



Heterosis of bacterial wilt (*Pseudomonas solanacearum*) resistance, yield and related traits in bell pepper (*Capsicum annuum*)

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ABSTRACT

The present investigation was carried out under natural field conditions at the Vegetable Experimental Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh during 2004-2009 crop growing seasons aiming at the development of high-yielding, bacterial wilt (*Ralstonia solanacearum*) resistant lines and hybrids of bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.). The forty bell pepper lines were screened for bacterial wilt resistance and resistant ones were selfed successively from 2004-2007 in the natural sick plots maintained at the vegetable research farm. Out of these, eleven inbreds were chosen as parents for the present study. Eight genetically diverse inbreds, used as lines were crossed with three well adapted varieties (testers) in line × tester mating design during spring-summer 2007 to obtain twenty four F₁ hybrids. Thirty five genotypes (eleven parents and twenty four crosses) were planted in a complete randomized block design with three replications during summer-rainy seasons, 2008 and 2009 and data were recorded for twelve phenological, fruit yield traits and bacterial wilt incidence. On the basis of mean performance, the lines EC-464115 and EC-464107 had high yield and other related traits along with bacterial wilt resistance. As far as F₁ hybrids are concerned, EC-464107 × Yolo Wonder and EC-464115 × California Wonder had high mean values along with high heterosis over better parents for fruit yield and related traits as well as resistant to the disease. Bacterial wilt disease observed in parents and hybrids confirmed the dominant nature of disease resistance, which can be exploited in combination with heterosis for yield. The genotypic correlation coefficients, in general, were higher than the corresponding phenotypic correlation coefficients, suggesting a strong inherent association among traits at genotypic level. High positive correlation of fruit yield has been observed with harvest duration, fruits/plant and marketable fruits/plant. Correlation analysis indicated that selection for earliness, more fruits, longer harvest duration 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 with the future cultivars/variety improvement programme. Bacterial wilt incidence had significant negative correlation with days to 50 per cent flowering, plant height, harvest duration and fruit length at both genotypic and phenotypic levels suggesting that delay in days to flowering will decrease the incidence of the disease. Similarly, with decrease in plant height and harvest duration, level of disease incidence will increase and vice-versa. Bacterial wilt incidence had non-significant negative correlation with fruit yield at genotypic, phenotypic and environmental levels suggesting their combined effect in the expression of bacterial wilt.

Key words: Bacterial wilt, Bell pepper, Correlations, Disease, Heterosis, Resistance

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) is one of the few vegetable crops in which F₁ hybrids are being cultivated at commercial scale over world. It is susceptible to numerous foliar, fruit and root pathogens that reduce yield and quality. Bacterial wilt caused by *Ralstonia solanacearum* (*Pseudomonas solanacearum*) is most severe disease of bell pepper in tropical and subtropical climates with high rainfall and warm temperature (Cerkaskas 2004, Elphinstone 2005). It is well known that bacterial wilt is

widely observed in Southeast Asia and is a serious problem in the cultivation of pepper crops, which are extensively cultivated and used as spices and vegetables (Mimura and Yoshikawa 2009). This disease seems to be a major hurdle in commercial cultivation of this crop and assumed an alarming proportion in some specific pockets of zone-I and zone-II of Himachal Pradesh. In an extensive survey of Himachal Pradesh conducted by Aggarwal *et al.* (2006) during May and June, 2001 and 2002 to monitor the prevalence of bacterial wilt in solanaceous vegetables (tomato, aubergine and capsicum), maximum wilt incidence was recorded in Mandi district (45%) followed by Kangra (41.37%), Kullu (28%), Hamirpur (16%) and Solan (12.68%).

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Ironically, none of the measures are effective, neither the chemical control measures nor the high-yielding varieties are resistant to this disease. Under these circumstances, selection of resistant lines and hybrids would pave the way in overcoming this problem. Attempts to screen a number of genotypes and elite breeding material under field conditions to identify resistant sources to this pathogen have also been made by Lopes *et al.* (2005), Sharma (2007), Singh and Sood (2003).

