Himachal Journal of Agricultural Research 43(2): 78-88 (2017)

Genetic variation, association of characters, and their contributions for improvement in bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.)

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Manuscript received:20.12.2017; Accepted: 05.03.2018

Abstract

Forty six genotypes of bell pepper were evaluated during the summer rainy season of 2015 at CSKHPKV, Palampur to study the extent of genetic variability, determine the association between different characters, understand the direct and indirect effects of component traits on marketable fruit yield, and identify desirable genotypes. Sufficient genetic variability was observed for all horticultural traits studied; that is, days to 50 per cent flowering, days to first picking, plant height, primary branches per plant, harvest duration, fruit length, fruit width, pericarp thickness, lobes per fruit, average fruit weight, fruit yield per plant, fruits per plant, marketable fruit yield per plant and marketable fruits per plant. On the basis of mean performance, the progenies P-30, P-39 P-33, P-11 and P-28 were the highest yielder. The phenotypic coefficient of variation (PCV) indicated higher values than genotypic coefficient of variation (GCV) for all the traits, indicating close association between phenotype and genotype. High heritability estimates along with high genetic advance were recorded for average fruit weight, fruit yield per plant and marketable fruit yield per plant indicating the role of additive gene action for their inheritance. Harvest duration and fruit width had high heritability estimates along with low genetic advance, indicating non-additive gene activity, and these could be improved through hybridization The maximum direct effect on marketable fruit yield per plant was exhibited by marketable fruits per plant, average fruit weight and fruit width, whereas days to 50 per cent flowering and marketable fruits per plant had negative direct effects. Adequate genetic variability was present within bell pepper germplasm to allow breeding improvement of marketable yield.

Key words: *Capsicum annuum* var. *grossum*, bell pepper, variability, heritability, genetic advance, correlations, path analysis.

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) in the state of Himachal Pradesh is an off-season crop grown during summer and rainy seasons and has generated cash revenues to the farmers by selling the produce in the neighbouring states and metropolitan cities. It is also grown as a cash crop (June-October) in Zone-I, Zone-II and Zone-III. There has been little work to develop improved cultivars for local conditions. Success of a breeding program depends on variability in the available germplasm and genetic relationship among desirable traits.

In addition the knowledge of correlation coefficients, partitioning of correlation coefficients into direct and indirect effects can improve selection efficiency. Correlation analysis measures relationships among traits but provides limited information because complex inter-relationships are not examined. Accordingly, correlation must be used with caution in making decisions regarding indirect criteria (Board *et al.*1997, Kang 1994). A path coefficient is a standardized, partial regression coefficient measuring direct influence of one trait and permits the separation of a correlation coefficient into components of direct and in direct effects (Dewey and Lu 1959). Partitioning of correlation coefficients into direct and indirect effects provides more useful information than correlation coefficients alone (Board *et al.* 1997, Dewey and Lu 1959).

There is limited information on direct and indirect path coefficients in bell pepper. The investigation was undertaken to assess the magnitude of genetic variability, to find out the

phenotypic and genotypic inter-relationships among marketable fruit yield and component traits, to assess the relative importance of direct and indirect contributions towards marketable fruit yield and to find out the superior progenies.

Materials and Methods

Plant material

The genetic material comprised of 46 genotypes of bell pepper (Table 1). The experiment was conducted at the Research farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya Palampur (H.P), India, situated at 32° 6' N latitude, 76° 3' E longitude, and elevation of 1290.8 m above sea level during the summer rainy (February-August) season 2015. The climate is humid temperate, having severe winters and mild summers. The experiment was conducted under field conditions. Recommended rates of manures and fertilizers were added. The soil of the experiment was silty clay loam and acidic (pH = 5.7) in reaction.

The experiment was arranged in a randomized complete block design with 3 replicates. Seeds, treated with Bavistin or Carbendazim (2 g/ kg seed) to avoid fungal diseases, were sown in raised nursery beds (3m long, 1 m wide, and 15 cm height) during January. Seedlings were ready for transplanting after 4-6 weeks when transplants were 10-15 cm tall. Twelve plants of each genotype were planted with an inter- and intra-plant distance of 60 x 45 cm. There were 20 t/ha of cow manure and 45N-75P-50K kg/ha applied at field preparation prior to transplanting of seedlings. Another dose of 45 kg/ha of N was applied about a month after transplanting and at fruit setting. Sufficient moisture was maintained during the growing season by applying flood irrigation at 7- to 10-day interval.

