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Gene action, heritability and combining ability studies in F_2 generation of bell pepper (*Capsicum annuum L. var. grossum*)

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Abstract
Six diverse homozygous parents, BWR-1, BWR-6-1, BWR-29, BWR-39, EC-464107 and EC-464115 were evaluated for gene action, heritability and combining ability using 6X6 diallel cross excluding reciprocals. The results showed that analysis of variance revealed significant differences due to parents, crosses and parent's vs crosses. Mean squares due to GCA and SCA were significant for all traits days to 50% flowering, days to first picking, plant height, primary branches per plant, harvest duration, lobes per fruit, fruit length, fruit width, pericarp thickness, average fruit weight, fruits per plant, fruit yield per plant, marketable fruits per plant, marketable fruit yield per plant and total soluble solids. Non-additive gene effects were more important than the additive gene effects in the inheritance of days to 50 per cent flowering, days to first picking, primary branches per plant, harvest duration, lobes per fruit, average fruit weight, fruits per plant, fruit yield per plant, marketable fruits per plant, marketable fruit yield per plant and total soluble solids. Additive gene effect was important for plant height, fruit length, fruit width and pericarp thickness. Average degree of dominance showed over dominance for days to 50 per cent flowering, harvest duration, fruits per plant, fruit yield per plant, marketable fruits per plant and marketable fruit yield per plant. Narrow-sense heritability estimates were high for plant height, fruit length, fruit width and pericarp thickness. BWR-6-1, BWR-39 and EC-464107 were good general combiners for fruits per plant, fruit yield per plant, marketable fruits per plant and marketable fruit yield per plant. BWR -1 X EC -464115 and BWR-6 -1 X EC -464107 were good specific combiners for fruits per plant, fruit yield per plant, marketable fruits per plant and marketable fruit yield per plant.

Keywords: Gene action, narrow-sense heritability, bell pepper, general combining ability, specific combining ability

Introduction

Bell pepper (*Capsicum annuum* L. var. *grossum*, 2n = 24), a member of the Solanaceae family, is also known as sweet pepper, capsicum, or Shimla mirch is an important off-season vegetable crop of Himachal Pradesh. Fruits of bell pepper are good source of Vitamin C, Vitamin E, carotenoids and pro vitamin A (Materska and Perucka, 2005) [18]. Consumption of bell pepper reduces risk of cardiovascular disease, promotes lung health and improves eye health (Nadeem *et al.*, 2011) [19]. Cultivated area of bell pepper in India is 34 thousand hectares with a production of 497 thousand metric tonnes (Anonymous, 2019) [3]. In Himachal Pradesh, bell pepper is an important off-season vegetable, grown during the summer and rainy seasons; and covers an area of about 2500 hectares with a production of 57,760 metric tonnes (Anonymous, 2018) [2].

The diallel analysis helps to obtain information on the genetic systems governing the inheritance of quantitative traits to be improved. 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 cross combinations known as general combining ability (GCA). It also gives information about the performance of cross combinations 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 can be used to identify the lines to be used as parents in a breeding program for improvement (Kearsey and Pooni, 1996) [11]. In addition, this technique enables the breeder to combine desirable genes that are found in two or more genotypes (Dabholkar, 1992) [5].

Determination of heritability is useful to study genetic change of a population undergoing. Selection (Falconer, 1981) [7] and to choose among alternative breeding programs (Hill, 1971) [10]. 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) [7]. 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) [26]. Generally, landraces are genetically diverse and constitute variable populations, where variation can be seen between and within populations (Zeven, 1998) [30] and represent a very important source of genetic diversity that can be exploited for plant breeding. Yield improvement is the main objective of any crop improvement programme. In India, high yielding disease and insect-pest resistance varieties of bell pepper are not available and the varieties which are in cultivation were introduced a long time ago and these too are not resistant for diseases and insect-pest. Bacterial wilt is a limiting factor in the cultivation of bell pepper. Yield losses can be reported from the wilt prone areas. 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. So, considering the importance of above mentioned points the present study was conducted to study the nature and magnitude of gene action along with combining ability in bell pepper.