In the light of above stated facts, there is an urgent need to evolve stable bacterial wilt resistant varieties/hybrids possessing desirable horticultural traits. The objective of the study was to determine the heterosis and correlations for yield, related traits and resistance to bacterial wilt disease of bell pepper. This if achieved could pave the way for the development of hybrid resistant to the disease.

MATERIALS AND METHODS

The present investigation was carried out under natural field conditions at the Vegetable Experimental Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh during 2004-2009 crop growing seasons aiming at the development of high yielding, bacterial wilt resistant lines and hybrids of bell pepper.

The forty bell pepper inbreds were screened for bacterial wilt resistance and resistant ones were selfed successively from 2004-2007 in the natural sick plots maintained at the vegetable research farm. Out of these eleven inbreds has been chosen as parents for the present study. The parental lines used in this study were selected primarily for bacterial wilt resistance, but they differ in their yielding ability, number of fruits, earliness, plant height, fruit shape, size, weight, pericarp thickness etc. Eight genetically, diverse genotypes, viz. Kandaghat Selection, EC 464115, EC 464107, HC 201, AC 48, SKAU-SP 613-1, PBC 631 and SKAU-SP 633-1, used as lines were crossed with three well adapted varieties (testers) California Wonder, Yolo Wonder and Solan Bharpoor by hand pollination using a standard procedure of emasculation in a line \times tester mating to generate diversity for resistance to bacterial wilt disease in twenty four F_1 hybrids during the 2007-08 bell pepper growing season (February 2007 to August 2007) and thus line \times tester full-sib crossed true to type seeds were produced. Selfed seeds of the parents were also obtained during the same season.

These eleven parents and their twenty four F_1 hybrids were planted in a completely randomized block design with three replications during summer-rainy seasons, 2008 and 2009. Plant spacing was kept at 60 cm \times 45 cm. Data were recorded for days to 50% flowering, days to first picking, plant height, harvest duration, fruit yield/plant, fruits/plant, marketable fruits/plant, fruit length, fruit width, pericarp thickness, average fruit weight, lobes/fruit and bacterial wilt incidence.

Data for bacterial wilt incidence were recorded on all

plants in each replication and the disease intensity was recorded under natural sick plots maintained at the farm. Data were recorded when the maximum infection (>60%) appeared in the presence of virulent inoculum in the soil. Bacterial ooze test was also carried out on all the wilted plants to confirm bacterial wilt. On the basis of percent incidence, the genotypes were categorized into resistant (<20%), moderately resistant (20-40%), moderately susceptible (40-60%) and susceptible (>60%) as per the scale given by Mew and Ho (1976).

Replications means for different characters recorded on the parents and hybrids were subjected to line \times tester analysis (Kempthorne 1957). Heterosis was calculated as increase or decrease in the mean F_1 performance over the better parent (BP) for the respective characters.

SPAR I (developed by Indian Agricultural Statistical Research Institute, New Delhi, India) software was used for statistical analysis. Data were subjected to analysis of variance (Panse and Sukhatme 1984). Heterosis was computed by using computer software programme Windowstat 8.0.. The phenotypic, genotypic and environmental coefficients of correlation were also computed.

RESULTS AND DISCUSSION

The results of field experiment revealed that there was sufficient genetic diversity among the genotypes (parents and F_1 hybrids) for all the thirteen traits studied (Table 2). The mean bacterial wilt incidence ranged from 0% to 95.74% on the Mew and Ho scale. On the basis of mean performance, the lines EC 464115, EC 464107, SKAU-SP 613-1, PBC 631 and SKAU-SP 633-1 were resistant to bacterial wilt, while Kandaghat Selection was moderately resistant. All the three testers were susceptible. Among the F_1 hybrids, EC 464115 \times California Wonder, EC 464115 \times Yolo Wonder, EC 464107 \times California Wonder, EC 464107 \times Yolo Wonder, EC 464107 \times Solan Bharpoor, SKAU-SP 613-1 \times California Wonder, SKAU-SP 613-1 \times Yolo Wonder, PBC 631 \times California Wonder, PBC 631 \times Yolo Wonder and PBC 631 \times Solan Bharpoor were resistant, whereas EC 464115 \times Solan Bharpoor and SKAU-SP 613-1 \times Solan Bharpoor were moderately resistant. This was in conformity with Singh and Sood (2003).

