



Determination of genetic variation for morphological and yield traits in bell pepper (*Capsicum annuum* var. *grossum*)

SONIA SOOD¹, NAVEEN KUMAR², K S CHANDEL³ and PARVEEN SHARMA⁴

CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176 062

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ABSTRACT

An experiment was conducted during 2008–09 to generate genetic information on yield and yield-contributing growth, fruit yield and related traits in bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.). The study was undertaken to assess genetic variation for yield, days to first picking, days to harvest, fruits/plant, fruit length, fruit girth, pericarp thickness, average fruit weight and lobes/fruit, and to quantify the relationship among these traits. Significant differences were observed for all the traits among 19 diverse genotypes except days to first picking and lobes/fruit, revealed presence of sufficient variability for these traits, which was confirmed by broad range of variability.

Little or no difference between genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) in all the traits indicated that these were less influenced by environment. The phenotypic coefficient of variation (PCV) exhibited higher values than genotypic coefficient of variation (GCV) for all the traits, indicating close association between phenotype and genotype. High estimates of PCV for fruit yield and fruits/plant indicated the importance of additive genes. High heritability coupled with high to moderate genetic advance was observed for fruit yield/plant, fruits/plant, fruit length, fruit girth, pericarp thickness and average fruit weight indicating role of additive gene action for its inheritance and could be improved through selection. Days to harvest had low heritability estimates along with low genetic advance, indicating non-additive gene activity and this could be improved through hybridization. In general, genotypic correlations were higher than the corresponding phenotypic correlations, revealing inherent association among traits. Character association analysis revealed that fruit yield/plant was strongly correlated with fruits/plant, which could be considered as one of the important selection criteria in the improvement of fruit yield. The lines DPC 4, DPC 6, DPC 7 and DPC 3 revealed the highest yield along with desirable fruit colour and other agromorphological traits and can be considered as a remunerating off-season crop during summer and rainy seasons in sub-temperate conditions of Himachal Pradesh. Adequate genetic variability was present within available bell pepper germplasm to allow breeding improvement of growth, fruit yield and related traits. The maximum direct effect on fruit yield/plant was exhibited by fruits/plant, followed by average fruit weight and days to harvest. This indicated that a selection procedure based on higher fruits/plant, average fruit weight and longer days to harvest may be effective in improving fruit yield.

Key words: Bell pepper, *Capsicum annuum* var. *grossum*, Correlation, Genetic advance, Genetic variability, Heritability, Path analysis, Yield characters

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) commonly known as sweet pepper or capsicum, holds a very coveted position as a leading off-season vegetable in Himachal Pradesh, generating cash revenues to the farmers by selling the produce in the neighbouring states and metropolitan cities. In recent years, its demand has increased tremendously with the emergence of pizza industry. In order to maximize such benefits, there is a need for genetic

restructuring of the bell pepper germplasm for increasing the productivity, considering preference of the consumers for the typical bell shaped fruits. However, the horticultural specifications required in bell pepper leaves the breeders with very limited options. The breeder therefore, faces the problem of improvement of crop with reduced variability. Success of a breeding programme depends on variability in the available germplasm and genetic relationship among desired traits.

In addition to knowledge of correlation coefficients, partitioning of correlation coefficients into direct and indirect effects can improve selection efficiency. Hence, an attempt was made with specific objectives to examine the genetic parameters of variability to identify major characters for

¹Associate Professor (e mail: soniasood2005@rediffmail.com), ²M Sc Student (e mail: kharyal@gmail.com), ³Professor (e mail: kschandel@yahoo.com), ⁴ Assistant Professor (e mail: dr.sharma69@rediffmail.com), Department of Vegetable Science and Floriculture

achieving higher yield.

