Vegetable Science (2018) 45 (1) : 31-37

Heterosis studies in bell pepper (*Capsicum annuum* L. var. *grossum* Sendt) under modified naturally ventilated polyhouse in mid hills of Himalayas

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Received: November 2017 / Accepted: April 2018

Abstract

The present investigation was envisaged to gather information on heterosis for earliness, yield and its contributing traits of bell pepper. The experiment was conducted at the Experimental farm of the Department of Vegetable Science and Floriculture, CSKHPKV, Palampur, Himachal Pradesh under modified naturally ventilated polyhouse. A wide range of heterosis over mid-parent, better parent and standard check was observed in F_1 generation for marketable fruit yield and its attributing traits. The cross combinations *viz.,* DARL-10 (L_9) × California Wonder (T_2), LC (L_{10}) × Solan Bharpur (T_1), Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), Kashmir Sel-1 (L_2) × Yolo Wonder (T_3) and Kandaghat Sel-9 (L_7) × Solan Bharpur (T_1) exhibited the highest significant desirable heterosis over standard check (Indra) for early maturity. The F_1 crosses *viz.,* Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1), DARL-10 (L_9) × California Wonder (T_2) and UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) were the top heterotic cross combinations over standard check for marketable fruit yield per plant and number of marketable fruits per plant. These cross combinations could be exploited in future breeding programme for development of early and high yielding hybrids suitable for cultivation under protected structure in mid hills of Himalayas.

Key words: *Capsicum annuum* L. var. *grossum*, Heterosis, Marketable fruit yield, Polyhouse, Hybrid vigour

Introduction

Bell pepper (*Capsicum annuum* var. *grossum* Sendt.) also known as sweet pepper or *Shimla Mirch* holds a coveted position as a leading off-season vegetable in Himachal Pradesh ensuring premium price to the growers. Presently, it is extensively grown in Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Arunachal Pradesh and Darjeeling and in some parts of West Bengal during summer months and as an autumn crop in Maharashtra, Karnataka, Tamil Nadu and Bihar. In spite of its importance, a few varieties are grown commercially. California Wonder an old introduction is still being grown extensively throughout the country. In recent times, the production scenario of capsicum has changed with the increasing popularity of hybrids cultivated on commercial scale under protected structure. Bell pepper is amongst the important vegetable crops suitable for protected cultivation due to favourable growth habit and pollination mechanism. Such cultivation system not only results higher yield but also ensures better quality produce than open environment. Lack of adequate hybrids from public sector for specific region is one of the challenging limitations in commercial cultivation of this crop. Thus, systematic effort is needed to identify the promising lines and develop suitable varieties or hybrids for protected cultivation. Under the condition of increasing productivity in the quickest possible time utilizing heterosis breeding is one of the most feasible and attractive option in this crop (Joshi and Singh 1980). Information on the magnitude of heterosis in different cross combination is a basic requisite for identifying desirable crosses that exhibit high extent of exploitable heterosis. The present investigation highlights the extent of heterosis for earliness, fruit yield and its contributing traits in bell pepper.

Materials and Methods

The experimental material for the present study comprises of 29 genotypes, 33 F_1 and 1 standard check (Indra). For selection of desirable parents on the basis of morphological observations the 29 genotypes were evaluated during summer-autumn, 2012. The F_1 population of 33 crosses (line × tester mating design) alongwith desirable parents (11 lines and 3 testers),

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selected from the 29 genotypes, and one standard check (Indra) were evaluated under modified naturally ventilated polyhouse at the Experimental Farm, Department of Vegetable Science and Floriculture during summer-autumn 2013. The Experimental Farm is situated at 32^0 6' N latitude and $76^0$3' E longitude at an elevation of 1290.80 m above mean sea level with East-West orientation. It is an ideal polyhouse with essential features like double door, side and top ventilation, drip and fogging facility and shading with 50 per cent green agro UV stabilized shade net. Healthy seedlings were raised in plug trays inside growth chamber. The experiment was laid out in randomized complete block design (RBD) with three replications. The crop was grown on 20 cm raised bed having 90 cm width. Each bed consisted of two rows of 1.5 m length accommodating ten plants per genotype of each entry. The plants were spaced at 45 × 30 cm inter and intra row spacing. All the recommended agronomic practices were followed to raise a healthy crop. The observations were recorded on randomly taken five plants of each genotype in each replication for the traits *viz.,* days to 50 per cent flowering, days to first harvest, number of marketable fruits per plant, pericarp thickness (mm), lobes per fruit, fruit length (cm), fruit width (cm), average fruit weight (g), marketable fruit yield per plant (kg), plant height (cm), harvest duration (days), ascorbic acid content (mg/100g) and capsaicin content (%) during both the years. The estimates of heterosis were calculated as the deviation of F_1 mean from the mid parent (MP), better parent (BP) and the standard check (SC).