The lines EC 464115 and EC 464107 had high yield alongwith bacterial wilt resistance. Although Kandaghat Selection had highest fruit yield among all the parents used in the study, but it was moderately resistant to bacterial wilt. As far as F_1 hybrids are concerned, EC 464107 \times Yolo Wonder and EC 464115 \times California Wonder had high fruit yield alongwith resistant to the disease. Although AC 48 \times Solan Bharpoor performed well for fruit yield and related traits, but did not possess bacterial wilt resistance. Therefore, it can not be recommended for cultivation in high rainfall, bacterial wilt prone areas. The disease incidence in the line PBC 631 was zero and able to decrease incidence of its

Table 1 Description of parental bell pepper lines of used in the study

Variety	Source	Description	Bacterial wilt resistance category
<i>Lines</i>			
Kandaghat Selection	UHF, Regional Research Station, Kandaghat, Himachal Pradesh, India	High fruit yield, long harvest duration, more fruits per plant, blocky fruit shape, pendent fruit position, average plant height and medium green fruits	Moderately resistant
EC 464115	AVRDC, Shanhua, Taiwan	High fruit yield, long harvest duration, more fruits per plant, blocky fruit shape, pendent fruit position, average plant height and pale yellow fruits	Highly resistant
EC 464107	AVRDC, Shanhua, Taiwan	Long harvest duration, blocky fruit shape, pendent fruit position, average plant height and light green fruits	Highly resistant
HC 201	IARI, Regional Research Station, Katrain, Himachal Pradesh, India	Early maturing, more fruits per plant, triangular fruit shape, erect fruit position, average plant height and medium green fruits	Moderately susceptible
AC 48	IARI, Regional Research Station, Katrain, Himachal Pradesh, India	Early maturing, thick pericarp, more fruit width, almost round fruit shape, semi-pendent fruit position, average plant height and pale yellow fruits	Moderately susceptible
SKAU-SP 613-1	Division of Olericulture, SKUAST (K), Shalimar, J & K, India	Campanulate fruit shape, semi-pendent fruit position, average plant height and dark green fruits	Resistant
PBC 631	AVRDC, Shanhua, Taiwan	Long fruits, elongate fruit shape, pendent fruit position, tall plants and medium dark green fruits	Highly resistant
SKAU-SP 633-1	Division of Olericulture, SKUAST (K), Shalimar, J & K, India	Blocky fruit shape, erect fruit position, average plant height and dark green fruits	Resistant
<i>Testers</i>			
California Wonder	IARI, Regional Research Station, Katrain, Himachal Pradesh, India	Early maturing, more average fruit weight, blocky fruit shape, semi-pendent fruit position, average plant height and dark green fruits	Susceptible
Yolo Wonder	IARI, Regional Research Station, Katrain, Himachal Pradesh, India	Early maturing, more fruit width, almost round fruit shape, thick pericarp, semi-pendent fruit position, average plant height and pale yellow fruits	Susceptible
Solan Bharpooor	UHF, Department of Vegetable Crops, Solan, Himachal Pradesh, India	Blocky fruit shape, pendent fruit position, average plant height and dark green fruits	Susceptible

counterparts of breeding in cross combinations. The F_1 hybrids and lines (excluding Kandaghat Selection, HC 201, AC 48 and their crosses) were resistant to bacterial wilt disease while the testers were susceptible. The Kandaghat Selection and its crosses were moderately susceptible showing the involvement of more than one gene for resistance which is confirmity with the Lafortune and Beramis (2005). The disease reaction in parents (Table 1) and respective hybrids (Table 2) confirmed the dominance of disease resistance, suggesting the possibility of exploiting heterosis in combination with bacterial wilt resistance. Earliness is highly desirable attribute in vegetables in the sense that prevailing prices in the market are invariably high in early season. The significant negative better parent heterosis (BPH) was recorded in six cross combinations for days to 50% flowering highest being in Kandaghat Selection \times Yolo Wonder (Table 3).

