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Deciphering genetics of bell pepper for agro-morphological and quality traits through generation mean analysis

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ABSTRACT

This study was aimed to estimate the gene action (additive, dominant and digenic-epistasis) for agro-morphological and quality traits in bell pepper. Generation mean analysis was performed involving four crosses that were derived from four diverse parents. Significance of scaling tests revealed that additive-dominance model was inadequate in all the crosses for all the traits, suggesting presence of higher order non-allelic interactions. For marketable fruits per plant, the cross combination C4 exhibited positive and higher dominance [h] and additive × additive [i] gene interactions coupled with duplicate type of epistasis. This suggested the exploitation of heterosis breeding as well as the selection of desirable segregants through pedigree method. For marketable fruit yield per plant, the cross EC-464115 × KS (C2) expressed higher dominance [h] gene action (relatively higher magnitude of dominance interaction). This suggested that exploitation of hybrid vigour will be rewarding. However, the cross C4 positive and higher dominance [h] and additive × additive [i] gene interactions coupled with duplicate type of epistasis again suggested the utilization of heterosis breeding in addition to the selection of desirable segregants through pedigree method. The mean performance revealed that the cross C1 showed the highest performance for the traits marketable fruits per plant and marketable fruit yield per plant whereas, the cross C2 for primary branches/ plant, ascorbic acid content and capsaicin content. Morphologically also, the F_1s derived from the above two crosses were having blocky, dark green fruits as compare to their parents which were having yellow-green fruits.

Keywords: *Capsicum annuum*, epistasis, heterosis, quality, yield.

INTRODUCTION

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) is one of the popular vegetable grown worldwide, admired by consumers for its delicate taste, exquisite flavour, attractive colour and pleasant aroma. In India, it plays crucial role in raising the livelihood of vegetable growers especially in hilly regions of the country like Himachal Pradesh, Uttrakhand and Jammu & Kashmir (Devi and Sood, 4). In these areas year round cultivation is now being practiced by the farmers either in open field conditions or in the protected structure. The demand for fresh fruit is driven mostly by hotels and catering industry of neighboring states and metropolitan cities thus, generating high cash revenues to their stockholders. Bell pepper is equally popular among its consumers due to its healthy nutritional profile. It is richest source of vitamin C and E, pro-vitamin A, ascorbic acid and carotenoids. Bell peppers contain a very rich polyphenol pattern, which includes hydroxycianmates, flavonols and flavones having great antioxidant activity. Capsaicin, the most abundant capsaicinoids (CAPS) in pepper also accounts for therapeutic effects, including antioxidants, anti-inflammatory, anticancer, antimicrobial and positive immunomodulatory effects. In India, it occupies area of 46,000 ha with production of 327,000 m tones and Himachal Pradesh is second largest capsicum producer in country after Karnataka (Horticultural Statistics at a Glance, 7). The present cultivation scenario of bell pepper demands development of improved cultivars capable to produce higher yield, resistance to various biotic and abiotic stresses along with the specific quality attributes.

Genetic improvement depends primarily on the effectiveness of selection among progenies that differ in genetic value. The additive and dominant effects and their interactions are known as gene actions and are reported to be associated with breeding value. Since, epistatic variance is unexplained by the additive and dominance components, generation mean analysis (GMA) given by Mather and Jinks (10) was used to estimates the gene actions that provides information on additive, dominance and epistatic effects. Furthermore, the relative magnitude of each component could help us to choose most efficient breeding procedure for maximizing the genetic gain under selection. This model has been used by many researchers to study the gene effects of quantitative traits in various vegetable crops. Further, the available information on the gene effects of fruit

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quality traits especially ascorbic acid and capsaicin content is limited. Hence, the present investigation was planned and executed by involving the potential parental lines using six generation model *i.e.* P_1, P_2, F_1, F_2, BC_1, and BC_2 in four bell pepper crosses for eight horticultural traits through GMA. These crosses were made among two exotic lines *viz.,* EC–464107 and EC–464115 augmented from World Vegetable Center, Taiwan, and two commercially grown Indian varieties Kandhaghat Selection (KS) and Sweet Happy-1 (SH–1). Moreover, the lines EC–464107 and EC–464115 were reported high in yield with longer harvest duration and having high resistance to bacterial wilt in our previous studies (Sood and Kumar, 14; Devi *et al*., 5). However, these two lines are slightly more pungent with yellowish–green fruits that are not much liked by the Indian consumers. Morphological traits like fruit colour and shape were also noted in parents and F_1 and it is hoped that results obtained herein would be of value for breeders.