Results and Discussion

High marketable yield is the basic objective of all the crop improvement programs and is of relevance to the farmers from economic point of view. A new genotype/ hybrid will achieve little or no success, unless it exceeds the potential adapted and recommended varieties in performance. For marketable fruit yield per plant out of 33 crosses, 20 showed positive heterosis over mid

Table 1: Estimation of heterosis (%) for days to 50 per cent flowering, days to first harvest and number of marketable fruits per plant over mid parent (MP), better parent (BP) and standard check (SC)

Hybrids	Days to 50% flowering			Days to first harvest			Number of marketable fruits per plant		
	MP	BP	SC	MP	BP	SC	MP	BP	SC
L_1 x T_1	-27.14*	-33.33*	-41.38*	-21.54*	-25.75*	-33.46*	69.79*	52.37*	101.24*
L_1 x T_2	-5.56*	-11.11*	-21.84*	-5.41*	-9.87*	-19.23*	2.65	1.38	37.30*
L_1 x T_3	-14.78*	-18.95*	-28.74*	-8.07*	-12.02*	-21.15*	29.56*	1.37	33.90*
L_2 x T_1	-29.46*	-30.53*	-47.70*	-26.13*	-30.51*	-36.92*	78.10*	57.03*	115.93*
L_2 x T_2	-0.75	-2.22	-24.14*	-8.28*	-13.14*	-21.15*	79.04*	77.68*	144.33*
L_2 x T_3	-23.42*	-25.36*	-40.80*	-26.50*	-30.08*	-36.54*	61.90*	24.88*	71.72*
L_3 x T_1	7.51*	7.09*	-21.84*	-0.48	-0.95	-20.00*	60.66*	52.68*	60.26*
L_3 x T_2	3.45	0.00	-22.41*	-1.66	-1.90	-20.38*	-2.60	-17.30*	12.00
L_3 x T_3	4.55	0.00	-20.69*	-0.71	-1.41	-19.23*	61.77*	44.73*	36.83*
L_4 x T_1	6.30*	6.30*	-22.41*	-1.43	-2.38	-20.38*	23.77*	7.19	53.70*
L_4 x T_2	5.34*	2.22	-20.69*	-1.65	-1.89	-20.00*	3.53	0.65	44.33*
L_4 x T_3	1.89	-2.17	-22.41*	-2.59	-2.82	-20.38*	-3.71	-26.80*	4.97
L_5 x T_1	-4.83*	-9.86*	-26.44*	-2.63	-3.32*	-21.54*	60.83*	50.10*	81.82*
L_5 x T_2	-32.13*	-33.80*	-45.98*	-19.43*	-19.43*	-34.62*	50.14*	42.21*	92.60*
L_5 x T_3	-7.14*	-8.45*	-25.29*	-3.30*	-3.76*	-21.15*	34.77*	8.90	31.91*
L_6 x T_1	3.05	0.00	-22.41*	0.96	0.48	-18.85*	31.58*	30.16*	39.64*
L_6 x T_2	1.48	1.48	-21.26*	-0.71	-0.95	-19.62*	-0.76	-11.07	20.43
L_6 x T_3	-1.10	-2.17	-22.41*	-2.13	-2.82	-20.38*	16.95	-0.85	6.37
L_7 x T_1	-26.07*	-26.92*	-45.40*	-20.10*	-20.67*	-36.54*	62.48*	50.94*	84.68*
L_7 x T_2	1.89	0.00	-22.41*	-0.48	-1.90	-20.38*	-5.96	-10.50	21.20
L_7 x T_3	0.75	-2.17	-22.41*	0.00	-1.88	-19.62*	60.82*	29.45*	58.39*
L_8 x T_1	6.23*	-0.68	-16.67*	0.72	0.00	-18.85*	9.77	5.80	11.06
L_8 x T_2	-3.20	-6.85*	-21.84*	-1.42	-1.42	-20.00*	-4.19	-17.65*	11.53
L_8 x T_3	-3.52	-6.16*	-21.26*	-1.42	-1.88	-19.62*	46.36*	29.26*	25.87*
L_9 x T_1	9.31*	6.30	-22.41*	1.47	-0.48	-20.38*	35.06*	8.85	86.74*
L_9 x T_2	-20.00*	-24.44*	-41.38*	-26.03*	-27.96*	-41.54*	69.46*	51.61*	160.10*
L_9 x T_3	9.30*	2.17	-18.97*	2.66	-0.47	-18.46*	-8.63	-34.44*	12.46
L_{10} x T_1	-28.57*	-29.13*	-48.28*	-25.30*	-25.48*	-40.38*	46.53*	45.54*	52.76*
L_{10} x T_2	4.62	0.74	-21.84*	-0.48	-1.42	-20.00*	17.27*	3.46	40.11*
L_{10} x T_3	2.66	-2.17	-22.41*	0.00	-1.41	-19.23*	28.35*	10.43	14.34
L_{11} x T_1	-22.51*	-27.08*	-39.66*	-15.38*	-15.38*	-32.31*	41.22*	40.18*	47.14*
L_{11} x T_2	1.08	-2.08	-18.97*	-1.19	-1.90	-20.38*	21.25*	6.92	44.80*
L_{11} x T_3	-31.91*	-33.33*	-44.83*	-19.24*	-19.43*	-34.62*	148.32*	113.75*	121.06*

