00	4.47	5.03	0.88	3.59	47.50	170.67	61.00	66.52	0.73	27.33	102.83	0.82	90.33	79.33
8	Kashmir Long	40.67	64.67	5.47	7.79	0.93	5.13	39.51	202.67	52.33	74.69	0.69	28.00	107.67	0.32	85.67	52.17
9	Sel 352	51.67	73.00	6.67	7.12	1.07	4.13	46.41	191.67	52.67	74.09	1.60	23.00	99.50	0.51	77.33	51.67
10	LCA 443	57.00	81.00	5.93	6.30	1.39	5.30	51.01	270.33	55.00	62.00	2.03	33.67	104.67	0.48	75.00	53.67
11	LCA 206	50.67	79.00	6.47	8.25	0.99	2.12	79.12	168.00	51.33	73.87	1.03	24.83	106.50	0.57	75.83	63.67
12	Pant C 1	52.17	82.00	6.20	5.03	1.05	2.09	87.38	182.33	62.00	54.87	0.76	27.00	121.67	0.62	78.83	62.00
13	Anugraha	45.33	68.00	6.87	7.93	0.71	2.52	101.19	255.33	65.00	64.60	0.62	34.00	97.00	0.50	86.00	59.17
14	Surajmukhi	63.67	80.67	7.40	7.12	0.93	4.68	52.25	244.33	63.33	56.07	0.66	34.33	111.83	0.86	104.00	66.83
15	Jawahar Mirch 283 × Pant C 1	40.00	69.00	6.13	6.87	1.15	4.08	97.79	398.67	47.33	77.90	0.88	**52.67**	104.67	0.37	102.67	50.67
16	Jawahar Mirch 283 × Anugraha	41.00	64.00	6.87	8.41	1.19	3.18	129.21	**411.33**	50.33	81.19	0.77	**51.83**	94.83	0.41	103.50	58.33
17	Jawahar Mirch 283 × Surajmukhi	40.33	76.67	6.73	8.77	1.17	3.07	105.87	324.67	54.33	87.15	0.98	49.50	96.83	0.56	105.00	49.83
18	Chilli Sonal × Pant C 1	40.00	62.00	7.20	5.18	1.01	2.42	117.88	285.67	48.00	74.96	0.93	31.83	117.33	0.37	77.33	46.17
19	Chilli Sonal × Anugraha	43.67	66.33	7.00	6.15	0.88	3.35	73.06	245.00	43.00	80.99	0.91	33.83	111.67	0.39	73.83	45.67
20	Chilli Sonal × Surajmukhi	40.33	74.33	6.27	7.58	0.93	2.19	236.28	**516.67**	59.33	85.91	0.97	**57.83**	99.67	0.49	85.33	59.33
21	PAU Sel Long × Pant C 1	41.00	71.00	6.73	7.28	0.73	2.51	146.81	368.00	53.00	71.82	0.84	44.50	107.17	0.48	91.67	67.67
22	PAU Sel Long × Anugraha	44.33	73.33	5.73	8.11	0.83	2.98	137.58	**410.00**	56.67	66.28	0.94	51.17	114.83	0.60	91.83	69.33
23	PAU Sel Long × Surajmukhi	39.33	68.67	6.93	7.98	0.93	3.23	155.31	**501.67**	60.67	87.20	1.36	**58.67**	127.67	0.69	108.00	66.67
24	Arka Lohit × Pant C 1	39.00	70.67	6.60	6.47	0.89	3.52	101.04	355.33	57.00	66.69	1.59	43.67	118.33	0.71	100.00	69.67
25	Arka Lohit × Anugraha	43.33	71.00	5.40	6.27	1.10	7.04	47.09	331.33	61.00	76.59	1.31	45.33	116.83	0.69	89.67	86.67

