Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 274-277
Received: 25-03-2019
Accepted: 27-04-2019

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Analysis of combining ability and studies of gene action for yield and yield contributing traits in a half diallel cross of capsicum (*Capsicum annuum* L. var. *grossum* Sendt.)

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Abstract
Six parental genotypes and their fifteen F_1 hybrids were used in the present study in a half diallel cross system (without reciprocals) to estimate the combining ability for yield and yield contributing traits in capsicum **(***Capsicum annuum* L. var. *grossum* Sendt.). The experiment was carried out at Vegetable Research and Demonstration Block of Uttarakhand University of Horticulture and Forestry, Bharsar, in a Randomized Block Design (RBD) with three replications. The analysis of variance for combining ability indicated that GCA and SCA mean squares were highly significant for all the characters under study which suggest that these parents performed differently in different combinations indicating interallelic interactions. Maximum yield contributing traits studied exhibited greater GCA variance than SCA varience, suggesting that these traits are controlled by additive gene action except yield per plant which are found to be under the control of non-additive gene action. Among the parents California Wonder emerged as good general combiner for yield per plant (0.16 kg), fruit diameter (0.71 kg) and fruit pericarp thickness (0.29 kg). The genotype Arka Mohini exhibited highly significant for average fruit weight (12.45 g), Solan Bharpur for number of fruits per plant (3.79) and EC802552 for fruit length (1.94 cm). The highest specific combining ability effect in fruit yield was observed in the cross California Wonder × LC-10 (0.41kg). Whereas, different cross combinations showed the good specific combining ability effects in different yield contributing traits in desirable direction. Thus the result concluded that the commercialization of superior capsicum hybrid and selection of suitable parents according to its combining ability can be utilized in further crop improvement programme.

Keywords: Combining ability, capsicum, gene action, half Diallel.

Introduction
Capsicum (*Capsicum annuum* L. var. *grossum* Sendt.) belongs to genus *Capsicum* of the nightshade family Solanaceae, comprising of 20 to 30 species. Capsicum is also known as bell pepper, sweet pepper, Shimla mirch, green pepper and vegetable paprika. Capsicum is grown worldwide for its delicious taste, pleasant flavour, nutritional qualities and is also the most leading crop under protected structures. Capsicum fruits are generally blocky, square, thick fleshed, three to four lobed, non-pungent and are eaten raw, used as a vegetable or widely used in stuffing, baking, pizza, preparation of soups and stews for imparting flavour. Nutritionally it is a rich source of Vitamin C ranging from 150-180 mg per 100 g and Vitamin A, constituting up to 12 per cent of total pigment content. Due to low productivity and high demand of capsicum in fresh market and processing industries, it is important to develop such hybrids having a complex of valuable attributes viz., uniformity, good quality, earliness, wider adaptability with high yield to boost up the production and to meet both market and farmers requirements. The pre-requisite for breeding programme is the screening and selection of parents together with information regarding nature of gene action controlling the various characters. Diallel analysis is a biometrical tool that provides the estimates of genetic parameters regarding heterosis and combining ability. Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature and magnitude of various types of gene actions involved in the expression of qualitative and quantitative traits (Khoja and Ahmad. 2008) [8]. The entire variability observed in the analysis for each trait was partitioned into its components *i.e*. general combining ability (GCA) and specific combining ability (SCA), which helps to select the parents and provides the information on gene action involved in the expression of traits and prescribes good and poor combiners, which help us in formulating an effective breeding strategy. The main objective of this part of study was to identify the parents with better

potential to transmit the desirable characteristics to the progenies and to sort out the best specific hybrids for yield and its component characters.