There were 5-7 harvests depending on genotypes; harvest intervals were 5-7 days. Fruit weight over all the harvests (total weight of all the harvests divided by the total number of fruits harvested) was determined. There are no specific guidelines describing marketability classes of pepper fruit in India. Consumers prefer small to medium-size fruit. Generally, large-sized fruits are preferred by Hotels and restaurants for other types of dishes. At marketable maturity, fruits of 10 randomly selected plants of each genotype in each replicate were harvested and fruit length, fruit width, pericarp thickness, lobes per fruit, average fruit weight, fruit yield per plant, fruits per plant, marketable fruit yield per plant and marketable fruits

Table 1. Details of the experimental material and fruit colour of the capsicum progenies grown at Palampur

Progeny	Pedigree	Fruit colour	Progeny	Pedigree	Fruit colour*
P-1	(P13 X KS)-9-8-2	GG (143 B)	P-24	(P14 X KS)-43-5-1	YYG (144A)
P-2	(P13 X KS)-12-1-1	YYG (144A)	P-25	(P14 X KS)-70-5-2	GG (143 A)
P-3	(P13 X KS)- 15-2-1	YGG (146A)	P-26	(P14 X KS)-52-1-1	YGG (146A)
P-4	(P13 X KS)-15-3-2	GG (143 B)	P-27	(P14 X KS)-52-2-7	GG (143 B)
P-5	(P13 X KS)-16-6-1	GG (143 B)	P-28	(P14 X KS)-70-8-1	YYG (144A)
P-6	(P13 X KS)-24-1-2	YGG (153C)	P-29	(P14 X KS)-53-3-2	GG (143 A)
P-7	(P13 X KS)-24-2-1	YGG (145 A)	P-30	(P14 X KS) -76-3-1	GG (141 A)
P-8	(P13 X KS)-24-3-1	YYG (144A)	P-31	(P14 X KS)- 54-2-1	GG (143 A)
P-9	(P13 X KS)-24-3-8	YGG (144 C)	P-32	(P14 X KS)-55-3-1	YYG (144A)
P-10	(P13 X KS)-28-4-1	YYG (144 A)	P-33	(P14 X KS)-57-4-1	YGG (146A)
P-11	(P13 X KS)-28-4-9	GG (143 B)	P-34	(P14 X KS)-57-6-1	YGG (146A)
P-12	(P13 X KS)-34-1-2	YGG (146 B)	P-35	(P14 X KS)-58-2-1	GG (143 B)
P-13	(P13 X KS)-38-1-4	GG (143 B)	P-36	(P14 X KS)-68-2-1	GG (143 B)
P-14	(P13 X KS)-38-2-1	GG (143 A)	P-37	(P14 X KS)- 70-4-1	GG (143 C)
P-15	(P13 X KS)-38-2-6	GG (143 A)	P-38	(P14 X KS)- 72-1-1	GG (141 A)
P-16	(P13 X KS)-38-10-2	YYG (144A)	P-39	(P14 X KS)- 73-1-1	YYG (144A)
P-17	(P13 X KS)-38-12-4	GG (141 A)	P-40	(P14 X KS)- 76-2-1	GG (143 A)
P-18	(P13 X KS)-42-1-2	YGG (146 B)	P-41	(P14 X KS)- 45-10-1	GG (143A)
P-19	(P13 X KS)-42-4-1	YYG (144A)	P-42	(P14 X KS)- 45-10-1	GG (143 A)
P-20	(P13 X KS)-83-8-2	GG (143 A)	P-43	(P14 X KS)- 57-2-1	GG (143 A)
P-21	(P13 X KS)-84-4-1	GG (143 A)	EC-464107	Resistant check	YGG (145 C)
P-22	(P13 X KS)-84-2-2	GG (143 A)	EC-464115	Resistant check	GG (143 A)
P-23	(P14 X KS)-43-6-1	GG (143 B)	California Wonder	Susceptible check	GG (135 A)

*From Royal Horticultural Society colour charts: GG = Green group, YGG = Yellow green group, YYG = Yellow yellow green group

per plant of different genotypes were determined.

Statistical Analysis

OP STAT (software developed by CCS Haryana Agricultural University, Hisar, India) software was used for statistical analysis and the data were subjected to analysis of variance (Panse and Sukhatme 1984).The genotypic and phenotypic coefficients of variation (GCV and PCV) for each character were calculated with the following formulae:

Genotypic coefficient of variation (GCV) $= \frac{\sigma^2 g \times 100}{\overline{X}}$

Phenotypic coefficient of variation (PCV) $\frac{\sigma^2 p \times 100}{\overline{X}}$

Where $\sigma^2 g$ = the genotypic variance, $\sigma^2 p$ = the phenotypic variance, and X= the grand mean of the trait.

Broad sense heritability and genetic advance were computed using the formulae given by Burton and De Vane (1953) and Johnson et al. (1955) as:

$$\text{Heritability } (h^2_{bs}) = \frac{\sigma^2 g}{\sigma^2 g + \sigma^2 e} X\ 100$$

and

Genetic advance (% of mean)

$$= K \times \sigma p \times h^2_{bs} / \overline{X} \times 100$$

Where K = Selection differential at 5% selection intensity; that is 2.06, σp = Phenotypic standard deviation, and h^2 = Heritability (broad sense).