Experimental site and soil characteristics
The experiment was conducted at the Experimental Farm of Department of Vegetable Science and Floriculture (32°6'N latitude and 76°3'E longitude), CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, during the summer-rainy season of 2020. The soil of the experimental plot was salty clay loam and acidic in nature (soil pH 5.0-5.6).

Climate
The experimental site is characterized by humid sub-temperate climate with severe winters, mild summers and high annual precipitation (2500 mm). Agro climatically, this region falls under Zone-II (Mid-hill zone) of Himachal Pradesh.

Plant materials
Six bell pepper genotypes (Table 1) were crossed in a diallel mating system excluding the reciprocals in 2019.

Table 1: Details of the parents used for inter-varietal hybridization

Sr. No.	Genotype	Plant type	Marketable fruit yield per plant (g)	Fruit shape and colour	Source
1.	BWR-1	Indeterminate	310.00	Blocky, Green	Department of Vegetable Science and Floriculture, CSK HPKV, Palampur, HP
2.	BWR-6-1	Indeterminate	342.73	Blocky, Green	
3.	BWR -29	Semi determinate	335.00	Blocky, Dark Green	
4.	BWR- 39	Semi determinate	434.27	Blocky, Dark Green	
5.	EC-464107	Indeterminate	282.33	Blocky, Yellow Green	AVRDC, Taiwan
6.	EC-464115	Indeterminate	318.33	Blocky, Light Green	

Seed sowing and transplanting
The nursery sowing was done on 13th January, 2020. The transplantation of seedlings was done on 13th April, 2020. Each entry comprised of 20 plants of F_2 cross combinations and 10 plants of parents, raised in three replications, with inter and intra-row spacing of 60 cm x 45 cm, respectively.

Crop cultural practices
Before transplanting of seedlings, field preparation was done by sloughing and harrowing. Well decomposed FYM was applied @ 20 tonnes/ha along with chemical fertilizers as per the recommended package of practices (90 kg N, 75 kg P_2O_5 and 50 kg K_2O/ha). At the time of transplanting, one third dose of nitrogen and full dose of phosphorus and potassium were applied. Remaining two third of nitrogen was top dressed, in two equal parts, after 30 and 45 days of transplanting, respectively. Five sprays of urea (1.5%) at an interval of about 8-10 days were given during the flowering and fruiting periods, in order to maintain the vegetative growth and vigor of the plants. After transplanting of seedlings, light irrigation was given and thereafter at weekly intervals. Proper drainage channels were made to drain out excess water from the field during the period of heavy rains. Spray of pesticide was done as per the recommendations made in the Package of Practices of Vegetable Crops. Harvesting of green firm fruits of marketable size was done by hand picking.

Data collection
The observations were recorded on randomly collected fifteen plants of F_2 over the three replications. Data were collected on days to 50% flowering, days to first picking, plant height, primary branches per plant, harvest duration, lobes per fruit, fruit length, fruit width, pericarp thickness, average fruit weight, fruits per plant, fruit yield per plant, marketable fruits per plant, marketable fruit yield per plant and total soluble solids.

Data analysis
For working out analysis of variance, the data were analyzed as per the method given by Panse and Sukhatme (1984) [21].

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

Where,
Y_{ij} = phenotypic observation of i^{th} genotype in j^{th} replication,
μ = general mean,
g_i = effect of i^{th} genotype,
r_j = effect of j^{th} replication, and
e_{ij} = error associated with i^{th} genotype in the j^{th} replication

The data obtained from the F_2 population was subjected to combining ability analysis Griffing's (1956) [8] experimental method 2 model I.

$$Y_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc}\sum_K \sum_L e_{ijKL}$$

Where,
Yij = phenotype of the hybrid between ith and jth parents in Kth block,
M = population mean,
Gi = general combining ability (GCA) effect of the ith parent
Gj = general combining ability (GCA) effect of the jth parent
Sij = specific combining ability (SCA) effect of the hybrid between ith and jth parents
Bc = block effect
eij KL = environment effect associated with ijKLth observation

Estimation of gca and sca variances
Components due to GCA = (Mg - Me′)/p+2
Components due to SCA = (Ms - Me′)

Where,
P = number of parents
Mg = mean squares due to gca
Ms = mean squares due to sca
Me′ = mean squares due to error

For computing the additive and dominance components of variance, following formulae have been used (Singh and Chaudhary, 1985) [25].

