The Bioscan 11(3):1963-1968,2016(Supplement on Genetics and Plant Breeding) www.thebioscan.com
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES

GENETIC COMBINING ABILITY, GENE ACTION AND HETEROSIS FOR BIOCHEMICAL AND ANTIOXIDANT CONTENT IN CHILLI PEPPER

MUNISH SHARMA[1]*, AKHILESH SHARMA[2] AND P. MUTHUKUMAR[3]
[1]Krishi Vigyan Kendra Mohali, [2]Department of Vegetable Science and Floriculture,
CSK Himachal Pradesh Agricultural University, Palampur-176062, INDIA
[3]Division of Vegetable Science,
IARI, CSK Himachal Pradesh Agricultural University, Palampur - 176 062, INDIA
e-mail: munish_uhf@yahoo.co.in

KEYWORDS
Chilli pepper
Additive
Dominance
Heterobeltiosis
Heterosis
Combining ability

Received on :
16.07.2016

Accepted on :
22.09.2016

***Corresponding author**

ABSTRACT
A study was conducted on chilli pepper to gather information on combining ability, gene action and heterosis for quality traits *viz* ascorbic acid, capsaicin, capsanthin and oleoresin. 33 F_1 were developed by following line × tester mating design comprising 11 lines and 3 testers and were evaluated in randomized block design with three replication at four environments. The results showed Arka Lohit and LCA 443 to be good general combiner for all four quality traits *viz*., ascorbic acid, capsaicin content, capsanthin and oleoresin. The magnitude of dominance variance ($ó_D^2$) was higher than additive variance ($ó_A^2$) for majority of the traits over the locations and pooled environments which indicated the involvement of non-additive gene action. The promising cross combinations LCA 443 × Pant C1, LCA 443 × Surajmukhi, Arka Lohit × Anugraha, PAU Sel Long × Surajmukhi, Kashmir Long × Pant C1 and Sel 352 × Surajmukhi were found superior for quality traits based on SCA. Maximum heterosis over Standard check was found in crosses Kashmir Long x Anugraha (18.42 %) check for ascorbic acid; Pusa Jwala × Pant C1 (10.97 %) for capsaicin; Jawahar Mirch 283 ×Anugraha (25.41%) for capsanthin and Kashmir Long × Pant C1 (26.89 %) over better parent for oleoresin. Therefore, it may be possible to take advantage of such heterotic effects to be fixed in the later generations to facilitate further selection.

INTRODUCTION

Chilli pepper (*Capsicum annuum* var. *annuum* L.) is one of the major spice crop of India. Immature fruits are the most important vegetable cum spice because of its colour, taste, pungency, flavour and aroma. Pepper is increasingly recognized as a rich source of health-related metabolites, such as ascorbic acid (vitamin C), carotenoids, flavonoids and capsaicinoids (Howard and Wildman, 2007). The important quality trait is pungency, which is caused by the presence of a group of alkaloids known as capsaicinoids. (Daood *et al.,* 2002). Capsanthin imparts colour to chilli. 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. India has immense potential to export different types of chillies around the world. The predominant breeding method of pepper in the country is limited to developing pure lines of homozygous and homogeneous genotypes having a low yield. Therefore, there is the need to create better varieties with higher yield and with export quality to satisfy a growing demand in food industry (Gueddes *et al.,* 2015). 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). With these points in view, heterosis and combining ability studies are prerequisite in any plant breeding programme, which provides the desired information regarding the varietal improvement or exploiting heterosis for commercial purposes (Singh *et al.,* 2013). The studies of heterosis in Chilli have also been reported by Satish and Lad (2007), Prasath and Ponnuswami (2008), Reddy *et al*. (2008), Patel *et al*. (2010), Chaudhary *et al*. (2014), Khalia and Hatem (2014), Kumar *et al*. (2014), Spaldon *et al*. (2015) and Patel *et al*. (2015).Therefore, the present investigation was undertaken to identify the potential combinations in order to have superior hybrids of excellent qualities and nature of gene action for various characters in chilli pepper.

