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Combining ability and heritability analysis for yield and yield contributing characters in chilli (*Capsicum annuum*) landraces

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Abstract

Six different homozygous divergent parents, CCA 2, CCA 5, BARI Morich 1, CCA 11, CCA 15 and CCA 19 were evaluated for combining ability using 6×6 diallel cross excluding reciprocals. The results showed that the general combining ability (GCA) was significant for all days to 50% flowering, fruit length, fruit width, fruit weight, days to fruit maturity (green), days to maturity (ripe), plant height, plant canopy width, number of seeds per plant, number of fruits per plant and yield per plant. Significant specific combining ability (SCA) was also observed for all the measured variables except fruit width. Both additive and non-additive effects influenced the performance of the hybrid in all the traits. The non-additive effects played a more important role than additive effects in studied traits. The parents CCA 5, BARI Morich 1 and CCA 19 were found as the reliable general combiners. Considering the SCA effects and mean performance, hybrids 36 and 23 were the best genotypes. Top two yield were obtained in hybrids 36 (BARI Morich 1× CCA 19) (898.87g yield per plant) and 23 (CCA 5× BARI Morich) (833.63g yield per plant). No parent and cross had significant GCA and SCA effects, respectively in all the traits studied. Broad sense heritability of all the 11 characters was above 90% indicating that all traits are highly heritable. Narrow sense heritability of days to 50% flowering, fruit length, fruit width, fruit weight, days to fruit maturity (green), days to maturity (ripe), plant height, plant canopy width were high (37.34-81.26), whereas the number of seeds per plant, number of fruits per plant and yield per plant were in medium range of narrow sense heritability (18.42-29.19). Estimates of heritability by mid parent-offspring regression indicated that all the studied traits were highly heritable.

Keywords: General combining ability, specific combining ability, Gene action, Capsicum *annuum*.
Abbreviations: ANOVA- Analysis of variance, AVRDC- Asian Vegetable Research and Development Centre, BARI- Bangladesh Agricultural Research Institute, EC- Emulcifiable concentrate, GOB-Govt. of Bangladesh, GCA- General combining ability, MoA-Ministry of Agriculture, Pvt. Ltd- Private Limited, SCA- Specific combining ability, WP- Water soluble powder.

Introduction

Chilli (*Capsicum annuum* L.), the world's second most important solanaceous vegetable after tomato, is grown worldwide both as a spice or vegetable crop. It is a diploid (2n=24) species and genetically self-pollinated and chasmogamous crop whose flowers open only after pollination (Lemma, 1998). However, 2 to 96% out-crossing was observed under open pollination (AVRDC, 2000). The diallel analysis helps to obtain information on the genetic systems governing the inheritance of attributes to be improved, and hence may help in predicting the performance in subsequent generations by assessing the potential of different crosses. Plant breeders use diallel analysis as an aid in selection and to investigate genetic properties of parents and their crosses. Diallel analysis provides information on average performance of individual lines in crosses known as general combining ability (GCA). It also gives information about the performance of crosses relative to the average performance of parents involved in the cross known as specific combining ability (SCA). Significant GCA and SCA effects provide information to determine the efficacy of breeding for improvements in given traits and they can be used to identify the lines to be served as parents in a breeding program for improvement (Kearsey and Pooni, 1996). In addition, this technique enables the breeder to combine desirable genes that are found in two or more genotypes (Dabholkar, 1992).

Determination of heritability is useful to study genetic change of a population undergoing selection (Falconer, 1981) and to choose among alternative breeding programs (Hill, 1971). Offspring-parent regression is a widely used estimator of heritability that is simple to compute and is unbiased even when selection of parents occurs (Falconer, 1981). This is the only method that has been proved unbiased in the presence of selection. Landraces are variable plant populations adapted to local agro-climatic conditions, which are locally named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological needs (Teshome et al., 1997). Generally, landraces are genetically diverse and constitute variable populations, where variation can be seen between and within populations (Zeven, 1998) and represent a very important source of genetic diversity that can be exploited for plant breeding.

Table 1. List of chilli (*Capsicum annuum*) accessions used in the study.