MATERIALS AND METHODS

For genetics of yield and its component traits, six populations that included the parents, first filial, backcross and second generation progenies (P_1, P_2, F_1, F_2, BC_1 and BC_2) of four crosses *viz*., EC-464107 × KS (C1); EC-464115 × KS (C2); EC-464107 × EC-464115 (C3) and EC-464107 × SH-I (C4) derived from four different parents were utilized. Significant differences for phenotypic and quality traits among the parents were decided based on CD value at 0.05 probability (Table 1 and Fig. 1). These populations were evaluated during summer-rainy season of 2013

Table 1: Distinguishing characters of bell pepper genotypes (parents).

Traits	Parental genotypes				CD @ 0.05	Significant parental differences
	EC-464107	EC-464115	Kandaghat Selection	Sweet Happy-I		
Growth habit	Indeterminate	Indeterminate	Determinate	Determinate		
Fruit position	Pendent	Pendent	Semipendent	Pendent		
Fruit color (RHS color chart)	YGG150B	YGG150C	GG143A	GG143A		
Days to 50 per cent flowering	44.33	42.00	43.33	40.17	2.81	C4
Primary branches /plant	4.53	3.87	2.73	3.33	0.60	C1, C2, C3 and C4
Fruit width (cm)	5.93	4.80	5.07	7.03	0.70	C1, C3 and C4
Average fruit weight (g)	35.07	30.63	27.70	51.90	15.17	C4
Marketable fruits/ plant	12.47	15.47	15.60	7.07	3.51	C4
Marketable fruit yield/ plant (g)	434.00	474.00	415.00	362.33	45.93	C2, C4
Ascorbic acid content (mg/100 g)	79.67	107.80	84.40	55.50	14.91	C2, C3 and C4
Capsaicin content (%)	0.097	0.067	0.080	0.083	0.021	C3

RHS Royal Horticulture Society, YGG yellow green group, GG green group

Fig. 1: Morphological appearance of four parents utilized in the crossing programme, a: EC-464107; b: EC-464115; c: Kandaghat Selection and d: Sweet Happy-1.

under open field conditions in a Randomized Block Design with three replications at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur located at 32˚60'N latitude, 76°30'E longitude, and 1290.8 m altitude. Observation were recorded on eight traits including two quality parameters *viz.,* days to 50 per cent flowering, branches per plant, fruit width (cm), average fruit weight (g), marketable fruits per plant, marketable fruit yield per plant (g), ascorbic acid content (mg/100g) and capsaicin content (%). To record the data on these traits, a total of 05 plants were selected randomly per replication in the non-segregating generations (P_1, P_2 and F_1), 30 plants per replication in the back cross generations (B_1 and B_2) and 60 plants in the segregating generation (F_2). The colour of the fruits compared with Royal Horticultural Society colour charts (12) and classified into green group (GG) and yellow green group (YGG) categories. The ascorbic acid content was estimated by 2, 6–dichlorophenol Indophenol Visual Titration Method as described by Ranganna (11). The capsaicin content in the fruits was determined by the colorimetric method using Folin–Ciocalteau reagent as described by Bajaj (1).The data was analyzed by using simple scaling test (Mather, 9), Joint scaling test (Cavalli, 3) and the estimation of various genic effects by best fit solution of Mather and Jinks (10). Heterosis effects were expressed as per cent increase (+) or (−) in the mean values of F_1 hybrid over the better parent or the standard checks Indira (SC–I) and California Wonder (SC–II) as reported by Hayman (6). Data was statistically examined with Windostat ver. 8.5 (http://www.windostat.org) developed by Indostat Services, Hyderabad, India.