MATERIALS AND METHODS

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. The present investigation was carried out at the Experimental Farm, 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 summer season of 2010 and 2011. All the lines used as female parents were crossed to each of the testers by hand pollination using line × tester model. Standard package of practices were followed to raise the crop. The observations were recorded on quality traits *viz*., ascorbic acid (mg/100g), capsaicin content (%), capsanthin (ASTA units) and oleoresin (ASTA units). Ascorbic acid content in chilli was estimated by '2,6-dichlorophenol-indophenol Visual Titration Method' as described by Ranganna (1979).

$$\text{Ascorbicacid(mg/100g)} = \frac{\text{Titre x Dye factor x Volume made up}}{\text{Aliquot of extract taken for estimatio x Weiht of sample taken for estimation}} \times 100$$

The capsaicin content in the fruits was determined by calorimetric method using Folin-Ciocalteau reagent described by Bajaj (1980).

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

Capsanthin was determined as per procedure given by A.O.A.C. (1980). ASTA colour value for capsicum = [(A_{ext} at 465 nm) × (16.4 I_f)]/g sample ASTA.

Oleoresin was determined as per procedure given by A.O.A.C. (1980). Colour value for oleoresin = [(A_{ext} at 460 nm) × (164 I_f)]/g sample

Where,

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

For working out the analysis of variance, the data were analysed by using model as suggested by Panse and Sukhatme (1967). The estimates of heterosis were calculated as the deviation of F_1 mean from the better parent (BP) and standard check [CH-1 (SC)].

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

Heterosis over standard check (%) =

$[(\overline{F}_1 - \overline{SC}_1)/\overline{SC}_1] \times 100$

RESULTS AND DISCUSSION

Analysis of variance for combining ability for various quality traits in chilli pepper pooled over environments is given in Table 1. The general combining ability effects for ascorbic acid (mg/100g) content of lines is shown in Table 2.Significant positive general combining ability (GCA) effects were high in PAU Selection Long, Pusa Sadabahar and Kashmir Long. Good general combiner lines for ascorbic acid content have also been observed by Khalil and Hatem (2014).For capsaicin content (%) the significant positive GCA effects were observed in Arka Lohit, Pusa Jwala, Pusa Sadabahar, Kashmir Long, Selection 352, LCA 443 and LCA 206 thereby depicted as good general combiners for capsaicin content (Table 2). However for capsanthin (ASTA units), 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. For oleoresin, the significant positive GCA effects were observed for lines Arka Lohit, Pusa Jwala, Pusa Sadabahar, 'Selection 352, LCA 443 and LCA 206 (Table 2). Good general combiner lines for capsaicin content,

Table 1: Analysis of variance for combining ability for various quality traits in chilli pepper pooled over environments

Source of variationdf	Locations 3	Replica-tions8	Lines10	Testers2	Line vs Testers20	Line × Location30	Tester × Location 6	Line vs Tester × Location60	Error256
Traits									
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

Table 2: Estimates of general combining ability (GCA) effects of lines for quality traits in chilli pooled over environments

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 %
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

Table 3: Estimates of GCA effects of testers for quality traits pooled over environments in chilli

Traits/Testers	Pant C 1	Anugraha	Surajmukhi	SE (gj) ±	SE (gi-gj)	CD 5 %
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

Table 4: Estimates of specific combining ability (SCA) effects pooled over environments for quality traits in chilli