F1 generation
σ2A = 2 σ2gca
σ2D = σ2sca
F2 generation
σ2A = 2 σ2gca
σ2D = 4 σ2sca

Where,
σ^2A = additive variance, and
σ^2D = dominance variance.

Heritability in narrow sense (h^2_{ns}) was calculated as per the following formula:
Heritability (h^2_{ns}) = (σ^2A) / (σ^2P) = (σ^2A)/(σ^2A+ σ^2D+ σ^2E)

Where,
H2 ns = estimated heritability in narrow sense
σ2A = additive genetic variance
σ2P = phenotypic variance
σ2D = dominant genetic variance
σ2E = environmental variance

Results and Discussion
Analysis of variance and gene action studies
Analysis of variance showed significant differences among the genotypes for quantitative traits and quality traits. Mean squares due to parents vs. crosses were significant for all the traits, except days to first picking and primary branches per plant (Table 1).

Table 1: Analysis of variance for quantitative and quality traits in bell pepper

Source of variation Traits	DF	Replications 2	Treatments 20	Parents 5	Crosses 14	Parents vs. Crosses 1	Error 40
(I) Quantitative traits							
(a) Phenological and structural traits							
Days to 50 per cent flowering		1.493	44.512*	35.156*	29.083*	307.302*	0.449
Days to first picking		1.196	72.708*	113.200*	63.381*	0.825	0.712
Plant height (cm)		1.441	202.695*	178.692*	215.542*	142.857*	0.650
Primary branches per plant		0.062	0.191*	0.105*	0.232*	0.053	0.040
Harvest duration (days)		0.252	74.455*	104.862*	66.483*	34.021*	0.403
Lobes per fruit		0.031	0.218*	0.105	0.237*	0.514*	0.047
(b) Fruit yield traits							
Fruit length (cm)		0.008	3.085*	2.085*	3.129*	7.457*	0.001
Fruit width (cm)		0.001	0.227*	0.239*	0.239*	0.004*	0.0001
Pericarp thickness (mm)		0.001	0.280*	0.423*	0.248*	0.007*	0.001
Average fruit weight (g)		1.631	29.196*	35.364*	28.842*	3.317*	0.300
Fruits per plant		0.006	31.315*	2.672*	20.945*	319.717*	0.178
Fruit yield per plant		13.726	26931.520*	8006.051*	12533.130*	323136.300*	1.997
Marketable fruits per plant		0.253	34.371*	2.301*	23.426*	347.954*	0.081
Marketable fruit yield per plant (g)		10.111	27591.510*	8138.094*	14071.370*	314140.700*	5.972
(II) Quality traits							
TSS		0.0005	0.191*	0.071*	0.214*	0.476*	0.001

*Significant at $p \leq 0.05$

Analysis for combining ability revealed that the mean squares due to GCA and SCA were significant for all the traits studied (Table 2). 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 epistemic gene effects (Kornegay and Temple, 1986) [15]. The lower σ^2g/σ^2s ratio indicates that the predominance of non-additive (dominance or epistasis) gene action. Marame *et al*. (2009) [17] 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.

Table 2: Analysis of variance for combining ability for quantitative and quality traits in bell pepper

Source of variation Traits	DF	GCA 5	SCA 15	Error 40
(I) Quantitative traits				
(a) Phenological and structural traits				
Days to 50 per cent flowering		7.426*	17.307*	0.149
Days to first picking		43.901*	17.681*	0.237
Plant height		196.039*	24.740*	0.216
Primary branches per plant		0.069*	0.062*	0.013
Harvest duration		37.107*	20.722*	0.134
Lobes per fruit		0.095*	0.065*	0.015
(b) Fruit yield traits				
Fruit length		2.696*	0.472*	0.0004
Fruit width		0.243*	0.019*	0.00004
Pericarp thickness		0.258*	0.038*	0.00003
Average fruit weight		23.722*	5.068*	0.100
Fruits per plant		7.048*	11.568*	0.059
Fruit yield per plant		3073.750*	10944.979*	0.665
Marketable fruits per plant		5.166*	13.553*	0.027
Marketable fruit yield per plant		3001.654*	11262.343*	1.990
(II) Quality traits				
TSS		0.072*	0.060*	0.00002

* Significant at $p \leq 0.05$

The information on type of gene action is of immense use to the plant breeder to determine the success of breeding programme. For days to 50 per cent flowering, non-additive gene action, over dominance and low narrow sense heritability was observed. Shukla *et al*., 1999 [23] stated that only non-additive gene effects were responsible for the expression of days to flowering.