RESULTS AND DISCUSSION

Gene action was ascertained for yield and its contributing traits, using GMA. Data was recorded on six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) of four bell pepper crosses. Mean square values obtained from analysis of variance were found significant ($P \leq 0.05$) for the traits *viz.*, primary branches per plant, average fruit weight, marketable fruits per plant, marketable fruit yield per plant and ascorbic acid content in all four cross combinations, suggesting that hybridization followed by recombination had created sufficient genetic variation for these traits. The significant differences were also found in the crosses C2, C3 and C4 for days to 50 % flowering and in the crosses C3 and C4 for fruit width indicating presence of genetic variability for above traits among these populations (Table 2). The results obtained on estimates of scaling tests and various genic effects are presented in Table 3. Significance of scaling tests, i.e. A, B, C and D revealed that additive-dominance model was inadequate in the crosses, among the traits that suggested the presence of digenic or higher order non-allelic interactions. Further, six parameter model was used to estimate the type of gene effects for these traits. Presence of gene action and non-allelic interactions varied crosswise as well as trait-wise. Further, significant differences between the two parents of each cross were used to explain the results more meaningfully (Table 1).

To catch the high price in beginning of season, early flowering and fruit bearing is very much desired trait. Fitting of six-parameter model for days to 50 per cent flowering showed that the cross combinations C4 exhibited dominance [h] gene effects in the desirable direction and relatively higher in magnitudes than

Table 2. Analysis of variance for yield and quality traits in four crosses of bell pepper.

S. N.	Traits	df	Mean sum of squares							
			C1		C2		C3		C4	
			G (5)	E(10)	G (5)	E(10)	G (5)	E(10)	G (5)	E(10)
1	Days to 50 per cent flowering		6.14	2.93	4.95*	1.34	8.23*	1.87	15.10*	4.50
2	Primary branches/plant		1.22*	0.15	0.70*	0.20	0.62*	0.12	0.86*	0.03
3	Fruit width (cm)		0.58	0.11	0.27	0.05	1.13*	0.13	1.92*	0.07
4	Average fruit weight (g)		23.62*	9.69	22.27*	6.44	107.96*	6.17	176.70*	15.04
5	Marketable fruits/plant		29.19*	4.36	13.68*	2.99	10.59*	1.86	31.86*	0.94
6	Marketable fruit yield/plant (g)		45129.66*	181.85	14329.35*	508.07	12730.39*	593.16	15119.34*	101.92
7	Ascorbic acid content (mg/100 g)		580.78*	50.99	970.56*	95.01	981.75*	33.09	254.22*	41.14
8	Capsaicin content (%)		0.00103	0.00006	0.00039	0.00014	0.00074	0.00004	0.00077	0.00025

Where, G: generation, E: error; *$P \leq 0.05$; C1: EC-464107 × KS; C2: EC-464115 × KS, C3: EC-464107 × EC-464115; C4: EC-464107 × SH-I additive [d] gene effects (Table 3).This indicates the possibility of development of early hybrids through heterosis breeding. Therefore, heterosis was estimated to interpret the dominance and dominance interactions. The estimated heterosis was compared with respect to two commercially grown cultivars *viz.,* Indira and California Wonder as standard checks. The comparison of the extent of heterosis of hybrids (Table 4) revealed that the hybrid C4 was the most consistent for earliness and exhibited significant negative heterosis over the better parent (−10.32 per cent) and standard check California Wonder (−10.74 per cent). Number of branches per plant is a direct component trait towards fruit yield. Hence, more primary branches are desirable for high fruit yield in pepper. The cross C1 showed dominance [h] gene component in undesired direction along with duplicate type of gene action indicating the usefulness of recurrent selection for the selection of desirable segregants. However, the cross C2 showed dominance [h] gene effects in desirable direction coupled with duplicate type of gene action, indicating the usefulness of heterosis breeding and this was also reflected from high estimates of heterosis in this hybrid that ranged from 25.44 to 68.01% over the commercial cultivars (Table 4).