For days to first picking, the number of hybrid revealing hybrid vigour over better parent were more (seven) compared to days to 50% flowering. Some of the hybrids exhibiting hybrid vigour for both the traits were common but it was not the case always. This implies that there exist genotypic differences in the plant processes after flowering till fruit maturity. Introgression of earliness will serve as escape mechanism to the disease by bell pepper plant. Variable magnitude of both flowering and early maturity has also been observed earlier by Geleta and Labuschagne (2004) and Sood and Kaul (2006). Increased plant height is a desirable trait to realize high marketable yield provided the environmental conditions are otherwise conducive for growth and fruiting over longer period. The taller plants have less disease incidence than dwarf ones. For plant height, fourteen hybrids surpassed the better parent. Increased harvest duration contributes towards highest marketable yield in bell pepper.

Table 2 Mean performance of bell pepper parents and hybrids grown in bacterial wilt sick plots at Palampur during summer-rainy seasons, 2008 and 2009

Parents and F ₁ hybrids	Days to 50% flowering	Days to first picking	Plant height (cm)	Harvest duration (days)	Fruit yield/plant (g)	Fruits/plant	Marketable fruits/plant	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Lobes/fruit	Bacterial wilt incidence (%)
Kandaghat Selection	41.00	58.00	35.33	52.00	359.33	12.87	12.20	5.58	3.97	4.05	29.44	3.66	28.75
EC 464115	39.33	58.33	43.00	58.33	329.67	12.65	12.33	7.82	3.87	3.86	26.55	3.00	0.00
EC 464107	39.67	60.00	45.70	54.00	305.00	10.15	10.13	7.40	3.65	3.97	29.47	3.33	0.00
HC 201	37.00	57.33	36.00	47.67	289.33	14.64	13.87	7.29	2.62	3.92	20.95	3.00	52.42
AC 48	37.67	58.33	29.00	38.00	186.00	6.25	6.26	6.25	4.84	6.89	29.55	2.33	52.28
SKAU-SP 613-1	39.33	58.00	30.10	44.00	178.33	7.30	7.27	6.90	2.98	4.15	23.71	3.66	19.13
PBC 631	41.67	66.33	57.50	50.33	186.00	9.47	8.40	10.11	2.75	3.20	22.11	3.33	0.00
SKAU-SP 633-1	38.67	58.67	33.45	51.67	267.00	8.73	9.46	6.75	2.97	3.66	28.21	3.00	19.05
California Wonder	37.33	55.67	36.61	40.33	200.33	4.80	4.80	6.10	4.42	3.91	45.02	3.33	90.50
Yolo Wonder	36.33	55.33	35.29	40.33	239.00	7.47	7.40	4.42	4.86	6.95	32.30	3.00	85.00
Solan Bharpoor	39.67	60.67	34.45	40.00	237.00	7.27	6.92	7.00	4.11	5.13	34.16	2.66	95.74
Kandaghat Selection × California Wonder	39.33	60.33	41.00	50.00	275.33	8.13	7.93	6.74	5.43	4.10	34.63	3.33	57.00
Kandaghat Selection × Yolo Wonder	37.00	53.00	38.55	56.00	410.00	10.60	10.47	4.70	4.90	6.97	38.72	3.33	52.50
Kandaghat Selection × Solan Bharpoor	38.33	53.00	37.60	62.67	484.00	14.27	14.13	7.24	4.97	3.79	34.61	3.00	80.75
EC 464115 × California Wonder	39.67	55.33	45.75	54.67	433.33	10.33	10.13	7.27	4.63	4.36	42.73	3.66	4.60
EC 464115 × Yolo Wonder	39.67	58.00	37.65	47.00	434.67	11.93	11.93	7.02	4.27	6.00	33.88	3.00	19.05
EC 464115 × Solan Bharpoor	40.33	55.33	40.00	54.33	275.33	11.00	11.65	7.26	3.81	4.05	23.51	3.00	23.81
EC 464107 × California Wonder	38.67	55.67	50.80	66.00	252.33	9.60	9.47	7.99	3.64	3.76	26.59	2.66	0.00
EC 464107 × Yolo Wonder	38.67	53.00	50.35	68.67	651.33	17.86	17.27	6.95	4.52	4.97	37.18	2.66	4.76
EC 464107 × Solan Bharpoor	38.00	57.67	52.54	66.67	336.00	15.53	14.57	7.87	3.60	4.09	25.59	3.00	4.76
HC 201 × California Wonder	38.33	55.67	42.60	66.00	345.00	11.87	11.66	8.04	3.82	5.02	29.56	3.67	71.43
HC 201 × Yolo Wonder	36.67	55.67	40.78	49.67	342.66	12.27	12.20	7.05	4.03	5.06	27.95	3.00	57.14
HC 201 × Solan Bharpoor	39.33	58.00	42.70	48.67	292.33	12.67	12.13	8.20	3.24	4.66	23.82	3.00	71.43
AC 48 × California Wonder	40.00	63.67	33.90	39.00	181.00	7.01	7.01	3.63	4.02	4.16	30.44	4.00	90.00
AC 48 × Solan Bharpoor	37.67	55.67	35.35	44.00	440.00	12.47	12.07	4.15	5.04	4.74	36.69	3.66	85.71