Estimates of genotypic and phenotypic correlations were obtained using the formula given by Al-Jibouri et al. (1958). Direct and indirect path coefficients were calculated as proposed by Dewey and Lu (1959).

Results and Discussion

Analysis of variance

Analysis of variance indicated that differences due to genotype were significant for all the traits. This indicates that sufficient genetic variability is available to be exploited in a breeding program as reflected in the broad ranges observed for each trait (Table 2).Sufficient genetic variability for many of the traits studied in capsicum had also been reported by earlier workers Ahmed *et al.* (2012); Sasu *et al.* (2013); Kumari (2013); Maga *et al.* (2013); Cebula *et al.* (2015); Muhammad *et al.* (2015) and Paola *et al.* (2016).

Mean performance of progenies

The progeny P-30 had the highest marketable fruit yield followed by P-39 and P-33 (Table 3). These progenies also performed better for fruit yield per plant, fruits per plant, marketable fruits per plant, harvest duration and average fruit weight, the main contributing traits towards increased marketable fruit yield. These lines also took minimum days to flowering and picking. The results agree with Sood *et al.* (2011), Ahmed *et al.* (2012), Afroza *et al.* (2013), Maga *et al.* (2013), Pandey *et al.* (2013),Cebula *et al.* (2015) Muhammad *et al.* (2015) and Paola *et al.* (2016) who used different genetic material. Fruit length was found maximum in P-8, whereas maximum fruit width was observed in P-19. Harvest duration was highest in P-18 and P-33 followed by P-39, P-28, P-24, P-20, P-13 and P-6. Progeny P-28 had the maximum number of fruits per plant followed by P-11 and P-6. The progenies P-28 also had the highest number of marketable fruits per plant followed by P-11 and P-6. Pericarp thickness was highest in P-33, whereas average fruit weight was highest in P-30 followed by P-31 and P-39. The progeny P-30 had highest yield and early flowering and picking and can be exploited in further improvement programme.

Parameters of variability

Analysis of parameters of variability (Table 4) indicated that phenotypic and genotypic coefficients of variation, expressed as percentages, were moderate for plant height, primary branches per plant, harvest duration, average fruit weight, fruit yield per plant, fruits per plant, marketable fruit yield per plant and marketable fruits per plant; low for pericarp thickness, fruit length, harvest duration, lobes per fruit, fruit width, days to 50 per cent flowering and days to first picking. In all cases, GCV was less than PCV, indicating the role of the environment (heterogeneity in soil fertility status or other unpredictable factors) in the expression of the traits under investigation. The characters possessing a high GCV stand a greater chance of improvement through selection and high heritability improves selection based on phenotypic value.

Heritability and genetic advance

Genetic advance is a useful indicator of progress that can be expected as a result of exercising selection on a population. In the present study, high heritability was present for most of the characters. However, high heritability along with high genetic advance was predicted for average fruit weight, fruit yield per plant and marketable fruit yield per plant, whereas high to moderate heritability coupled with high to moderate genetic advance was found for fruit length and marketable fruits per plant. This indicates an additive gene action for these traits and their possible improvement through selection. High to moderate heritability, accompanied by low genetic

Table 2. Range and mean values for marketable fruit yield and component characters of 46 progenies

Component	Days to 50 % flowering	Days to first picking	Plant height (cm)	Primary branches /plant	Harvest duration (days)	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Lobes /fruit	Average fruit weight (g)	Fruit yield /plant (g)	Fruits /plant	Marketable fruits /plant	Marketable fruit yield /plant (g)
Range	39.33-51.67	67.00-74.00	30.64-59.69	3.40-8.97	9.00-42.00	3.48-6.64	4.15-5.59	3.33-4.70	2.70-4.13	12.47-63.16	93.33-2311.67	6.33-75.00	6.33-74.00	80.00-2265.00
MSS	25.78*	12.15*	141.91*	6.52*	63.14*	1.19*	0.45*	0.44*	0.36*	229.16*	505518.40*	344.08*	505646.90*	336.20*
Mean	47.46	69.42	47.12	6.70	38.10	4.81	4.94	4.04	3.58	32.58	1439.70	45.13	43.63	1417.70
SE (m)	1.63	1.38	2.55	0.51	1.20	0.115	0.106	0.28	0.125	1.08	46.43	1.71	1.54	60.10
CD (P=0.05)	4.57	3.89	7.16	1.44	3.37	0.32	0.30	0.80	0.35	3.04	130.50	4.80	4.32	168.91

MSS = Mean sum of squares; SE (m) = Standard error of mean; CD = Critical difference for comparing means of any two genotypes
* Significant at 5% level

Table 3. Mean values for marketable fruit yield and component characters of 46 capsicum progenies