Parent	Accession	Place of Collection	Center of Origin	Main famous characteristic
1	CCA 2	Bangladesh	Landrace of Bangladesh	Hot, light green, medium, wrinkled fruit with low bearing habit, medium plant height
2	CCA 5	Bangladesh	Landrace of Bangladesh	Green, smooth, medium, hot fruit with moderate bearing habit, medium plant height
3	BARI Morich 1 (Bangla lonka)	Bangladesh (Only released variety of BARI)	Srilanka	Hot, smooth, medium, green fruit with moderate bearing habit, bushy type
4	CCA 11	Thailand	Unknown	Very long, pale green fruit with low bearing habit, plant height low
5	CCA 15	Bangladesh	Landrace of Bangladesh	Hot, light green, small, thin fruit with moderate bearing habit, light bushy type
6	CCA 19	Bangladesh	Landrace of Bangladesh	Hot, wrinkled, medium, deep green fruit with moderate bearing habit, medium plant height

The Bangladeshi chilli landraces are heterogeneous and serve as a reservoir of genetic variability for the plant breeders. But, the yield of these land races is very low in Bangladesh. During 1998-1999 to 2005-2006, average yield was 0.89 ton/ha (BBS, 2007) which is much lower than neighboring country India. In India, during 2003-2004 to 2007-2008, the average chilli production was 1.6 tons/ha (MoA, 2010). Improving the crop through developing high-yielding varieties with desirable qualities could reverse the existing trend of low productivity of the crop. In Bangladesh, no pure line variety has been developed through gene recombination and very few hybrid varieties have been developed by private seed companies. Efforts to improve the crop have been constrained mainly by a lack of adequate information on the genetic control of characteristics of the yield and yield related traits of Bangladeshi landraces. Considering the importance of chilli and in view of the above-mentioned constraints, the present study was undertaken to estimate the general combining ability (GCA), specific combining ability (SCA) and heritability.

Results and Discussion

Analysis of variance

The analysis of variance (ANOVA) for yield and yield contributing characters indicated significant differences among genotypes for all the traits studied (Table 3). ANOVA for combining ability showed that GCA variance was significant for all the traits. Significant SCA variance was observed for all the measured variables except fruit width. For almost all characters both additive and non-additive gene action influenced the performance of the hybrids. The non-additive effects played a more important role than additive effects. The magnitudes of GCA and SCA effects are indicative of the relative importance of additive and non-additive gene actions in the inheritance of a trait, respectively. The large GCA: SCA variance ratio suggests the importance of additive gene effects, while a low ratio signifies presence of dominant and/or epistatic gene effects (Kornegay and Temple, 1986). The lower σ^2g/σ^2s ratio indicates that the predominance of non-additive (dominance or epistasis) gene action is important for all the traits (Table 4). The results suggested the possibility of the hybrid vigor exploitation because of the significant non-additive effects for all the traits. These effects could be important in maximizing these traits. A very few researchers reported the gene action in chilli. They reported that fruit length and fruit diameter have the additive gene effect (Lohithaswa et al., 2001). Only non-additive gene effects were responsible for the expression of days to flowering, plant height, number of fruits per plant, days to fruit ripening and fruit yield per plant (Shukla et al., 1999). However, both additive and non-additive gene actions, with the latter predominating, for days to 50% Flowering, days from fruit set to fruit maturity, fruit length and girth, and fresh fruit, 100-dry fruit and 100-seed weights have also been reported (Bhagyalakshmi et al., 1991). Marame et al. (2009) studied the results of a diallel cross in hot pepper in Ethiopia and observed highly significant genotypic differences for plant height, number of fruits per plant, days to maturity, fruit length, single fruit weight and canopy diameter. Variance components due to specific combining ability (dominance) were larger than general combining ability (additive) for number of fruits per plant, days to maturity, single fruit weight and canopy diameter. This indicates that there are differences among the previous research findings. The present investigation has similarity with the results of Shukla et al. (1999), Bhagyalakshmi et al. (1991) and Marame et al. (2009). Difference in findings may be due to difference in genetical background of the parents and growing environments.