*Significant at 5% level of significance

Table 2: Estimation of heterosis (%) for pericarp thickness, lobes per fruit and fruit length over mid parent (MP), better parent (BP) and standard check (SC)

Hybrids	Pericarp thickness			Lobes per fruit			Fruit length		
	MP	BP	SC	MP	BP	SC	MP	BP	SC
L_1 x T_1	59.68*	47.64*	17.70*	1.63	-8.53	-9.90	-16.14*	-20.94*	5.97
L_1 x T_2	-13.56	-27.25*	-15.11	3.12	-2.75	-4.20	5.63	-1.72	16.65*
L_1 x T_3	-9.90	-16.40	-22.12*	-5.09	-10.71	-12.04	17.61*	11.44	32.27*
L_2 x T_1	57.78*	54.38*	4.51	-2.44	-10.09	-15.97	-3.76	-10.98	19.32*
L_2 x T_2	-9.11	-29.33*	-17.53*	15.19	11.39	4.11	4.39	-1.00	12.78
L_2 x T_3	9.30	-7.35	-13.69	19.52*	15.28	7.75	1.68	-1.75	11.93
L_3 x T_1	18.34*	-2.92	2.59	33.54*	26.42*	-0.37	-14.59*	-22.09*	4.43
L_3 x T_2	-6.76	-11.16	3.67	15.33	4.17	-9.06	-8.52	-11.98	-2.73
L_3 x T_3	-16.71*	-21.64*	-17.20	9.62	-0.75	-13.82	-1.76	-3.65	6.48
L_4 x T_1	-2.73	-19.58*	-16.69	11.31	3.24	-4.86	-7.70	-13.35*	16.14
L_4 x T_2	-9.97	-15.02*	-0.83	2.39	-0.30	-8.12	-16.24*	-21.74*	-7.95
L_4 x T_3	-19.39*	-23.45*	-20.70*	-2.24	-5.07	-12.51	6.24	1.11	18.92*
L_5 x T_1	35.95*	30.09*	-11.94	5.65	-4.67	-6.63	-23.34*	-28.36*	-3.98
L_5 x T_2	-10.14	-31.26*	-19.78*	-4.13	-9.34	-11.20	-1.25	-7.32	7.95
L_5 x T_3	-13.95	-28.41*	-33.31*	-8.24	-13.44	-15.22	-3.21	-7.46	7.78
L_6 x T_1	-15.95	-22.36*	-37.98*	-2.44	-13.20	-12.23	-3.73	-21.20*	5.63
L_6 x T_2	-28.83*	-40.06*	-30.05*	0.40	-6.46	-5.54	-6.82	-14.46	-12.61
L_6 x T_3	-34.11*	-38.80*	-42.99*	-0.55	-7.57	-6.54	22.56*	10.53	17.44*
L_7 x T_1	54.18*	41.55*	14.61	15.66*	2.57	4.48	-22.45*	-29.42*	-5.40
L_7 x T_2	8.61	-8.01	7.35	9.18	1.37	3.27	-8.87	-12.09	-3.35
L_7 x T_3	-41.04*	-44.89*	-48.66*	1.43	-6.05	-4.30	22.21*	20.16*	32.10*
L_8 x T_1	-9.27	-21.13*	-27.71*	42.02*	29.74*	2.24	-10.82	-24.88*	0.68
L_8 x T_2	-31.49*	-38.84*	-28.63*	12.06	-2.14	-14.57	33.37*	26.59*	29.32*
L_8 x T_3	-40.29*	-40.77*	-44.82*	20.39*	5.38	-8.50	37.68*	28.29*	36.31*
L_9 x T_1	3.21	-3.64	-24.79*	14.77	4.05	0.84	-17.05*	-34.00	-11.53
L_9 x T_2	12.73	-5.94	9.77	16.17*	10.40	7.00	20.51*	7.01	9.32
L_9 x T_3	-37.79*	-42.38*	-46.74*	-7.01	-11.85	-14.57	11.55	-2.62	3.47
L_{10} x T_1	43.92*	35.74*	3.67	19.10*	10.94	1.31	-3.21	-22.68*	3.64
L_{10} x T_2	-17.94*	-32.12*	-20.78*	0.47	-1.74	-10.27	8.54	-3.17	-1.08
L_{10} x T_3	-0.74	-9.68	-15.86	9.43	6.75	-2.52	-0.30	-12.57	-7.10
L_{11} x T_1	8.27	1.29	-21.29*	-0.31	-11.91	-9.52	-7.32	-26.45*	-1.42
L_{11} x T_2	-42.72*	-52.29*	-44.32*	-12.83	-19.36	-17.18*	16.24*	2.89	5.11
L_{11} x T_3	14.41	4.93	-2.25	12.32	3.64	6.44	30.02*	13.16	20.23*