Progenies	Days to 50 percent flowering	Days to first picking	Plant height (cm)	Primary branches/ plant	Harvest duration (days)	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Lobes/ fruit	Average fruit weight (g)	Fruit yield/plant (g)	Fruits /plant	Marketable fruits/plant	Marketable fruit yield/plant (g)
P-1	49.67	70.67	46.08	8.40	37.00	4.15	4.19	3.40	3.60	25.63	900.00	35.00	32.00	860.00
P-2	44.33	68.33	59.65	8.73	39.33	4.81	5.53	3.87	3.53	35.69	1901.67	53.33	52.00	1801.67
P-3	44.00	68.33	49.90	5.33	39.33	4.87	5.23	4.47	3.57	35.70	1298.33	38.00	36.00	1250.00
P-4	51.67	71.00	50.91	6.20	39.33	4.42	4.17	4.00	3.47	20.52	735.00	40.33	37.67	711.67
P-5	49.33	70.00	48.44	6.20	37.67	4.98	4.98	4.40	3.63	30.44	1385.00	43.67	43.00	1316.67
P-6	53.67	72.00	38.85	5.27	39.00	4.14	4.15	3.73	3.67	20.27	1211.67	62.33	61.33	1175.00
P-7	45.33	68.00	41.85	5.40	40.00	5.31	4.97	4.33	3.33	23.72	840.00	42.33	40.67	816.67
P-8	46.33	68.67	51.11	4.40	38.67	6.64	5.24	3.37	3.60	28.43	943.33	49.33	48.33	930.00
P-9	50.33	69.33	41.17	5.73	38.33	3.77	5.23	4.67	4.00	33.08	1593.33	35.33	33.00	1536.67
P-10	46.33	68.67	54.49	5.33	38.67	4.45	5.21	3.53	3.50	33.74	1505.67	34.00	32.67	1460.67
P-11	53.00	67.33	59.69	6.00	39.00	5.02	5.02	4.50	3.33	25.28	2075.00	63.00	62.67	2035.00
P-12	51.00	74.00	54.23	6.60	38.33	4.76	5.32	3.47	3.43	45.15	1433.33	34.67	34.00	1406.67
P-13	46.67	67.33	39.51	5.47	40.00	5.12	5.46	3.73	3.90	30.94	1231.67	41.67	40.33	1208.33
P-14	46.67	68.00	40.19	5.13	39.33	5.59	5.14	3.67	3.03	31.99	1448.33	39.67	39.33	1415.00
P-15	48.00	75.33	49.49	5.13	37.33	3.99	5.23	4.47	3.67	26.73	1346.67	42.00	41.00	1325.00
P-16	52.00	71.00	37.55	6.83	36.67	4.51	5.32	3.87	4.03	32.50	1228.33	40.33	39.67	1388.33
P-17	46.00	68.00	48.50	5.47	39.33	5.55	4.99	4.07	3.33	34.12	1625.00	53.00	51.00	1571.67
P-18	47.33	68.33	53.68	5.13	42.00	4.41	5.53	3.60	4.00	36.72	1521.67	42.00	41.00	1555.00
P-19	49.00	70.00	55.61	8.93	37.33	4.30	5.59	4.07	4.13	30.72	1425.00	45.00	44.33	1385.00
P-20	45.33	67.67	56.33	7.43	40.00	4.35	5.25	4.33	3.93	32.00	1456.67	42.67	42.00	1441.67
P-21	48.00	67.33	45.73	6.43	39.33	5.16	4.89	3.87	3.80	35.01	1481.67	43.00	42.33	1463.33
P-22	46.00	76.00	49.45	8.60	36.67	5.06	4.98	4.27	3.93	26.95	1163.33	48.33	47.00	1133.33
P-23	45.33	68.00	46.16	6.60	39.33	4.04	5.29	4.53	3.40	28.37	1440.00	54.00	53.67	1426.67
P-24	45.00	67.00	37.94	6.23	40.33	4.05	4.62	4.13	3.53	44.18	1635.00	43.00	42.33	1606.67
P-25	48.00	68.33	48.39	8.60	39.00	3.48	4.67	3.33	4.00	29.97	1468.33	52.33	50.33	1448.33
P-26	51.33	68.00	44.79	7.83	39.33	4.74	4.49	3.67	3.93	30.48	1373.33	46.67	43.67	1323.33
P-27	53.00	70.67	42.59	7.40	36.67	4.96	4.88	3.80	3.93	28.56	1373.33	47.67	47.00	1346.67
P-28	46.67	67.33	48.55	5.97	40.00	5.56	5.01	4.00	3.80	29.03	1899.00	75.00	74.00	1936.67
P-29	45.00	68.00	47.77	7.63	39.33	5.31	4.99	4.47	3.93	34.58	1923.33	60.33	59.00	1898.33
P-30	47.67	69.67	41.98	8.63	38.33	4.96	4.97	4.00	3.73	63.16	2311.67	37.00	33.33	2265.00
P-31	47.00	69.00	50.57	7.57	38.00	5.61	4.89	3.93	2.93	47.93	1611.67	36.33	33.33	1586.67
P-32	44.00	69.00	39.67	7.07	38.00	5.05	4.68	4.27	3.73	34.40	1533.33	45.00	45.00	1510.00
P-33	39.33	68.33	30.67	4.10	42.00	5.39	5.15	4.70	3.70	40.95	2233.33	54.00	53.00	2233.33
P-34	48.67	68.33	44.23	7.10	39.00	4.15	4.37	3.93	3.60	43.63	1626.67	37.33	36.33	1610.00
P-35	48.67	69.33	51.31	7.60	38.00	5.42	5.37	4.60	3.00	33.22	1690.00	51.00	49.33	1726.67
P-36	50.67	72.67	58.01	8.97	38.00	4.55	4.94	4.07	3.40	43.13	1711.67	42.00	41.00	1683.33
P-37	46.00	68.00	55.27	8.93	39.33	4.32	5.08	4.40	3.53	33.33	1213.33	33.67	31.33	1156.67
P-38	46.00	69.00	51.20	7.27	39.67	4.41	4.93	3.80	3.57	24.48	991.67	41.33	40.33	958.33
P-39	42.00	69.67	42.07	6.93	41.33	4.49	5.11	4.60	3.37	45.43	2266.67	61.67	54.00	2260.00
P-40	46.00	69.67	45.23	8.30	38.33	4.41	4.35	4.07	3.83	21.54	1273.33	51.00	50.67	1263.33
P-41	45.67	70.00	39.61	3.63	38.33	4.59	4.87	3.60	3.73	34.07	1431.67	41.00	39.67	1385.00
P-42	45.00	68.00	53.07	3.40	38.67	5.19	4.57	3.67	3.40	39.25	1850.00	42.67	40.67	1833.33
P-43	48.67	68.33	51.99	7.53	38.33	6.18	4.69	3.73	2.80	34.95	1230.00	39.33	39.00	1230.00
EC-464107(R)	46.33	70.33	46.43	7.03	35.67	5.42	4.21	4.23	2.70	24.17	1133.33	52.67	51.00	1096.67
EC- 464115(R)	47.33	71.00	47.30	7.33	36.33	4.47	4.25	4.50	2.93	22.26	1161.67	55.67	51.33	1161.67
California Wonder(S)	49.67	70.33	30.64	8.29	9.00	5.21	5.08	4.43	3.85	12.47	93.33	6.33	6.33	80.00
SE (m)	1.63	1.38	2.55	0.51	1.20	0.115	0.106	0.28	0.125	1.08	46.43	1.71	1.54	60.10
CD (P=0.05)	4.57	3.89	7.16	1.44	3.37	0.32	0.30	0.80	0.35	3.04	130.50	4.80	4.32	168.91