GCA effect of the parents

Estimates of the GCA effect and mean of the parents in F_1 generation are shown in Table 4. We found that some of the parents are good general combiners for yield and yield contributing characters. The parent CCA 5 was found as a good general combiner for yield per plant along with days to 50% flowering, number of fruits per plant, days to fruit maturity (green and ripe) and plant canopy width. The GCA effects of yield per plant and number of fruits per plant in the parents BARI Morich 1 and CCA 19 were also positively high and significant. Good general combiners for number of fruits per plant, plant canopy width and yield of chilli were reported by a number of researchers (Lohithaswa et al., 2001; Nandadevi and Hosamani, 2003; Shukla et al., 1999; Lohithaswa et al., 2000; Bhagyalakshmi et al., 1991). Although significant GCA was observed in all the traits but no parent was found having significant GCA in all the traits studied. Considering the situation, CCA 5 was indicated as the best general combiner. It showed negative GCA effects for days to 50% flowering and days to fruit maturity (green

Table 2. Expected MS of combining ability (Bulmer, 1980).

Sources of variation	df	Expectations of mean squares
GCA	p –1	(P-2) Vg + Ve
SCA	p (p -1) / 2	Vs + Ve
Error	M	Ve

Where, Vg = variance due to GCVs = variance due to SCA Ve = environmental variance p = number of parents.

These variances were translated into different components of phenotypic variance as: Additive genetic variance $V_A = 2\,Vg$, Total genetic variance $V_G = 2\,Vg + Vs$, Phenotypic variance $Vp = 2\,Vg + Vs + Ve$, Heritability in broad sense (h^2_b) and narrow sense (h^2_n) were estimated as- $h^2_b = (V_G / Vp) \times 100$, $h^2_n = (V_A / Vp) \times 100$. Narrow sense heritability was also estimated from parent-offspring regression as-

I. $$b_{op} = \frac{Cov(PO)}{V(P)}$$

Where, b_{op} = Regression coefficient of offspring on mid Parent.

Cov (PO) = Mid parent-offspring covariance V (P) = Mid parent variances. The regression coefficient was tested against zero by conventional t-test using standard error as-

$$S_b = [\frac{SS(O) - b \times SP(PO)}{(N-2) \times SS(O)}]^{1/2}$$

Where, S_b = standard error of b_{op}. Where, SS (O) = sum of squares due to offspring. SP (PO) = sum of products due to parent-offspring N = number of observations 't' = bop / S_b

and ripe) in the parent indicates early flowering and early fruit maturity (green and ripe) and highly positive significant GCA effects for plant canopy width, number of fruits per plant and yield per plant indicates wider canopy bears more fruits with higher yield per plant. Presence of high GCA effects towards the desirable direction in number of fruits per plant and yield per plant in BARI Morich 1 and CCA 19 made them good general combiners. In majority of the cases, good general combiners showed better mean performance indicating that the parent may be selected either based on GCA, mean performance or by combination of them. Similar views were also suggested for parent selection by Ahmed et al. (1999) and Geleta et al. (2004).

SCA effect of the crosses

SCA effects of the crosses in F_1 generation are given in Table 5. The table shows that there were a good number of crosses with significant SCA effects in desirable direction for yield and yield contributing characters. The SCA effect showed that the best specific combination for days to 50% flowering with significant negative values were 23, 25, 34, 46, where as hybrids 15, 16, 25, 34, 46 and 56 showed significant positive values of SCA effects for fruit length. The hybrids 36 and 16 showed significant high positive SCA effects for number of fruits per plant. Maximum positive SCA effect and *per se* performance (Table 6) for yield per plant was observed in hybrid 36. Significant SCA effects for days to 50% flowering, fruit weight, number of seeds per fruit and days to fruit maturity (green and ripe) were observed in hybrid 36 and direction of SCA effects of all the traits occurred in desirable way except days to 50% flowering. Nandadevi et al. (2003) observed high positive significant SCA effect for green fruit yield per plant in two crosses among 15 F_1. Lohithaswa et al. (2000) evaluated ten parental genotypes of chilli (*Capsicum annuum*) and their 45 F_1s from a half-diallel cross in 3 different environments and they identified 15 crosses as good specific combinations for fruit yield and other related traits.

The SCA effects of all traits under study were significant, but no cross was significant for all the traits. Considering the SCA effects and *per se* performance, crosses 36 and 23 were the best and all the three parents, CCA 5, BARI Morich 1 and CCA 19, involved in the crosses were identified as good general combiners. Hybrids were descended from one or two parents with maximum values for yield and yield related traits and at least one of the parents with significant positive GCA and SCA effects identified, indicating the efficiency of diallel method in Chilli breeding. Similar data were found for fruit width, fruit weight and fruit wall thickness by Geleta and Labuschagne (2004a) working with three way and simple hybrids in *C. annuum*. According to Griffing (1956b), choosing the hybrids with high specific combining ability effects, and including at least one parent with high or average GCA effects for a particular trait is a good strategy for plant breeding. Geleta and Labuschagne (2004b) showed that fruit yield crosses ranged 123.4–538.8 g/plant in *C. annuum*. Single cross, three-way cross and doubled cross of *C. annuum* varieties produced 173, 229 and 218 g fruit yield/plant, respectively (Geleta and Labuschagne, 2004a). These authors considered those hybrids with high yield potential.

