



## Assessment of combining ability for yield and quality components in hot pepper (*Capsicum annuum* L.)

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### Abstract

Six parental genotypes and their thirty F<sub>1</sub> hybrids in a full diallel cross system with reciprocals, were used in the present study to estimate combining ability for five quantitative and five qualitative traits in hot pepper. The mean sum of squares due to general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) were significant for all the characters which suggest that these parents could have performed differently in different combinations indicating interallelic interactions. All the traits studied exhibited greater SCA variance than GCA, suggesting that these traits are controlled by non-additive gene action. Analysis of the GCA effects of parents for various traits revealed that LCA625, K1 and PKM1 were the best general combiners for almost all the traits. Estimates of SCA effects showed that the hybrids LCA625 × K1, K1 × Arka Lohit and Pusa Jwala × PKM1 were found to be the best combiners for yield and its attributes. The hybrid K1 × Arka Lohit was the best reciprocal combiner for quality parameters based on its better mean performance and combining ability. These results suggest that commercial production of hot pepper hybrids and isolation of pure lines from these hybrids is a possible way to enhance the yield and fruit quality.

**Additional key words:** chilli; growth; capsaicin; dry yield; GCA; SCA; RCA

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### Introduction

Hot pepper (*Capsicum annuum* L.) is the universal vegetable cum spice of India. In India it is cultivated in all the states and union territories of the country. The most important states growing chilli are Andhra Pradesh, Orissa, Maharashtra, West Bengal, Rajasthan and Tamil Nadu. Andhra Pradesh alone commands 46% of the chilli production in India. As per the latest statistics, India produced 11,000,452 tonnes of dry chillies from an area of 9,036,028 hectares. No country in the world has so much area and production of chilli. Almost 90% of chilli production is consumed indigenously while only 10% is exported. Demand Hot pepper has two important commercial qualities. Some varieties

are famous for red colour because of the pigment capsanthin, others are known for biting pungency attributed by capsaicin. India is the only country rich in many varieties with different quality factors. In the world, both domestic consumption and export are maximum in India. As a product, oleoresin of hot pepper with low, medium or high pungency is also exported in large quantities (Manjula *et al.*, 2011). Chilli powder is another important product of export. Indian chillies and its products are brought out by many countries, viz., Sri Lanka, Bangladesh, South Korea and USA for dry chillies and USA, Germany, Japan, UK and France for oleoresin. India can supply chilli as in whole, crushed, powder or oleoresin forms in consistent colour and required pungency (Sharanakumar *et al.*, 2011).

Hot peppers have been standing out by their increasing preference in the consumer market. Even though increase in cultivation and commercialization of hot pepper in the last few years (Nascimento *et al.*, 2014) there is increasing demand in India for new cultivars that have higher yield, quality, pest and disease resistance, all of which can be achieved through breeding programmes.

Diallel analysis is a biometrical tool that provides the estimates of genetic parameters regarding heterosis and combining ability. It gives additional information on presence or absence of epistasis, average degree of dominance and distribution of dominant and recessive genes in the parents (Rego *et al.*, 2011; Nascimento *et al.*, 2014). Application of diallel techniques to self-pollinated crops for improving yield and quality may be appropriate (Griffing, 1956). The concept of combining ability was developed by Sprague & Tatum as early as 1942. According to them, the general combining ability (GCA) is the comparative ability of the lines or parents to combine with other lines. Specific combining ability (SCA) is the deviation in the performance of a specific cross from the performance expected on the basis of GCA effects of the parents involved in the cross. The expression of heterosis is highly associated with SCA of crosses.

Study of combining ability is useful in predicting the performance of hybrid. Simultaneously the genetic distance also plays a major role in to assess the hybrid vigour component (e.g. Rodríguez *et al.*, 2003, 2008). Hence, combining ability analysis is extensively used to study nature and magnitude of genotypic variability and facilitate correct choice of desirable parents in a hybrid development programme. The knowledge of gene effects on expression of any trait greatly helps the plant breeder in making to draw strategies of breeding population, selection method, type of variety and extent of testing. Combining ability analysis also gives a clear picture of elite parent which can be fitted as a general combiner over a series of cross combinations and in a specific cross to exploit heterosis.

Roja & Sprague (1952) and Griffing (1956) stated that the GCA includes the additive genetic portion, while SCA includes non-additive genetic portion of the total variation. Hayman (1957) found that in the absence of epistasis, GCA is composed of both additive and dominance while SCA involves mainly dominance effects. Extensive work has been done in chilli by various research workers on the combining ability of the exotic and indigenous genotypes for various characters. Jagadeesha & Wali (2008) studied 18 divergent lines and 45 F<sub>1</sub> hybrids and reported that the parents VN2, BKaddi, Arka Lohit, Phule5 and LCA312 exhibited high GCA which may be utilized in recurrent selection programme for improvement in

fruit quality traits. Rego *et al.* (2009) crossed eight lines of *Capsicum baccatum* in a complete diallel and revealed that GCA effects of the parents and SCA effects of the crosses were significant. Khalil & Hatem (2014) evaluated six parents and 15 hybrids for yield and quality traits and found significant variance for all the traits. Estimates of GCA effects showed that the best combiner parents were found to be those of W515 and Big Dipper for fruits number, W515 and LS22 for total yield as fruits number and weight, Big Dipper for fruit diameter. For pericarp thickness and ascorbic acid content, the parental genotype Big Dipper was the best combiner, while LS22 for total soluble solids content. Estimates of SCA effects showed that the F<sub>1</sub> cross Big Dipper×B1610 reflected the highest value in all traits. From this prospective, the objective of the study was to estimate the general combining ability (GCA), specific combining ability (SCA) and reciprocal effects using each five quantitative and qualitative traits and to determine the most promising crosses for exploiting heterosis among the six parents.