Table 3: Estimates of components of genetic variance for quantitative and quality traits in bell pepper

Source of variation Traits	σ^2g	σ^2s	σ^2A	σ^2D	σ^2A/ σ^2D	$[1/4(\sigma^2D/\sigma^2A)]^{1/2}$	h^2ns (%)
(I) Quantitative traits							
(a) Phenological and structural traits							
Days to 50 per cent flowering	-1.23	4.29	-2.47	17.16	0.14	1.31	16.65
Days to first picking	3.28	4.36	6.55	17.44	0.37	0.81	27.04
Plant height	21.41	6.13	42.82	24.52	1.75	0.38	63.38
Primary branches per plant	0.01	0.01	0.02	0.05	0.40	0.79	2.83
Harvest duration	2.05	5.14	4.09	20.58	0.19	1.12	16.50
Lobes per fruit	0.01	0.01	0.02	0.04	0.50	0.70	10.43
(b) Fruit yield traits							
Fruit length	0.27	0.12	0.55	0.47	1.17	0.46	54.05
Fruit width	0.03	0.005	0.06	0.02	3.00	0.28	73.81
Pericarp thickness	0.03	0.01	0.06	0.04	1.50	0.41	59.12
Average fruit weight	2.33	1.24	4.66	4.96	0.94	0.51	47.91
Fruits per plant	-0.56	2.87	-1.13	11.51	0.09	1.59	10.82
Fruit yield per plant	-983.90	2736.07	-1967.80	10944.31	0.18	1.17	21.92
Marketable fruits per plant	-1.05	3.38	-2.09	13.53	0.15	1.27	18.30
Marketable fruit yield per plant	-1032.58	2815.08	-2065.17	11260.35	0.18	1.17	22.45
(II) Quality traits							
TSS	0.01	0.015	0.02	0.06	0.33	0.86	4.87

σ^2g = GCA variance; σ^2s = SCA variance; σ^2A = Additive variance; σ^2D = dominance variance; σ^2A/σ^2D = GCA/SCA ratio; $[1/4(\sigma^2D/\sigma^2A)]^{1/2}$ = Average degree of dominance; h^2ns = Narrow sense heritability

Hasanuzzaman *et al*., 2012 [9] and Thakur *et al*., 2019 [27] noticed presence of additive gene effect, partial dominance and high narrow sense heritability for plant height (Table 3). For lobes per fruit, non-additive gene action, partial dominance and low narrow sense heritability was present.

Hasanuzzaman *et al*., 2012 [9] detected additive gene action, partial dominance and high narrow sense heritability was noticed for fruit length and fruit width. Ahmed *et al*., 2019 [1] and Mahmoud, 2014 [16] noticed preponderance of additive gene action, partial dominance and high narrow sense heritability for pericarp thickness. Bhagyalakshmi *et al*., 1991 [4] and Shukla *et al*., 1999 [23] revealed the presence of non-additive gene action, partial dominance and medium narrow sense heritability for average fruit weight.

Shukla *et al*., 1999 [23] and Marame *et al*., 2009 [17] observed opulence of non-additive gene action, over dominance and low narrow sense heritability for fruits per plant. Shukla *et al*., 1999 [23] and Sharma *et al*., 2016 [22] noticed predominance of non-additive gene action, over dominance and low narrow sense heritability for fruit yield per plant.

Non-additive gene action, over dominance and low narrow sense heritability was predominant for marketable fruits per plant. Contrary to the results, Khan and Sridevi, 2018 [14] observed high heritability and Mahmoud, 2014 observed medium narrow sense heritability. Yunandra *et al*. 2018 [29] detected non-additive gene action, over dominance and low narrow sense heritability for marketable fruit yield per plant. However, Ahmed *et al*., 2019 [1] noticed moderate heritability in narrow sense heritability for the trait. Danojevic *et al*., 2018 [6] also noticed low narrow sense heritability for total soluble solids. However, Mahmoud, 2014 noticed higher values of narrow sense heritability for total soluble solids.