*Significant at 5% level of significance

parent, 16 over better parent and 7 over the standard check (Indra). The extent of heterosis over mid parent, better parent and standard check ranged between -20.36 to 113.19 per cent, -22.94 to 102.93 per cent and -41.06 to 60.60 per cent, respectively. Maximum standard heterosis of 60.60, 39.07 and 31.46 per cent was recorded in the crosses *viz.,* Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1) and DARL-10 (L_9) × California Wonder (T_2), respectively. Shrestha et al. (2011) and Sharma et al. (2013) have also observed heterobeltiosis and standard heterosis in variable number of hybrid combinations for fruit yield per plant in bell pepper. The highest standard heterosis to the extent of 160.10, 144.33, 121.06, 115.93 and 101.24 per cent was recorded in the crosses, DARL-10 (L_9) × California Wonder (T_2), Kashmir Sel-1 (L_2) × California Wonder (T_2), UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3), Kashmir Sel-1 (L_2) × Solan Bharpur (T_1) and ARCH-19 (L_1) × Solan Bharpur (T_1), respectively for number of marketable fruits per plant, while for average fruit weight, the maximum heterobeltiosis to the extent of 27.81 per cent was recorded in the cross Kashmir Sel-1 (L_2) × Solan Bharpur (T_1). The crosses, Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1) and UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) were observed to be potential crosses as this displayed standard heterosis for fruit yield and most of its contributing traits. The higher marketable fruit yield per plant in the hybrid combinations may be attributed to the enhance photosynthetic activity resulting from favourable micro-climate inside the polyhouse which in turn increases the yield component traits.

Earliness is economically desirable trait in bell pepper as the market prices are invariably high early in the season which brings remunerative returns to the growers. The magnitude of heterosis for days to 50 per cent flowering over mid parent (MP), better parent (BP) and standard check (SC) ranged from -32.13 (L_5 × T_2) to 9.31 (L_9 × T_1), -33.80 (L_5 × T_2) to 7.09 (L_3 × T_1) and -48.28 (L_{10} × T_1) to -16.67 (L_8 × T_1) per cent, respectively, while for days to first harvest the value ranged from -26.50

Table 3: Estimation of heterosis (%) for fruit width, average fruit weight and marketable fruit yield per plant over mid parent (MP), better parent (BP) and standard check (SC)

Hybrids	Fruit width			Average fruit weight			Marketable fruit yield per plant		
	MP	BP	SC	MP	BP	SC	MP	BP	SC
L_1 x T_1	13.67	-1.52	1.50	34.69*	23.26*	-30.61*	90.91*	87.50*	39.07*
L_1 x T_2	-14.42	-32.86*	-10.90	-6.73	-14.87	-41.94*	15.87	7.59	-20.20*
L_1 x T_3	9.28	-8.13	1.83	-14.93*	-26.29*	-43.39*	15.37	2.23	-24.17*
L_2 x T_1	0.26	-1.52	1.50	41.12*	27.81*	-26.38*	113.19*	102.93*	60.60*
L_2 x T_2	-16.31*	-26.81*	-2.87	-20.88*	-27.02*	-50.23*	77.26*	59.83*	26.49*
L_2 x T_3	-19.28*	-23.44*	-15.14	0.91	-11.70	-32.19*	71.84*	48.12*	17.22*
L_3 x T_1	-8.99	-12.86	-10.18	24.89*	15.55	-36.49*	65.05*	42.13*	1.66
L_3 x T_2	-29.73*	-39.89*	-20.23*	-6.27	-15.36*	-42.28*	12.64	2.08	-35.10*
L_3 x T_3	1.69	-5.89	4.31	-11.68	-24.24*	-41.82*	46.50*	39.31*	-20.20*
L_4 x T_1	-13.14	-14.57	-8.94	-5.75	-14.28	-51.08*	-1.51	-7.69	-24.50*
L_4 x T_2	-14.02*	-22.48*	2.87	-8.75	-16.19*	-42.84*	13.44	0.81	-17.55*
L_4 x T_3	-8.62	-10.37	-0.65	-13.05	-24.21*	-41.80*	27.62*	8.50	-11.26
L_5 x T_1	-3.02	-9.44	-6.66	7.50	-2.76	-43.83*	44.26*	42.59*	1.99
L_5 x T_2	-17.72*	-31.14*	-8.62	-12.34	-19.05*	-44.79*	59.80*	52.61*	6.62
L_5 x T_3	-7.24	-16.20*	-7.11	-20.67*	-30.50*	-46.63*	11.46	1.42	-29.14*
L_6 x T_1	-8.13	-8.90	-4.50	1.92	-11.16	-44.14*	12.65	9.26	-21.85*
L_6 x T_2	-7.12	-16.87*	10.31	-1.91	-5.74	-35.71*	15.95	12.81	-24.17*
L_6 x T_3	-1.94	-4.59	5.74	-7.64	-16.01*	-35.50*	10.11	1.97	-36.46*
L_7 x T_1	-4.02	-6.90	2.09	19.88*	0.39	-30.46*	64.41*	51.56*	28.48*
L_7 x T_2	-30.78*	-36.79*	-16.12	-16.25*	-16.89*	-42.43*	-6.70	-18.36*	-30.79*
L_7 x T_3	-10.01	-10.48	-0.78	-8.73	-13.20	-33.34*	49.18*	25.00*	5.96
L_8 x T_1	-7.66	-10.26	-7.51	-13.46	-30.99*	-45.77*	-20.36*	-22.94*	-41.06*
L_8 x T_2	-26.82*	-36.60*	-15.86	0.02	-6.60	-26.59*	17.26	7.36	-17.88*
L_8 x T_3	-15.06*	-20.26*	-11.62	-25.09*	-25.95*	-41.80*	9.41	-4.33	-26.82*
L_9 x T_1	-14.28	-16.47*	-9.27	6.73	0.91	-47.06*	22.38*	9.96	-1.32
L_9 x T_2	-29.94*	-36.30*	-15.47	-13.99	-23.91*	-48.11*	71.49*	46.49*	31.46*
L_9 x T_3	-9.16	-10.07	-0.33	26.20*	6.21	-18.44*	24.77*	2.21	-8.28
L_{10} x T_1	-19.19*	-25.09*	-9.60	32.92*	17.90*	-28.80*	62.47*	52.31*	8.94
L_{10} x T_2	-22.21*	-25.73*	-1.44	13.83*	7.31	-26.81*	63.25*	61.98*	2.98
L_{10} x T_3	-14.41*	-17.90*	-0.91	19.73*	6.93	-17.88*	56.35*	49.74*	-6.29
L_{11} x T_1	-23.41*	-26.95*	-17.04	13.23	-8.75	-30.29*	36.56*	30.25*	2.65
L_{11} x T_2	-14.13*	-20.31*	5.74	-16.45*	-20.93*	-39.59*	22.79*	10.92	-12.58
L_{11} x T_3	8.78	7.47	22.06*	11.02	10.73	-14.96*	86.86*	61.34*	27.15*