## Material and methods

The experiment was conducted in the Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, India during 2013-2015. Six homozygous inbreds *viz.*, Arka Lohit (P1), K1 (P2), LCA334 (P3), LCA625 (P4), PKM1 (P5) and Pusa Jwala (P6) were used as parents and the promising hybrid CO CH 1 obtained from Department of Vegetable Crops, TNAU, Coimbatore was used as standard check (Table 1). The parents were crossed in all possible combinations, both direct and reciprocal (full diallel), to get the maximum number of hybrids. The pollen was collected from each male parent as soon as the flower buds were opened. The flower buds from plants of six female parents were emasculated in the last day evening and covered with coloured bags. In the morning, to pollinate, pollen grains from each one of the stigma of each emasculated flowers. Labels were used to identify the fruits from each different type of crosses.

The parents and progeny seeds were treated 24 hours before sowing with 4 g of *Trichoderma asperellum* var. *viride*, and sowed in 98 cells portrays. Seeds were watered with rosecan to facilitate quick germination and good growth of seedlings. The main field was prepared to a fine tilth and 25 t/ha of FYM was applied at the last ploughing. Prior to transplanting, at the time of field preparation about 2 kg/ha of *Azospirillum* and Phosphobacteria each were mixed with 20 kg of FYM and 30:60:30 kg/ha NPK in the form of urea, single

**Table 1.** The outstanding attributes of the parents and check used for the study

Parent number	Name of the genotype	Description/Identifying characters
P1	Arka Lohit	A pure line selection from IHR 324 (local collection). Plants are tall. Fruits dark green, smooth, straight, turning deep red on maturity. Fruits highly pungent and suitable for irrigated and rainfed cultivation. Duration 180 days. Yield 25 t/ha (green chilli) and 3 t/ha (dry pod).
P2	K1	It is a pure line selection from local Sattur samba developed at Agricultural Research Station, Kovilpatti, India. The plants are tall and spreading. The crop duration is 210 days, yields 1.8 tonnes of dry pods/hectare and suitable for rainfed cultivation in southern districts of Tamil Nadu. The ripe fruits are red, long and contain high capsaicin.
P3	LCA334	The plants are medium tall with medium branching, dark green leaves, bearing dark green fruit, thick fleshed, medium sized fruits, fruits are shiny and smooth in nature, rich in ascorbic acid content and total soluble solids.
P4	LCA625	The plants are tall with spreading branches. The fruits are green when unripe and bright shiny red on ripening. High yielder (Dry pod 4.2 t/ha). The fruits are long, attractive red in colour, shiny and smooth in nature, it has a high capsaicin and oleoresin content and hence suitable for export purpose.
P5	PKM1	Hybrid derivative of the cross between AC. No. 1797×CO 1. It is suitable for cultivation under irrigated conditions. Bold pods, which are dark red in colour. Average yield 3 t/ha (dry pod).
P6	Pusa Jwala	Plants are dwarf, bushy, light green, fruits 9-10 cm long, light green, ripe fruits light red, highly pungent, fairly tolerant to thrips and mites. Average yield 8.5 t/ha (green chilli) and 1.8 t/ha (dry pod).
Check	CO CH1	F1 hybrid developed by crossing Selection 1×CA 97. Fruits are long, smooth and dark green. It possesses 0.58 % capsaicin. Suitable for green and dry chilli. Moderately resistant to fruit rot. Average yield 28 t/ha. (Green chilli) and 6.74 t/ha (dry pod).

super phosphate and muriate of potash, respectively was applied to the soil. The seedlings were transplanted in the second week of November 2013. Seedlings with age of 45 days old were transplanted with a plant spacing of 45 cm at the rate of one seedling. Fifty plants of each of the thirty  $F_1$ s, six of parents were planted at a distance of 60×45 cm in a randomized block design with three replications during November 2014 to April 2015. Additionally 30 kg N/ha was given in equal splits on 30, 60 and 90 days after planting. Soil moisture was maintained during the growing season with flood irrigation at 5 days intervals. The recommended package of practices including plant protection measures obligatory to raise the good crop were followed in field (CPG, 2013). Data were collected from individual plants of  $F_1$  generation of hot pepper for each five quantitative traits *viz.*, branches per plant, fruits per plant, fruit shape, individual dry pod weight, dry pod yield per plant.

The observation for five quality characters were recorded from fifteen competitive plants selected randomly from each replication. The ascorbic acid content of hot pepper pod was estimated as per the standard procedure (Sadasivam & Manickam, 1992) and expressed in mg/100 g. The capsaicin content (%) of dry pod was estimated adopting the procedure given

by Sadasivam & Manickam (1992). The extractable colour in hot pepper was estimated as per the procedure of Woodbury (1997) and expressed in ASTA units. Oleoresin content was analysed as per the procedure of Mathai (1988). A drop of juice was used to record the total soluble solid ( $^{\circ}$ Brix) with the help of hand refractometer.

### Statistical analysis

The statistical parameters like mean, range were calculated as per the standard methods of analysis (Panse & Sukhatme, 1957).

### Diallel analysis

A diallel analysis was carried out using the data of six parents and resultant thirty  $F_1$  hybrids. "Null hypothesis" was tested to show that there were no genotypic differences among the progenies. This was worked out using randomized block design. In randomized block design three sources were used *viz.*, blocks, genotypes and error. For blocks (b) the degree of freedom was (b-1), the degrees of freedom for genotypes was (g-1). In genotypes the results is expected as  $s^2e$  (error variance) +  $s^2g$  (genotypic variance). The degree of freedom for error was reported as (b-1) (g-1) and their result is expected as  $s^2e$ .

### Griffing's combining ability analysis

Estimation of general and specific combining ability was done by following Griffing (1956b) method I of diallel analysis, which included parents, F<sub>1</sub>s and reciprocals.

#### General combining ability effect (GCA)

$$g_i = 1 \cdot \sum_{p=1}^p (X_{i.} + X_{.i}) - \frac{1}{p} \sum_{i=1}^p \sum_{j=1}^p X_{ij}$$

where p= number of parent; X<sub>i.</sub>=row total of parents in the array; X<sub>.i</sub>= column total of parents in the array M, x; X<sub>..</sub>= grand total of diallel table.