Combining ability analysis

The combining ability analysis facilitates the partitioning of genotypic variation of crosses into variation due to general combining ability (main effects) and specific combining ability (interaction), which is a measure of additive and non-additive gene action. The knowledge of general (GCA) and specific (SCA) combining ability helps in selection of parents as well as crosses to formulate an effective breeding methodology. Studies on combining ability of parents are essential in choosing parents as its analysis is an important technique to understand the genetic potential of parents and their hybrids.

None of the parent exhibited significant desirable GCA effects for all the traits. BWR-6-1 was a good general combiner for days to first picking, harvest duration, fruit width, pericarp thickness, fruits per plant, fruit yield per plant, marketable fruits per plant and marketable fruit yield per plant (Table 4). BWR-39 was good general combiner for primary branches per plant, lobes per fruit, fruit width, pericarp thickness, average fruit weight, fruit yield per plant, marketable fruit yield per plant and TSS. EC-464107 was good general combiner for days to 50 per cent flowering, days to first picking, plant height, harvest duration, fruit length, fruits per plant, marketable fruits per plant and TSS. 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, BWR-6-1 was indicated as the best general combiner.

Different parents expressing high GCA effects for fruit yield and component traits have also been reported by Khalil *et al*. (2004), Singh and Chaudhary (2005) [25] and Yadahalli *et al*. (2017) [28].

No single cross exhibited significant SCA effects for all the traits. For days to 50 per cent flowering BWR-6-1 X EC-464115 (average x poor) was best for earliness (Table 5). For days to first picking BWR-29 X EC-464115 (good x poor) was the best cross combination. For fruit length, BWR-6-1 X EC-464115 (poor x good), BWR-29 XEC-464107 (poor x good) and BWR-1 X EC-464107 (poor x good), were the three best specific combiners. For average fruit weight BWR-1 X BWR-39 (poor x good), BWR-1 X BWR-29 (poor x good) and BWR-29 X EC-464107 (good x poor) were the three best specific combiners.

Table 4: Estimates of general combining ability (GCA) effects of parents for quantitative and quality traits in bell pepper

Traits Parents	Quantitative traits														Quality traits
	Phenological and structural traits						Fruit yield traits								
	DFF	DFP	PH	PBPP	HD	LPF	FL	FW	PT	AFW	FPP	FYPP	MFPP	MFYP	TSS
BWR-1	-0.33*	3.04*	0.04	0.07	-2.69*	0.14*	-0.39*	0.14*	0.01*	-1.14*	-0.90*	-31.38*	-0.43*	-25.53*	-0.10*
BWR-6-1	0.13	-1.87*	-7.67*	0.07	1.82*	-0.04	-0.13*	0.03*	0.22*	-0.25*	0.64*	21.98*	1.19*	28.93*	-0.05*
BWR-29	-1.27*	-0.82*	0.03	-0.10*	0.98*	0.00	-0.24*	0.11*	0.10*	2.26*	-1.27*	-2.91*	-0.93*	-0.37	-0.08*
BWR-39	0.08	1.72*	-1.25*	0.09*	-2.15*	0.11*	-0.65*	0.14*	0.10*	2.02*	-0.13	16.57*	-0.61*	12.08*	0.15*
EC-464107	-0.27*	-3.14*	1.04*	-0.01	2.60*	-0.16*	0.84*	-0.27*	-0.19*	-1.67*	0.56*	-11.11*	0.20*	-15.53*	0.03*
EC-464115	1.68*	1.08*	7.81*	-0.12*	-0.56*	-0.04	0.57*	-0.15*	-0.24*	-1.22*	1.11*	6.85*	0.58*	0.44	0.06*
SE(gi)±	0.12	0.15	0.15	0.04	0.12	0.04	0.006	0.002	0.001	0.102	0.078	0.263	0.053	0.455	0.001
SE (gi-gj)±	0.19	0.24	0.23	0.06	0.18	0.06	0.010	0.003	0.002	0.158	0.122	0.407	0.082	0.705	0.002