To develop a good looking hybrid/cultivar in bell pepper, it is important to have a good balance between length and breadth of the fruit. For fruit width, in the cross C1 pedigree selection shall prove effective on account of desirable additive [d] and additive × additive [i] gene effects. However, in the cross C3, relatively higher magnitude of dominance [h] gene effects than additive components [d] and [i] indicated the effectiveness of heterosis breeding for getting fruits with more width. In present investigation, none of the cross exhibited desirable significant positive heterosis for fruit width indicating larger fruits of standard checks. In contrary to this, Sood and Kumar (14) have confirmed considerable heterosis for fruit width in bell pepper. Average fruit weights along with more fruits per plant are most important traits for obtaining higher yield in bell pepper. Presence of dominance [h] and additive × additive [i] gene interactions were in negative direction coupled with duplicate type of gene action in C4 suggested the selection of desirable segregants after breaking undesirable linkages through intermating (biparental).

Table 3. Simple scaling test and estimates of generation mean parameters for various horticultural traits in bell pepper.

Traits	Simple scaling test				χ^2 (3p df)	Gene effects ± Standard error						Epistasis
	A	B	C	D		[m]±SE	[d]± SE	[h]± SE	[i]± SE	[j]± SE	[l]± SE	
Days to 50 per cent flowering												
C1	*	*	*	*	S	45.17*±0.14	-0.80*±0.15	-14.67*±0.80	-12.67*±0.63	-0.80*±0.24	18.00*±1.28	D
C2	*	*	*	*	S	45.00*±0.06	-0.13*±0.22	-9.67*±0.54	-10.67*±0.48	1.03±0.27	16.00*±1.00	D
C3	*	*	*	*	S	47.03*±0.02	0.23*±0.22	-10.43*±0.54	-10.60*±0.44	-0.93±0.28	6.07*±1.07	D
C4	*	-	-	*	S	39.97*±0.00	1.17*±0.14	-6.38*±0.64	-1.80*±0.28	-0.92±0.49	3.57*±1.29	D
Branches/plant												
C1	-	-	*	*	S	3.97*±0.03	0.77*±0.05	-1.70*±0.18	-1.67*±0.13	-0.13±0.06	1.93*±0.32	D
C2	-	-	*	*	S	3.20*±0.01	0.67*±0.09	2.33*±0.21	1.87*±0.19	0.10±0.11	-2.40*±0.42	D
C3	*	*	-	*	S	3.67*±0.02	-0.67*±0.09	0.17±0.25	1.07*±0.19	-1.00*±0.12	-1.80*±0.48	-
C4	*	*	*	*	S	3.00*±0.00	0.13*±0.02	1.07*±0.07	1.33±0.05	0.47±0.01	0.53±0.15	-
Fruit width (cm)												
C1	*	*	*	*	S	4.70*±0.02	0.20*±0.00	0.47±0.14	0.80*±0.10	-0.23*±0.06	0.93*±0.25	-
C2	*	*	*	*	S	5.17*±0.02	-0.40±0.03	-2.50*±0.16	-2.53*±0.09	-0.27*±0.05	4.20*±0.29	D
C3	*	*	*	*	S	4.23*±0.01	0.20*±0.07	2.60*±0.15	2.40*±0.14	-0.37*±0.08	0.13±0.29	-
C4	*	*	*	*	S	4.60*±0.02	-0.13*±0.03	2.42*±0.12	3.33*±0.09	0.42*±0.05	-0.97±0.20	-
Average fruit weight (g)												
C4	*	*	*	*	S	34.70*±0.09	-1.63*±0.12	-10.35*±1.11	-9.13*±0.43	6.78±0.91	50.97*±2.13	D

*Significant (if the value of parameter divided by its standard error exceeds 1.96); C1: EC-464107 × KS; C2: EC-464115 × KS, C3: EC-464107 ×EC-464115;C4: EC-464107 ×SH-I; p: parameter; S: significant at respective error degree of freedom; m: mean; SE: standard error; [d], [h], [i], [j], [l]: net directional effects of loci contributing to additive, dominance, additive ×additive, additive ×dominance and dominance ×dominance components, respectively