*Significant at 5% level of significance

($L_2 \times T_3$) to 2.66 ($L_9 \times T_3$), -30.51 ($L_2 \times T_1$) to 0.48 ($L_6 \times T_1$) and -41.54 ($L_9 \times T_2$) to -18.46 ($L_9 \times T_3$) per cent, respectively (Table 2). For these traits, significant desirable standard heterosis was recorded in the crosses, LC (L_{10}) × Solan Bharpur (T_1), Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), DARL-01 (L_5) × California Wonder (T_2), Kandaghat Sel-9 (L_7) × Solan Bharpur (T_1), UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) for days to 50 per cent flowering and DARL-10 (L_9) × California Wonder (T_2), LC (L_{10}) × Solan Bharpur (T_1), Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), Kashmir Sel-1 (L_2) × Yolo Wonder (T_3) and Kandaghat Sel-9 (L_2)× Solan Bharpur (T_1) for days to first harvest (Table 1). Sharma et al. (2013) has also reported significant negative heterosis for days to 50% flowering and first harvest.

Pericarp thickness is a desirable attribute as it imparts fruit firmness and such fruits are better suited for long distant transportation, better shelf life and processing. The improved shelf-life resulting from thicker pericarp helps in reducing post-harvest losses. The heterosis for this character ranged from -42.72 ($L_{11} \times T_2$) to 59.68 ($L_1 \times T_1$), -52.29 ($L_{11} \times T_2$) to 54.38 ($L_2 \times T_1$) and -48.66 ($L_7 \times T_3$) to 17.70 ($L_1 \times T_1$) per cent over mid parent, better parent and standard check, respectively (Table 2). Significant positive heterosis over standard check was recorded in only one hybrid combination *viz.,* ARCH-19 (L_1) × Solan Bharpur (T_1). Rao et al. (2017) has also reported positive heterosis for pericarp thickness. More number of lobes in the fruits is generally preferred in bell pepper from consumers' point of view. The range of heterosis for lobes per fruit varied from -12.83 ($L_{11} \times T_2$) to 42.02 ($L_8 \times T_1$), -19.36 ($L_{11} \times T_2$) to 29.74 ($L_8 \times T_1$) and -17.18 ($L_{11} \times T_2$) to 7.75 ($L_2 \times T_3$) per cent over mid parent, better parent and standard check, respectively. Only two cross combinations, SEL-10-2 (L_8) × Solan Bharpur (T_1) and PRC-1 (L_3) × Solan Bharpur (T_1) exhibited significant positive heterobeltiosis for this trait. However, none of the cross combinations could express significant positive heterosis over the

Table 4: Estimation of heterosis (%) for plant height and harvest duration over mid parent (MP), better parent (BP) and standard check (SC)