In the present study, yield of hybrids 36 and 23 were 833.63 g and 898.87 g /plant, respectively, which were much higher than previous reports. We suggest that there is an opportunity for developing F_1 hybrid with high values for these characters.

Heritability

Estimation of heritability and mid parent-offspring regression for yield and yield contributing traits are presented in Table 6. Broad sense heritability of all the 11 characters was above 90%, indicating that traits are highly heritable. Wide variation in narrow sense heritability was observed in these traits. Narrow sense heritability of days to 50% flowering, fruit length, fruit width, fruit weight, days to fruit maturity (green), days to maturity (ripe), plant height, plant canopy width were high and number of seeds per plant, number of fruits per plant, yield per plant were medium according to classification of Robinson, (1965).

Estimates of heritability by mid parent-offspring regression of the 11 different traits ranged from 0.14 to 1 (Table 7). All the characters except fruit weight had equal variance for parents (Not shown in Table). Mid-parent offspring regressions are most reliable when parental variances are equal (Falconer, 1981). Mid-parent offspring regression indicated that all the characters were highly heritable with presence of high additive variance. Parent offspring regression is a widely used estimator of heritability that is simple to compute and is unbiased even the selection of

Table 3. Analysis of variance for different yield parameters of Parents and F_1 in chilli (*Capsicum annuum*)

	df	Days to 50% flowering	Fruit length (cm)	Fruit width (mm)	Fruit weight (g)	Number of seeds per fruit	Number of fruits per plant	Days to fruit maturity (green)	Days to fruit maturity (ripe)	Plant height (cm)	Plant canopy width (cm)	Yield per plant (g)
Genotype	20	165.53**	2.87**	1.85 **	2.63**	511.22**	11180.9**	24.40**	30.90**	215.72**	158.00**	136820**
Replication	2	38.16*	0.04	1.33	0.08	16.26	98.37*	18.14*	5.062	6.369	111.66*	2468.82
Error	40	9.94	0.11	0.50	0.05	29.29	97.75	5.61	7.92	13.46	27.90	1385.24
Total	62	61.04	1.00	0.96	0.89	184.33	3672.98	12.08	15.24	78.48	72.57	45108.7
CV		7.10	4.40	7.40	7.40	8.10	5.80	6.50	5.40	6.30	7.70	7.50

* P<0.05, ** P<0.01 respectively

Table 4. Analysis of variance for combining ability of different yield parameters of chilli (*Capsicum annuum*) in F_1 Generation

	df	Days to 50% flowering	Fruit length (cm)	Fruit width (mm)	Fruit weight (g)	Number of seeds per fruit	Number of fruits per plant	Days to fruit maturity (green)	Days to fruit maturity (ripe)	Plant height (cm)	Plant canopy width (cm)	Yield per plant (g)
GCA	5	358.15**	7.87**	4.00**	4.96**	309.88**	10024.63**	43.30**	33.19**	477.70**	188.89**	74907.66**
SCA	15	109.58**	0.90**	0.51	1.12**	547.24**	12119.29**	15.78**	25.63**	79.41**	143.05**	164847.81**
Error	40	3.31	0.04	0.16	0.02	9.76	32.58	1.87	2.64	4.49	9.30	461.75
σ^2A		59.14	1.31	0.64	0.82	50.02	1665.34	6.90	5.09	78.87	29.93	12407.65
σ^2D		106.26	0.87	0.35	1.10	537.48	12086.71	13.91	23.00	74.93	133.75	164386.07
σ2g		29.57	0.65	0.32	0.41	25.01	832.67	3.45	2.55	39.43	14.97	6203.83
σ2s		106.26	0.87	0.35	1.10	537.48	12086.71	13.91	23.00	74.93	133.75	164386.07
σ^2g/σ^2s		0.28	0.75	0.90	0.37	0.05	0.07	0.25	0.11	0.53	0.11	0.04

