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Estimation of heterosis for yield and quality components in chilli (*Capsicum annuum* L.)

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Ten genotypes including five lines (Kashi Anmol, Pant C-1, Japani Longi, Kashi Sinduri and Pusa Jwala) and five testers (R-Line, VR-339, AKC-89/38, DC-16 and Punjab Lal) of chilli were crossed to derive 25 F_1 hybrids. The 35 genotypes (10 parents and 25 F_1 hybrids) were evaluated for yield and quality (capsaicin and oleoresin) traits. Highly significant correlation was observed between fruit yield per plant and average fruit weight (g). The direct and indirect effect on yield revealed that the maximum direct effect was exhibited by average fruit weight followed by number of fruits per plant via yield per plant. The crosses Pusa Jwala × VR-339, Pusa Jwala × DC-16 and Pant C-1 × VR-339 exhibited higher level of heterobeltiosis for most of the traits. The higher specific combing ability (SCA) for yield was obtained in crosses Kashi Sinduri × Punjab Lal followed by Pant C-1 × VR-339 and Pusa Jwala × VR-339. Among the hybrids, Pusa Jwala × VR-339 had higher yield as well as capsaicin content, moreover, Kashi Sinduri × AKC-89/38 exhibited highest oleoresin content. These best hybrids (Pusa Jwala × VR-339, Kashi Sinduri × Punjab Lal and Pant C-1 × VR-339) might be utilized for further chilli improvement programme.

Key words: Chilli, heterosis, correlation, combining ability, capsaicin, oleoresin.

INTRODUCTION

The genus *Capsicum* consists of a diverse range of plants and fruits, and varies enormously with respect to morphology, yield and nutrition related parameters. Chillies are grown as annual crop, although it can also be grown as perennial shrub in suitable climatic conditions. Among the five cultivated species, *Capsicum annuum* L. is most widely cultivated for its pungent (hot pepper) and non pungent (sweet pepper) fruits throughout the world (Bosland and Votava, 2000). Chilli comprises wide spectrum of chemicals including steam-volatile oil, fatty oils, capsaicinoids, carotenoids, vitamins, protein, fiber and mineral elements (Bosland and Votava, 2000). The presence of capsaicinoids is specific to the genus *Caps*icum, which varies widely among varieties, seasons, places of origin, etc (Prasath et al., 2007). The chilli fruits are consumed at different ripening stage (green, red or partial red-ripe). India ranks first in dry chilli production in the world whereas, for the green chillies, the production is low (Anonymous, 2012). Heterosis breeding has been advantageous for increased chilli production. For effective transfer of desirable genes controlling both quantitative and qualitative traits in the resultant progenies,

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Abbreviations: GCA, General combing ability; **SCA,** specific combing ability; **PCV,** phenotypic coefficient of variation; **BP,** mean of better parent; **MP,** mean of mid parent value; **ECV,** environmental coefficients of variation; **h^2b,** heritability in broad sense.

Table 1. Genotypes of chilli employed in the present investigation.

Genotype	Specific traits	Source
Kashi Anmol	High yielding spreading	IIVR, Varanasi, Uttar Pradesh
Pant C-1	Pungent	GBPA&T, Pantnagar, Uttarakhand
Japani Longi	Erect bunch fruited	IIVR, Varanasi, Uttar Pradesh
Kashi Sinduri	Long paprika	IIVR, Varanasi, Uttar Pradesh
Pusa Jwala	Parrot green pungent	IARI, New Delhi
R-LINE	Restorer dark green pungent	AVRDC, Taiwan
VR-339	High yielding long dark fruited	IIVR, Varanasi, Uttar Pradesh
AKC89/38	Round fruited pungent dark colour	PDKV, Akola, Maharashtra
DC-16	Good general combiner	IIVR, Varanasi, Uttar Pradesh
Punjab Lal	High capsaicin and oleoresin content	PAU, Ludhiana, Punjab

it is necessary to exploit the better combining breeding materials (Kearsey and Farquhar, 1998). Since yield is a complex trait, governed by a large number of component traits, it is imperative to know the interrelationship between yield and its component traits to arrive at an optimal selection index for improvement of yield. Several hybrids have been developed in hot chillies; however, the hybrid development programme should be continuous so as to make the seeds available to the growers at affordable cost. This investigation was planned to identify good combiners and heterotic cross combinations for yield as well as quality and its component traits in chilli.