Hybrids	Plant height			Harvest duration		
	MP	BP	SC	MP	BP	SC
L_1 x T_1	31.62*	25.07*	43.92*	21.67*	9.56	30.24*
L_1 x T_2	33.20*	25.41*	47.16*	-10.75	-12.30	-4.47
L_1 x T_3	33.41*	15.12*	19.29*	2.31	-2.21	6.53
L_2 x T_1	64.99*	56.58*	100.65*	23.44*	18.26	35.74*
L_2 x T_2	13.03*	8.26*	38.74*	8.30	3.76	19.09
L_2 x T_3	45.06*	15.09*	47.49*	6.58	-0.60	14.09
L_3 x T_1	-7.30*	-17.65*	-5.24	2.99	-4.25	0.69
L_3 x T_2	26.40*	11.33*	30.63*	-10.37	-16.67	-12.37
L_3 x T_3	30.01*	19.71*	6.97	-2.17	-6.57	-7.22
L_4 x T_1	-43.21*	-46.47*	-30.41*	-20.57*	-22.43*	-14.43
L_4 x T_2	19.35*	13.55*	47.59*	-14.51	-16.51	-7.90
L_4 x T_3	34.28*	5.99	37.76*	-6.89	-11.53	-2.41
L_5 x T_1	24.53*	19.15*	37.12*	1.78	0.96	7.90
L_5 x T_2	23.56*	17.13*	37.44*	20.91*	19.94	28.18*
L_5 x T_3	25.47*	7.61*	13.13*	2.67	-0.96	5.84
L_6 x T_1	-17.12*	-27.04*	-16.05*	0.65	0.65	5.84
L_6 x T_2	13.61*	-0.83	16.37*	-18.63	-18.63	-14.43
L_6 x T_3	61.35*	50.00*	31.28*	-8.57	-11.11	-6.53
L_7 x T_1	9.24*	4.08	32.25*	13.71	7.58	26.80*
L_7 x T_2	10.61*	6.38*	35.17*	-11.56	-16.33	-1.37
L_7 x T_3	27.56*	1.53	29.01*	4.75	-3.50	13.75
L_8 x T_1	-11.93*	-26.20*	-15.07*	9.15	3.27	8.59
L_8 x T_2	42.19*	18.23*	38.74*	1.21	-4.25	0.69
L_8 x T_3	48.31*	45.83*	13.45*	7.12	4.15	3.44
L_9 x T_1	3.29	-3.53	27.89*	-4.01	-9.06	6.87
L_9 x T_2	3.68	-2.28	29.55*	6.79	1.17	18.90
L_9 x T_3	14.82*	-10.02*	19.29*	-10.94	-17.84	-3.44
L_{10} x T_1	-4.84	-6.52	11.51*	11.15	9.15	14.78
L_{10} x T_2	25.21*	24.18*	48.14*	2.16	0.33	5.50
L_{10} x T_3	2.44	-16.49*	-0.38	4.79	3.73	5.15
L_{11} x T_1	59.58*	44.23*	65.96*	-16.15	-20.26	-20.26
L_{11} x T_2	12.19*	0.52	17.95*	-8.25	-12.75	-12.75
L_{11} x T_3	85.09*	67.44*	55.59*	19.29	16.61	-16.61

*Significant at 5% level of significance

standard check (Indra). Similar observations have also been recorded by Sood and Kumar (2010), which corroborate the present findings.

Fruit length and fruit width have direct influence on fruit shape. In order to develop an appealing hybrid acceptable to the consumers, an appropriate balance between length and width of the fruit is important. For fruit length the magnitude of heterosis over mid parent, better parent and standard check varied from -23.34 (L_5 × T_1) to 37.68 (L_8 × T_3), -29.42 (L_7 × T_1) to 28.29 (L_8 × L_3) and -12.61 (L_6 × T_2) to 36.31 (L_8 × T_3) per cent, respectively. Nine cross combinations exhibited significant positive heterosis over standard check. Maximum standard heterosis to the extent of 36.31 % was recorded in the hybrid combination SEL-10-2 (L_8) × Yolo Wonder (T_3). These finding are in agreement with those of Mamedov and Pyshnaja (2001) and Geleta and Labushagne (2004). The magnitude of heterosis for fruit width ranged from -30.78 (L_7 × T_2) to 13.67 (L_1 × T_1), -39.89 (L_3 × T_2) to 7.47 (L_{11} × T_3) and -20.23 (L_3 × T_2) to 22.06 (L_{11} × T_3) per cent over mid parent, better parent and standard check, respectively (Table 3). Only one cross combination namely, UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) exhibited significant positive standard heterosis for this trait. The results are in conformity with the finding of Sharma et al. (2013), who have also reported variable heterosis for this trait.

Average fruit weight is one of the most important characters which accounts for yield. The magnitude of heterosis over mid parent, better parent and standard check varied from -25.09 (L_8 × T_3) to 41.12 (L_2 × T_1), -30.99 (L_8 × T_1) to 27.81 (L_2 × T_1) and -51.08 (L_4 × T_1) to -14.96 (L_{11} × T_3) per cent, respectively. Three top crosses out of eight hybrids were Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1) and LC (L_{10}) × Solan Bharpur (T_1). Three cross combinations Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1) and LC (L_{10}) × Solan Bharpur (T_1) exhibited significant heterobeltiosis. However, none of the hybrid combinations could express

Table 5: Estimation of heterosis (%) for ascorbic acid content and capsaicin content over mid parent (MP), better parent (BP) and standard check (SC)