S. No.	Traits/ Crosses	Ascorbic acid (mg/ 100g)	Capsaicin content (%)	Capsanthin (ASTA units)	Oleoresin (ASTA units)
1	Jawahar Mirch 283 × Pant C 1	9.12*	-0.06*	-2.86*	-5.01*
2	Jawahar Mirch 283 × Anugraha	-6.75*	0.02*	7.09*	5.36*
3	Jawahar Mirch 283 × Surajmukhi	-2.36*	0.05*	-4.23*	-0.36
4	Chilli Sonal × Pant C 1	8.79*	-0.06*	-3.11*	-1.30*
5	Chilli Sonal × Anugraha	2.75*	0.000	-4.67*	-5.89*
6	Chilli Sonal × Surajmukhi	-11.53*	0.06*	7.78*	7.19*
7	PAU Sel Long × Pant C 1	-10.23*	-0.07*	-4.08*	-1.80*
8	PAU Sel Long × Anugraha	-0.89*	0.04*	-2.42*	1.78*
9	PAU Sel Long × Surajmukhi	11.12*	0.03*	6.50*	0.02
10	Arka Lohit × Pant C 1	9.07*	-0.02*	9.67*	-4.02*
11	Arka Lohit × Anugraha	9.02*	0.02*	0.09	9.26*
12	Arka Lohit × Surajmukhi	-18.09*	0.01*	-9.76*	-5.24*
13	LCA 436 × Pant C 1	-6.53*	0.04*	2.34*	6.92*
14	LCA 436 × Anugraha	-2.03*	-0.02*	-0.69*	-7.71*
15	LCA 436 × Surajmukhi	8.57*	-0.02*	-1.65*	0.78*
16	Pusa Jwala × Pant C 1	-5.37*	0.05*	-4.74*	2.62*
17	Pusa Jwala × Anugraha	8.93*	-0.03*	10.00*	-0.68*
18	Pusa Jwala × Surajmukhi	-3.56*	-0.02*	-5.25*	-1.94*
19	Pusa Sadabahar × Pant C 1	-3.80*	0.02*	-1.45*	-5.18*
20	Pusa Sadabahar × Anugraha	0.04	0.04*	-1.10*	4.61*
21	Pusa Sadabahar × Surajmukhi	3.76*	-0.06*	2.55*	0.57
22	Kashmir Long × Pant C 1	-2.85*	0.18*	15.27*	11.82*
23	Kashmir Long × Anugraha	5.11*	-0.11*	-4.69*	-6.70*
24	Kashmir Long × Surajmukhi	-2.25*	-0.06*	-10.58*	-5.12*
25	Sel 352 × Pant C 1	2.63*	-0.02*	-5.41*	-1.23*
26	Sel 352 × Anugraha	-6.37*	0.01*	-4.94*	0.01
27	Sel 352 × Surajmukhi	3.73*	0.01*	10.35*	1.21*
28	LCA 443 × Pant C 1	11.12*	0.03*	-8.55*	4.05*
29	LCA 443 × Anugraha	-9.13*	0.000	-2.71*	-4.3*
30	LCA 443 × Surajmukhi	-1.99*	-0.03*	11.26*	0.32
31	LCA 206 × Pant C 1	-11.95*	-0.08*	2.92*	-6.88*
32	LCA 206 × Anugraha	-0.66	0.05*	4.03*	4.32*
33	LCA 206 × Surajmukhi	12.61*	0.04*	-6.96*	2.56*
	SE (Sij) ±	0.43	0.000	0.33	0.33
	SE (Sij-Skl) ±	0.60	0.000	0.47	0.47
	CD 5 %	0.86	0.00	0.66	0.66

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. Among the testers, Surajmukhi was observed to be good general combiner for ascorbic acid, capsaicin content, capsanthin and oleoresin over the environments (Table 3). For quality traits, Arka Lohit and LCA 443 observed to be good general combiner for all four traits.

In contrast to GCA effects, SCA effects represent the dominance and epistasis components of genetic variation which are non-fixable and associated 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. For ascorbic acid (mg/100g) content significant positive SCA effects, were observed in LCA 206 × Surajmukhi, LCA 443 × Pant C1, PAU Sel Long × Surajmukhi, Jawahar Mirch 283 × PC-1, Arka Lohit × PC 1 and Arka Lohit × Anugraha (Table 4). However for capsaicin content (%) eight crosses out of fourteen cross combinations namely Kashmir Long × Pant C1, Chilli Sonal × Surajmukhi, Jawahar Mirch 283 × Surajmukhi, PAU Selection Long × Anugraha, LCA 436 × Pant C1, Pusa Sadabahar × Anugraha, LCA 206 × Surajmukhi and PAU Selection Long × Surajmukhi were the

Table 5: Genetic component of variance for various quality traits in chilli pepper

Genetic Components/ Traits	σ_{GCA}^2 (Average)	σ_{GCA}^2lines × env	σ_{GCA}^2 tester × env	σ_{SCA}^2	σ_{SCA}^2 × env	σ_A^2	σ_D^2	Heritability % (Narrow sense)	Genetic advance	% contribution of		
										Lines	Testers	Interaction
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