Table 4. Estimates of parameters of variability for marketable fruit yield and component characters of 46 capsicum progenies

Trait		PCV (%)	GCV (%)	h^2_{bs} (%)	GA as (%) of mean
Quantitative traits					
a)	**Phenological and structural traits**				
	Days to 50 % flowering	7.85	5.14	42.81	6.92
	Days to first picking	4.04	2.11	27.09	2.26
	Plant height (cm)	16.47	13.56	67.71	22.98
	Primary branches /plant	24.51	20.64	70.92	35.81
	Harvest duration (days)	12.83	11.62	82.02	21.68
b)	**Fruit yield traits**				
	Fruit length (cm)	13.51	12.86	90.67	25.23
	Fruit width (cm)	8.44	7.57	80.41	13.98
	Pericarp thickness (mm)	13.71	6.47	22.22	6.28
	Lobes /fruit	10.79	8.95	68.8	15.29
	Average fruit weight (g)	27.23	26.62	95.54	53.59
	Fruit yield /plant (g)	28.88	28.33	96.26	57.26
	Fruits /plant	24.33	23.43	92.73	46.47
	Marketable fruits /plant	24.77	24.01	93.93	47.93
	Marketable fruit yield /plant (g)	29.57	28.65	93.84	57.16

PCV = Phenotypic coefficient of variation
GCV= Genotypic coefficient of variation
h_{bs}^2= Heritability (broad sense)
GA = Genetic advance

advance for harvest duration, fruit width, plant height and lobes per fruit, is indicative of non-additive gene actions predominance, which could be exploited through heterosis breeding. Low heritability associated with low genetic advance for days to 50 per cent flowering, days to first picking and pericarp thickness indicates the preponderance of non-additive genes for its inheritance. Similar results were obtained by (Sharma et al 2009 and Naik *et al.* 2014) for pericarp thickness (Sharma *et al.* 2009, Sood *et al.* 2009, 2011) for days to 50 per cent flowering.

