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Over environments evaluation of bell pepper hybrids developed through modified triple test cross mating design for earliness, yield and quality under North-Western Himalayas

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Abstract

Hybridization among diverse parents is a great way to create variability within a genus with a narrow genetic base. During *Kharif*, 2021 and 2022, an experiment was conducted in bell pepper at the research farm of Department of Vegetable Science and Floriculture, CSKHPKV, Palampur (HP) using randomized complete block design under open field conditions to evaluate 15 diverse parents (12 lines and three testers) and their 36 F_1 hybrids developed through triple test cross mating design along with two standard checks for eight yield and quality traits. Significant variations were noticed among all the genotypes for all the characters under study. Based on the overall mean performance in pooled environments, cross-combinations viz., HPB-7 × California Wonder, HPB-7 × HPB-39-CW, HPB-2-16 × HPB-39, HPB-6-1 × California Wonder and HPB-29 × HPB-39 were found top highest yielders. Besides the highest yielders, they were reported earliest in flowering and picking, containing more primary branches and a good amount of capsanthin, TSS and ascorbic acid content. Hence, these cross-combinations can be directly released as hybrids after multi-location/farmers' field testings or can be used in further breeding programmes.

Keywords: Bell pepper, *Capsicum annuum* L. Var. *Grossum*, over environments, triple test cross.

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Introduction

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt), often recognized as sweet pepper, Shimla mirch or capsicum, is a famous vegetable worldwide due to its nutritious value and subtle flavor (Devi and Sood 2018). It belongs to the family Solanaceae, with chromosome number $2n=2x=24$. Bell pepper contains good ascorbic acid, vitamin A and other minerals (Devi *et al.* 2021). In recent years, the growth of the continental food sector has raised the demand for bell pepper in the market (Sood *et al.* 2011). Because of its steady demand and insufficient supply due to mediocre productivity, it consistently commands a premium price in the market for different colored capsicum (Pandey *et al.* 2021).

Moreover, various agronomic practices (Verma *et al.* 2020, Chandela *et al.* 2021) and soil-less cultivation (Spehia *et al.* 2020) have increased bell pepper production. Also, molecular markers studies have added information for further genetic enhancement of crops (Das *et al.* 2021, Gupta *et al.* 2021). Low productivity is the scarcity of high-yielding indigenous varieties and hybrids resistant to biotic and abiotic stresses (Anuradha and Sood 2019). The Indian bell pepper seed market is controlled by imported private-sector hybrids and cultivars, which raises farmers' input costs

(Mishra *et al.* 2021). As a result, there is an urgent need to boost the crop improvement programme to generate new varieties or hybrids capable of meeting the demands of both farmers and consumers.

Materials and Methods

The evaluation trial was conducted at the Vegetable Research Farm of Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, during *kharif* season, 2021 and 2022 under open field conditions. The experimental material consisted of twelve lines viz., Kandaghat Selection, HPB-HY-22, HPB-AC-48, HPB-AC-49, HPB-2-16, HPB-3-10, HPB-1, HPB-6-1, HPB-7, HPB-22, HPB-29, HPB-35 and three testers namely, HPB-39, California Wonder and their F_1 , HPB-39-CW (HPB-39 × California Wonder) (Table 1), which were crossed to generate 36 cross-combinations during *kharif* 2020. The seeds of experimental material were sown in the nursery beds on 10th February, 2021 and 2022 inside poly-tunnel. The seedlings were transplanted in a Randomized Complete Block Design (RCBD) with three replications by maintaining row to row and plant to plant spacing of 60 × 45 cm, in a plot size 3.0 × 3.0 m, accommodating seven plants in each entry per replication. The data were recorded on five randomly selected plants in each replication for days to 50% flowering, days to first picking, primary branches per plant, lobes per fruit, marketable fruit yield per plant (g), capsanthin content (ASTA units), TSS (°Brix) and ascorbic acid content (mg/100g), and the mean values along with standard errors, coefficients of variation, critical differences, ranges and grand means were computed using OPSTAT software. Capsanthin content in bell pepper was calculated according to the procedure given by AOAC (1980), whereas ascorbic acid was calculated through procedure described by Sadasivam and Balasubraminan (1987). TSS content recorded with "Digital Refractometer".

Results

A wide range of variation was observed in the mean performance of 15 parents, 36 cross-combinations and two standard checks for different traits in all the environments. The mean values of cross-combinations were compared with best check for every trait. Tables 2 and 3 summarize the mean performance of genotypes, standard errors, coefficients of variation, critical differences and grand means for different traits under study.