Materials and Methods

The experimental materials comprised of six diverse parents *viz.*, California Wonder, Arka Mohini, Solan Bharpur, EC802552, LC-8 and LC-10 along with its 15 F_1 hybrids generated by half-diallel in all possible combinations excluding reciprocals with Indham Bharat as standard check (Table 1). The experiment was laid out during 2016-2017 in randomized block design with three replications at the Vegetable Research and Demonstration Block, UUHF, Bharsar, Uttarakhand (India). Each plot consisted of 8 plants. Inter and intra row spacing was kept 60 and 45 cm, respectively. The observations were recorded on five randomly selected plants from each treatment and replications for six yield attributing characters *viz.*, fruit length (cm), fruit diameter (cm), average fruit weight (g), fruit pericarp thickness (mm), number of fruits per plant and yield per plant (kg).

Table 1: Parental lines used for crossing programme and standard check with their features.

Parents used	Source	Features
California Wonder	IARI, New Delhi	Plants are vigorous, upright and prolific. Fruits are smooth, 3-4 lobed with medium thick flesh. Yield potential of 12.5-15 t/ha in 125-140 days.
Arka Mohini	IIHR, Bangalore	Determinate plant habit with dark green foliage. Thick fleshed 3-4 lobed dark green blocky fruits. Fruits pendent, which turn red on ripening. Yield potential of 20 t/ha. Duration of 160 days.
Solan Bharpur	UHF, Solan	More number of fruits per plant. Phytophthora tolerant bell pepper variety. Deep green in colour. Yield: 30 t/ha.
AVPP0701 (EC802552)	World Veg, Taiwan	Long shaped, light green colour fruits.
LC-8	Shimla, HP	More number of fruits per plant.
LC-10	Bilaspur, HP	Long shaped, more number of fruits per plant.
Commercial check		**Features**
Indam Bharath	(Indo-American Hybrid Seeds (India) Pvt. Ltd.)	Medium height plant with deep blocky 3-4 lobes. Medium dark green turning red at maturity. Very attractive shiny colour. With average fruit weight of 150g, with length of 8-10cm.

Statistical analysis

The combining ability analysis for parental genotypes and their crosses were carried out following Method 2 and Model 1 of Griffing (1956) [3].

General combining effect of i^{th} parent:

$$g_i = (1/p+2)\ [\Sigma(Xi+Xii) - 2/p\ X.]$$

Specific combining effect of i x j^{th}cross

$S_{ij} = X_{ij} - (1/p+2)\ (X_i + X_{ii} + X_j + X_{jj}) + [2/\ (p+1)\ (p+2)\ X.]$

Where, X_i = Total of the array of i^{th} parent; X_{ij} = Mean Value of i x j^{th} cross; X = Grand total of parents + crosses; X_j = Total of the array of j^{th} parent and X_{jj} = Mean value of j^{th} parent.

Results and Discussion

The analysis of variance for general combining ability (GCA) of parents and specific combining ability (SCA) of crosses were found highly significant for all the traits under study revealing the importance of both additive and non-additive gene effects in the inheritance of all the traits (table 2). The GCA for the most of the characters viz., fruit length, fruit diameter, average Fruit weight and number of fruit per plant were higher in magnitude than their respective SCA variances, indicating the preponderance of additive gene effects for these characters. The SCA for the character yield per plant (kg) was higher in magnitude than their respective GCA variances, indicating the preponderance of non-additive gene effects for this character. Kadambavanasundaram (1980) [5] 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.

Fruit length

Only EC802552 (1.94) was exhibited significant positive GCA effect among all the parents and which indicated their good general combining ability (table 3). Out of fifteen hybrid combinations, six were found good specific cross combinations due to their significant positive SCA effects (table 4). The crosses, Solan Bharpur × EC802552 (2.30) having highest fruit length. These results find support from Venkataramana *et al.* (2005) [10].

Fruit diameter

Data pertaining to estimates of GCA effects revealed that two parents *viz.*, California Wonder (0.71) and Arka Mohini (0.63) were found good general combiners as they showed the significant positive GCA effects (table 3). The estimation of specific combining ability effects for fruit diameter showed that only one hybrid combination exhibited significant positive value *viz.*, California Wonder × Arka Mohini (0.77), which indicated that this cross was good specific cross combiner (table 4). These results also find support from Hasanuzzaman *et al.* (2012) [4].