Correlation studies

The genotypic correlation coefficients, in general, were higher than the corresponding phenotypic correlation coefficients, suggesting a strong inherent association among traits at the genetic level (Table 5). Similar results have also been reported by Sood *et al.* (2007), Thakur *et al.* (2013), Kumari (2013) and Rana *et al.* (2015) in bell pepper. At the phenotypic level, marketable fruit yield had a significant positive association with fruits per plant, average fruit weight, marketable fruit yield per plant and marketable fruits per plant. At the genotypic level, marketable fruit yield was positively associated with fruits per plant and marketable fruits per plant, indicating that selection for these traits would also lead to improvement in marketable fruit yield. High positive correlations were observed for days to 50 per cent flowering with days to first picking; days to first picking with fruit yield per plant and marketable fruit yield per plant; harvest duration with average fruit weight, fruit yield per plant, fruits per plant, marketable fruits per plant and marketable fruit yield per plant; fruit width with lobes per fruit, average fruit weight, fruit yield per plant and marketable fruit yield per plant; average fruit weight with fruit yield per plant and marketable fruit yield per plant; fruits per plant with marketable fruits per plant and marketable fruit yield per plant at phenotypic level whereas, at genotypic level days to first picking with fruits per plant and marketable fruits per plant; plant height with marketable fruits per plant; fruit width with pericarp thickness. Naik *et al.* (2010), Sharma *et al.* (2010), Maga *et al.* 2013, Thakur *et al.* 2013 and Rana *et al.* (2015) reported positive association of marketable fruit yield with fruits per plant.

Table 5. Estimates of phenotypic (P) and genotypic (G) correlations for component characters of 46 capsicum progenies

		Days to first picking	Plant height (cm)	Primary branches\plant	Harvest Duration (days)	Fruit length (cm)	Fruit Width (cm)	Pericarp thickness (mm)	Lobes /fruit	Average fruit weight (g)	Fruit yield /plant (g)	Fruits /plant	Marketable fruits /plant	Marketable fruit yield /plant (g)
Days to 50 % flowering	P	0.239*	0.128	0.168*	-0.181*	-0.160	-0.190*	-0.146	0.042	-0.205*	-0.248*	-0.135	-0.110	-0.258*
	G	0.486*	0.119	0.249*	-0.293*	-0.219*	-0.234*	0.496*	0.157	-0.328*	-0.368*	0.176*	0.156	-0.343*
Days to first picking	P		0.061	0.156	-0.272*	-0.131	-0.079	-0.008	0.036	-0.091	-0.179*	-0.110	-0.122	-0.184*
	G		-0.001	0.229*	-0.204*	-0.300*	-0.120	0.091	0.028	-0.209*	-0.360*	0.174*	0.176*	-0.347*
Plant height (cm)	P			0.233*	0.246*	0.007	0.164	-0.090	-0.129	0.045	0.129	0.169*	0.158	0.104
	G			0.231*	0.363*	-0.020	0.222*	0.216*	0.256*	0.083	0.164	0.154	0.167*	0.145
Primary branches per plant	P				-0.218*	-0.193*	-0.084	0.079	0.046	0.015	-0.080	-0.093	-0.103	-0.077
	G				-0.275*	-0.236*	-0.093	0.102	0.097	0.024	-0.096	0.126	0.145	-0.110
Harvest Duration(days)	P					-0.089	0.032	-0.063	-0.043	0.369*	0.512*	0.525*	0.512*	0.506*
	G					-0.096	0.028	0.221*	0.055	0.415*	0.593*	0.583*	0.565*	0.592*
Fruit length (cm)	P						0.122	0.015	-0.341*	0.051	0.015	0.094	0.108	0.024
	G						0.130	0.128	0.445*	0.056	0.001	0.084	0.105	0.006
Fruit Width (cm)	P							0.084	0.211*	0.212*	0.209*	-0.085	-0.068	0.220*
	G							0.259*	0.288*	0.253*	0.243*	0.115	0.089	0.252*
Pericarp thickness (mm)	P								-0.097	-0.037	0.142	0.102	0.081	0.146
	G								0.136	-0.111	0.249*	0.214*	0.203*	0.244*
Lobes /fruit	P									-0.048	0.012	-0.020	-0.005	0.016
	G									-0.054	-0.012	0.098	0.065	-0.002
Average fruit weight (g)	P										0.703*	-0.056	-0.091	0.695*
	G										0.727*	-0.042	0.080	0.725*
Fruit yield /plant (g)	P											0.507*	0.484*	0.989*
	G											0.529*	0.503*	0.999*
Fruits /plant	P												0.986*	0.510*
	G												0.996*	0.540*
Marketable fruits / plant	P													0.490*
	G													0.515*