Table 3 Continued

Traits	Simple scaling test				χ^2 (3p df)	Gene effects ± Standard error						Epistasis
	A	B	C	D		[m]±SE	[d]±SE	[h]±SE	[i]±SE	[j]±SE	[l]±SE	
Marketable fruits/plant												
C1	-	*	*	*	S	15.77*±0.07	0.17*±0.19	10.23*±1.06	2.20*±0.48	1.73*±0.50	4.73±2.05	-
C2	*	*	*	*	S	14.27*±0.09	4.20±0.08	16.47*±0.61	13.33*±0.39	4.27*±0.46	-15.33*±1.05	D
C3	*	*	*	*	S	15.93*±0.03	-0.10*±0.17	7.37*±0.58	6.33*±0.36	1.40±0.25	-18.47*±1.15	D
C4	*	*	*	*	S	12.67*±0.04	3.20*±0.09	14.77*±0.35	11.47*±0.23	0.50±0.20	-27.93*±0.65	D
Marketable fruit yield/plant (g)												
C1	*	*	*	*	S	491.57*±0.72	35.27±1.72	410.77*±5.50	80.27*±4.50	25.77*±2.47	232.20*±9.79	C
C2	*	*	*	*	S	497.93*±0.87	101.50*±0.94	202.77*±7.05	43.93*±3.95	72.00*±5.40	16.07±12.75	-
C3	*	*	*	*	S	436.27*±0.90	4.17±1.74	199.53±7.61	49.53*±5.00	24.17*±5.48	271.87*±13.91	-
C4	*	*	*	*	S	439.23*±0.84	77.13*±0.92	402.10*±4.50	249.33*±3.82	41.30±1.63	-357.40*±6.89	D
Ascorbic acid content (mg/100g)												
C1	*	*	*	*	S	52.97*±0.18	-19.53±0.86	52.33*±2.36	51.20*±1.88	-17.17*±1.59	16.13*±4.54	C
C2	*	*	*	*	S	71.13*±0.33	-15.90*±0.86	-3.90*±3.55	-9.13±2.15	-27.60*±1.99	128.60*±6.74	D
C3	*	*	*	*	S	59.57*±0.39	-5.50*±0.16	-7.70*±2.09	19.53*±1.60	8.57±1.27	43.13*±3.19	D
C4	*	*	*	*	S	62.00*±0.19	-12.37*±0.88	35.48*±2.81	31.67*±1.92	-24.45*±1.05	-33.37±5.47	-
Capsaicin content (%)												
C1	*	*	*	*	S	0.047*±0.000	-0.007*±0.001	0.015±0.003	0.040*±0.002	-0.015*±0.002	0.037*±0.006	-
C2	*	*	*	*	S	0.057*±0.000	-0.003*±0.002	-0.040*±0.005	-0.020*±0.005	0.003±0.003	0.067*±0.010	D
C3	*	*	*	*	S	0.077*±0.000	0.003±0.001	-0.102*±0.003	-0.090*±0.002	-0.020±0.001	0.160*±0.004	D
C4	*	*	*	*	S	0.060*±0.001	-0.013±0.001	0.030*±0.006	0.027*±0.003	-0.020*±0.004	0.073*±0.011	C

* = Significant (if the value of parameter divided by its standard error exceeds 1.96) p=parameter; S= significant at respective error degree of freedom, m = Mean, SE=Standard error; [d], [h], [i], [j], [l]=net directional effects of loci contributing to additive, dominance, additive × additive , additive × dominance, and dominance × dominance components, respectively

However, the cross was not able to display hybrid vigour for high fruit weight as compared to standard checks (Table 4). In contrast to this, variable reports on heterosis for this trait are available in literature.