Table 6: Estimates of heterosis (%) for various quality traits over better parent (BP) and standard check (SC) in chilli pooled over environments

Sr No	Hybrids	ascorbic acid (mg/100g) % increase/ decrease over		capsaicin content (%)		capsanthin (ASTA units)		oleoresin (ASTA units)	
		BP	SC	BP	SC	BP	SC	BP	SC
1	Jawahar Mirch 283 × Pant C 1	-14.33*	0.41	-40.10*	-51.48*	29.33*	13.76*	-28.31*	-47.28*
2	Jawahar Mirch 283 × Anugraha	-4.55*	-11.16*	-12.75*	-45.15*	25.71*	25.41*	-17.95*	-39.29*
3	Jawahar Mirch 283 × Surajmukhi	-7.96*	-6.39*	-40.45*	-32.91*	5.43*	20.35*	-22.63*	-38.99*
4	Chilli Sonal × Pant C 1	-10.20*	5.26*	-51.04*	-60.34*	-1.92*	-13.73*	-27.96*	-47.02*
5	Chilli Sonal × Anugraha	10.24*	2.61*	-29.66*	-56.96*	-14.82*	-15.02*	-41.84*	-56.97*
6	Chilli Sonal × Surajmukhi	-11.08*	-9.57*	-47.94*	-41.35*	-6.57*	6.66*	-16.49*	-34.15*
7	PAU Sel Long × Pant C 1	-19.23*	-5.33*	-22.40*	-37.13*	16.03*	4.05*	3.80*	-23.66*
8	PAU Sel Long × Anugraha	9.15*	5.97*	14.57*	-27.00*	6.63*	6.38*	2.96*	-23.82*
9	PAU Sel Long × Surajmukhi	15.69*	17.66*	-28.09*	-18.99*	8.71*	24.10*	3.01*	-18.77*
10	Arka Lohit × Pant C 1	-7.83*	8.03*	8.85*	-11.81*	27.81*	12.43*	9.89*	-13.28*
11	Arka Lohit × Anugraha	4.08*	10.81*	35.26*	-10.97*	2.35*	2.11*	24.45*	-1.80
12	Arka Lohit × Surajmukhi	-18.29*	-13.01*	-14.23*	-3.38*	-13.54*	-1.30	11.47*	-12.03*
13	LCA 436 × Pant C 1	-25.81*	-13.05*	-22.92*	-37.55*	33.46*	17.39*	-8.28*	-32.55*
14	LCA 436 × Anugraha	0.85	-6.13*	-23.08*	-49.37*	14.72*	14.45*	-38.53*	-54.52*
15	LCA 436 × Surajmukhi	2.53*	4.27*	-47.94*	-41.35*	6.03*	21.04*	-20.36*	-37.20*
16	Pusa Jwala × Pant C 1	-23.36*	-13.69*	0.77	10.97*	2.46*	-9.87*	3.61*	1.80
17	Pusa Jwala × Anugraha	7.70*	2.11*	-11.88*	-2.95*	7.43*	7.17*	-4.93*	-6.59*
18	Pusa Jwala × Surajmukhi	-9.97*	-8.44*	-5.24*	6.75*	-14.42*	-2.31*	0.82	-0.95
19	Pusa Sadabahar × Pant C 1	-9.10*	6.54*	-12.65*	-9.70*	-19.55*	-14.53*	-6.36*	-14.03*
20	Pusa Sadabahar × Anugraha	19.12*	12.86*	-14.29*	-11.39*	-18.74*	-13.67*	1.58	-6.74*
21	Pusa Sadabahar × Surajmukhi	15.06*	17.02*	-25.47*	-16.03*	-14.06*	-1.89*	4.10*	-4.42*
22	Kashmir Long × Pant C 1	-7.55*	8.36*	30.21*	5.49*	12.58*	16.60*	26.89*	-6.68*
23	Kashmir Long × Anugraha	20.70*	18.42*	5.52*	-35.44*	-8.64*	-5.39*	-9.86*	-33.30*
24	Kashmir Long × Surajmukhi	10.64*	12.52*	-29.59*	-20.68*	-16.21*	-4.35*	-3.96*	-24.26*
25	Sel 352 × Pant C 1	-22.78*	-9.49*	8.85*	-11.81*	10.22*	-3.05*	14.39*	-15.88*
26	Sel 352 × Anugraha	-8.49*	-14.83*	42.76*	-12.66*	-1.81*	-2.04*	9.71*	-18.82*
27	Sel 352 × Surajmukhi	-6.47*	-4.88*	-14.61*	-3.80*	7.60*	22.83*	13.83*	-10.24*
28	LCA 443 × Pant C 1	-6.87*	9.15*	5.21*	-14.77*	6.97*	-5.91*	18.26*	-13.03*
29	LCA 443 × Anugraha	-3.54*	-6.39*	26.21*	-22.78*	1.37	1.13	-2.09	-27.56*
30	LCA 443 × Surajmukhi	-0.82	0.87	-27.34*	-18.14*	9.07*	24.52*	8.07*	-14.78*
31	LCA 206 × Pant C 1	-27.65*	-15.20*	-9.90*	-27.00*	2.20*	-10.11*	-2.17	-28.06*
32	LCA 206 × Anugraha	5.16*	-2.12*	23.78*	-14.35*	-8.17*	-8.39*	9.38*	-19.07*
33	LCA 206 × Surajmukhi	8.85*	10.70*	-17.98*	-7.59*	-23.86*	-13.08*	9.02*	-14.03*
Range		-27.65 to 20.70	-15.20 to 18.42	-51.04 to 42.76	-60.34 to 10.97	-23.86 to 33.46	-15.02 to 25.41	-41.84 to 26.89	-56.97 to 1.80
No of significant genotypes		12	16	10	3	19	16	16	-