*Significant at 5 % level

Path coefficient studies

Partitioning of genotypic correlations into direct and indirect effects was done to determine relative importance of components. It was determined that direct and indirect effects obtained at genotypic level were different from those at phenotypic level. (Table 6), which might be due to varying degree of influence of environment. This was supported by results of component variance analysis and correlation at the environmental level. In a few cases, that is plant height and fruits per plant were observed to be negative at phenotypic level, but the corresponding value at the genotypic level was positive. This type of change in direction and magnitude of direct and indirect effects from genotypic level to phenotypic level, and vice versa, might be due to the environmental factors influencing various traits. The path analysis at the genotypic level may not provide a true picture of direct and indirect causes, and it is advisable to sunderstand the contribution of different traits towards the fruit yield per plant at the genotypic level. For path analysis at the genotypic level, marketable fruit yield per plant was the dependent variable to all the traits used for correlation and considered as casual variables. Fruit yield per plant, which had the highest genotypic correlation, exhibited the highest direct effect on marketable fruit yield per plant. Fruit yield per plant was also indirectly, and positively, affected by marketable fruits per plant. Marketable fruits per plant was positively correlated with marketable fruit yield per plant (r = 0.490) but showed a negative direct path. This implies that number of marketable fruits per plant did not have any direct contribution toward marketable fruit yield but had an indirect contribution through other characters. Fruit width also had a positive correlation with marketable fruit yield per plant and moderate positive direct path. Fruit width was positively correlated with marketable fruit yield per plant (r = 0.220) but indirectly with fruit yield per plant (r = 0.238).

Fruits per plant, marketable fruits per plant, average fruit weight and fruit width were important components of marketable fruit yield per plant. Selection for one or more of these traits could be used for improvement in marketable fruit yield. It is now realized that the association between the characters, whose degree is being measured, does not exist by itself that a complicated interaction pathway is involved in which various other attributes may also take part. Therefore, it would be interesting to study the direct and indirect contribution of each trait towards marketable fruit yield.

Of all the characters studied fruit yield per plant was the most important character for its direct contribution towards marketable fruit yield per plant. Besides, its highest direct effect indirect contribution through marketable fruits per plant followed by average fruit weight. The low residual effects (0.0195) indicated that characters included in the present investigation accounted for most of the variation present in the dependent variable (marketable fruit yield per plant) Table 6. While days to 50 per cent flowering, days to first picking, harvest duration, average fruit weight, fruits per plant and marketable fruits per plant showed indirect effect on marketable fruit yield per plant. As observed in the present investigation, the large contribution of average fruit weight on marketable fruit yield has been reported by (Sood *et al.* 2011; Ahmed *et al.* 2012; Afroza *et al.* 2013; Maga *et al.* 2013, Kumari 2013 and Rana *et al.* 2015).

Conclusion

There was adequate genetic variability within the germplasm evaluated for the improvement of marketable fruit yield and component characters. The genetic variation observed suggests that a positive response to direct selection is possible for the traits studied.Correlation and path coefficient analysis study revealed that direct selection for traits like marketable fruits per plant, average fruit weight and fruit width could be a effectively used as selection indices for the improvement of bell pepper. Similarly days to 50 per cent flowering, days to first picking, harvest duration, average fruit weight, fruits per plant and marketable fruits per plant showed indirect effects on marketable fruit yield per plant.

Table 6. Estimates of direct and indirect effects of component characters on marketable fruit yield at phenotypic (P) and genotypic (G) levels