MATERIALS AND METHODS

The experimental material for the present investigation comprised 19 bell pepper genotypes, viz. DPC 1, DPC 2, DPC 3, DPC 4, DPC 5, DPC 6, DPC 7, DPC 8, DPC 9, Sweet General 1, Sweet Happy 1, Sweet Holyland 1, Sweet Star 1, UV 10 1, Golden Dragon 1, Red Lantern 1, STPC Wonder 1, Yiguan Seed China 1 and Swarna 1. These were evaluated in randomized complete block design with three replications for two consecutive years 2008 and 2009 at the Experimental Farm, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (situated at 32°6' N latitude, 76°3' E longitude at an elevation of 1290.8 m above mean sea level under sub-temperate mid hill conditions) in Himachal Pradesh. The seedlings were transplanted with inter- and-intra row spacing of 45 cm each, during first week of April. The recommended cultural and plant protection measures were followed to raise a healthy crop (package of practices, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur). There were 5–7 harvests depending upon the genotypes; harvest interval was seven days. Observations were recorded on five randomly taken competitive plants for nine quantitative traits, viz days to first picking, days to harvest, yield/plant (g), fruits/plant, fruit length (cm), fruit girth (cm), pericarp thickness (mm), average fruit weight (g) and lobes/fruit. In addition, observations on four

agromorphological traits, viz. general fruit shape, fruit shape at pedicel attachment, fruit shape at blossom end and fruit position were also recorded as per the 'Minimal Descriptor of Vegetable Crops' for bell pepper suggested by Srivastava *et al.* (2001), whereas characterization of fruit colour was done as per the 'Royal Horticulture Society Colour Charts' (RHCC). According to Minimal Descriptor of Agri-Horticultural crops-II: Vegetable crops, different genotypes were categorized with specific numbers and groups for fruit shapes (1, elongate; 2, almost round; 3, triangular; 4, companulate and 5, blocky), fruit shapes at pedicel attachment (1, acute; 2, obtuse; 3, truncate; 4, cordate and 5, lobate), blossom end fruit shape (1, pointed; 2, blunt; 3, sunken; 4, sunken and pointed) and fruit position (3, pendent; 5, intermediate; 7, erect). The pooled data over the years were statistically analyzed as per the standard procedure for variability (Panse and Sukhatme 1984). Heritability in broad sense and genetic advance (% of mean) were calculated as per Burton and De Vane (1953) and Johnson *et al.* (1955), respectively. Estimates of genotypic and phenotypic correlations were obtained using the formulae given by Al-Jibouri *et al.* (1958). Direct and indirect path coefficients were calculated as proposed by Dewey and Lu (1959).

RESULTS AND DISCUSSION

The 19 genotypes involved in the study varied significantly among themselves for all the horticultural traits studied except days to first picking and lobes/plant (Table 1), as revealed by

Table 1 Mean values for fruit yield and related horticultural traits of 19 bell pepper genotypes

Genotype/trait	Days to first picking	Days to harvest	Fruit yield/plant (g)	Fruits/plant	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Lobes/fruit
DPC 1	51.00	71.00	223.00	5.33	9.70	3.03	3.53	41.47	2.00
DPC 2	51.00	71.00	285.00	5.66	7.10	3.29	3.47	50.29	3.00
DPC 3	51.00	71.00	356.00	5.83	6.70	6.26	6.22	61.14	4.00
DPC 4	51.00	71.00	483.00	10.33	10.15	4.03	3.71	46.77	4.00
DPC 5	51.00	71.00	340.00	5.83	10.90	4.36	5.65	58.28	2.00
DPC 6	51.00	53.00	409.00	6.33	8.75	5.78	5.56	64.60	3.00
DPC 7	51.00	53.00	358.00	4.33	9.35	5.08	6.15	82.69	3.00
DPC 8	51.00	47.00	199.00	2.86	8.30	5.32	5.76	70.29	3.00
DPC 9	51.00	47.00	230.00	3.83	7.30	6.41	5.14	60.21	3.00
Sweet General 1	51.00	53.00	297.00	5.16	8.55	5.06	4.37	57.28	3.00
Sweet Happy 1	51.00	39.00	151.00	3.00	7.88	5.12	4.89	50.55	3.00
Sweet Holyland 1	51.00	47.00	162.00	3.40	7.15	5.08	3.99	46.42	3.00
Sweet Star 1	51.00	53.00	237.00	4.50	8.70	6.88	8.00	52.77	4.00
UV 10-1	51.00	64.00	222.00	3.50	13.50	5.61	4.82	63.42	3.00
Golden Dragon 1	51.00	53.00	227.00	3.83	8.30	6.23	4.61	59.34	3.00
Red Lantern 1	58.00	53.00	204.00	4.16	8.12	6.13	4.44	49.00	3.00
STPC Wonder 1	51.00	64.00	204.00	4.16	8.40	3.96	4.72	49.00	3.00
Yiguan Seed China 1	51.00	53.00	163.00	2.83	8.50	5.36	5.34	57.64	4.00
Swarna 1	51.00	47.00	175.00	3.50	8.25	5.83	4.09	50.00	4.00
SE (d)	2.22	7.47	4.17	0.16	0.35	0.18	0.13	2.21	0.00
CD ($P=0.05$)	NS	14.65	8.18	0.30	0.68	0.34	0.25	4.33	NS
CV%	5.30	16.09	1.97	4.09	4.85	4.14	3.13	4.80	0.00