MATERIALS AND METHODS

This investigation was carried out to identify good combiners and heterotic cross combinations for yield and quality traits in chilli. Ten genotypes including five lines (Kashi Anmol, Pant C-1, Japani Longi, Kashi Sinduri and Pusa Jwala) and five testers (R-Line, VR-339, AKC-89/38, DC-16 and Punjab Lal) (Table 1) were crossed to obtain 25 F_1 hybrids. These 35 genotypes (10 parents and 25 resulting F_1 hybrids) were evaluated in a randomized complete block design (RCBD) with three replications at Indian Institute of Vegetable Research, Varanasi during 2007 - 2008. The maximum temperature during that period ranged from 18.9 to 27.2°C and maximum relative humidity ranged from 63 to 92% while the minimum relative humidity ranged from 30 to 83%. The soil type of experimental field was alluvial with average fertility level pH range of 6.6 - 7.4. Recommended package and practices were applied to raise good crops (Bose and Som, 1986).

The observations were recorded on nine horticultural traits, viz. number of fruits per plant, fruit length (cm), fruit diameter (cm), average fruit weight (mean of 10 fruits weight) (g), plant height (cm), yield per plant (g), capsaicin content (%) and oleoresin content (%).

Capsaicin content in chilli powder was estimated by the method of Thimmaiah (1999) and oleoresin content was estimated by the procedure as suggested by Mathew et al. (1971) as per the following formula:

$$\text{Oleoresin content (\%)} = \frac{\text{Dried weight of the residue}}{\text{Fresh weight of the sample}} \times 100$$

The heterosis of F_1s over the better parent (BPH) and mid parent (MPH) was calculated by using the formula:

$$\text{Percent heterosis over better parent (BPH)} = \frac{F_1 - BP}{BP} \times 100$$

$$\text{Percent heterosis over mid parent (MPH)} = \frac{F_1 - MP}{MP} \times 100$$

Where, F_1 = Mean value of F_1s, BP = mean of better parent and MP = mean of mid parent value.

Analysis of combining ability was carried out following Kempthorne (1957). The genetic parameters such as phenotypic, genotypic and environmental coefficients of variation (GCV, PCV and ECV), heritability in broad sense (h^2b), genetic advance and correlation coefficients for each character were estimated as suggested by Tsegaye et al. (2007).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) indicated significant differences between parents for all seven traits, namely, number of fruits per plant, fruit length, fruit width, average fruit weight, fruit yield per plant, plant height and yield per plant (Table 2). The mean sum of squares of parental genotypes for all the characters was highly significant, which indicates that there was substantial variation in characters among genotypes.

The ANOVA for general and specific combining ability for all seven traits were found significant (Table 2). The ratio of general combing ability (GCA) and specific combing ability (SCA) variance revealed preponderance of non-additive genetic variances for all traits except yield per plant (g) that is governed by additive gene action.

The magnitude of phenotypic coefficient of variation (PCV) values for all the traits were higher than the corresponding (GCV) values (Table 3) indicating that these characters may be under influence of the environmental effect to some extent. The highest difference between GCV and PCV was observed for the fruit width (GCV = 12.18, PCV

Table 2. ANOVA for line × tester analysis and its combining ability for seven quantitative traits in chilli.