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S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
26	Arka Lohit × Surajmukhi	42.33	72.00	7.07	7.25	1.10	4.98	89.42	**445.33**	58.00	89.39	1.04	**53.83**	97.83	0.78	86.83	71.33
27	LCA 436 × Pant C 1	41.33	67.33	6.13	7.53	1.20	3.91	149.83	**585.33**	61.00	76.33	1.25	**69.67**	100.17	0.53	103.33	57.00
28	LCA 436 × Anugraha	41.33	65.00	6.60	7.68	0.94	3.72	134.59	**500.67**	62.33	68.79	1.38	**58.30**	98.17	0.42	96.00	42.67
29	LCA 436 × Surajmukhi	43.00	63.67	6.47	7.69	0.88	4.72	82.00	387.33	58.33	78.82	1.78	**53.83**	117.67	0.43	108.50	57.00
30	Pusa Jwala × Pant C 1	41.67	65.00	6.67	6.14	0.92	2.56	99.09	253.33	51.33	51.49	0.92	32.17	93.50	0.91	78.83	85.33
31	Pusa Jwala × Anugraha	41.00	61.67	5.93	6.85	0.85	2.99	99.55	297.67	52.33	62.82	1.05	37.83	113.83	0.79	99.67	79.67
32	Pusa Jwala × Surajmukhi	39.00	62.67	5.20	7.03	0.71	3.76	88.48	332.67	50.33	70.83	1.13	38.67	104.00	0.82	80.33	87.17
33	Pusa Sadabahar × Pant C 1	46.00	65.00	6.40	7.43	0.92	2.86	93.93	268.33	60.33	79.61	1.39	34.33	116.33	0.73	77.33	69.50
34	Pusa Sadabahar × Anugraha	40.00	75.00	6.67	5.21	0.89	2.55	118.02	301.33	64.67	68.57	0.74	31.83	126.33	0.66	77.83	78.33
35	Pusa Sadabahar × Surajmukhi	39.67	64.67	7.40	8.43	1.01	2.07	196.45	**406.00**	65.00	81.71	0.68	41.83	128.17	0.67	87.17	81.33
36	Kashmir Long × Pant C 1	37.00	57.33	4.07	7.87	0.92	4.17	101.92	**424.67**	47.33	75.63	1.21	**56.83**	118.00	0.83	101.83	77.17
37	Kashmir Long × Anugraha	38.00	57.00	5.00	10.81	0.85	3.19	98.12	313.00	49.33	76.98	0.79	42.17	131.83	0.52	84.67	60.00
38	Kashmir Long × Surajmukhi	40.00	64.00	6.93	8.48	1.00	3.86	84.97	328.00	51.67	71.01	0.67	41.00	120.00	0.65	85.00	61.83
39	Sel 352 × Pant C 1	50.33	69.33	7.07	5.29	1.12	4.07	96.97	395.00	51.00	82.20	1.09	50.00	101.00	0.71	85.83	72.33
40	Sel 352 × Anugraha	41.33	58.33	6.20	6.82	0.95	4.84	77.33	374.00	53.67	71.15	1.17	45.33	97.67	0.72	87.33	67.33
41	Sel 352 × Surajmukhi	45.00	63.00	6.27	6.25	0.91	3.83	109.76	**420.00**	50.33	95.63	1.27	**51.83**	108.50	0.80	109.67	71.50
42	LCA 443 × Pant C 1	40.00	66.33	6.00	7.96	1.23	4.35	89.20	388.33	47.33	84.07	1.06	49.33	122.67	0.65	87.67	74.83
43	LCA 443 × Anugraha	50.00	69.00	7.07	9.59	1.11	4.65	79.08	368.00	47.33	80.86	1.22	**51.83**	107.67	0.64	90.83	65.33
44	LCA 443 × Surajmukhi	45.00	70.33	6.53	7.55	1.22	5.14	77.82	400.00	57.00	83.33	1.28	42.50	115.00	0.67	103.83	76.33
45	LCA 206 × Pant C 1	51.33	69.00	5.93	7.73	0.91	3.05	90.83	277.33	51.00	65.26	1.15	31.17	88.67	0.63	79.67	54.83
46	LCA 206 × Anugraha	40.00	67.33	6.47	10.69	0.92	2.07	109.65	227.33	54.00	72.93	1.14	33.50	106.50	0.66	81.67	67.67
47	LCA 206 × Surajmukhi	51.33	65.67	6.20	6.55	0.84	2.15	136.02	292.00	62.00	84.71	1.11	43.00	118.67	0.76	78.00	74.00
48	CH-1	43.00	63.67	6.27	6.52	1.15	4.95	64.20	318.00	51.67	65.81	1.69	39.33	111.67	0.78	89.50	83.33
	Mean	44.86	68.95	6.29	7.33	0.99	3.62	96.00	320.74	54.42	73.57	1.08	40.84	108.54	0.61	87.86	65.14
	CV (%)	2.40	1.70	7.50	2.88	3.63	1.48	5.55	5.43	1.49	2.18	7.81	7.48	2.37	3.01	1.84	2.93
	CD at P ≤ 0.05	1.75	1.90	0.76	0.34	0.06	0.09	8.65	28.27	1.31	2.60	0.14	4.96	4.18	0.03	2.63	3.10