analysis of variance over the years. These results support the selection programme for the better quality of bell pepper. The maximum number of fruits/plant was harvested from DPC 4 (10.33), though had small sized fruits with low average fruit weight. The highest average fruit weight was obtained from DPC 7 (82.69 g). The genotype Sweet Star 1 was with maximum fruit width (6.88 cm) and pericarp thickness (8.00 mm). DPC 1 to DPC 5 (71 days) had longer days to harvest which is desirable to have staggered and more number of pickings. Fruit yield/plant is the most important horticultural trait of a crop. The highest fruit yield/plant was recorded in DPC 4 (483 g). Similar pattern of variability in germplasm evaluation of different sizes for various horticultural traits in capsicum have earlier been reported by Verma *et al.* (2004), Sood *et al.* (2007) and Sood *et al.* (2009). The estimates of various genetic parameters exhibited a wide range of

variability for all these traits (Table 2). The degree of variability shown by different characters can be judged by the values of GCV and PCV. A close proximity in the phenotypic and genotypic coefficients of variability (Table 2) was observed indicating a little influence of environment in the expression of various horticultural traits studied except days to first picking. This suggests that selection will be effective on the basis of phenotype alone with equal chance of success. Sood *et al.* (2007) also reported similar results for fruit yield in Capsicum. Fruits/plant and fruit yield/plant had the highest magnitude of phenotypic and genotypic coefficients of variability. Similarly, days to harvest, pericarp thickness and fruit girth also exhibited fairly high estimates of these components. This indicated better scope of phenotypic selection through these traits for improvement in bell pepper. The estimates of heritability act as a predictive instrument in

Table 2 Range, mean, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability and genetic advances (GA) in bell pepper

Trait	Range	General Mean \pm sem	Variance			Coefficient of variation			Heritability (h ²) (%)	GAK= 2.06	GA% of mean
			P	G	E	PCV	GCV	ECV			
Days to first picking	51.00–58.00	51.37 \pm 1.57	7.52	0.11	7.42	5.34	0.64	5.30	1.00	0.08	0.16
Days to harvest	39.00–71.00	56.89 \pm 5.29	162.19	78.39	83.80	22.38	15.56	16.09	48.00	12.68	22.29
Fruit yield/plant (g)	151.00–483.00	259.21 \pm 2.95	8493.82	8467.69	26.13	35.56	35.50	1.97	99.69	189.27	73.02
Fruits/plant	2.82–10.33	4.65 \pm 0.11	3.08	3.04	0.04	37.73	37.51	4.09	99.00	3.57	76.82
Fruit length (cm)	6.70–13.50	8.72 \pm 0.24	2.56	2.39	0.18	18.37	17.72	4.85	93.00	3.07	35.21
Fruit width (cm)	3.03–6.88	5.20 \pm 0.12	1.16	1.11	0.05	20.70	20.28	4.14	96.00	2.13	40.93
Pericarp thickness (mm)	3.47–8.00	4.97 \pm 0.09	1.25	1.23	0.02	22.31	22.29	3.13	98.00	2.26	45.47
Average fruit weight (g)	41.47–82.69	56.38 \pm 1.56	99.47	92.14	7.33	17.69	17.03	4.80	93.00	19.03	33.76
Lobes/fruit	2.00–4.00	3.16 \pm 0.00	0.36	0.36	0.00	19.07	19.07	0.00	100.00	1.24	39.28

Table 3 Estimation of correlation coefficients at the phenotypic and genotypic levels