#### Specific combining ability effects (SCA)

$$S_{ij} = \frac{1}{2} (X_{ij} + X_{ji}) - \frac{1}{2p} (X_{i.} + X_{.i} + X_{j.} + X_{.j}) + \frac{1}{p^2} X_{..}$$

$$S_{ij} = \frac{1}{2} (X_{ij} + X_{ji}) - \frac{1}{2p} (X_{i.} + X_{.i} + X_{j.} + X_{.j}) + \frac{1}{p^2} X_{..}$$

where p= number of parents; X<sub>ij</sub>= array means of F<sub>1</sub>; X<sub>ji</sub>= array means of reciprocal F<sub>1</sub>; X<sub>i.</sub>= row total of first parent; X<sub>.i</sub>= column total of first parent; X<sub>j.</sub>= row total of second parent; X<sub>.j</sub>= column total of second parent; X<sub>..</sub>= grand total of diallel table.

#### Reciprocal effects (RCA)

$$r_{ij} = \frac{1}{2} (X_{ij} - X_{ji})$$

The variances of these effects were estimated as follows:

$$\text{Var}(g_i) = p - \frac{1}{2p^2} \sigma_e^2$$

$$\text{Var}(s_{ij}) = \frac{1}{2} (p^2 - 2p + 2) \sigma_e^2$$

$$\text{Var}(r_{ij}) = \frac{1}{2} \sigma_e^2$$

The square root of the variance provides the corresponding standard error for calculating critical differences.

## Results and discussion

### GCA effects of the parents

The success of any plant breeding programme greatly depends on right choice of parents. The potential of a

variety is judged by comparing the mean performance and combining ability of the parents (Singh, 1994). Kadambavanasundaram (1980) suggested that the parents with high *per se* performance may not always be able to transmit their superior traits into hybrids and so assessment of combining ability is most needed. General combining ability (GCA) of a parent is a factor that predicts the performance of a parent over a series of cross combinations. Since GCA of a genotype is due to additive and additive×additive interaction effects, the ultimate goal of any breeder could be either to produce a variety which is homozygous for all the desired genes or to develop such parents that would produce superior hybrid. Thus combining ability assumes greater importance to assess the genetic potentialities of a genotype. Dhillon (1975) had also pointed out that the combining ability had given useful information on the choice of parents in form of expected performance of the hybrids and their progenies. The combining ability studies in the present investigation revealed that the parents possessed high GCA effects for different characters. Based on the GCA effects, the best parents identified as good combiners for various characters are furnished in Table 2.

At present, development of high yielding hybrids along with quality enhancement is aimed in vegetable improvement programme. Parents with high *per se* and significant GCA for various characters have been highlighted in Table 3. In this study some of the parents are good general combiners for yield and quality contributing characters. From this table, it is obvious that the parents ranking top in *per se* did not necessarily appear as top rankers when GCA effect was considered. However, for certain traits there was considerable agreement between *per se* and GCA of parents. Estimates of general combining ability value for the parental lines showed that the best inbreds for

**Table 2.** Parents with high and significant GCA effect for yield and quality traits

Parent	Character
Arka Lohit	Capsaicin, total soluble solids
K1	Branches per plant
LCA334	—
LCA625	Fruits per plant, individual dry pod weight, ascorbic acid, oleoresin
PKM1	Fruit shape
Pusa Jwala	Capsaicin, colour value

**Table 3.** Mean performance and general combining ability effects of parents for yield and quality characters

Parents	Branches /plant		Fruits /plant		Fruit shape		Dry pod weight		Dry pod yield	
	Mean	GCA	Mean	GCA	Mean	GCA	Mean (g)	GCA	Mean (g)	GCA
Arka Lohit	7.28	0.03	98.48	-1.51**	3.28	0.02	0.75	0.01*	73.50	-1.08
K1	8.53W	0.53**	92.00	6.93**	2.58	0.10**	0.54	0.03**	49.68	9.74**
LCA334	7.00	-1.04**	86.52	-19.27**	2.72	-0.11**	0.62	-0.07**	55.18	-22.30**
LCA625	8.95	0.47**	104.75	8.76**	3.07	-0.02	0.78	0.04**	81.11	10.54**
PKM1	8.52	-0.02	80.08	3.95**	3.10	0.12**	0.66	0.001	53.03	3.98**
Pusa Jwala	9.38	0.01	90.85	1.22**	2.30	-0.12**	0.72	-0.01**	64.80	-0.88
SE (gi)	--	0.110	--	0.117	--	0.018	--	0.006	--	0.613
SE d	0.590	--	0.632	--	0.099	--	0.035	--	62.88	--
CD ( $p=0.05$ )	1.77	--	1.260	--	0.199	--	0.071	--	103.96	--
	Ascorbic acid		Capsaicin		Colour value		Oleoresin		Total soluble solids	
	Mean (mg/100 g)	GCA	Mean (%)	GCA	Mean (ASTA)	GCA	Mean (%)	GCA	Mean (°Brix)	GCA
Arka Lohit	123.41	-0.72*	0.71	0.04**	71.82	-3.30**	14.58	0.38**	6.30	0.29**
K1	120.28	-1.75**	0.53	0.01*	58.59	-1.10	12.47	-0.19**	5.63	-0.11*
LCA334	108.37	-2.21**	0.49	-0.06**	67.80	-4.77**	13.18	-0.26**	7.10	-0.11*
LCA625	116.55	8.66**	0.66	0.00	78.18	7.74**	14.61	0.62**	5.86	0.25**
PKM1	79.54	-10.60**	0.50	-0.03**	46.78	-8.25**	12.69	-0.38**	4.83	-0.43**
Pusa Jwala	112.85	6.64**	0.75	0.04**	81.70	9.68**	13.56	-0.15*	6.26	0.11*
SE (gi)	--	0.320	--	0.004	--	0.591	--	0.063	--	0.049
SE d	0.009	--	0.022	--	0.229	--	8.299	--	3.294	--
CD ( $p=0.05$ )	0.018	--	0.043	--	0.456	--	16.553	--	6.571	--