best specific combiners (Table 4). For capsanthin (ASTA units), the crosses Kashmir Long × Pant C1 and Selection 352 × Surajmukhi had obtained position among the best five in pooled environments out of 12 crosses in pooled environments having desirable specific combining ability effects (Table 4). Chilli Sonal × Surajmukhi and Jawahar Mirch 283 × Anugraha were the other best specific combiners. For oleoresin (ASTA units) the crosses Kashmir Long × Pant C1, Arka Lohit × Anugraha, Chilli Sonal × Surajmukhi, LCA 436 × Pant C1and Jawahar Mirch 283 × Anugraha had showed a high SCA effects. For quality traits, different cross combinations with significant and positive SCA effects have been reported for ascorbic acid (Saritha *et al*., 2005), capsaicin (Prasath and Ponnuswami 2008), Capsanthin (Singh and Hundal 2001; Saritha *et al*. 2005; Prasath and Ponnuswami 2008) and oleoresin (Saritha *et al*., 2005).

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). The nature of gene action has been inferred from the estimates of GCA and SCA variances. The estimates of $ó_{SCA}^2$werehigher than $ó_{GCA}^2$(average) for majority of the traits. The results of analysis of variance were also confirmed from the study of additive ($ó_A^2$) and dominant ($ó_D^2$) component of variances. The differences in variances due to $ó_{SCA}^2$and dominance variance ($ó_D^2$) 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 ($ó_D^2$) was higher than additive variance ($ó_A^2$) for majority of the traits over the locations and pooled environments which indicated the involvement of non- additive gene action (Table 5).The same has been reported for capsanthin and oleoresin by Adarsh and Kumari (2015). 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. 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.