		Days to harvest	Fruits/ plant	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Lobes/ fruit	Fruit yield/ plant (g)
Days to first picking	P	-0.00	-0.05	-0.09	0.16	-0.05	-0.13	-0.04	-0.08
	G	-0.76	-0.28	-0.31	0.90	-0.64	-0.80	-0.31	-0.74
Days to harvest	P		0.51*	0.31	-0.43	-0.15	-0.20	-0.13	0.44
	G		0.76	0.39	-0.67	-0.22	-0.21	-0.18	0.62
Fruits/plant	P			0.17	-0.36	-0.19	-0.19	0.10	0.88*
	G			0.18	-0.37	-0.19	-0.20	0.10	0.88
Fruit length (cm)	P				-0.16	0.00	0.14	-0.26	0.20
	G				-0.18	0.01	0.17	-0.27	0.21
Fruit width (cm)	P					0.59*	0.34	0.46*	-0.16
	G					0.62	0.37	0.47	-0.17
Pericarp thickness (mm)	P						0.53*	0.27	0.09
	G						0.55	0.27	0.09
Average fruit weight (g)	P							-0.01	0.26
	G							-0.01	0.27
Lobes/fruit	P								0.07
	G								0.07

* $P= 0.05$

exercising the reliability of phenotypic value. Therefore, it helps the breeder to make selection for a particular character when heritability is high. The genetic advance is a useful indicator of the progress that can be expected as a result of exercising selection on the pertinent population.

The heritability was very high for all the traits studied except days to first picking and days to harvest indicated less influence of environment in the expression of these traits. The heritability along with genetic advance is more useful than the heritability alone in predicting the resultant effect of selecting best individual genotype as it suggests the presence of additive gene effects. The higher estimates of heritability coupled with higher genetic advance for fruit yield/plant and fruits/plant, whereas high heritability with moderate genetic advance for fruit length, fruit girth, pericarp thickness, average fruit weight and lobes/fruit. Indicated that heritability of these traits is mainly owing to additive effects and consequently a high genetic gain is expected from selection under such situations. However, low heritability accompanied by low genetic advance for days to harvest and days to first picking is an indicative of non-additive genes effects for their inheritance and these traits can be improved through hybridization and hybrid vigour. Ben-Chaim and Paran (2000) reported similar results for days to 50% flowering and days to first picking.

The genotypic correlations were higher than their corresponding phenotypic for all the traits studied suggesting strong inherent association between these traits at genotypic level (Table 3), which was in agreement with the results obtained by Dipendra and Gautam (2003), Sood *et al.* (2007) and Sood *et al.* (2009) for fruits/plant. Fruit yield showed positive association with fruits/plant (0.88), days to harvest

with fruits/plant (0.51), thus indicating that selection for fruits/plant would simultaneously lead to an improvement in fruit yield and days to harvest. Similarly, fruit girth showed positive association with pericarp thickness (0.59) and pericarp thickness with average fruit weight (0.53), thus indicating that selection for pericarp thickness would simultaneously lead to an improvement in fruit girth and average fruit weight.

The genotypic correlations were partitioned into direct and indirect effects to know the relative importance of the components. It was determined that direct and indirect effects obtained at genotypic level were different from those at the phenotypic level (Table 4), 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, lobes/fruit and pericarp thickness were observed to be negative at phenotypic and genotypic level respectively, the corresponding value at the genotypic/phenotypic level was positive. This type of change in direction and magnitude of direct and indirect effect from genotypic level to phenotypic level and vice-versa, might be due to environmental factors influencing various traits. The path analysis at the phenotypic level may not provide a true picture of direct and indirect causes, and it is advisable to understand the contribution of different traits toward the fruit yield/plant at the genotypic level. For path analysis at the genotypic level, fruit yield/plant was the dependent variable to all other traits used for correlation and considered as casual variables. Fruits/plant, which had the highest genotypic correlation, exhibited the highest direct effect on fruit yield/plant. Fruits/plant was also indirectly and positively affected by the days to harvest and pericarp thickness. Days to harvest

Table 4 Estimate of direct and indirect effect of fruit yield and component traits at phenotypic (P) and genotypic (G) level