Hybrids	Ascorbic acid content			Capsaicin content		
	MP	BP	SC	MP	BP	SC
L_1 x T_1	80.89*	56.31*	16.84*	-8.11	-22.73*	25.93
L_1 x T_2	-11.25*	-20.69*	-24.70*	-11.76	-31.82*	11.11
L_1 x T_3	-5.88	-12.96*	-23.42*	-41.77*	-47.73*	-14.81
L_2 x T_1	91.01*	82.24*	9.22*	-51.43*	-57.50*	-37.04*
L_2 x T_2	22.33*	-0.23	-5.27	15.63	-7.50	37.04*
L_2 x T_3	48.34*	24.69*	9.72*	-4.00	-10.00	33.33*
L_3 x T_1	33.54*	10.47	-8.13	-26.98*	-30.30*	-14.81
L_3 x T_2	9.11*	2.34	-2.83	92.98*	66.67*	103.70*
L_3 x T_3	-21.19*	-23.35*	-32.55*	-20.59	-22.86	0.00
L_4 x T_1	9.74	-11.21*	-21.82*	20.83*	-12.12	114.81*
L_4 x T_2	-0.18	-3.81	-8.67	-33.33*	-54.55*	11.12
L_4 x T_3	-12.07*	-12.10*	-22.61*	4.95	-19.70*	96.30*
L_5 x T_1	40.74*	35.10*	-26.47*	4.65	-19.64*	66.67*
L_5 x T_2	51.85*	15.96*	10.10*	-17.50	-41.07*	22.22
L_5 x T_3	12.20*	-11.98*	-22.55*	20.88*	-1.79	103.70*
L_6 x T_1	-17.47*	-32.97*	-41.57*	-5.71	-17.50	22.22
L_6 x T_2	-4.49	-8.41	-13.03	28.13*	2.50	51.85*
L_6 x T_3	-26.25*	-26.59*	-35.41*	-12.00	-17.50	22.23
L_7 x T_1	107.94*	104.44*	15.15*	-27.87*	-29.03*	-18.52
L_7 x T_2	58.86*	26.55*	20.16*	-16.36	-25.81	-14.81
L_7 x T_3	21.98*	0.03	-11.98*	-6.06	-11.43	14.81
L_8 x T_1	-1.67	-4.02	-45.14*	20.93*	-7.14	92.59*
L_8 x T_2	14.93*	-7.94	-12.59*	15.00	-17.86*	70.37*
L_8 x T_3	-22.22*	-35.85*	-43.55*	1.10	-17.86*	70.36*
L_9 x T_1	11.08	-6.52	-25.52*	23.40*	-9.37	114.80*
L_9 x T_2	33.42*	22.70*	16.50*	-40.91*	-59.37*	-3.70
L_9 x T_3	-43.04*	-45.73*	-52.25*	5.05	-18.75*	92.59*
L_{10} x T_1	77.88*	63.61*	6.06	-18.99*	-34.69*	18.52
L_{10} x T_2	35.06*	13.64*	7.90	-26.03*	-44.90*	0.00
L_{10} x T_3	-3.46	-16.17	-26.24*	-35.71*	-44.91*	0.00
L_{11} x T_1	110.26*	86.82*	86.82*	-57.50*	-66.00*	-37.04*
L_{11} x T_2	39.42*	0.77	0.77	18.92	-12.00	62.96*
L_{11} x T_3	67.63*	24.11*	24.11*	-20.00*	-32.00*	25.93

*Significant at 5 % level of significance

significant positive heterosis over the standard check. Sharma et al. (2013) reported positive heterosis over better parent for this trait. Plant height plays an important role for bell pepper cultivation under protected structure as indeterminate plants result in better utilization of vertical space thereby increasing the marketable fruit yield. The respective range of relative heterosis, heterobeltiosis and economic heterosis for plant height varied from -43.21 ($L_4 \times T_1$) to 85.09 ($L_{11} \times T_3$), -46.47 ($L_4 \times T_1$) to 67.44 ($L_{11} \times T_3$) and -30.41 ($L_4 \times T_1$) to 100.65 ($L_2 \times T_1$) per cent, respectively (Table 4). The cross combinations *viz.,* Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), UHFSP(Y)-11 (L_{11}) × Solan Bharpur (T_1) and UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) exhibited significant heterosis over the standard check. This finding is in consonance with those of Geleta and Labuschagne (2004), who have also reported positive heterosis for this trait. The heterosis for harvest duration ranged from -20.57 ($L_4 \times T_1$) to 23.44 ($L_2 \times T_1$), -22.43 ($L_4 \times T_1$) to 19.94 ($L_5 \times T_2$) and -20.26 ($L_{11} \times T_1$) to 35.74 ($L_2 \times T_1$) per cent over mid parent, better parent and standard check, respectively. Four crosses *viz.,* Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1), DARL-01 (L_5) × California Wonder (T_2) and Kandaghat Sel-9 (L_7) × Solan Bharpur (T_1) exhibited significant positive standard heterosis. Significant positive heterosis for this trait was also reported by earlier researchers *viz.,* Mamedov and Pyshnaja (2001) and Sood and Kumar (2010).