Source of variance	D.F.	Fruits per plant	Fruit length (cm)	Fruit width (mm)	10 Fruit weight (g)	Fruit weight per plant (g)	Plant height (cm)	Yield per plant (g)
Replication	2	27.84	0.0694	0.0244	4.193	261.75	3.12	44.91
parents	9	1589.62**	11.936**	0.1611**	667.50**	9502.79**	274.54**	10755.50**
Females	4	2023.83**	10.81**	0.0725**	1046.38**	944.82	205.98**	10053.17**
Males	4	1313.95**	7.91**	0.02041**	41.43**	6809.10**	294.41**	12651.05**
Female × Male	1	955.41**	32.48**	0.3434**	164.26**	20509.44**	469.33**	5982.60**
Hybrids	24	915.79**	8.37**	0.07611**	249.83**	9462.16**	103.24**	12990.90**
Parents *vs.* hybrids	1	7630.10**	12.46**	0.1239**	107.28**	79321.41**	236.19**	103327.50**
Error (L × T)	68	71.79	0.1223	0.0123	4.88	1073.06	8.032	682.64
Line (Female)	4	1666.25**	5.72**	0.0384	835.84**	8348.37**	109.46**	17187.39**
Tester (Male)	4	1482.25**	28.49**	0.1982**	156.39**	11604.94**	349.03**	11886.38**
Line × Tester	16	586.56**	4.005**	0.550**	126.69**	9204.92**	40.24**	12217.92**
GCA variance (σ^2g)	-	65.85	0.87	-0.03	24.63	51.45	12.60	154.60
SCA variance (σ^2s)	-	-298.56	-8.16	0.12	-9.90	-800.01	-102.93	110.51
σ^2g/σ^2s	-	-0.22	-0.11	-0.25	-2.49	-0.06	-0.12	1.40
Error	48	66.96	0.083	0.01595	4.785	587.82	6.36	713.63

*, ** Significant at 5 and 1% level, respectively.

Table 3. Mean, range, genotypic and phenotypic coefficient of variation heritability and genetic advance in hybrid of chilli.

Character	Grand mean	Range	Coefficient of variation		Heritability (h^2b)	G.A in percent of mean
			G.C.V	P.C.V		
Fruits per plant	66.47	43.73 - 111.20	25.30	28.41	0.81	46.87
Fruit length (cm)	5.70	2.31 - 9.56	29.15	29.59	0.97	59.12
Fruit width (mm)	1.16	0.86 - 1.40	12.18	16.33	0.56	18.96
Average fruit weight (g)	26.71	87.67 - 322.67	33.84	34.81	0.95	67.76
Plant height (cm)	50.84	40.20 - 61.40	11.18	12.33	0.84	21.04
Yield per plant (g)	174.95	65.40 - 308.22	36.56	39.62	0.85	69.51

= 16.33), which means the environment has maximum influence on fruit width (Table 3).

The high genetic advance coupled with high heritability of average fruit weight (GA = 67.76%, h^2b = 95%), yield per plant (GA = 69.51%, h^2b = 0.85%), fruit weight per plant (GA = 60.13%, h^2b = 0.83%) and fruit length (GA = 59.12%, h^2b = 97%) suggested appreciable level of improvement for these characters subjected to selection. High estimates of heritability for above characters suggested that selection based on phenotypic performance would be effective as propounded by Johnson et al. (1955). Low heritability is noted for an important character, that is, number of fruits per plant (h^2b = 31.16%).

Therefore, it is obvious that selection for number of fruits per plant alone may not be effective in the early generation when the individual plants are selected on the basis of phenotypic performance. High heritability coupled with high genetic advance has been reported for yield and fruit weight per plant in chillies (Munshi and Behra, 2000; Sreelathakumary and Rajamony, 2004; Singh and Yadav, 2008).