* Significant at $p \leq 0.05$ DFF = Days to 50 per cent flowering; DFP = Days to first picking, PH = plant height; PBP = Primary branches per plant; HD = Harvest duration; LPF = Lobes per fruit; FL= Fruit length; FW = Fruit width; PT = Pericarp thickness; AFW = Average fruit weight; FPP = Fruits per plant; FYPP = Fruit yield per plant; MFPP = Marketable fruits per plant; MFYP = Marketable fruit yield per plant; and TSS = Total soluble solids

Table 5: Estimates of specific combining ability (SCA) effects of different cross combinations for quantitative and quality traits in bell pepper

Traits Parents	Quantitative traits														Quality traits
	Phenological and structural traits							Fruit yield traits							
	DFF	DFP	PH	PBP	HD	LPF	FL	FW	PT	AFW	FPP	FYPP	MFPP	MFYP	TSS
BWR-1 X BWR-6-1	-2.49*	0.41	3.94*	-0.02	-1.72*	0.28*	0.06*	0.15*	-0.23*	1.27*	-0.70*	-15.15*	-1.26*	-14.49*	-0.11*
BWR-1 X BWR-29	-2.21*	4.50*	-2.62*	0.35*	-4.28*	-0.15	-0.10*	-0.01*	-0.06*	2.35*	-0.85*	-7.65*	-1.34*	-10.19*	-0.31*
BWR-1 X BWR-39	-4.56*	6.22*	0.45	0.29*	-6.41*	-0.19	-0.01	0.03*	0.43*	3.98*	-0.93*	44.80*	-0.53*	45.36*	-0.14*
BWR-1 X EC-464107	-3.61*	-3.99*	1.76*	0.06	2.97*	-0.19	0.70*	0.23*	0.17*	-1.46*	0.78*	12.80*	1.60*	21.70*	-0.07*
BWR-1 X EC-464115	-0.56	-3.34*	0.79*	-0.10	7.73*	0.03	0.44*	-0.01*	-0.09*	-1.09*	4.70*	123.98*	5.48*	133.00*	0.40*
BWR-6-1 X BWR-29	-2.34*	0.35	-2.51*	0.02	0.01	0.23*	-0.35*	-0.03*	0.16*	1.03*	1.74*	81.65*	3.64*	80.02*	0.10*
BWR-6-1 X BWR-39	-1.96*	3.01*	2.63*	-0.31*	-3.45*	-0.02	-0.09*	0.04*	-0.06*	-2.42*	0.13	-2.83*	1.11*	0.70	-0.42*
BWR-6-1 X EC-464107	-3.01*	1.86*	1.27*	-0.07	-0.94*	-0.02	0.24*	-0.04*	-0.07*	0.61*	4.04*	128.3*	4.17*	134.11*	0.05*
BWR-6-1 X EC-464115	-5.09*	-0.16	-8.10*	0.43*	1.62*	-0.60*	1.36*	-0.01*	0.08*	0.35	3.82*	122.42*	3.99*	127.40*	-0.12*
BWR-29 X BWR-39	5.71*	2.02*	-1.61*	-0.20*	-0.28	0.22*	-0.10*	0.14*	-0.09*	-0.64*	0.18	-13.94*	-0.43*	-18.46*	0.15*
BWR-29 X EC-464107	-3.07*	-0.05	2.64*	-0.03	1.24*	-0.25*	1.28*	-0.28*	0.24*	1.83*	2.69*	126.80*	2.83*	127.01*	-0.21*
BWR-29 X EC-464115	-1.29*	-7.14*	9.47*	-0.12	5.73*	-0.17	0.20*	0.15*	0.10*	1.56*	0.54*	47.38*	0.45*	47.64*	-0.11*
BWR-39 X EC-464107	-0.02	0.61	-3.89*	0.38*	0.37	-0.22*	-0.02*	-0.15*	-0.28*	-3.31*	3.28*	48.45*	3.30*	41.50*	0.18*
BWR-39 X EC-464115	1.03*	-4.02*	9.21*	-0.32*	3.40*	-0.01	-0.13*	-0.08*	-0.19*	-0.16	1.26*	17.83*	0.19	8.19*	0.14*
EC-464107 X EC-464115	2.51*	-1.36*	0.85*	-0.08	0.98*	0.19	-0.21*	-0.05*	0.00	-1.74*	0.70*	-35.50*	-0.89*	-53.60*	-0.35*
SE(Sij) ±	0.342	0.431	0.412	0.101	0.325	0.111	0.018	0.005	0.004	0.280	0.215	0.723	0.145	1.250	0.004
SE(Sij-Sik) ±	0.511	0.644	0.615	0.151	0.485	0.165	0.027	0.008	0.007	0.418	0.321	1.079	0.217	1.866	0.006