Yield with its component traits ultimately regulate the performance of a variety/hybrid remains as the major selection criteria, and determined by numerous genes with specific interactions that make breeding for yield improvement difficult. From economic viewpoint, it is the marketable fruit yield which is of relevance to the farmers. A given genotype may give higher gross yield but, it is not necessary that the marketable yield will also be higher. For marketable fruits per plant, the cross combination C4 exhibited positive and higher dominance [h] and additive × additive [i] gene interactions coupled with duplicate type of epistasis. This suggested the exploitation of heterosis breeding as well as the selection of desirable segregants through pedigree method. Heterosis estimates for this cross also showed hybrid vigour over both the checks. Sood and Kumar (14) have also reported significantly positive heterobeltiosis and economic heterosis over the standard check Bharat for marketable fruits per plant. For marketable fruit yield per plant, the cross EC-464115 × KS (C2) expressed higher dominance [h] gene action (relatively higher magnitude of dominance interaction). This suggested that exploitation of hybrid vigour will be rewarding. However, the cross C4 positive and higher dominance [h] and additive × additive [i] gene interactions coupled with duplicate type of epistasis suggested the utilization of heterosis breeding in addition to the selection of desirable segregants through pedigree method. These crosses also showed significant positive heterosis over the better parent and over both the standard checks. Sharma *et al*. (13) have also reported hybrid vigour for marketable fruit yield per plant with variable magnitude in good number of cross combinations. The variation for heterosis in different studies may be attributed to the differences in the genotypes involved in the cross combinations and growing conditions.

Table 4. Observed heterosis over better parent and standard checks Indira and California Wonder for fruit yield and quality traits in bell pepper.

S. N.	Traits Crosses	Days to 50 per cent flowering			Primary branches/plant			Fruit width			Average fruit weight		
		% increase/decrease over			% increase/decrease over			% increase/decrease over			% increase/decrease over		
		BP	SC I	SC II	BP	SC I	SC II	BP	SC I	SC II	BP	SC I	SC II
1	C1	-4.44	5.83	0.32	-20.00*	20.00*	60.71*	-12.54*	-14.97*	-30.75*	-0.48	-60.42*	-45.48
2	C2	5.16	10.42*	4.66	-2.40	25.44*	68.01*	-2.50	-18.96*	-34.00*	-7.74	-63.31*	-49.46*
3	C3	3.17	8.33*	2.69	-26.82*	9.78	47.02*	-5.73	-8.36	-25.37*	23.89	-53.85*	-36.43
4	C4	-10.32*	-5.83	-10.74*	-18.30*	22.56*	64.14*	-21.01*	-8.96	-25.86*	-18.56	-52.04*	-33.94
S. N.	Traits Crosses	Marketable fruits/plant			Marketable fruit yield/ plant			Ascorbic acid content			Capsaicin content		
		% increase/decrease over			% increase/decrease over			% increase/decrease over			% increase/decrease over		
		BP	SC I	SC II	BP	SC I	SC II	BP	SC I	SC II	BP	SC I	SC II
1	C1	41.45*	393.66*	193.05*	74.00*	95.90*	64.50*	-1.50	20.50	35.50*	-40.00*	-25.00*	-33.33*
2	C2	20.20	317.60*	147.90*	27.30*	56.60*	31.40*	-6.00	46.90*	65.10*	-37.37*	-37.50*	-44.44*
3	C3	-3.04	235.57*	99.20*	21.20*	49.00*	25.10*	-38.30*	-3.60	8.40	-30.00*	-16.67*	-22.22*
4	C4	4.78	192.32*	73.53*	52.10*	43.00*	20.00*	-33.80*	3.50	16.30	-10.00*	12.50*	0.01

*P ≤ 0.05, where C1: EC-464107 × KS; C2: EC-464115 × KS; C3: EC-464107 × EC-464115; C4: EC-464107 × SH-I; SC I: Standard Check 1 (Indira); SC I: Standard Check II (California Wonder)

Ascorbic acid (Vitamin C) has unique anti-oxidant properties and also strengthens the immune system of the body against diseases. Bell pepper fruits are rich source of ascorbic acid and considerable attention has been given to evolve high ascorbic acid varieties throughout the world. Positive and higher dominant [h] gene effects revealed the importance of heterosis breeding in the cross C4 whereas, duplicate type of gene action was observed in the crosses C2 and C3 indicated the use of recurrent selection and biparental approach in selecting desirable segregants. Positive and significant heterosis for this trait was recorded in the cross C2 over the standard checks Indira and California Wonder. The results of present investigation were also supported by earlier findings of Kumar and Tata (8) who evaluated 40 F_1 hybrids of chilli for this trait at different maturity stages and reported positive heterosis over the mid and better parents. Capsaicin is produced by glands in the pepper's placenta which has many health benefits and primarily used as pain killer and anti-carcinogenic. But for vegetable purpose, varieties with low capsaicin (pungency) content are desired by the consumers. Presence of non-additive [h] gene effects in the cross C3 indicated the possibilities of selecting segregants with lower capsaicin content through heterosis breeding. Heterosis in negative direction is desirable for this trait. The hybrid C3 exhibited significant negative heterobeltiosis and negative standard heterosis over both the commercial checks, thus indicating reduction in pungency. Recently, both decreased and increased heterobeltiosis and economic heterosis for capsaicin content in chillies were also reported by Butcher *et al.* (2).