Contd.

Table 2 (Concluded)

Parents and F ₁ hybrids	Days to 50% flowering	Days to first picking	Plant height (cm)	Harvest duration (days)	Fruit yield/plant (g)	Fruits/plant	Marketable fruits/plant	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Average fruit weight (g)	Lobes/fruit	Bacterial wilt incidence (%)
AC 48 × Yolo Wonder	38.00	55.33	34.00	49.00	325.33	7.20	7.07	4.96	4.57	5.23	46.03	3.00	71.43
SKAU-SP 613-1 × California Wonder	39.00	58.33	39.25	47.00	260.00	8.67	8.53	6.70	4.52	4.17	28.84	3.66	19.05
SKAU-SP 613-1 × Yolo Wonder	37.00	53.00	34.67	56.33	373.67	13.13	13.20	5.70	4.81	5.47	29.46	3.00	19.05
SKAU-SP 613-1 × Solan Bharpoor	38.67	58.00	36.85	50.00	333.33	7.93	7.80	5.14	3.40	4.05	39.64	3.00	28.57
PBC 631 × California Wonder	39.00	53.33	60.75	53.33	339.67	11.33	10.86	9.67	3.20	3.38	30.22	2.66	0.00
PBC 631 × Yolo Wonder	37.00	55.67	61.75	56.67	399.00	13.40	13.27	8.92	3.82	4.67	30.06	2.33	0.00
PBC 631 × Solan Bharpoor	39.67	60.66	58.00	50.67	301.67	9.87	9.73	11.30	2.95	3.78	30.93	3.00	0.00
SKAU-SP 633-1 × California Wonder	38.00	51.33	61.75	49.33	327.33	10.33	10.33	9.09	3.33	3.30	31.48	3.00	66.67
SKAU-SP 633-1 × Yolo Wonder	37.67	51.00	57.79	62.67	463.33	17.50	17.32	6.44	3.34	4.42	26.81	3.00	57.14
SKAU-SP 633-1 × Solan Bharpoor	37.33	53.33	60.56	49.00	356.67	13.15	12.60	7.23	3.16	3.56	27.06	3.00	57.14
SE(d)	1.10	3.30	1.12	6.74	35.54	0.66	0.75	0.33	0.71	0.40	2.48	0.30	8.41
CD (P=0.05)	2.23	6.56	2.21	12.96	66.94	1.64	1.46	0.67	0.49	0.26	4.96	0.58	16.80

Table 3 Estimation of better parent heterosis for phenological and structural traits of bell pepper grown in bacterial wilt sick plots at Palampur during summer-rainy seasons, 2008 and 2009