\* Significant at 5% level. \*\* Significant at 1% level

each characters are as follows: K1 (P2), LCA625 (P4) for branches per plant, LCA625 (P4), K1 (P2) for fruit number, K1 (P2), PKM1 (P5) for fruit shape, K1 (P2), LCA625 (P4) for dry pod weight, LCA625 (P2), K1 (P2) for dry pod yield, LCA625 (P4), Pusa Jwala (P6) for ascorbic acid, Arka Lohit (P1), Pusa Jwala (P6) for capsaicin, Pusa Jwala (P6), LCA625 (P4) for colour value, LCA625 (P4), Arka Lohit (P1) for oleoresin and LCA625 (P4), Arka Lohit (P1) for total soluble solids. By and large, the parent LCA625 (P4) had highly significant GCA for eight characters (Table 4). For most of the characters, its mean values also corresponded with high magnitude of its GCA. The parent LCA625 (P4) could be employed in breeding programme for overall improvement. The next best choice would be K1 (P2) which had significant GCA for five characters. This parent will be a better choice when the aim is primarily to increase the fruiting characters. Involving these parents in hybridization would result in the identification of

superior hybrid combinations with favourable genes and interactions for the various traits since they are under the influence of additive genes. If a parent possessed significant GCA effects for as many traits as possible, it is well chosen for hybridization rather than parents with low GCA effects or based on mean performance. The other parent chosen for hybridization should possess favourable GCA effects for other traits, so that favourable recombinants for all the traits could be obtained. If only one trait is to be improved, both the parents should have desirable gene effects for the trait. This assumption is based on the principle that additive gene action is reflected by gene effects (Sprague & Tatum, 1942). Certain parents which performed well by their mean performance but failed to exhibit high GCA effects. Such low association suggests non-additive gene effects in those parents which are evidenced by higher SCA variances than GCA variances. This finding agrees with that reported by Khalil & Hatem (2014).

**Table 4.** Best performing parents based on *per se* values and GCA effect in chilli

Characters	<i>per se</i>	GCA	<i>per se</i> and GCA
Branches /plant	Pusa Jwala, LCA625	K1, LCA625	K1
Fruits/plant	LCA625, Arka Lohit	LCA625, K1	LCA625, K1
Fruit shape	Arka Lohit, PKM1	K1, PKM1	PKM1
Individual dry pod weight	LCA625, Arka Lohit	K1, LCA625	LCA625, Arka Lohit
Dry pod yield/plant	LCA625, Arka Lohit	LCA625, K1	LCA625
Ascorbic acid	Arka Lohit, K1, LCA625	LCA625, Pusa Jwala	LCA625
Capsaicin	Pusa Jwala, Arka Lohit	Arka Lohit, Pusa Jwala	Arka Lohit, Pusa Jwala
Colour value	Pusa Jwala, LCA625	Pusa Jwala, LCA625	Pusa Jwala, LCA625
Oleoresin	LCA625, Arka Lohit	LCA625, Arka Lohit	LCA625, Arka Lohit
Total soluble solids	LCA334, Arka Lohit	LCA625, Arka Lohit	LCA625, Arka Lohit

### Evaluation of hybrids based on specific combining ability and reciprocal effects

The estimated results of the analysis of variance for general and specific combining abilities and reciprocal combining effects are presented in Table 5. The estimates of GCA and SCA variances help to infer the type of gene action and relative importance of the character expression in breeding programme. Magnitude of SCA variance was greater than GCA variance for all the quality traits, indicating the preponderance role of non-additive type of gene action in the expression of these traits. The results of the present study are in consonance to the findings of Khereba *et al.* (2008) and Jaya Rame Gowda (2009).

The hybrid  $P_1 \times P_3$  was the best performing for branches per plant on the basis of their SCA effects and mean values (Table 7) and this hybrid was based on low  $\times$  low GCA effects. The reciprocal hybrids  $P_4 \times P_2$ ,  $P_3 \times P_1$  and  $P_6 \times P_5$  were the best performing on the basis of

**Table 5.** Analysis of variance for combining ability mean squares in chilli

Characters	GCA	SCA	RCA
Branches /plant	3.86**	2.98**	3.02**
Fruits/plant	1238.70**	571.55**	1307.90**
Fruit shape	0.13**	0.07**	0.16**
Dry pod weight	0.02**	0.002**	0.014**
Dry pod yield/plant	1731.32**	511.64**	1501.16**
Ascorbic acid	576.48**	454.02**	303.37**
Capsaicin	0.024**	0.007**	0.006**
Colour value	616.00**	240.41**	68.02**
Oleoresin	1.95**	0.65**	1.04**
Total soluble solids	0.92**	0.58**	0.25**

\* Significant at 5% level. \*\* Significant at 1% level

their RCA effect and mean values and these reciprocal hybrids were the consequential of high  $\times$  high, low  $\times$  low and low  $\times$  low GCA effects. The *per se* performance was found to be high for reciprocal cross  $P_4 \times P_2$  and this cross showed the role of additive  $\times$  additive gene action. Such combinations could be used for selecting recombinants as pure lines in the later generations. Additive gene action for this trait was also reported by Asish Ghosh (2005).