Appendix VII Mean values of fourteen parents, thirty three F_1s and one check for the characters studied at pooled over environments

S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283	51.67	73.67	5.90	8.31	1.00	3.27	80.87	264.58	51.17	65.79	0.73	28.88	94.38	0.50	74.83	54.17
2	Chilli Sonal	47.58	64.17	6.63	7.41	0.91	2.21	91.10	199.50	41.42	64.82	0.78	30.38	93.38	0.28	75.50	30.63
3	PAU Sel Long	53.67	75.67	6.50	7.27	0.94	3.43	65.04	223.00	52.17	64.29	1.28	31.53	106.96	0.50	79.70	53.33
4	Arka Lohit	49.50	66.00	6.58	7.95	1.28	5.06	52.59	265.82	52.67	64.32	0.67	21.29	117.29	0.52	70.92	65.86
5	LCA 436	53.58	71.25	6.37	8.76	1.33	6.32	38.76	245.45	53.08	70.95	1.99	33.54	100.88	0.52	77.06	54.53
6	Pusa Jwala	48.42	70.00	6.10	9.12	0.82	2.34	112.09	261.75	47.00	54.30	0.85	33.10	104.46	0.87	78.05	82.00
7	Pusa Sadabahar	60.92	81.83	6.06	5.29	0.97	3.60	51.55	185.92	60.67	60.08	0.67	26.83	104.38	0.82	94.42	76.63
8	Kashmir Long	42.25	63.25	5.70	8.64	1.13	5.15	53.16	274.11	52.08	67.38	0.68	31.18	108.08	0.35	92.04	53.25
9	Sel 352	51.25	70.50	6.40	6.23	1.21	4.22	54.57	230.58	53.25	67.84	1.63	24.92	101.55	0.45	75.17	51.25
10	LCA 443	61.00	80.42	5.58	7.08	1.44	5.09	56.04	282.13	52.58	61.65	2.25	28.93	106.92	0.45	74.37	49.71
11	LCA 206	54.83	80.92	6.50	8.48	0.84	2.03	88.52	179.41	51.83	76.63	0.92	23.63	100.50	0.54	73.90	59.01
12	Pant C 1	59.63	82.67	6.18	5.13	1.03	2.07	88.30	183.17	62.58	55.23	0.77	27.83	129.13	0.64	78.18	61.38
13	Anugraha	50.75	68.50	7.67	8.12	0.74	2.32	104.26	241.59	63.42	61.30	0.64	30.18	102.54	0.48	88.67	61.75
14	Surajmukhi	61.88	79.83	7.95	6.52	0.97	4.57	62.21	284.32	62.33	65.45	0.65	33.13	112.04	0.89	101.46	65.81
15	Jawahar Mirch 283 × Pant C 1	45.42	70.83	6.68	7.10	1.09	3.79	119.05	**450.26**	47.00	63.32	0.83	**57.88**	110.63	0.38	101.10	44.00
16	Jawahar Mirch 283 × Anugraha	46.17	67.92	7.47	8.66	1.07	3.09	176.85	**543.35**	51.42	80.23	0.72	**62.05**	97.88	0.43	111.46	50.67
17	Jawahar Mirch 283 × Surajmukhi	46.67	73.00	6.85	8.58	1.09	2.91	153.49	**443.73**	54.67	81.01	1.01	54.39	103.13	0.53	106.97	50.92
18	Chilli Sonal × Pant C 1	43.50	63.00	7.00	6.22	0.99	2.39	112.55	268.64	47.67	67.52	1.08	34.93	115.96	0.31	76.68	44.21
19	Chilli Sonal × Anugraha	44.75	64.67	7.22	6.76	0.94	3.16	94.04	296.49	42.33	71.09	0.81	32.00	113.04	0.34	75.53	35.92
20	Chilli Sonal × Surajmukhi	43.50	75.58	6.85	7.65	0.89	2.31	206.18	**472.82**	58.50	77.95	1.04	**57.76**	99.63	0.46	94.79	54.96
21	PAU Sel Long × Pant C 1	47.42	72.08	6.47	7.98	0.84	2.50	152.80	381.82	53.17	67.62	0.85	48.13	104.29	0.49	92.48	63.71
22	PAU Sel Long × Anugraha	48.17	74.33	6.88	7.71	0.83	2.69	151.07	406.38	57.50	65.03	0.93	48.88	116.75	0.58	94.54	63.58
23	PAU Sel Long × Surajmukhi	46.17	73.33	7.02	8.16	0.94	3.08	170.57	**524.04**	61.42	77.22	1.40	**63.28**	129.63	0.64	110.29	67.79
24	Arka Lohit × Pant C 1	47.92	73.83	6.97	7.30	0.87	3.44	114.29	392.62	55.75	65.79	1.59	50.83	119.02	0.69	99.92	72.38
25	Arka Lohit × Anugraha	47.92	72.08	6.17	7.44	1.04	6.91	57.71	399.38	60.08	69.24	1.24	**56.36**	122.08	0.70	90.75	81.96