		Days to 50 % flowering	Days to first picking	Plant height (cm)	Primary branches/ plant	Harvest Duration (days)	Fruit length (cm)	Fruit Width (cm)	Pericarp thickness (mm)	Lobes /fruit	Average fruit weight (g)	Fruityield /plant (g)	Fruits/ plant	Marketable fruits/plant	Correlation with marketable fruit yield (g)
Days to 50 %	P	**-0.0053**	-0.0008	-0.0039	0.0024	0.0001	-0.0005	-0.0041	-0.0004	0.0004	-0.0049	-0.2369	0.0031	-0.0060	-0.258*
flowering	G	**-0.0096**	0.0156	0.0025	-0.0046	0.0261	-0.0042	-0.0083	0.0335	0.0180	-0.0053	-0.3620	-0.0908	0.0679	-0.343*
Days to first	P	-0.0013	**-0.0030**	-0.0019	0.0022	0.0001	-0.0004	-0.0017	0.0000	0.0001	-0.0022	-0.1713	0.0025	-0.0067	-0.184*
picking	G	-0.0047	**0.0320**	0.0000	-0.0043	0.0181	-0.0057	-0.0043	-0.0061	0.0183	-0.0034	-0.3542	-0.0902	0.0765	-0.347*
Plant height (cm)	P	-0.0007	-0.0002	**-0.0305**	0.0033	-0.0001	0.0000	0.0035	-0.0003	-0.0001	0.0011	0.1233	-0.0039	0.0087	0.104
	G	-0.0012	0.0000	**0.0207**	-0.0043	-0.0323	-0.0004	0.0078	0.0146	-0.0156	0.0013	0.1607	0.0794	-0.0725	0.145
Primary branches/	P	-0.0009	-0.0005	-0.0071	**0.0144**	0.0001	-0.0006	-0.0018	0.0002	0.0003	0.0004	-0.0772	0.0022	-0.0057	-0.077
plant	G	-0.0028	0.0073	0.0048	**-0.0186**	0.0246	-0.0045	-0.0033	-0.0069	0.0081	0.0004	-0.0952	-0.0657	0.0636	-0.110
Harvest duration	P	-0.0010	-0.0009	-0.0075	-0.0032	**-0.0004**	-0.0003	0.0007	-0.0002	0.0000	0.0088	0.4898	-0.0120	0.0282	0.506*
(days)	G	0.003	-0.0065	0.0075	0.0051	**-0.0889**	-0.0018	0.0010	0.0150	-0.0026	0.0067	0.5832	0.3017	-0.2457	0.592*
Fruit length (cm)	P	0.0009	0.0004	-0.0002	-0.0028	0.0000	**0.0032**	0.0026	0.0000	-0.0008	0.0012	0.0142	-0.0022	0.0059	0.024
	G	0.0021	-0.0096	-0.0004	0.0044	0.0085	**0.0189**	0.0045	0.0086	-0.0342	0.0009	0.0007	0.0437	-0.0459	0.006
Fruit width (cm)	P	0.0010	0.0003	-0.0050	-0.0012	0.0000	0.0004	**0.0213**	0.0002	0.0003	0.0050	0.1997	0.0019	-0.0037	0.220*
	G	0.0023	-0.0039	0.0046	0.0017	0.0025	0.0024	**0.0351**	-0.0176	0.0211	0.0040	0.2378	-0.0583	0.0377	0.252*
Pericarp thickness	P	0.0008	0.0000	0.0028	0.0011	0.0000	0.0001	0.0018	**0.0028**	-0.0002	-0.0009	0.1360	-0.0023	0.0045	0.146
(mm)	G	0.0048	0.0029	-0.0045	-0.0019	0.0197	-0.0024	0.0092	**-0.0675**	-0.0149	-0.0018	0.2451	0.1108	-0.0882	0.244*
Lobes/ fruit	P	-0.0006	-0.0001	0.0005	0.0013	0.0000	-0.0009	0.0023	-0.0002	**0.0029**	-0.0009	0.0204	-0.0002	0.0011	0.016
	G	-0.0033	0.0112	-0.0062	-0.0029	0.0044	-0.0124	0.0142	0.0193	**0.0523**	-0.0009	-0.0066	-0.0870	0.0587	-0.002
Average fruit	P	0.0011	0.0003	-0.0014	0.0002	-0.0002	0.0002	0.0045	-0.0001	-0.0001	**0.0237**	0.6718	0.0013	-0.0050	0.695*
weight (g)	G	0.0032	-0.0067	0.0017	-0.0004	-0.0369	0.0011	0.0088	0.0075	-0.0028	**0.0161**	0.7142	-0.0217	0.0347	0.725*
Fruit yield/ plant	P	0.0018	0.0006	-0.0039	-0.0012	-0.0002	0.0001	0.0045	0.0004	0.0001	0.0167	**0.9562**	-0.0116	0.0266	0.989*
(g)	G	0.0036	-0.0115	0.0034	0.0018	-0.05828	0.0000	0.0085	-0.0168	-0.0004	0.0117	**0.9828**	0.2738	-0.2188	0.999*
Fruits/ plant	P	0.0007	0.0004	-0.0051	-0.0013	-0.0002	0.0003	-0.0018	0.0003	0.0000	-0.0013	0.4844	**-0.0229**	0.0543	0.510*
	G	0.0017	-0.0056	0.0032	0.0024	-0.0519	0.0016	-0.0040	-0.0145	-0.0088	-0.0007	0.5202	**0.5174**	-0.4334	0.540*
Marketable	P	0.0016	0.0004	-0.0048	-0.0015	-0.0002	0.0004	-0.0014	0.0002	0.0001	-0.0022	0.4629	-0.0226	**0.0550**	0.490*
fruits/plant	G	0.0015	-0.0056	0.0035	0.0027	-0.0502	0.0020	-0.0030	-0.0137	-0.0071	-0.0013	0.4941	0.5151	**-0.4353**	0.515*

*Significant at 5% level; Residual effect: P = 0.0195, G = - 0.0013; Bold values indicate direct effects and the non-bold indicate indirect effects

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