Average fruit weight

Among all the parents, Arka Mohini (18.65), California Wonder (12.45) and EC802552 (2.26) were found good general combining effects (table 3). The specific combining ability effects for this trait have been represented in the table (table 4), which indicated that seven cross combinations were good specific combiners, among them the cross California Wonder × Solan Bharpur (14.19) had highest fruit weight. Earlier reports by Gandhi *et al.* (2000) [2] and Perez *et al.* (2009) [9] support these findings.

Fruit pericarp thickness

Significant positive GCA effects among the parents, were exhibited by California Wonder (0.29) and Arka Mohini (0.22), which established it as good general combiner (Table 3). The specific combining ability for this trait revealed that five hybrid combinations exhibited significant positive values of SCA and the cross California Wonder × Arka Mohini (0.88) is the highest among them (table 4).

Number of fruits per plant

For number of fruits per plant, the parents Solan Bharpur

(3.79), LC-8 (2.58) and LC-10 (1.82) exhibited the significant positive GCA effects, indicated that these were good general combiners (table 3). The specific combining ability effects for this trait have been represented in the table 4. Out of fifteen hybrid combinations, nine were found good specific cross combinations due to their significant positive SCA effects. The crosses, LC-8 × LC-10 (4.68) having highest number of fruits per plant. Similar results had also been reported earlier by Doshi (2003) [1].

Yield per plant

The results of GCA and SCA effects for yield per plant have been presented in the table 3 and table 4, respectively. Among the parents, California Wonder (0.16) and LC-10 (0.07) were found good general combiners due to their significant positive GCA effects. Out of all cross combinations, nine crosses revealed significant positive SCA effects, indicated their good specific combining ability. Among those crosses, California Wonder × LC-10 (0.41) emerged as one of the highest yield bearing cross. These results were also supported by Kamble *et al*. (2009) [6] and Khalil and Hatem (2014) [7].

In conclusion, none of the parents under present investigation showed good general combining ability for all the characters. And none of the crosses were found to be good specific combiner for all the traits under study. California Wonder emerged as good general combiner for five traits including yield. The cross, California Wonder × LC-10 emerged as good specific combiner for yield and can be commercially exploited after assessing their stability for yield.

Table 2: Analysis of variance for combining ability of all parameters in capsicum.

Source of variation	d.f	Fruit Length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit pericarp thickness (mm)	Number of fruits per plant	Yield per plant (kg)
GCA	5	8.61**	2.48**	1494.53**	0.45**	89.10**	0.08**
SCA	15	2.23**	0.16**	95.07**	0.27**	17.82**	0.11**
Error	40	0.07	0.01	3.92	0.02	0.10	0.00

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

Table 3: Estimates of general combining ability (GCA) effects of parents for all parameters in capsicum.

Parameters Parents	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit pericarp thickness (mm)	Number of fruits per plant	Yield per plant (kg)
California Wonder	-0.69**	0.71**	12.45**	0.29**	-0.74**	0.16**
Arka Mohini	0.18	0.63**	18.65**	0.22**	-4.97**	-0.04*
Solan Bharpur	-0.77**	-0.34**	-12.56**	-0.24**	3.79**	0.01
EC802552	1.94**	0.03	2.26**	0.10	-2.47**	-0.11**
LC-8	-0.72**	-0.44**	-15.50**	-0.27**	2.58**	-0.09**
LC-10	0.06	-0.58**	-5.30**	-0.10	1.82**	0.07**
SE (gi)	0.088	0.034	0.639	0.047	0.102	0.010
$CD_{(0.05)}$	0.195	0.077	1.418	0.105	0.226	0.023

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

Table 4: Estimates of specific combining ability effects of crosses for all parameters in capsicum.