Highly significant genotypic correlation was observed for average fruit weight (0.752), with significant correlation with fruits per plant (0.496) (Table 6). It suggests that increase in these characters would result in increase in yield. Average fruit weight was also significantly correlated with fruit length (0.472) and negatively correlated with fruits per plant (-0.183). Negative genotypic correlation was found between fruit length and number of fruits per plant (-0.118), fruit width and fruits per plant (-0.150), fruit and fruit length (-0.367); and average fruit weight and fruits per plant (-0.183), which indicate that increase in fruits per plant would result in decrease in fruit weight. The direct and indirect effect (Table 5) on yield revealed that the maximum direct effect was exhibited by average fruit weight (P = 732, G = 0.704) followed by fruits per plant (0.589) via yield per plant. Similar results have been reported in chillies by Palsudesai et al. (2006), Hosamani and Shivkumar (2008) and Ganeshreddy et al. (2008), where they observed significant correlation of various

Table 4. Best three heterotic F_1s and GCA and SCA effects for six characters in chilli.

Character	Hybrids (F_1)	BP (%)	MP (%)	Parent	GCA	Hybrids (F_1)	SCA
Fruits per plant	Pusa Jwala × DC-16	161.55	163.71	DC-16	16.73	Pant C-1 × VR-339	24.19
	Pusa Jwala × VR-339	127.63	160.19	PantC-1	13.87	Pant C-1 × DC-16	14.12
	Japanese Longi × DC-16	96.43	110.57	Pusa Jwala	5.71	Kashi Sinduri × R Line	15.14
Fruit length (cm)	Pant C-1 × Punjab Lal	52.38	71.63	R Line	2.15	Japanese Longi × AKC-89/38	2.24
	Pant C-1 × DC-16	51.68	59.42	Kashi Sinduri	0.80	Pant C-1 × Punjab Lal	1.34
	Pant C-1 × R Line	37.99	74.91	Pusa Jwala	0.52	PusaJwala × VR-339	1.04
Fruit width (mm)	Japanese Longi × DC-16	20.69	34.62	AKC-89/38	0.14	JapaneseLongi × DC-16	0.26
	Japanese Long I × Punjab Lal	12.68	21.48	Kashi Sinduri	0.08	Japanese Longi × VR-339	0.14
	Kashi Sinduri × R Line	7.57	9.04	VR-339	0.08	KA-2 × AKC-89/38	0.12
Average fruit weight (g)	Pant C-1 × Punjab Lal	123.33	123.33	Kashi Sinduri	12.95	Kashi Sinduri × PunjabLal	11.60
	Pant C-1 × DC16	90.00	93.22	VR-339	2.92	KA-2 × AKC-89/38	8.10
	Pusa Jwala × R Line	22.34	49.35	R Line	4.00	Pusa Jwala × VR-339	7.68
Plant height (cm)	Kashi Sinduri × Punjab Lal	17.15	20.63	R Line	4.96	PusaJwala × R Line	5.97
	Pusa Jwala × R Line	12.73	18.88	PantC-1	3.37	KA-2 × DC-16	3.72
	KA-2 × Punjab Lal	15.68	23.68	VR-339	2.69	JapaneseLongi × VR-339	3.16
Yield per plant (g)	Pusa Jwala × VR-339	220.53	264.47	Kashi Sinduri	37.11	Kashi Sinduri × PunjabLal	99.77
	Pusa Jwala × DC-16	205.53	312.85	VR-339	27.06	Pant C-1 × VR-339	92.59
	Pant C-1 × VR339	239.00	247.77	RLine	21.26	Pusa Jwala × VR-339	70.80

yield attributing traits with fruit yield.

Considering yield and number of fruits per plant, out of 25 F_1s, 3 cross combinations *viz.,* Pusa Jwala × DC-16 (161.55%) exhibited highest heterobeltiosis followed by Pusa Jwala × VR-339 (127.63%) and Japani Longi × DC-16 (96.43%) (Table 4). The corresponding values for these crosses for mid parent heterosis was 163.71, 160.19 and 110.57%, respectively. Regarding fruit length, Pant C-1 × Punjab Lal, Pant C-1 × DC-16 and Pant C-1 × R line showed 52.38, 51.68 and 37.99% heterosis over better parent, respectively. For these crosses, heterosis over mid parent for fruit length was observed to be 71.63, 59.42 and 74.91, respectively. For yield per plant (g) the crosses Pusa Jwala × VR-339 (220.53%), Pusa Jwala × DC-16 (205.53%) and Pant C-1 × VR-339 (239%) may be exploited for hybrid vigour in chilli (Tembhurne and Rao, 2012; Sharma et al., 2013). The high heterotic response as observed in most of the crosses further supported the predominant role of non-additive component in the inheritance of the character studied.