The identification of potential cross combination on the basis of heterosis with respect to various horticultural traits in chilli is of paramount importance for F_1 hybrid breeding. 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 health potential to human body. The heterobeltiosis and economic heterosis of ascorbic acid content ranged (Table 6) from -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). Kashmir Long × Anugraha, PAU Selection Long × Surajmukhi, Pusa Sadabahar × Anugraha and Pusa Sadabahar × Surajmukhi showed a potential cross combinations for both heterobeltiosis and economic heterosis out of 16 crosses in two environments. Heterosis for ascorbic acid has also been reported earlier by Gondane and Deshmukh (2004), Kumar and Tata (2010) and Jindal *et al*. (2015). High capsaicin content is desirable quality trait in chilli, since it is associated with pungency and spicy flavour. 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 ranged for heterosis over BP and SC, respectively (Table 6). Selection 352 × Anugraha, Arka Lohit × Anugraha, Kashmir Long × Pant C1, LCA 443 × Anugraha and LCA 206 × Anugraha were exhibiting high heterosis over BP over the locations in respective years. On the other hand, only three crosses namely, Pusa Jwala × Pant C1, Pusa Jwala × Surajmukhi and Kashmir Long × Pant C1showed economic heterosis. The results are in close proximity with those of Milerue and Nikornpun (2000) and Prasath and Ponnuswami (2008). Capsanthin is a 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 -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 × Anugrahashowed a high heterotic variability (Table 6). On the other hand, Jawahar Mirch 283 × Anugraha, LCA 443 × Surajmukhi, PAU Selection Long × Surajmukhi, Selection 352 × Surajmukhi and LCA 436 × Surajmukhi for economic heterosis. Prasath and Ponnuswami (2008) also observed hybrid vigour in 1/3rd of cross combinations studied. Oleoresin 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 -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 16 crosses 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 (Table 6). Prasath and Ponnuswami (2008) also observed hybrid vigour for oleoresin. Further, evaluation of hybrids based on combination of SCA and heterosis parameters would be more meaningful than on individual traits.

It is concluded that in the present context based on these parameters, the promising cross combinations LCA 443 × Pant C1, LCA 443 × Surajmukhi, Arka Lohit × Anugraha, PAU Sel Long × Surajmukhi, Kashmir Long × Pant C1 and Sel 352 × Surajmukhi were found superior for quality traits. These crosses exhibited significant SCA effects coupled with high GCA of female parent for majority of quality traits. Therefore, additive component seemed to influence the quality traits 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.

REFERENCES

Adapawar, R. M., Kale, P. B., Kale, V. S., Parlawar, N. D. and Yadgirwar, B. M. 2006. Heterosis for yield and yield components in chilli. *Annals of Plant Physiology.* **20(1):** 69-73.

Adarsh, M. N. and Kumari, P. 2015. Combining ability and gene action studies for important horticultural traits in chilli, *Capsicum annuum*. *International J. Farm Sciences.* **5(1):** 251-262.

Allard, R. W. 1960. Principles of Plant Breeding. *John Wiley and Sons, Inc. New York, London.* pp. 89-90.

A.O.A.C. 1980. Official methods of analysis. Association of official analytical chemists. (William Horwitz, ed.), Benzamin Franklin Station, Washington, D.C.

Bajaj, K. L. 1980. Calorimetric determination of capsaicin in capsicum fruits. *J. Association of official Analytical Chemist.* **63(6):**1314-1316.

Chaudhary, A., Kumar, R. and Solankey, S. S. 2014. Estimation of heterosis for yield and quality components in chilli (Capsicum annuum L.). *African J. Biotechnology*. **12(47):** 6605-6610.

Cockerham, C. C. 1961. Implication of genetic variances in hybrid breeding programme. *Crop Science.* **1:** 47-52.

Daood, H. G., Illes, V., Gnayfeed, M. H., Meszaros, B., Horvath, G. and Biacs, P. A. 2002. Extraction of pungent spice paprika by supercritical carbon dioxide and sub critical propane. *J. Supercrit Fluids.* **23:**143-152.

Fasoulas, A. 1981. Principles and methods of plant breeding. *Publ. No. 11 Aristotelian Univ, Thessaloniki, Greece.*

Gondane, B. G. and Deshmukh, D. T. 2004. Exploitation of heterosis in chilli. *J. Soils and Crops.* **14(2):** 376-382.

Gueddes, Samia., Ben, Mansour., Dhouha, Saidana. Ali., Ben, Dhiab. and Saleh, R. 2015. Estimation of Heterosis and Genetic Control of Fruit Traits in Tunisian Hot Pepper Varieties (*Capsicum annuum* L.) Grown in an Open Field. *Int. J. Curr. Res. Biosci. Plant Biol.* **2(11):** 68-78.

Hayman, B. I. 1960. The theory and analysis of diallel cross III. *Genetics.* **45:** 155-172.

Howard, L. R. and Wildman, R. E. C. 2007. Antioxidant vitamin and phytochemical content of fresh and processed pepper fruit (Capsicum annuum). In R. E. C. Wildman (Ed.), Handbook of nutraceuticals and functional foods (2nd ed.,Boca Raton: CRC Press. pp. 165-191.