Parents	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit pericarp thickness (mm)	Number of fruits per plant	Yield per plant (kg)
CW × AM	0.13	0.77**	11.26**	0.88**	-0.24	0.01
CW × SB	1.19**	-0.26*	14.19**	0.83**	-0.72*	0.40**
CW × EC802552	-2.61**	-0.16	-4.53**	0.11	-0.77*	-0.15**
CW × LC-8	0.38	-0.28*	-9.90**	-0.41**	3.62**	0.06
CW × LC-10	0.53	-0.27*	2.62	0.39*	4.06**	0.41**
AM × SB	-0.39	-0.32*	-4.91*	-0.25	-4.98**	-0.38**
AM × EC802552	0.78*	-0.60**	6.25**	0.14	4.25**	0.40**
AM × LC-8	1.42**	-0.02	11.17**	0.34*	-4.92**	-0.20**
AM × LC-10	-0.92**	-0.26*	-4.09*	-0.46**	2.57**	0.17**
SB × EC802552	2.30**	-0.15	9.01**	-0.42**	2.96**	0.19**
SB × LC-8	-0.17	0.16	0.86	-0.04	3.08**	0.12**
SB × LC-10	-0.16	0.12	0.86	-0.08	4.67**	0.34**
EC802552xLC-8	2.02**	-0.43**	7.55**	0.17	1.40**	0.31**
EC802552 × LC-10	1.59**	-0.06	10.32**	0.73**	-6.54**	-0.35**
LC-8 × LC-10	-0.58*	-0.06	2.10	0.02	4.68**	0.32**
SE (sij)	0.242	0.095	1.754	0.130	0.280	0.028
$CD_{(0.05)}$	0.537	0.210	3.895	0.290	0.621	0.062

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

Where, CW= California Wonder, AM= Arka Mohini, SB= Solan Bharpur.

Table 5: per se performance and combining ability values of top three parents and cross combinations.

Traits	*Per se* performance		Combining ability	
	Parents	Crosses	GCA of parents	SCA of crosses
Fruit length (cm)	EC802552 (11.06) LC-10 (9.12) A M (9.07)	EC802552 × LC-10 912.82) S B × EC802552 (12.70) EC802552 × LC-8 (12.47)	EC802552 (1.94**) A M (0.18) LC-10 (0.06)	S B × EC802552 (2.30**) EC802552 × LC-8 (2.02**) EC802552 × LC-10 (1.59**)
Fruit diameter (cm)	C W (7.01) A M (6.96) EC802552 (6.25)	C W × A M (7.61) C W × EC802552 (6.07) A M × LC-8 (5.66)	C W (0.71**) A M (0.63**) EC802552 (0.03)	C W × A M (0.77**) S B × LC-8 (0.16) S B × LC-10 (0.12)
Average Fruit weight (g)	A M (99.38) C W (89.99) EC802552 (62.13)	C W × A M (114.27) A M × EC802552 (99.08) A M × LC-8 (86.24)	A M (18.65**) C W (12.45**) EC802552 (2.26**)	C W × S B (14.19**) C W × A M (11.26**) A M × LC-8 (11.17**)
Fruit pericarp thickness (mm)	A M (3.91) EC802552 (3.62) C W (3.47)	C W × A M (5.18) C W × S B (4.67) EC802552 × LC-10 (4.51)	C W (0.29**) A M (0.22**) EC802552 (0.10)	C W × A M (0.88**) C W × S B (0.83**) EC802552 × LC-10 (0.73**)
Number of fruits per plant	S B (21.91) LC-8 (18.07) LC-10 (15.75)	S B × LC-10 (27.12) S B × LC-8 (26.29) LC-8 × LC-10 (25.92)	S B (3.79**) LC-8 (2.58**) L C-10 (1.82**)	LC-8 × LC-10 (4.68**) S B × LC-10 (4.67**) A M × EC802552 (4.25**)
Yield per plant (kg)	C W (1.11) A M (1.05) LC-10 (0.86)	C W × LC-10 (1.73) C W × S B (1.70) S B × LC-10 (1.56)	C W (0.16**) LC-10 (0.07**) S B (0.01)	C W × LC-10 (0.41**) C W × S B (0.40**) A M × EC802552 (0.40**)

*, ** significant at 5% and 1% level, respectively. S
Where C W = California Wonder; AM = Arka Mohini; S B = Solan Bharpur.

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