Crosses	Days to 50% flowering	Days to first picking	Plant height	Harvest duration	Fruit yield/plant	Fruits/plant	Marketable fruits/plant	Fruit length	Fruit width	Pericarp thickness	Average fruit weight	Lobes/fruit	Bacterial wilt incidence
Kandaghat Selection x California Wonder	-5.65*	4.60	11.31*	-5.06	-23.38*	-33.70*	-34.97*	10.55	19.83*	1.15	-23.07*	-18.18*	100.01*
Kandaghat Selection x Yolo Wonder	-9.68*	-8.05	9.09*	7.59	13.27	-13.59*	-14.21*	-15.82*	0.69	0.53	19.89*	-9.09	83.34*
Kandaghat Selection x Solan Bharpoor	-6.45*	-12.09*	5.92	18.99	35.53*	16.30*	15.85*	3.38	21.09*	-26.12*	1.32	-18.18*	183.34*
EC 464115 x California Wonder	0.00	-4.02	3.19	-6.29	31.34*	-19.27*	-17.84*	-6.99	6.26	11.51*	-5.09	-11.11	
EC 464115 x Yolo Wonder	0.00	0.00	-14.11*	-19.43	22.75*	-6.77	-3.24	-10.27*	-12.20*	-13.72*	4.90	-10.00	
EC 464115 x Solan Bharpoor	0.84	-8.24	-7.74*	-6.29	-21.44*	-14.06*	-10.81	-7.20	-7.38	-21.05*	-31.16*		
EC 464107 x California Wonder	-2.52	-8.24	11.38*	21.34	-15.61	-6.49	-6.58	8.02	-17.57*	-5.29	-40.92*	-11.11	
EC 464107 x Yolo Wonder	-2.52	-12.09*	11.60*	25.61*	114.49*	72.08*	70.39*	-6.08	-6.99	-28.44*	15.13*	-20.00*	
EC 464107 x Solan Bharpoor	-4.20	-8.24	14.83*	21.34	29.43*	51.30*	43.75*	6.40	-12.41*	-20.27*	-25.08*		
HC 201 x California wonder	1.77	-4.02	16.06*	41.13*	19.35	-16.04*	-15.87*	10.34*	-13.57*	28.17*	-34.34*	22.22*	36.36*
HC 201 x Yolo Wonder	-1.79	-4.02	12.68*	4.26	18.43	-13.21*	-12.02*	-3.25	-17.00*	-27.15*	-13.47	-10.00	9.09
HC 201 x Solan Bharpoor	0.85	-4.40	16.73*	2.84	-0.46	-10.38	-12.50*	12.63*	-21.25*	-9.10*	-30.26*		36.36
AC 48 x California Wonder	6.19*	9.20	-8.30*	-3.31	-15.81	11.86	11.86	-41.97*	-16.93*	-39.64*	-32.37*	33.33*	72.72*
AC 48 x Yolo Wonder	2.70	-4.02	-3.22	21.49	34.87*	-3.57	-4.50	-20.69*	-6.10	-24.70*	42.01*	-10.00	36.36
AC 48 x Solan Bharpoor	-3.42	-8.24	2.86	11.67	87.76*	71.56*	74.04*	-40.67*	4.20	-31.12*	7.41	22.22*	63.63*
SKAU-SP 613-1 x California Wonder	0.00	0.00	7.12*	6.82	13.95	19.27	17.43	-2.94	8.82	0.56	-35.94*	10.00	
SKAU-SP 613-1 x Yolo Wonder	-5.13	-8.05	-1.70	28.79	62.62*	78.57*	78.38*	-17.47*	-7.13	-21.29*	-8.79	-10.00	
SKAU-SP 613-1 x Solan Bharpoor	-1.71	-4.40	4.68	13.64	32.63*	9.17	7.34	-26.52*	-17.11*	-21.05*	16.05*	-10.00	49.99
PBC 631 x California Wonder	-5.60*	-19.19*	5.41*	5.30	60.31*	29.77*	29.37*	-4.39	-27.68*	-13.47*	-32.87*	-11.11	
PBC 631 x Yolo Wonder	-9.60*	-15.66*	6.87*	12.58	66.95*	53.44*	57.94*	-11.77*	-21.38*	-32.76*	-6.91	-30.00*	
PBC 631 x Solan Bharpoor	-5.60*	-8.08	2.44	-0.66	27.29*	12.98	15.87	11.84*	-28.22*	-26.38*	-9.45		
SKAU-SP 633-1 x California Wonder	1.75	-12.07*	67.52*	-3.92	22.60	9.15	9.15	34.67*	-24.59*	-15.69*	-30.08*	0.00	249.96*
SKAU-SP 633-1 x Yolo Wonder	-0.88	-12.07*	66.67*	22.88	73.53*	84.86*	82.39*	-4.64	-31.32*	-36.40*	-16.98*	10.00	199.95*
SKAU-SP 633-1 x Solan Bharpoor	-3.42	-12.09*	72.52*	-3.92	33.33*	39.08*	33.10*	3.24	-21.98*	-30.60*	-20.77*		199.97*
SE (d)	1.11	2.74	1.11	6.53	30.95	0.81	0.74	0.33	0.22	0.20	2.41	0.30	9.91