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S. No.	Traits/ Genotypes	Days to 50% flowering	Days to first harvest	Primary branches / plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Harvest duration (days)	Plant height (cm)	Average dry fruit weight (g)	Dry fruit yield/ plant (g)	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
26	Arka Lohit × Surajmukhi	46.42	66.58	7.48	7.35	1.04	5.08	102.65	**520.96**	56.67	71.44	1.07	**64.37**	95.83	0.76	87.72	73.42
27	LCA 436 × Pant C 1	43.92	67.50	6.58	7.78	1.16	4.02	153.15	**615.23**	59.67	70.74	1.49	**70.59**	95.79	0.49	104.33	56.29
28	LCA 436 × Anugraha	43.92	66.42	6.62	9.19	0.97	3.58	150.32	**536.98**	62.25	67.57	1.31	**58.87**	103.42	0.40	101.72	37.96
29	LCA 436 × Surajmukhi	47.67	66.83	7.20	8.11	1.05	4.49	96.03	430.67	56.75	70.35	1.71	54.38	114.88	0.46	107.58	52.42
30	Pusa Jwala × Pant C 1	46.33	64.83	6.80	7.16	0.94	2.38	129.43	305.16	51.58	54.96	1.00	38.89	95.08	0.87	80.10	84.96
31	Pusa Jwala × Anugraha	45.33	63.00	7.27	8.22	0.84	2.71	130.28	351.01	50.92	57.34	1.01	44.04	112.50	0.77	95.25	77.96
32	Pusa Jwala × Surajmukhi	44.83	62.33	6.70	8.14	0.78	3.75	123.63	**464.19**	50.50	65.32	1.01	55.07	100.88	0.84	86.83	82.67
33	Pusa Sadabahar × Pant C 1	50.50	71.92	7.05	7.22	0.86	2.82	87.99	247.45	57.67	68.83	1.35	31.18	117.38	0.71	75.96	71.75
34	Pusa Sadabahar × Anugraha	49.17	77.83	7.50	5.99	0.86	2.55	103.59	264.44	62.83	66.71	0.66	33.87	124.33	0.70	76.73	77.83
35	Pusa Sadabahar × Surajmukhi	47.00	71.75	7.43	7.91	1.06	2.10	209.20	433.58	64.08	77.07	0.65	49.43	128.92	0.66	87.19	79.77
36	Kashmir Long × Pant C 1	41.58	59.75	5.35	8.02	1.00	3.92	97.36	381.86	46.42	64.93	1.28	52.23	119.38	0.83	103.63	77.88
37	Kashmir Long × Anugraha	42.00	59.67	5.27	9.76	0.93	3.18	111.62	354.70	47.75	69.04	0.74	44.33	130.46	0.51	84.08	55.67
38	Kashmir Long × Surajmukhi	42.67	62.42	6.68	8.34	0.96	4.19	104.24	440.63	51.33	65.86	0.67	52.35	123.96	0.62	85.01	63.21
39	Sel 352 × Pant C 1	50.92	72.67	6.48	6.08	1.12	4.16	93.56	385.71	50.33	71.41	1.05	52.65	99.71	0.69	86.17	70.21
40	Sel 352 × Anugraha	44.50	61.75	6.48	7.30	0.96	4.66	86.95	404.98	52.50	66.28	1.20	53.88	93.83	0.69	87.06	67.75
41	Sel 352 × Surajmukhi	48.83	65.75	6.87	6.41	1.02	3.72	115.92	431.10	50.92	80.42	1.33	**58.27**	104.79	0.76	109.17	74.92
42	LCA 443 × Pant C 1	44.92	70.17	6.71	7.36	1.19	4.38	89.87	393.17	47.58	75.97	1.06	44.61	120.25	0.67	83.63	72.58
43	LCA 443 × Anugraha	49.08	70.42	7.05	8.83	1.09	4.57	87.62	400.88	47.08	70.78	1.29	52.43	103.13	0.61	89.88	60.46
44	LCA 443 × Surajmukhi	46.08	71.50	6.81	7.58	1.23	5.10	103.89	**529.68**	55.00	75.48	1.48	**60.54**	111.13	0.65	110.67	71.13
45	LCA 206 × Pant C 1	53.83	71.42	6.28	7.95	0.92	2.96	77.48	229.25	50.33	68.15	0.94	30.71	93.42	0.57	79.89	60.04
46	LCA 206 × Anugraha	46.58	69.00	6.72	10.14	0.84	1.81	173.48	307.40	52.42	70.47	1.16	37.97	107.83	0.68	81.42	67.54
47	LCA 206 × Surajmukhi	55.50	70.17	6.93	7.28	0.83	2.14	130.74	281.08	59.92	77.38	1.03	39.45	121.96	0.73	77.25	71.75
48	CH-1	48.08	66.75	5.85	6.58	1.24	4.97	73.47	365.40	51.75	60.18	1.71	47.93	110.17	0.79	88.88	83.46
	Mean	48.63	70.00	6.66	7.64	1.00	3.57	107.09	353.67	53.79	68.18	1.09	43.75	109.24	0.60	88.73	63.35
	CV (%)	2.63	1.90	6.58	3.34	3.58	1.40	5.44	5.16	1.55	4.37	8.32	6.61	2.00	2.80	1.96	2.63
	CD at P ≤ 0.05	2.08	2.16	0.71	0.41	0.06	0.08	9.44	29.56	1.35	4.83	0.15	4.69	3.55	0.03	2.82	2.70