SE(Sij-Skl)±	0.473	0.596	0.570	0.140	0.449	0.153	0.025	0.007	0.006	0.387	0.298	0.999	0.201	1.728	0.005

* Significant at $p \leq 0.05$ DFF = Days to 50 per cent flowering; DFP = Days to first picking, PH = plant height; PBP = Primary branches per plant; HD = Harvest duration; LPF = Lobes per fruit; FL = Fruit length; FW = Fruit width; PT = Pericarp thickness; AFW = Average fruit weight; FPP = Fruits per plant; FYPP = Fruit yield per plant; MFPP = Marketable fruits per plant; MFYP = Marketable fruit yield per plant; and TSS = Total soluble solids

For fruits per plant BWR-1 X EC- 464115 (poor x good), BWR- 6- 1 X EC- 464107 (good x good) and BWR- 6- 1 X EC- 464115 (good x good) were the three best specific combiners. For fruit yield per plant BWR- 6-1 X EC- 464107 (good x poor), BWR- 29 X EC- 464107 (poor x poor) and BWR-1 X EC- 464115 (poor x good) were three best specific combiners. For marketable fruits per plant BWR-1 X EC-464115 (poor x good), BWR-6-1 X EC- 464107 (good x good) and BWR-6- 1 X EC-464115 (good x good) were the three best specific combiners. For marketable fruit yield per plant, with BWR-6-1 X EC- 464107 (good x poor), BWR-1 X EC-464115 (poor x average) and BWR- 6- 1 X EC- 464115 (good x average) were the three best specific combiner. For total soluble solids BWR-1 X EC- 464115 (poor x good), BWR-39 X EC- 464107 (good x good) and BWR-29 X BWR- 39 (poor x good) were the three best specific combiners. The results corroborate the findings of Khalil and Hatem (2014) [12], Yadahalli *et al*. (2017) [28], Ahmed *et al*. (2019) [1] and Nalwa and Kumar (2019) [20].

On the basis of specific combining ability effects, three cross combinations *viz.*, BWR- 1 X EC- 464107, BWR- 29 X EC- 464115 and BWR-29 X EC- 464107 were identified as good specific combiners for quantitative and quality traits in bell pepper.

Conclusion

The selection can be done in early generations where both the parents were good general combiners as high SCA effect is due to additive x additive gene action, whereas in the remaining crosses (good x poor, poor x good and poor x poor) selection should be deferred to later generations. Pedigree method would be effective strategy for future breeding.