The selection for high yielding genotype should be based mainly on the fruits per plant (Gill *et al.*, 1973). The hybrids  $P_1 \times P_3$  and  $P_2 \times P_3$  were found to be superior based on their SCA effects and *per se* performance for fruits per plant and all these hybrids were the outcome of low  $\times$  low GCA effects of their respective parents. The reciprocal hybrids *viz.*,  $P_4 \times P_2$ ,  $P_6 \times P_5$  and  $P_5 \times P_4$  were found to be superior ones based on their SCA effects and *per se* performance for number of fruits per plant (Table 7) and all these hybrids were the outcome of high  $\times$  high GCA effects of their respective parents. The *per se* performance was found to be high for reciprocal crosses  $P_4 \times P_2$ ,  $P_5 \times P_4$  and  $P_6 \times P_5$ . All these three hybrids were good combiners with high  $\times$  high parental GCA effects suggesting the influence of additive  $\times$  additive gene effects on these hybrids. Hence, these parents appeared to be worthy in varietal improvement programme. It was suggested that population involving these parents, in multiple crossing programme, might be developed for isolating desirable lines. Thus, the present studies are in accordance with the outcomes of Jagadeesha & Wali (2008), Prasath & Ponnuswami (2008) and Sitaesmi *et al.* (2010).

Best performing hybrids for fruit shape based on SCA effects were  $P_1 \times P_3$  and  $P_1 \times P_4$  and these hybrids were the outcome of low  $\times$  low GCA effects of their corresponding parents (Table 7). The hybrids *viz.*,  $P_6 \times P_2$ ,  $P_3 \times P_1$  and  $P_6 \times P_5$  were the high performing hybrids based on RCA effects and all these hybrids

**Table 6.** Estimates of genetic components of variation for various traits in chilli

Characters	$\sigma^2$ GCA	$\sigma^2$ SCA	$\sigma^2$ RCA	$\sigma^2$ GCA : $\sigma^2$ SCA
Branches/plant	0.307	2.847	1.404	0.107
Fruits/plant	103.20	1307.704	285.67	0.078
Fruit shape	0.010	0.163	0.037	0.067
Dry pod weight	0.001	0.014	0.001	0.114
Dry pod yield/plant	143.82	1495.73	253.11	0.096
Ascorbic acid	47.91	301.89	226.27	0.158
Capsaicin	0.002	0.005	0.003	0.356
Colour value	50.91	235.37	31.489	0.216
Oleoresin	0.157	0.592	0.495	0.265
TSS	0.074	0.545	0.109	0.136

$\sigma^2$ GCA: variance due to GCA  $\sigma^2$  SCA: variance due to SCA  $\sigma^2$  RCA: variance due to RCA

were the outcome of low $\times$ high, low $\times$ low and low $\times$ high GCA effects of their respective parents. These hybrids involved one good and one poor combiner showing dominance $\times$ additive gene action which could be exploited by conventional breeding procedures such as pedigree selection. Jagadeesha & Wali (2008) observed dominance, additive and duplicate complementary epistasis as common type of gene action for fruit shape.

For individual dry pod weight, the hybrids surpassed based on the highest SCA effect were  $P_2 \times P_6$ ,  $P_1 \times P_5$  and  $P_2 \times P_5$  and all these hybrids were the outcome of high $\times$ low GCA effects of their corresponding parents. The reciprocal hybrids viz.,  $P_6 \times P_5$ ,  $P_6 \times P_2$  and  $P_3 \times P_1$  were the best performing hybrids based on RCA effects and these hybrids were the outcome of low $\times$ low, low $\times$ high and low $\times$ high GCA effects of their respective parents (Table 7). Interestingly, the *per se* performance was found to be high for reciprocal cross  $P_6 \times P_5$  which clearly indicated the significance of cytoplasmic effects controlling these trait and suggesting dominance $\times$ additive and dominance $\times$ dominance type of interaction for individual fresh fruit and individual dry pod weight. This cross could be effectively used to exploit the reciprocal differences for dry pod weight. Hence, these parents involved in the above mentioned crosses appeared to be worthy in the varietal improvement programme. It was also suggested that population involving these parents, in multiple crossing programme, might be developed for isolating desirable lines. Prasath & Ponnuswami (2008);

JayaRame Gowda (2009); Sitaresmi *et al.* (2010); Savitha (2011) were of the opinion that the weight of fruits in chillies was governed by both additive and non additive gene effects. Dry pod yield per plant forms the major objective of the present study and the breeding procedures are focused on increasing the potentiality of this trait. The hybrids  $P_1 \times P_3$  and  $P_2 \times P_3$  were found to be superior ones based on their SCA effects for dry pod yield per plant and these hybrids were the product of low $\times$ low, and high $\times$ low GCA effects of their parents. The reciprocal hybrids viz.,  $P_6 \times P_2$  and  $P_6 \times P_5$  had the low $\times$ high GCA combination resulting in high positive significant SCA suggesting dominant $\times$ additive gene interaction. The hybrids,  $P_4 \times P_{22}$ ,  $P_5 \times P_4$  and  $P_2 \times P_1$  were the best performing hybrids based on RCA effects (Table 7) and these hybrids were the outcome of high $\times$ high, high $\times$ high and high $\times$  low GCA effects of their respective parents. The *per se* performance was found to be high for reciprocal cross  $P_4 \times P_{22}$ , this cross showed additive $\times$ additive type of interaction. Hence, it was clearly indicated the significance of cytoplasmic effects controlling this trait and crosses could be effectively used to exploit the reciprocal differences. According to Thakur *et al.* (1980), 12 pairs of genes were responsible for governing this character. These results are in accordance with the outcomes of Khereba *et al.* (2008) and Somashekhar *et al.* (2008).