Brief Biodata of student

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Academic Qualifications:

Qualification	Year	School/ Board/ University	Marks (%)/ OCPA	Division	Major Subjects
10^{th}	1998	Jawahar Navodaya Vidyalaya, C.B.S.E. New Delhi	63.80	First	Maths, Science, Social Science, English, Hindi
10+2	2000	Jawahar Navodaya Vidyalaya, C.B.S.E. New Delhi	59.40	First	Physics, Chemistry, Biology, English, Hindi
B.Sc. (Horticulture)	2006	Dr. Y.S. Parmar, UHF, Nauni, Solan	7.41	First	All Horticulture and allied subjects with Vegetable Science as elective
M.Sc. Horticulture (Vegetable Science)	2008	Dr. Y.S. Parmar, UHF, Nauni, Solan	8.21	First	Major: Vegetable Breeding Minor: Plant Breeding and Genetics, Plant Pathology
Ph.D. Agriculture (Vegetable Science)	2012	CSK HPKV, Palampur	7.72	First	Major: Vegetable Breeding Minor: Plant Breeding and Genetics, Plant Pathology Supporting: Biotechnology

Title of thesis in M.Sc.
"Genetic assessment of some newly introduced tomato genotypes"

Fellowships/Scholarships/Gold Medals/Awards/Any Other Distinction:
Senior Research Fellowship
University Merit Scholarship
Certificate of Honour in M.Sc.

- **Qualified National Eligibility Test**
- **Selected in HPHS (Himachal Pradesh Horticulture Services)**