In the present study, none of the lines or testers exhibited significant GCA effects for all the characters (Table 6). The lines identified as promising combiner for different characters were Pant C-1 for number of fruits per plant and plant height, Pusa Jwala for number of fruits per plant and fruit length and Kashi Sinduri for fruit length, fruit width, and average fruit weight per plant and yield per plant. Among the testers, VR-339 was found to be good combiner for fruit width, average fruit weight per plant, plant height and yield per plant, R-Line for fruit length, average fruit weight, plant height and yield per plant, DC-16 for number of fruits per plant, and AKC-89/38 for fruit width. In terms of better general combiner, Pant C-1, DC-16 were found to be good general combiners for number of fruits per plant while Kashi Sinduri, VR-339 and R-Line were found to be good general combiners for yield per plant. It is therefore suggested that the above mentioned genotypes may be exploited in hybrid breeding program for increasing fruit weight and number of fruits in chilli. The crosses exhibiting best SCA effects for fruits per plant were Pant C-1 × VR-339, Pant C-1 × DC-16 and Kashi Sinduri × R-Line; for fruit weight per plant, Pusa Jwala × VR-339, Kashi Sinduri × R-Line and Pant C-1 × VR-339 (Table 4).

In general, the crosses which were heterotic as well as good specific combiner for fruits per plant, fruit weight per plant (g) and yield per plant were Pant C-1 × VR-339, Pant C-1 × DC-16, Pusa Jwala × VR-339, Kashi Sinduri × R-Line and Kashi Sinduri × Punjab Lal. Pant C-1 × VR-339, Pant C-1 × DC-16 and Kashi Sinduri × R-Line involving both the high general combiners for fruits per plant, fruit yield perplant and could; therefore, be due to additive and additive × additive type of gene interaction which are fixable in nature.

High general combining ability of the parents therefore seems to be reliable criterion for the prediction of specific combining ability. For number of fruits per plant, KA-2 × DC-16 and Kashi Sinduri × Punjab Lal involved low × high general combiner, while KA-2 × AKC-89/38 and Kashi Sinduri × R-Line involved low × low general combiners. Heterosis in the cross involving low × high general combiner might be due to dominant × additive type of interaction which is partially fixable and the crosses involving both the poor combining parents and showing high SCA

Table 5. Phenotypic and genotypic correlation coefficient for six characters in chilli.

Character		Fruit length (cm)	Fruit width (mm)	Average fruit weight (g)	Plant height (g)	Yield per plant (g)
Fruits/ plant	P	-0.091	-0.065	-0.152	0.222	0.535**
	G	-0.118	-0.150	-0.183	0.155	0.496*
Fruit length (cm)	P		-0.259	0.459*	0.289	0.332
	G		-0.367	0.472**	0.323	0.351
Fruit width (mm)	P			0.243	0.072	0.180
	G			0.325	0.094	0.211
Average fruit weight (g)	P				0.219	0.730**
	G				0.233	0.752**
Plant height (cm)	P					0.304
	G					0.278

P, Phenotypic; G, genotypic.

Table 6. Phenotypic and genotypic path analysis of six characters in chilli.