The high performing hybrids for ascorbic acid based on SCA effects were  $P_3 \times P_6$ ,  $P_2 \times P_3$  and  $P_1 \times P_3$  (Table 8)

**Table 7.** *Per se* performance and specific combining ability effects of direct and reciprocal crosses for yield traits

Hybrids	Branches /plant		Fruits /plant		Fruit shape		Dry pod weight		Dry pod yield/plant	
	Direct crosses (SCA)									
	Mean	SCA/ RCA	Mean	SCA/ RCA	Mean (cm)	SCA/ RCA	Mean (g)	SCA/ RCA	Mean (g)	SCA/ RCA
P1 × P2	9.20	-1.50**	127.67	-23.68**	2.85	-0.55**	0.80	-0.05**	98.28	-29.48**
P1 × P3	13.50	3.25**	173.80	36.13**	3.63	0.28**	0.84	-0.00	143.10	36.45**
P1 × P4	9.00	-0.66*	132.85	0.42	3.29	0.35**	0.83	0.03*	102.28	1.50
P1 × P5	8.20	0.03	106.52	-19.24**	3.23	0.00	0.70	0.05**	73.51	-6.58**
P1 × P6	8.63	-0.55	125.50	-9.82**	2.95	-0.11*	0.68	0.03	85.63	-1.80
P2 × P3	8.00	-0.06	110.65	6.32**	3.08	0.01	0.74	0.02	81.29	7.38**
P2 × P4	9.97	-2.34**	163.00	-16.00**	3.30	-0.11*	0.84	-0.02	132.37	-16.60**
P2 × P5	8.50	-0.57	138.43	-13.46**	3.50	-0.00	0.82	0.04*	110.85	-5.31**
P2 × P6	9.20	-0.32	130.72	-22.85**	3.64	-0.09	0.83	0.06**	102.00	-22.70**
P3 × P4	8.30	0.11	108.35	-7.32**	3.20	-0.00	0.66	-0.00	70.85	-5.49**
P3 × P5	7.27	-0.36	98.50	-20.01**	3.27	0.00	0.70	0.03*	68.80	-9.21**
P3 × P6	7.00	-0.58	112.36	0.18	2.85	0.05	0.53	0.00	59.47	0.67
P4 × P5	9.43	-0.94*	155.28	-16.38**	3.17	-0.13**	0.79	-0.02	120.67	-17.53**
P4 × P6	8.89	0.53	130.48	-9.14**	2.95	-0.05	0.72	-0.00	93.03	-7.50**
P5 × P6	10.00	-1.10**	154.19	-12.15**	3.59	-0.13**	0.78	-0.05**	125.72	-15.41**
<b>SE (sij)</b>		0.295		0.316		0.049		0.017		1.647
Reciprocal crosses (RCA)										
P2 × P1	12.20	0.95**	175.03	14.25**	3.97	0.09*	0.92	0.07**	157.25	21.98**
P3 × P1	7.00	2.09**	101.54	26.78**	3.06	0.25**	0.70	0.09**	70.19	32.91**
P4 × P1	10.32	-0.01	132.00	-6.50**	2.57	-0.25**	0.76	0.00	99.27	-5.79**
P5 × P1	8.13	-1.02**	145.00	-8.36**	3.22	-0.11*	0.60	-0.09**	86.67	-19.92**
P6 × P1	9.73	-0.04	145.15	3.93**	3.17	-0.02	0.62	-0.07**	89.23	-7.72**
P3 × P2	8.13	-0.58*	98.00	-15.08**	3.05	-0.10*	0.69	0.02	66.53	-10.65**
P4 × P2	14.67	2.14**	195.00	31.54**	3.54	0.15**	0.88	0.05**	165.58	31.57**
P5 × P2	9.65	-0.60*	165.35	9.25**	3.51	0.09*	0.74	0.01	121.48	5.31**
P6 × P2	9.84	-0.20	176.43	13.66**	3.83	0.56**	0.85	0.09**	147.40	18.71**
P4 × P3	8.07	-0.40	123.00	-5.57**	3.21	0.16**	0.67	-0.03*	81.83	-9.01**
P5 × P3	8.00	-0.46	138.53	2.08**	3.25	0.06	0.63	0.00	87.22	-0.78
P6 × P3	8.17	-0.55*	112.00	-1.52**	2.74	-0.14**	0.52	-0.11**	58.13	-15.12**
P5 × P4	11.32	0.75**	188.05	27.19**	3.06	0.02	0.83	0.03*	155.73	26.56**
P6 × P4	7.82	-1.30**	148.76	-2.12**		-0.02	0.73	-0.02	108.04	-6.23**
P6 × P5	12.20	1.93**	178.50	29.41**		0.26**	0.88	0.11**	156.54	40.91**
<b>SE (rij)</b>		0.251		0.268		0.042		0.015		1.399

\* Significant at 5% level. \*\* Significant at 1% level

and these hybrids resulted from low×high, low×low, low×low GCA effects of their parents. The reciprocal hybrids *viz.*, P<sub>5</sub>×P<sub>4</sub>, P<sub>6</sub>×P<sub>2</sub> and P<sub>6</sub>×P<sub>5</sub> were the high performing hybrids based on RCA effects and these hybrids were the outcome of low× high, high×low and high×low GCA effects of their parents. The hybrid *viz.*, P<sub>3</sub>×P<sub>6</sub>, P<sub>5</sub>×P<sub>4</sub>, P<sub>6</sub>×P<sub>2</sub> and P<sub>6</sub>×P<sub>5</sub> had one parent as good combiner. Here, the character is under the control of non additive gene action. The *per se* performance

was found to be high for reciprocal cross P<sub>6</sub>×P<sub>5</sub> and this cross showed additive×dominance gene action, the conventional breeding technology needs some modification for capitalizing the genetic effects. In this context, instead of continuous selfing for a number of generations prior to selection, alternate intermating and selfing might be adopted to increase the span of selection. This would enhance the frequency of potential transgressive segregants in such breeding



**Table 8.** *Per se* performance and specific combining ability effects of direct and reciprocal crosses for quality traits