* P<0.05, ** P<0.01 respectively

Table 5. GCA effects and mean performance for different yield parameters of the six different chilli parents

Parent		Days to 50% flowering	Fruit length (cm)	Fruit width (mm)	Fruit weight (g)	Number of seeds per fruit	Number of fruits per plant	Days to fruit maturity (green)	Days to fruit maturity (ripe)	Plant height (cm)	Plant canopy width (cm)	Yield per plant (g)
CCA 2 (1)	GCA	0.13	-0.62**	-0.34*	-0.50**	6.46**	4.56*	1.42**	0.82	5.26**	2.37*	-58.27**
	Mean	45.00	5.56	8.59	1.80	80.97	109.40	40.30	57.30	71.72	71.54	189.60
CCA 5 (2)	GCA	-3.93**	-0.12	0.08	0.08	-1.04	10.97**	-2.26**	-1.58**	4.27**	2.73*	52.37**
	Mean	37.67	7.08	10.02	2.80	64.57	141.10	33.17	50.17	64.44	69.31	313.67
BARI Morich 1 (3)	GCA	0.57	-0.48**	0.15	0.07	-2.97**	11.10**	-0.11	-0.65	-7.48**	-0.49	77.40**
	Mean	36.33	6.49	9.68	3.04	41.37	82.13	38.67	54.30	35.37	62.48	245.47
CCA 11 (4)	GCA	-5.37**	1.01**	0.69**	0.86**	-3.39**	-41.13**	0.41	0.63	-2.54**	-5.14**	-46.62**
	Mean	36.33	9.35	11.39	5.95	89.20	75.00	41.37	57.43	53.72	58.98	281.73
CCA 15 (5)	GCA	5.13**	0.38**	-0.54**	-0.27**	-1.55	-4.14*	-0.87	-0.91	-0.80	-1.11	-49.36**
	Mean	49.67	7.53	7.45	1.78	58.17	179.96	36.47	51.83	52.52	59.98	313.67
CCA 19 (6)	GCA	3.46**	-0.17*	-0.04	-0.25**	2.48*	18.65**	1.41**	1.69**	1.29	1.65	24.48**
	Mean	48.33	7.40	9.82	2.77	69.33	136.70	41.30	60.07	64.84	73.09	373.30
S.E. (gi)		0.62	0.064	0.14	0.04	1.05	1.95	0.46	0.55	0.72	1.05	7.31

* P<0.05, ** P<0.01 respectively.

parents occurs (Falconer, 1981). This is the only method that has been proved unbiased in the presence of selection. The result differed slightly with previous one. This may be due to the method of calculation. The estimates of heritability are influenced by various factors, viz. type of genetic material, sample size, sampling method, conduct of experiment, method of calculation and effect of linkage (Fehr, 1987).

A number of researchers reported the heritability of traits in chilli. The estimated heritability was observed in days to 50% flowering (82.9%), fruit length (74.00 - 99.40%), fruit girth (89%), fruit weight (92.40%), number of fruits per plant (81.1-96.18%), number of seeds per fruit (74.00 - 99.40%), plant height (93.4-98.12%) and total green fruits per plant (88.40%) (Shirshat et al., 2007; Ibrahim et al., 2001; Bhagyalakshmi et al., 1990; Ukkund et al., 2007). The high heritability indicates the existence of additive genes in the expression of traits that could be easily exploited (Bharadwaj et al., 2007). The present investigation is in close agreement with previous investigations of different researchers done in different environments with different genotypes. The observed high broad sense heritability estimates indicated genetic variances with lesser influence of the environment and the potential effectiveness of selection of the hybrids for traits of interest (Allard, 1960).

Selection of a trait should fairly be easy if heritability of that trait is very high. This is because there would be a close correspondence between genotype and phenotype due to a relatively smaller contribution of environment to the phenotype. Nevertheless, for a trait with low heritability, selection may be considerably difficult or virtually impractical due to the masking effect of the environment on the genotypic effects (Singh, 1990). Based on previous reports and results of the present study, in respect of all the traits, high heritability estimates appear to be important for effective improvement of chilli.

Materials and methods

Experimental site and soil characteristics

The experiment was conducted at Research and Development Farm of Lal Teer Seed Limited at Basan (North 23.9763^o and East 090.3539^o), Gazipur, Bangladesh from October, 2007 to July, 2009. The soil of the experimental plot was clay loam, slightly acidic in nature (soil pH 6-6.5) and low nitrogen content.