Trait	Level	Days to first picking	Days to harvest	Fruits/plant	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Lobes/fruit (g)	Fruit yield/plant
Days to first picking	P	0.012	0.000	-0.051	0.004	0.012	-0.002	-0.056	0.003	-0.079
	G	0.086	-0.250	-0.188	0.015	0.069	-0.091	-0.356	-0.023	-0.739
Days to harvest	P	0.000	0.070	0.498	-0.015	-0.032	-0.005	-0.085	0.009	0.440
	G	-0.065	0.329	0.511	-0.019	-0.051	0.002	-0.092	0.014	0.620
Fruits/plant	P	-0.001	0.036	0.972	-0.008	-0.027	-0.007	-0.083	-0.007	0.876*
	G	-0.024	0.251	0.669	-0.009	-0.028	0.019	-0.002	0.007	0.883
Fruit length (cm)	P	-0.001	0.022	0.166	-0.050	-0.012	0.000	0.061	0.017	0.203
	G	-0.026	0.127	0.119	-0.049	-0.014	-0.001	0.076	-0.020	0.212
Fruit width (cm)	P	0.002	-0.030	-0.349	0.008	0.075	0.021	0.143	-0.031	-0.160
	G	0.077	-0.219	-0.246	0.009	0.077	-0.063	0.165	0.035	-0.165
Pericarp thickness (mm)	P	-0.001	-0.011	-0.181	0.000	0.045	0.035	0.225	-0.018	0.094
	G	0.077	-0.072	-0.125	0.000	0.048	-0.102	0.248	0.020	0.093
Average fruit weight (g)	P	-0.002	-0.014	-0.187	-0.007	0.025	0.019	0.428	0.000	0.262
	G	-0.068	-0.068	-0.004	-0.008	0.029	-0.056	0.447	0.000	0.270
Lobes/fruit	P	0.000	-0.009	0.096	0.013	0.035	0.010	-0.002	-0.068	0.073
	G	-0.027	-0.061	0.066	0.013	0.036	-0.028	-0.002	0.075	0.074

* $P=0.05$. Residual effect: P, 0.0299; G, 0.1744; Bold values denote direct effect and non-bold indicate indirect effect

also had a positive correlation with fruit yield/plant ($r = 0.620$) and moderate positive direct path (0.329). Days to harvest was positively correlated with fruit yield ($r = 0.620$) but indirectly with fruits/plant. Average fruit weight had a low positive correlation with fruit yield/plant ($r = 0.270$) but was counterbalanced by high direct path. Fruit length was positively correlated with fruit yield/plant ($r = 0.212$) but showed a negative direct path. This implies that fruit length did not have any direct contribution towards fruit yield/plant, but had indirect contribution through other characters. Fruits/plant, days to harvest and average fruit weight were important components of fruit yield/plant. Selection for these traits could be used for improving quality by improving fruit yield. A large residual effect in path coefficient analyses usually indicates that there are traits other than those included in pathways that contribute to the dependent variable. Path coefficient analyses did not account for all variation in fruit yield as indicated by the magnitude of residual effects (Table 4), indicating that there are other traits also that contributed to fruit yield.

On the basis of yield performance, genotype DPC 4 performed the best followed by DPC 6, DPC 7 and DPC 3. These genotypes were also studied for fruit colour and other agromorphological traits. Fruit shape of these four genotypes is blocky with lobate pedicel attachment. The blocky fruit shape is most desirable for Indian market (Sood *et al.* 2011). DPC 3, DPC 4 and DPC 6 had sunken blossom end, whereas DPC 7 with blunt end. Fruit position was pendent in all the three genotypes except DPC 4, in which it was semi-pendent or intermediate. Adetula and Olakojo (2006) observed significant differences among the genotypes for fruit position. As far as fruit colour is concerned, all genotypes belonged to Green Group (GG of RHSCC) with varying colour intensities. Green colour is desirable fruit colour in bell pepper (Sood and Kumar 2011).

There was adequate genetic variability within the germplasm evaluated for the improvement of fruit yield, growth and related traits. The genetic variation observed suggests that a positive response to direct selection is possible for all the traits studied. Correlation and path coefficient analysis indicated that selection for more fruits, longer days to harvest and high average fruit weight could be criteria for simultaneously increasing fruit yield in bell pepper. Therefore, due attention should be paid to improve these traits while making selection of high-yielding genotypes or for choosing parents for heterosis breeding. Four genotypes, viz. DPC 4, DPC 6, DPC 7 and DPC 3 are found promising and can be utilized in future breeding programmes for developing superior varieties/hybrids.

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