Jindal, S. K., Kaur, D., Dhaliwal, M. S. and Chawla, N. 2015. Combining ability and heterosis for qualitative traits in chili pepper (*Capsicum annuum*L.) *International J. Horticulture.* **5:** No.5, 1-13.

Jinks, J. L. 1983. Biometrical genetics of heterosis *[R Frankel, ed.], New York.* pp. 1-46.

Khalil, Mona. R. and Hatem, M. K. 2014. Study on Combining Ability and Heterosis of Yield and Its Components in Pepper (*Capsicum annum*, L.). *Alex. J. Agric. Res.* **59(1):** 61-71.

Kumar, Owk. Aniel. and Tata, Sape. Subba. 2010. Ascorbic acid heterosis in chili peppers (*capsicum* l.). *J. Phytology.* **2(2):** 16-23.

Kumar, R. L., Sridevi, O., Kage, U. K., Salimath, P. M., Madalageri, D. and Natikar, P. 2014. Heterosis Studies in Chilli (Capsicum annuumL.). *International J. Horticulture.* **4(8):** 40-43.

Lohithaswa, H. C., Manjunath, A. and Kulkarni, R. S. 2001. Implications of heterosis, combining ability and *per se* performance in chilli (*Capsicum annuum* L.) *Crop Improvement.* **28(1):** 69-74.

Matzinger, D. P. and Kempthorne, O. 1956. The modified diallel table with partial inbreeding and interactions with environment. *Genetics.* **41:** 822-833.

Panse, V. G. and Sukhatme, P. V. 1967. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi. p. 381.

Prasath, D. and Ponnuswami, V. 2008. Heterosis and combining ability for morphological, yield and qualitycharacters in paprika type chilli hybrids *Indian J. Horticulture.* **65(4):** 441-44.

Patel, Kanhaiya. Lal., Sharma, D. and Mehta, N. 2015. Heterosis study for yield components in chilli (capsicum annuum L.). *The Bioscan.* **10(4):** 1963-1968

Patel, M. P., Patel, A. R., Patel, J. B. and Patel, J. A. 2010. Heterosis for green fruit yield and its components in chilli (Capsicum annuum var. longicum (D.G) Sendt) over environments. *Electronic J. Plant Breeding.* **1(6):** 1443-1453.

Ranganna, S. 1979. *Manual of analysis of fruits and vegetable products*. *Tata Mc Graw Hill Book Company* New Delhi.

Reddy, M. G., Kumar, H. D. M. and Salimath, P. M. 2008. Heterosis Studies in Chilli (Capsicum annuumL.). *Karnataka J. Agriculture Science.* **21(4):** 570-571.

Satish, R. G. and Lad, D. B. 2007. Heterosis Studies in chilli (Capsicum annum L.). *J. Maharashtra Agriculture University*. **32:** 68-71.

Saritha, J. K., Kulkarni, R. S., Rao, A. M. and Manjunath, A. 2005. Genetic divergence as a function of combining ability in chilli (*Capsicum annuum* L.). *Indian J. Genetics and Plant Breeding.* **65(4):** 331-332.

Sharma, A. and Vidyasagar. 2005. Genetic architecture and combining ability studies for morphological and physiological traits in garden pea (*Pisum sativum* L.*). Himachal J. Agricultural Research*. **31(1):** 54-60.

Spaldon, Sonam., Sharafat, Hussain., Nayeema, Jabeen. and Padma, Lay. 2015. Heterosis studies for earliness, fruit yield and yield attributing traits in chilli (Capsicum annum L.). *The Bioscan*. **10(2):** 893-898.

Singh, Rajinder. and Hundal, J. S. 2001. Manifestation of heterosis in chilli (*Capsicum annuum* L.). *Vegetable Science.* **28(2):** 124-126.

Singh, M., Lamalakshmi, Devi., Aglawe, S., Kousar, N. and Behera, C. 2013. Estimation of heterosis in different crosses of bread wheat (Triticum aestivum L.). *The Bioscan.* **8(4):** 1393-1401.

Sprague, G. F. 1966. Quantitative genetic in plant improvement Proceeding of Symposium. *The Iowa State Univ, Amesiowa*. pp 315-334.