Plant materials

Six chilli genotypes (Table 1) were crossed in a diallel mating system excluding the reciprocals in 2007-2008. These six genotypes, had been selfed for more than six generations, supplied by Lal Teer Seed Limited, Bangladesh, Limited.

Seed sowing, cultivation and crossing

In 2007-2008, the parental materials were sown in 26 September, 2007 in the tray and transplanted in the field in 3 November, 2007. Crossing was done in 6×6 diallel fashion excluding reciprocals during December, 2007 to April, 2008. The mature F_1 fruits were harvested and dried and then seeds were threshed and stored in gene bank. In 2008-2009, the seeds of six parents and their 15 F_1's were sown in the seedling tray in 10th September 2008. The media in the seedling tray prepared by using coconut coir, ash and decomposed cow dung at a ratio of 50%, 25% and 25%, respectively. The seedlings at the age of 4 to 5 leaves were transplanted to the field. The transplantation of seedlings was done on 16th October 2008. Raised beds were prepared for transplanting and the width of bed was 1.5 meter. The plant to plant and row to row distance was 50 and 70 cm, respectively. Bed to bed distance was 1.0 meter that was used as drain.

Fertilizer application and intercultural operation

Cow dung, Urea, Triple super phosphate (TSP), muriate of potash (MP), Gypsum and Zinc Oxide were applied at the rate of 15 tons, 200, 300, 200, 110 and 5 Kg per hectare, respectively. The entire amount of cow dung, TSP, Zinc Oxide, Gypsum and one-third of the urea and MP was applied at the time of final land preparation while the rest of the urea and MP was applied at two equal installments, 25 and 50 days after transplanting. At the time of transplanting, Dursban 20EC (active ingredient: chlorpyrifos, Dow AgroSciences India Pvt. Ltd) and Ridomil MZ 68 WP (active ingredients: 4% Metalaxyl-M and S-isomer and 64% Mancozeb, Syngenta) were applied at the rate of 5 ml/L and 3g/L accordingly for soil treatment. Irrigation was given as and when necessary. Weeding was done every 20 days.

Data collection

Ten random samples (plants) from each plot (replication) from parents and F_1 were taken for data collection. Data were collected on days to 50% Flowering, fruit length, fruit width, fruit weight, number of seeds per fruit, number of fruits per plant, days to fruit maturity (green), days to fruit maturity (ripe), plant height, plant canopy width, yield per plant.

Data analysis

Combining ability of the diallel cross was analyzed following method 2 (parents and one set of F_1s but no reciprocals) and model 1 (fixed effects model) of Griffing (1956a). The analysis was performed on individual environments using the DIALLEL-SAS 05 program (Zhang et al., 2005). The general linear model of combining ability for an individual environment (Zhang and Kang, 1997) was as follows:

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

Where,
y_{ijk} = Observed trait value from each experimental unit (i and j, parents; k, replication)
μ = general mean
g_i = General combining ability (GCA) of the ith parent
g_j =General combining ability (GCA) of the jth parent
s_{ij} =Specific combining ability (SCA) associated with the ith and jth cross
b_k = Effect of the kth replicate
e_{ijk} = Error associated with each observation
Genetic Components of GCA and SCA were estimated as (Singh and Chaudhury, 2005):

i. Component due to GCA:

$$\frac{1}{n-1}\sum g_i^2 = \frac{Mg - M'e}{2n}$$

Mg= Mean Square of GCA
M'e= Mean error
n= No. of Parents

Table 6. Estimate of SCA effects for different yield parameters of chilli crosses.