Hybrids	Ascorbic acid		Capsaicin		Colour value		Oleoresin		TSS	
	Direct crosses (SCA)									
	Mean (mg/100 g)	SCA/ RCA	Mean (%)	SCA/ RCA	Mean (ASTA)	SCA/ RCA	Mean (%)	SCA/ RCA	Mean (°Brix)	SCA/ RCA
P1 × P2	104.61	-16.98**	0.68	-0.12**	83.54	5.81**	13.57	0.08	6.87	0.40**
P1 × P3	132.90	11.24**	0.65	0.05**	72.83	3.53*	14.87	0.30*	7.58	0.25*
P1 × P4	125.02	-11.02**	0.61	0.00	92.10	1.88	14.60	0.03	7.07	-0.21*
P1 × P5	98.45	-19.50**	0.66	0.03*	68.25	-4.59**	13.41	0.58**	6.18	0.18
P1 × P6	115.53	-4.50**	0.73	0.00	94.98	1.63	13.06	-0.52**	6.93	0.14
P2 × P3	138.32	20.35**	0.61	0.06**	86.10	0.08	13.70	0.13	6.30	-0.39**
P2 × P4	124.46	-9.53**	0.63	-0.06**	111.79	12.33**	15.97	0.79**	7.63	0.71**
P2 × P5	85.70	-10.39**	0.75	0.07**	76.83	3.12*	14.46	0.44**	6.50	0.17
P2 × P6	130.68	-13.89**	0.58	-0.08**	95.50	4.54**	14.10	-0.01	6.07	-0.27**
P3 × P4	138.35	4.88**	0.58	-0.03**	87.91	0.31	14.45	0.01	6.37	0.18
P3 × P5	122.67	10.40**	0.64	0.08**	80.10	5.67**	13.59	-0.63**	5.58	-0.73**
P3 × P6	158.39	20.36**	0.62	0.02	94.62	-0.26	13.84	0.77**	6.84	-0.17
P4 × P5	127.51	-14.05**	0.60	0.02	81.42	5.11**	14.73	0.16	6.73	0.42**
P4 × P6	134.59	-0.83	0.65	0.02	95.25	4.35**	14.98	-0.08	7.07	0.03
P5 × P6	103.71	-30.28**	0.63	-0.08**	105.68	14.08**	12.74	0.28	7.30	0.73**
<b>SE (sij)</b>		0.861		0.013		1.349		0.144		0.113
	Reciprocal crosses (RCA)									
P2 × P1	138.57	-0.10	0.93	0.11**	92.65	-4.55**	13.06	-1.00**	6.93	-0.21
P3 × P1	110.41	0.42	0.54	-0.01	91.48	-9.32**	14.58	0.14	6.28	0.65**
P4 × P1	147.08	3.93*	0.61	-0.06**	93.94	-0.92	16.09	-0.74**	6.60	0.23
P5 × P1	137.47	5.10**	0.59	-0.01	72.83	-2.29	16.35	-1.47**	6.90	-0.36**
P6 × P1	124.54	-10.05**	0.72	0.00	94.42	0.27	14.95	-0.94**	7.18	-0.12
P3 × P2	97.62	-2.23*	0.47	-0.03**	75.69	5.20**	14.27	-0.28	5.43	0.43**
P4 × P2	143.52	2.90**	0.76	0.05**	99.53	6.12**	15.08	0.44*	7.06	0.28*
P5 × P2	106.50	-15.71**	0.53	-0.00	84.08	-3.62*	13.86	0.30	5.73	0.38**
P6 × P2	158.48	15.51**	0.67	-0.02	104.13	-4.31**	13.76	0.16	6.73	-0.14
P4 × P3	128.59	2.84**	0.65	0.04**	92.04	-2.06	14.91	-0.23	7.27	-0.44**
P5 × P3	101.86	0.91	0.48	0.03*	78.58	0.76	12.46	0.56**	4.83	0.37**
P6 × P3	117.67	9.42**	0.58	-0.01	88.04	3.29*	15.48	-0.82	5.80	0.52**
P5 × P4	155.62	19.32**	0.55	-0.02	101.17	-9.87**	14.68	0.02	6.74	-0.00
P6 × P4	136.25	-4.06**	0.61	-0.04**	121.68	-13.21**	14.38	0.30	6.73	0.17**
P6 × P5	164.28	13.78**	0.79	0.06**	98.72	3.47*	15.35	-1.30**	6.51	0.39
<b>SE (rij)</b>		0.731		0.011		1.588		0.169		0.133

\* Significant at 5% level. \*\* Significant at 1% level

materials. These results are in corroboration with findings of Geleta & Labuschagne (2006) and Khalil & Hatem (2014).

The best performing hybrids for capsaicin content based on SCA effects were P3×P5, P2×P5 and P2×P3 and these hybrids were resultant of low×high, high×low and high×low GCA effects of their parents. The reciprocal hybrids *viz.*, P2×P1, P6×P5 and P4×P2 were the high performing hybrids based on RCA

effects and these hybrids were the outcome of high×high, high×low and low×high GCA effects of their respective parents. The combination P2×P1 registered the highest positive SCA (Table 8), which is a representation of high (positive) ×high (positive) GCA combination suggesting additive×additive gene interaction. This hybrid would throw desirable segregants as the additive gene effects are fixable. This was closely followed by the cross P<sub>3</sub>×P<sub>5</sub> representing

**Table 9.** Best performing F1 hybrids for fruit yield and quality traits in chilli

Based on <i>per se</i>	Number of fruits, individual fresh and dry pod weight and yield	P4 × P2, P2 × P1, P6 × P5
	Fruit yield and quality	P6 × P5, P4 × P2, P2 × P1
	Number of fruits, individual fresh and dry pod weight, fruit yield and quality	P6 × P5, P4 × P2, P2 × P1
Based on SCA (direct crosses)	Number of fruits, individual fresh and dry pod weight and yield	P1 × P3, P2 × P3, P3 × P6
	Fruit yield and quality	P3 × P6, P2 × P4, P1 × P3
	Number of fruits, individual fresh and dry pod weight, fruit yield and quality	P1 × P3, P3 × P6
Based on RCA (reciprocal crosses)	Number of fruits, individual fresh and dry pod weight and yield	P6 × P5, P4 × P2, P3 × P1
	Fruit yield and quality	P6 × P5, P4 × P2, P3 × P2
	Number of fruits, individual fresh and dry pod weight, fruit yield and quality	P6 × P5, P4 × P2,
Based on heterosis over check hybrid	Number of fruits, individual fresh and dry pod weight and yield	P4 × P2, P6 × P5, P2 × P1
	Fruit yield and quality	P6 × P5, P2 × P4, P2 × P1
	Number of fruits, individual fresh and dry pod weight, fruit yield and quality	P6 × P5, P2 × P1

a low (negative) × low (negative) GCA combination suggesting the action of epistasis gene action. While the cross  $P_6 \times P_5$ ,  $P_2 \times P_5$  and  $P_2 \times P_3$  represents a high×low GCA combination probably by additive×dominant interaction. These hybrids had the greatest chance of producing transgressive segregants in later generation. These results were in conformity to the findings of Prasath & Ponnuswami (2008), Jaya Rame Gowda (2009), Savitha (2011) and Munish Sharma (2012).