References

1. Ahmed ME, Alballat IA, Ommran S, Alkadah KAG. Heterotic, combining ability and heritability of fruit yield and quality traits in blocky yellow sweet pepper. Egyptian Journal of Plant Breeding. 2019;23(6):1267-1297.
2. Anonymous. Area and production of vegetables in Himachal Pradesh. Department of Agriculture (H.P.), Shimla-5; c2018.
3. Anonymous. Indian Horticulture Database. National Horticulture Board, Ministry of Agriculture, Government of India, Gurgaon, India; c2019.
4. Bhagyalakshmi PV, Shankar CR, Subrahmanyam D, Babu VG. Heterosis and combining ability studies in chilies. Indian Journal of Genetics. 1991;51:420-423
5. Dabholkar AR. Elements of Biometrical Genetics. Concept Publishing Company, New Delhi, India; c1992.
6. Danojevic D, Medic-Pap S, Cervenski J. Selection and heritability of F_2 sweet pepper offspring from the cross Amphora x Piquillo de Lodosa. Ratarstvo *i* Povrtarstvo. 2018;55(2):80-86
7. Falconer DS. Introduction to Quantitative Genetics. 2nd ed. Longman, New York; c1981.
8. Griffing B. Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Sciences. 1956;9:463-493
9. Hasanuzzaman M, Hakim MA, Fersdous J, Islam MM, Rahman L. Combining ability and heritability analysis for yield and yield contributing characters in chilli (*Capsicum annuum*) landraces. Plant Omics Journal. 2012;5(4):337-344.
10. Hill WG. Investment appraisal for national breeding programmes. Anita Prod. 1971;13:37-50.
11. Kearsey MJ, Pooni HS. The genetic analysis of quantitative traits. Chapman & Hall, London; c1996.
12. Khalil MR, Hatem MK. Studies on combining ability and heterosis of yield and its components in pepper (*Capsicum annuum* L.). Alexandria Journal of Agricultural Research. 2014;59(1):61-71.
13. Khalil RM, Ali FA, Metwally AM, Farag ST. Breeding studies on pepper. Acta Horticulture. 2004;637:161-168
14. Khan I, Sridevi O. Variability, correlation and path analysis in F_2 population of cross between hot pepper and bell pepper. International Journal of Chemical Studies. 2018;6(5):1002-1006.
15. Kornegay JL, Temple SR. Inheritance and combining ability of leaf hopper defense mechanism in common bean. Crop Science. 1986;26:1153-1158.
16. Mahmoud IM. Inheritance of some important traits in sweet pepper (*Capsicum annuum* L.). Journal of Plant Production. 2014;5(11):1931-1943.
17. Marame F, Dessalegne L, Fininsa C, Sigvald R. Heterosis and heritability in crosses among Asian and Ethiopian parents of hot pepper genotypes. Euphytica. 2009;168:235-247.
18. Materska M, Perucka I. Antioxidant activity of the main phenolic compounds isolated from hot pepper fruit (*Capsicum annuum* L.). Journal of Agriculture and Food Chemistry. 2005;53(5):1750-1756.
19. Nadeem M, Anjum FM, Khan MR, Saeed M, Riaz A. Antioxidant potential of bell pepper (Capsicum annum L.)-A review. Pakistan Journal of Food Science. 2011;21(1-4):45-51.
20. Nalwa C, Kumar M. Combining ability analysis for seed yield and component traits in diallel crosses of red sweet pepper (*Capsicum annuum* L. var. *grossum* Sendt.). The Pharma Innovation Journal. 2019;8:238-241.
21. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi; c1984. p. 359.
22. Sharma S, Singh Y, Sharma A, Sharma KC. Generation mean analysis for yield and contributing traits in sweet pepper. Indian Journal of Horticulture. 2016;73(4):526-531.
23. Shukla MR, Patel JA, Doshi KM, Patel SA. Line x tester analysis of combining ability in chilli (*Capsicum annuum* L.). Vegetable Science. 1999;26:45-49.
24. Singh AK, Chaudhary BR. Combining ability and generation mean analysis in Capsicum. Indian Journal

of Genetics and Plant Breeding. 2005;65(2):151-152.
25. Singh RK, Chaudhary BD. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, India; c1985.
26. Teshome A, Baum BR, Fahrig L, Torrance JK, Arnason TJ, Lambert JD. *Sorghum* [*Sorghum bicolor* (L.) Moench] landrace variation and classification in north Shewa and south Welo, Ethiopia. Euphotic. 1997 Nov;97(3):255-63.
27. Thakur H, Jindal SK, Sharma A, Dhaliwal MS. Genetic control of leaf curl virus disease, horticultural and biochemical traits in chilli (*Capsicum annuum* L.). International Journal of Chemical Studies. 2019;7(4): 1970-1976.
28. Yadahalli P, Srinivasa V, Lakshamana D, Hadapad B. Combining ability studies for growth and yield characters in bell pepper (*Capsicum annuum* L.*).* Environment and Ecology. 2007;35:1521-1525.
29. Yunandra SM, Maharijaya A. Inheritance study for yield components of pepper (*Capsicum annuum* L.). IOP Conference Series: Earth and Environmental Science. 2018;6(3):133-142.
30. Zeven AC. Landraces: a review of definitions and classifications. Euphytica. 1998;104:127-139.