Character		Fruit length (cm)	Fruit width (mm)	Average fruit weight (g)	Plant height (g)	Yield per plant (g)	Fruit length (cm)
Fruits/ plant	P	0.589	0.001	-0.001	-0.112	-0.005	0.535
	G	0.496	0.010	0.008	-0.129	0.003	0.496
Fruit length (cm)	P	-0.053	-0.007	-0.003	0.336	-0.006	0.332
	G	-0.058	-0.087	0.019	0.332	0.006	0.351
Fruit width (mm)	P	-0.038	0.002	0.011	0.178	-0.001	0.180
	G	-0.074	0.032	-0.051	0.229	0.002	0.211
Average fruit weight (g)	P	-0.090	-0.003	0.003	0.732	-0.005	0.730
	G	-0.091	-0.041	-0.017	0.704	0.004	0.752
Plant height (cm)	P	0.131	-0.002	0.001	0.160	-0.021	0.304
	G	0.007	-0.028	-0.005	0.164	0.019	0.278

P, Phenotypic; G, genotypic.

Table 7. Fruit quality traits of parental lines of chilli.

Parent	Fruit colour	Oleoresin (%)	Capsaicin (%)
Kashi Anmol (KA-2)	Green	8.8	0.9
Pant C-1	Light Green	9.73	1.07
Japani Longi	Green	8.2	0.93
Kashi Sinduri	Green	12.13	0.3
Pusa Jwala	Yellow	9.4	0.88
R-Line	Dark Green	8.13	0.71
VR-339	Light Green	11.7	1.21
AKC 89/38	Green	9.86	1.25
DC-16	Dark Purple	12.06	0.93
Punjab Lal	Light Green	10.1	1.11

may be due to intra and inter-allelic interaction. Overall, the crosses Kashi Sinduri × Punjab Lal, Pant C-1 × VR-339 and Pusa Jwala × VR-339 showing high SCA for yield also exhibited high or average SCA effects for yield component traits. These crosses exhibited significant SCA effects indicating the presence of non-additive gene

Table 8. Fruit quality traits of promising chilli hybrids (F_1's).

Hybrid	Fruit colour	Oleoresin (%)	Capsaicin (%)
KA-2 × R Line	Green	12.26	0.71
KA-2 × VR339	Green	10.53	1.15
KA-2 × AKC-89/38	Green	8.93	1.06
KA-2 × Punjab Lal	Green	10.53	0.95
Pant C1 × R line	Green	10.86	1.09
PantC1 × VR 339	Light Green	8.73	1.19
Pant C1 × AKC-89/38	Green	9.60	1.13
Pant C1 × DC 16	Dark Purple	9.26	0.97
Japani Longi × VR-339	Green	10.26	0.76
Japani Longi × AKC-89/38	Green	11.06	1.15
Japani Longi × DC 16	Dark Purple	11.20	0.97
Kashi Sinduri × R line	Green	12.33	0.65
Kashi Sinduri × VR-339	Green	10.46	0.64
Kashi Sinduri × AKC-89/38	Green	11.80	0.69
Kashi Sinduri × DC 16	Dark Purple	10.46	0.70
Kashi Sinduri × Punjab Lal	Green	9.46	1.02
Pusa Jwala × VR 339	Light Green	9.86	1.72
Pusa Jwala × Punjab Lal	Light Green	10.05	1.36

action. Similar results were reported by Prasath and Ponnuswami (2008a).

For quality components, the parental lines AKC-89/38 (1.25%) and VR-339 (1.21%) recorded highest capsaicin content (%) while, Kashi Sinduri (12.13%) and DC- 16 (12.06%) recorded highest oleoresin content (Table 7). Among the hybrids (Table 8), Pusa Jwala × VR-339 (1.72%) followed by Pusa Jwala × Punjab Lal (1.36%) recorded highest capsaicin content moreover, Kashi Sinduri × R Line (12.33%) followed by KA-2 × R Line (12.26%) exhibited highest oleoresin content (%) as reported by Ben-Chaim et al. (2006), Prasath et al. (2007) and Prasath and Ponnuswami (2008b).

In the present study based on *per se* performance, heterosis and SCA effects, the hybrids Pusa Jwala × VR-339, Kashi Sinduri × Punjab Lal and Pant C-1 × VR-339 were found superior for yield and quality traits. The three short listed hybrids may be utilized for further chilli breeding programme.

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