Cross	Days to 50% flowering	Fruit length (cm)	Fruit width (mm)	Fruit weight (g)	Number of seeds per fruit	Number of fruits per plant	Days to fruit maturity (green)	Days to fruit maturity (ripe)	Plant height (cm)	Plant canopy width (cm)	Yield per plant (g)
1×2	6.76**	-0.06	0.14	0.37**	-11.11**	-62.42**	1.43	-1.13	-2.67	0.92	-129.78**
1×3	2.26	0.07	0.23	0.75**	7.19**	16.34**	0.45	0.44	3.69*	10.20**	149.65**
1×4	-2.80	-0.34*	0.27	-1.08**	-4.23	14.84**	0.37	0.93	-10.40**	-16.49**	-77.69**
1×5	-2.30	1.20**	-0.05	0.37**	-2.60	42.92**	-2.65*	-1.50	4.20*	2.81	172.09**
1×6	-3.33	0.57*	0.07	0.33	8.64	144.28**	-2.85	-6.74**	-0.46	6.18	337.94**
2×3	-4.69**	-0.08	-0.15	-0.09	3.25	65.33**	-0.91	-2.53	5.07**	-5.11	171.61**
2×4	1.93	0.10	-0.25	0.39**	6.27*	21.63**	-1.12	0.16	7.67**	11.78**	205.96**
2×5	-9.57**	0.67**	-0.10	0.17	4.07	55.38**	0.63	2.50	-4.70*	1.23	195.38**
2×6	4.61	-0.26	-0.15	0.25	-1.79	38.29**	-3.73	-2.34	-0.39	0.70	203.49**
3×4	-3.24*	0.63**	-0.36	0.04	3.50	34.39**	-1.20*	-0.10	1.93	1.92	165.13**
3×5	10.59**	-0.54**	0.53	-0.60**	-5.06	-74.59**	0.18	0.04	-0.31	-2.77	-309.52**
3×6	14.78**	0.04	0.22	0.47*	30.48**	195.19**	-4.61*	-5.74*	5.72	6.05	706.32**
4×5	5.87**	-0.59**	0.38	0.23*	-4.75	-20.03**	-2.67*	-4.37**	3.25	4.82	-12.70
4×6	-5.83*	0.57*	-0.83	-1.67**	-58.77**	-8.81	-4.83*	-5.67*	-3.26	-3.35	33.87
5×6	6.67*	0.75**	1.37*	1.51**	19.76**	-23.66**	-0.24	-0.67	6.09*	6.71	194.45**

1= CCA 2, 2= CCA 5, 3= BARI Morich 1 (Bangla longka), 4= CCA 11, 5= CCA 15, 6= CCA 19. * P<0.05, ** P<0.01 respectively.

Table 7. Estimate of heritability and mid parent – offspring regression for different yield parameters of chilli

Character	Broad Sense heritability (h^2_b)	Narrow Sense heritability (h^2_n)	Mid parent– offspring regression (b ± SE)
Days to 50% flowering	98.85	61.82	1.00±0.27**
Fruit length (cm)	99.25	81.26	0.82 ± 0.04**
Fruit width (mm)	93.49	78.92	0.55 ± 0.03**
Fruit weight (g)	99.50	68.82	0.41 ± 0.03**
Number of seeds per fruit	98.60	21.52	0.40 ± 0.05**
Number of fruits per plant	99.81	29.19	0.45 ± 0.09**
Days to fruit maturity (green)	94.87	56.75	0.55 ± 0.05**
Days to fruit maturity (ripe)	93.55	37.34	0.47 ± 0.04**
Plant height (cm)	98.58	74.87	0.71 ± 0.03**
Plant canopy width (cm)	96.01	38.56	0.80 ± 0.05**
Yield per plant (g)	99.77	18.42	0.62 ± 0.15**

** P≤0.01

ii. Component due to SCA:

$$\frac{2}{n(n-1)}\sum \sum_{i<j} s_{ij}^2 = Ms - M'e$$

Ms= Mean Square of SCA

M'e= Mean error

The ratio of GCA variance to SCA variance was estimated as:

$$\left(\frac{1}{n-1}\sum g_i^2\right)/\left(\frac{2}{n(n-1)}\sum \sum_{i<j} s_{ij}^2\right)=\left(\frac{Mg-M'e}{2n}\right)/(Ms-M'e)$$

Estimation of heritability

Heritability of the characters was estimated in F_1 generations from the combining ability analysis of a diallel cross using fixed model expectations of mean squares for GCA and SCA (Table 2) (Bulmer, 1980).

Conclusion

In presence of high heritability, three parents, CCA 5, BARI Morich 1 and CCA 19, exhibited high GCA in yield per plant and yield related traits and may be utilized for improvement in fruit quality traits and yield. The use of population improvement method in the form of diallel selective mating, recurrent selection or mass selection where traits were controlled by additive variances might lead to release of new varieties with higher yield. Significant SCA and *per se* performance of hybrids 36 and 23 indicates there is an opportunity for developing F_1 hybrids.

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