* Significant at P=0.05

It is desirable to take advantage of off-season marketing for a longer period. Out of twenty four hybrids, two expressed hybrid vigour over better parent. Maluf *et al.* (1999) and Mamedov and Pyshnaja (2001) also reported similar observations for positive heterosis.

Higher yield is basic objective for all the crop improvement programmes. The F_1 hybrids were superior to parents in fruit yield. Better parent heterosis (114.49%) for fruit yield/plant was highest in cross EC 464107 \times Yolo Wonder. The significant positive better parent heterosis for fruit yield was recorded in fourteen F_1 hybrids. Heterobeltiosis for this trait has also been recorded earlier by Geleta and Labuschagne (2004), Khalil *et al.* (2004), Pandey *et al.* (2002) and Sood and Kaul (2006) for other bell pepper genotypes in different environments. The higher marketable fruit yield in the hybrids may be attributed to earliness, increase in harvest duration, marketable fruits/plant and average fruit weight.

Number of fruits is a direct component that contributes towards yield in bell pepper. For fruits/plant, significant better parent heterosis was noticed in nine cross combinations. Whereas nine F_1 hybrids reported significant better parent

heterosis for marketable fruits/plant. The cross combination SKAU-SP 633-1 \times Yolo Wonder revealed highest better parent heterosis for both fruits/plant and marketable fruits/plant. Hybrid vigour in variable number of hybrids for fruits/plant has also been reported earlier by Geleta and Labuschagne (2004), Mamedov and Pyshnaja (2001) and Pandey *et al.* (2002). Fruit length and fruit width have direct influence on fruit shape. To develop a good looking hybrid, it is important to have good balance between length and width of the fruits. In case of fruit length, four expressed better parent heterosis. As far as fruit width is concerned significant heterosis over better parent was observed only in two hybrids.

Pericarp thickness is responsible for fruit firmness and prolongs harvest shelf-life in bell pepper. For these traits, only HC 201 \times California Wonder and EC 464115 \times California Wonder could reveal heterobeltiosis. In bell pepper, medium sized fruits are preferred over large sized fruits. Better parent heterosis was reported only in four F_1 's for average fruit weight. Generally more number of lobes in the fruits is preferred. Only HC 201 \times California Wonder, AC 48 \times California Wonder and AC 48 \times Solan Bharpoor expressed

Table 4 Genotypic and phenotypic correlations among the traits of bell pepper grown in bacterial wilt natural sick plots at Palampur during summer-rainy season, 2008 and 2009 (pooled)