High heterosis was not necessarily responsible for high mean performance, or vice versa, because some time high heterotic response of a hybrid may be due to poor performance of its parents. In such cases mean performance seems to be more appropriate for selecting the best cross-combinations compared with heterotic effects. The mean performance of hybrids in comparison with extent of heterosis revealed that there was almost complete correspondence between the top-best hybrids on the basis of extent of heterosis and mean performance (Table 4 and Table 5). The hybrid cross combination C4 was best for days to 50 per cent flowering, C2 for primary branches per plant, ascorbic acid content and capsaicin content. The hybrid C1 was the top best for the traits *viz*., marketable fruit yield per plant and marketable fruits per plant (Table 5). Sood and Kumar (14) have also worked out the mean performance of bell pepper hybrids and revealed that mean performance of hybrids and their heterotic response had strong positive association and crosses *viz*., EC-464107 × Yolo Wonder, KS × Solan Bharpoor, SKAU-SP-633-1 × Yolo Wonder, AC-48 × Solan Bharpoor and EC-464115 × California Wonder which had high mean performance for yield, had highly significant heterosis compared with the standard check Bharat.

Table 5. Mean values of standard checks and four crosses for fruit yield and quality traits in bell pepper.

S. N.	Traits Parent/cross	Days to 50 per cent flowering	Primary branches / plant	Fruit width (cm)	Average fruit weight (g)	Marketable fruits/ plant	Marketable fruit yield/ plant (g)	Ascorbic acid content (mg/100 g)	Capsaicin content (%)
1	Indira	40.00	3.00	6.10	88.13	4.47	385.33	69.00	0.077
2	CW	42.17	2.24	7.49	63.98	7.53	459.00	61.37	0.087
3	C1	42.33	3.60	5.17	34.87	22.07	755.00	83.17	0.063
4	C2	44.17	3.77	4.97	32.33	18.67	603.33	101.33	0.053
5	C3	43.33	3.30	5.57	40.67	15.00	604.00	66.50	0.067
6	C4	37.67	3.67	5.57	42.27	13.07	550.93	71.40	0.093
SE (m)		0.95	0.20	0.23	5.10	5.02	15.47	5.01	0.007
CD (5%)		2.81	0.60	0.70	15.17	3.51	45.93	14.91	0.021
CV (%)		3.91	10.35	7.07	19.77	15.58	5.34	11.14	16.13

Where, KS: Kandaghat Selection; SH-1: Sweet Happy-1; CW: California wonder; C1: EC-464107 × KS; C2: EC-464115 × KS; C3: EC-464107 × EC-464115; C4: EC-464107 × SH-I

In pepper breeding, beside the yield traits, fruit morphology is also very important. Morphological characterization of these hybrids suggested that fruit colour in the parents EC-464107 and EC-464115 was yellow green (YGG150B and YGG150C) but in their hybrid combinations with KS, they produced medium light green (GG144B) and medium dark green fruits (GG144A). Similarly, fruit colour in the parent SH-I was noted as dark green (GG143A) and it produced medium dark green (GG144A) coloured fruits when crossed with EC-464107 as a female parent. All the parents and F_1's were having blocky fruit shape.

Conclusively, epistasis gene actions played important role in the inheritance of above traits and nature and magnitude of gene effects varied with the breeding material used in different crosses. Thereby, specific breeding strategy has to be adopted for a particular cross to bring about enviable improvement in a particular trait. In majority of cases, high magnitude of dominance gene effects along with high heterosis estimates suggested that heterosis breeding could be exploited to achieve high fruit yield in bell pepper.

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