In a breeding programme of hot pepper with the aim to improve the total extractable colour yield, it is not sufficient to develop genotypes with high fruit yield alone. For colour value, hybrids  $P_5 \times P_6$ ,  $P_2 \times P_4$  and  $P_1 \times P_2$  were best performing based on SCA effects and these were resultant of low×high, low×high and low × low GCA effects of their parents. The reciprocal hybrids *viz.*,  $P_4 \times P_2$ ,  $P_3 \times P_2$  and  $P_6 \times P_5$  were the high performing hybrids based on RCA effects and these hybrids were the outcome of high×low, low× low and high×low GCA effects of their respective parents. The *per se* performance was found to be high in the cross  $P_2 \times P_4$  and showed dominant×additive gene action. For the cross  $P_2 \times P_4$  selection for this trait could be postponed to later generations in recombination breeding. These results are in accordance with the findings of Prasath & Ponnuswami (2008); Savitha (2011).

The best performing hybrids based on SCA effects were  $P_2 \times P_4$ ,  $P_3 \times P_6$  and  $P_1 \times P_5$ . These hybrids were the outcome of low×high, low×low and high×low GCA effects of their respective parents for oleoresin. The reciprocal

hybrids *viz.*,  $P_5 \times P_3$  and  $P_4 \times P_2$  were the best performing hybrids based on RCA effects and these hybrids were the outcome of low×low and high×low GCA effects of their respective parents. The *per se* performance were found to be high for direct cross  $P_2 \times P_4$  and this cross showed dominance×additive gene action and to exploit this genetic variance, conventional breeding procedures such as pedigree selection could be worthwhile. These results were in conformity with the findings of Saritha *et al.* (2005), Savitha (2011) and Munish Sharma (2012).

The hybrids  $P_5 \times P_6$ ,  $P_2 \times P_4$  and  $P_1 \times P_3$  were found to be superior hybrids based on their SCA effects and *per se* performance for total soluble solids content. These hybrids were the products of low×high, low×high and high×low GCA effects of their individual parents. The reciprocal hybrids *viz.*,  $P_3 \times P_1$ ,  $P_6 \times P_3$  and  $P_3 \times P_2$  were the best performing hybrids based on RCA effects and these hybrids were the outcome of low×high, high×low and low×low GCA effects of their respective parents. The *per se* performance was found to be high for direct crosses  $P_2 \times P_4$  and  $P_5 \times P_6$  which showed dominance×additive gene action. Hence biparental breeding would be effective for exploitation of this trait. These hybrids could produce desirable transgressive segregants in the advanced generation. For harnessing non additive gene action in these hybrids, cyclic method of breeding involving selected recombinants and their inter crossing would be more desirable for improving total soluble solids content. Present results were in conformity with finding of Khalil & Hatem (2014).

**Table 10.** Promising  $F_1$  hybrids for fruits, quality and high yield in chilli

Number of fruits, individual fresh and dry pod weight, and yield	$P_4 \times P_2$ , $P_6 \times P_5$ , $P_2 \times P_1$
Number of fruits, individual fresh and dry pod weight, quality and yield	$P_2 \times P_1$ , $P_4 \times P_2$
Quality and yield	$P_2 \times P_1$

The  $F_1$  combinations that surpassed their parents for maximum number of components of merit were  $P_4 \times P_2$  (LCA625×K1),  $P_2 \times P_1$  (K1×Arka Lohit),  $P_6 \times P_5$  (Pusa Jwala×PKM1),  $P_1 \times P_3$  (Arka Lohit×LCA334) and  $P_2 \times P_4$  (K1×LCA625). Further, it was also found that the hybrids  $P_4 \times P_2$  (LCA625×K1) and  $P_6 \times P_5$  (Pusa Jwala×PKM1) were adjudged as the best crosses based on their number of fruits, individual dry weight and yield which are considered as the main objectives of development of hybrids with high yield and quality. The next best hybrid was  $P_1 \times P_3$  (Arka Lohit×LCA334) as evidenced from better scores of number of fruits, fruit length, yield and quality traits. For quality improvement coupled with yield enhancement, the cross  $P_2 \times P_1$  (K1×Arka Lohit) was found to be best as evidenced from the scores obtained for all quality traits and yield in the present investigation (Tables 9 and 10).

In conclusion, analysis of the GCA effects of parents for ten traits studied revealed that  $P_4$  (LCA625),  $P_2$  (K1) and  $P_5$  (PKM1) were the best general combiners for almost all the traits. The hybrids  $P_4 \times P_2$  (LCA625×K1),  $P_2 \times P_1$  (K1×Arka Lohit) and  $P_6 \times P_5$  (Pusa Jwala×PKM1) were found to be the best combiners for yield and its attributes. The hybrid  $P_2 \times P_1$  (K1×Arka Lohit) was the best reciprocal combiner for quality parameters based on their better mean performance and combining ability. Significant SCA and *per se* performance of hybrids  $P_4 \times P_2$ ,  $P_2 \times P_1$  and  $P_6 \times P_5$  indicates there is an opportunity for developing  $F_1$  Hybrids. Further, isolation will enhance the genetic base of the populations by finding new recombinants to increase the yield and fruit quality.

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