Bell pepper is a rich source of ascorbic acid and thus, has enormous potential. The respective relative heterosis, heterobeltiosis and standard heterosis for ascorbic acid content varied from -43.04 ($L_9 \times T_3$) to 110.26 ($L_{11} \times T_1$), -45.73 ($L_9 \times T_3$) to 104.44 ($L_7 \times T_1$) and -52.25 ($L_9 \times T_3$) to 86.82 ($L_{11} \times T_1$) per cent, respectively (Table 5). The cross combinations *viz.,* UHFSP(Y)-11 (L_{11}) × Solan Bharpur (T_1), UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) and Kandaghat Sel-9 (L_7) × California Wonder (T_2) exhibited highest significant positive heterosis over standard check. Farag and Khalil (2007) and Sharma et al. (2013) have also reported heterosis for increased ascorbic acid content in bell pepper. Comparatively, low level of capsaicin content is a desirable preposition in bell pepper as its higher concentration imparts pungency and spicy flavour to the fruit rendering them undesirable for consumers. Hence, heterosis in negative direction is preferred for this trait. The range of heterosis over mid parent, better parent and standard check varied from -57.50 ($L_{11} \times T_1$) to 92.98 ($L_3 \times T_2$), -66.00 ($L_{11} \times T_1$) to 66.67 ($L_3 \times T_2$) and -37.04 ($L_2 \times T_1$ and $L_{11} \times T_1$) to 114.81 ($L_4 \times T_1$) per cent, respectively. Only two cross combinations *viz.,* UHFSP(Y)-11 (L_{11}) × Solan Bharpur (T_1) and Kashmir Sel-1 (L_2) × Solan Bharpur (T_1) displayed significant negative heterosis over the standard check. Milerue and Nikornpun (2000) and Prasath and Ponnuswami (2008) have also reported variable heterosis for this trait.

Conclusion

On the basis of the present investigation, the cross combinations *viz.,* Kashmir Sel-1 (L_2) × Solan Bharpur (T_1), ARCH-19 (L_1) × Solan Bharpur (T_1) and UHFSP(Y)-11 (L_{11}) × Yolo Wonder (T_3) were observed to be potential crosses exhibiting highly significant standard heterosis for marketable fruit yield per plant and most of its component traits. The cross combinations viz., DARL-10 (L9) × California Wonder (T2), LC (L10) × Solan Bharpur (T1), Kashmir Sel-1 (L2) × Solan Bharpur (T1), Kashmir Sel-1 (L2) × Yolo Wonder (T3) and Kandaghat Sel-9 (L7) × Solan Bharpur (T1) exhibited significant negative heterosis for earliness. These cross combinations offer high scope for the exploitation of heterosis for development of early and high yielding bell pepper hybrids suitable for protected cultivation.

Lkkjka'k

शिमला मिर्च में अगेतीपन, उपज एवं उपज में योगदान देने वाले घटकों के प्रति ओज की सूचना ज्ञात करने के लिये वर्तमान अध्ययन किया गया। इस प्रयोग को शोध प्रक्षेत्र सब्जी एवं पुष्प विज्ञान विभाग, सी एस के, हिमाचल प्रदेश कृषि विश्वविद्यालय, पालमपुर (हिमाचल प्रदेश), में प्राकृतिक रूप से परिवर्तित हवादार पालीहाउस दशा में किया गया। प्रथम संतारी में बाजार योग्य फल उपज एवं उपज घटकों हेतु ओज की विस्तृति औसत माध्य पितृ, उत्तम पितृ व मानक नियंत्रक में पाया गया। संकर संयोजनों जैसे– डी ए आर एल–10 (एल–9) x कैलिफोर्निया वण्डर (टी–2), डी ए आर एल–10 (एल–10) x सोलन भरपूर (टी–1), कश्मीर सेल–1 (एल–2) x सोलन भरपूर (टी–1), कश्मीर सेल–1 (एल–2) x येलो वण्डर (टी–3), तथा कण्डाघाट सेल–9 (एल–7) x सोलन भरपूर (टी–1) अगेतीपन हेतु उचच सार्थक वांछित ओज का प्रदर्शन किया। एफ–संकरों जैसे– कश्मीर सेल–1 (एल–2) x सोलन भरपूर (टी–1), ए आर सी एच–19 (एल–1) x सोलन भरपूर (टी–1), डी ए आर एल–10 (एल–9) x कैलिफोर्निया वण्डर (टी–2) तथा यू एच एफ एस पी (वाई)–11 (एल–11) x येलो वण्डर (टी–3) बाजार योग्य फल उपज प्रति पौध व प्रति पौध बाजार योग्य फलों की संख्या हेतु मानक नियंत्रक की तुलना में ओज की दृष्टि से अतिउत्तम पाये गये। मध्य हिमालय के क्षेत्रों में इन संकर संयोजनों को भविष्य के प्रजनन कार्यक्रम (संरक्षित दशा के लिए) में अगेतीपन व अधिक उपज वाले संकर किस्मों का विकास किया जा सकता है।

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