Traits		Days to first picking	Plant height	Harvest duration	Fruits/plant	Marketable fruits/plant	Fruit length	Fruit width	Pericarp thickness	Average fruit weight	Lobes/fruit	Bacterial wilt incidence	Fruit yield/plant
Days to 50% flowering	G	0.193	0.171	0.134	-0.167	-0.178	0.457*	-0.299	-0.603*	-0.180	0.386*	-0.481*	-0.231
	P	0.314	0.082	-0.033	-0.076	-0.076	0.230	-0.169	-0.324*	-0.156	0.137	-0.261	-0.133
Days to first picking	G		-0.263	-0.371*	-0.641*	-0.651*	0.198	-0.161	-0.256	-0.146	0.311	-0.276	-0.684*
	P		-0.105	-0.181	-0.277	-0.314	0.052	-0.109	-0.109	-0.170	0.189	-0.126	-0.357*
Plant height	G			0.531*	0.443*	0.425*	0.717*	-0.446*	-0.432*	-0.218	-0.473*	-0.414*	0.304
	P			0.330*	0.415*	0.399*	0.689*	-0.422*	-0.424*	-0.189	-0.300	-0.384*	0.278
Harvest duration	G				0.799*	0.805*	0.359*	-0.128	-0.224	-0.144	-0.265	-0.573*	0.725*
	P				0.544*	0.540*	0.243	-0.035	-0.169	-0.049	-0.237	-0.395*	0.486*
Fruits/plant	G					1.000*	0.214	-0.170	-0.087	-0.300	-0.364*	-0.254	0.804*
	P					0.993*	0.199	-0.122	-0.075	-0.271	-0.200	-0.233	0.782*
Marketable fruits/plant	G						0.199	-0.159	-0.073	-0.297	-0.344*	-0.246	0.806*
	P						0.184	-0.120	-0.063	-0.267	-0.199	-0.225	0.786*
Fruit length	G							-0.593*	-0.458*	-0.415*	-0.625*	-0.533*	-0.038
	P							-0.535*	0.450*	-0.345*	-0.347*	-0.485*	-0.026
Fruit width	G								0.592*	0.625*	0.475*	0.354*	0.257
	P								0.549*	0.560*	0.285	0.325*	0.255
Pericarp thickness	G									0.235	0.210	0.305	0.101
	P									0.201	0.151	0.285	0.093
Average fruit weight	G										0.209	0.290	0.294
	P										0.097	0.240	0.342*
Lobes/fruit	G											0.447*	-0.191
	P											0.274	-0.080
Bacterial wilt incidence	G												-0.132
	P												-0.123

significant heterobeltiosis for this trait.

The understanding of inheritance of disease is very essential for formulating a systematic breeding programme for developing resistant variety with desirable horticultural traits. There is availability of numerous hybrids which are being marketed by the private sector seed companies. However all these hybrids do not possess resistance to bacterial wilt disease which is most limiting factor in its cultivation in humid, tropical, subtropical and warm temperate areas of the world (Kelman 1953). Wang *et al.* (1996) concluded that the use of resistant varieties is the most simple, effective and widespread method of disease control as well as core of integrated management strategies. Thus, it becomes imperative to study the heterosis of bacterial wilt. Significant negative heterosis for bacterial wilt incidence over mid parent has been reported in twelve cross combinations, whereas none of the hybrids expressed heterobeltiosis for this trait.

The genotypic correlation coefficients, in general, were higher than the corresponding phenotypic correlation coefficients, suggesting a strong inherent association among traits at genotypic level (Table 4).

At phenotypic level, fruit yield had a high significant association with harvest duration, fruits/plant, marketable fruits/plant and average fruit weight, whereas significant negative association with days to first picking. At genotypic level, fruit yield was positively associated with harvest duration, fruits/plant and marketable fruits/plant, whereas significant negatively associated with days to first picking. High positive correlations of fruit yield has been observed with harvest duration, fruits/plant and marketable fruits/plant. Correlation analysis indicated that selection for earliness, more fruits, longer harvest duration 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 with the future cultivars/ improvement programme. Bacterial wilt incidence had significant negative correlation with days to 50% flowering, plant height, harvest duration and fruit length at both genotypic and phenotypic levels indicating that delay in days to flowering will favour the incidence of the disease. Similarly, with decrease in plant height and harvest duration, level of disease incidence increases. Bacterial wilt incidence had non-significant negative correlation with fruit yield both at genotypic and phenotypic levels suggesting their combined effect in the expression of bacterial wilt.

The research has indicated that bell pepper hybrids resistant to bacterial wilt disease have been developed. Therefore, hybrids that are resistant and high yielding can be developed within the Indian ecosystem after further testing.

Correlation analysis indicated that selection for earliness, more plant height, longer harvest duration and more fruit length could be criteria for simultaneously increasing bacterial wilt resistance in bell pepper.

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