Days to 50% flowering

The mean value of days to 50% flowering ranged from 35.54 days to 46.00 days in pooled over environments. Among the parents, HPB-39 (36.50 days) took minimum days to 50% flowering, whereas HPB-35 (46.00 days) took the maximum number of days to reach 50% flowering (Table 2). Ten cross-combinations viz., HPB-AC-48 × HPB-39 (35.54 days),

Table 1: List of genotypes used for triple test cross analysis

S. No.	Lines	S. No.	Lines
1.	Kandaghat Selection (L_1)	11.	HPB-29 (L_{11})
2.	HPB-HY-22 (L_2)	12.	HPB-35 (L_{12})
3.	HPB-AC-48 (L_3)		Testers
4.	HPB-AC-49 (L_4)	1.	HPB-39 (T_1)
5.	HPB-2-16 (L_5)	2.	California Wonder (T_2)
6.	HPB-3-10 (L_6)	3.	HPB-39-CW (HPB-39 × California Wonder) (T_3)
7.	HPB-1 (L_7)		Standard checks (SC)
8.	HPB-6-1 (L_8)	1.	Bomby (SC_1)
9.	HPB-7 (L_9)	2.	Capsicum Hybrid (SC_2)
10.	HPB-22 (L_{10})		

SC_1 = Standard check 1, SC_2 = Standard check 2

HPB-AC-48 × California Wonder (36.00 days), HPB-AC-49 × HPB-39-CW (36.13 days) HPB-7 × California Wonder (36.55 days), HPB-AC-48 × HPB-39-CW (36.67 days) HPB-7 × HPB-39 (36.88 days), HPB-AC-49 × California Wonder (37.00 days), HPB-3-10 × HPB-39 (37.05 days), HPB-6-1 × HPB-39-CW (37.13 days) and HPB-29 × HPB-39 (37.17 days) were significantly superior over the best check 'Capsicum Hybrid' (39.88 days), while 16 cross-combinations were found statistically at par with best check.

Days to first picking

The mean value for days to first picking in pooled over environments ranged from 50.00 days to 62.00 days with a grand mean of 55.41 days. Among the parents, HPB-39 (50.67 days) recorded minimum days, whereas HPB-HY-22 (62.00 days) took the maximum number of days to first picking (Table 2). Fifteen cross-combinations were superior and 13 cross-combinations were statistically at par while comparing with best check 'Capsicum Hybrid' (55.63 days). Cross-combinations, HPB-29 × HPB-39 (50.00 days), HPB-AC-48 × HPB-39 (51.17 days), HPB-AC-49 × HPB-39-CW (52.17 days), HPB-AC-48 × HPB-39-CW (52.33 days) and HPB-7 × California Wonder (52.33 days) were placed at top five amongst rest in superiority for days to first harvest over combined analysis.

Primary branches per plant

In the present study, parent, HPB-1 (3.09) had the maximum number of primary branches per plant, whereas parent HPB-2-16 (2.60) observed the minimum number of primary branches per plant (Table 2). The mean value for this trait ranged from 2.50 to 3.22 with a grand mean of 2.82. Nine cross-combinations viz., HPB-22 × California Wonder (3.22), HPB-2-16 × California Wonder (3.15), HPB-35 × HPB-39 (3.12), HPB-6-1 × California Wonder (3.08), HPB-1 × California Wonder (3.02), HPB-3-10 × HPB-39-CW (3.00), HPB-29 × HPB-39-CW (3.00), HPB-7 × HPB-39-CW (3.298) and HPB-1 × HPB-39-CW (2.97) were found statistically at par with best

Table 2: Mean performances of 15 parents, their 36 cross-combinations along with standard checks under three environments viz., Kharif 2021 (E_1), Kharif2022 (E_2) and in pooled over environments

S.NO.	Genotypes/ Treatments	Days to 50% flowering			Days to first picking			Primary branches per plant			Lobes per plant		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
Line													
1	Kandaghat Selection	42.00	42.33	42.17	59.75	59.00	59.38	3.00	3.10	3.05	3.33	3.17	3.25
2	HPB-HY-22	44.00	46.00	45.00	63.00	61.00	62.00	2.82	2.73	2.78	3.07	2.93	3.00
3	HPB-AC-48	37.42	36.00	36.71	51.00	53.00	52.00	2.61	2.83	2.72	3.00	3.00	3.00
4	HPB-AC-49	37.92	36.67	37.29	54.67	55.33	55.00	2.80	2.83	2.82	3.17	3.00	3.08
5	HPB-2-16	41.09	39.67	40.38	56.67	54.67	55.67	2.67	2.52	2.60	3.07	3.17	3.12
6	HPB-3-10	42.33	41.00	41.67	60.67	58.67	59.67	2.73	2.80	2.77	3.00	3.00	3.00
7	HPB-1	40.25	38.67	39.46	53.67	55.00	54.34	3.17	2.92	3.05	4.00	4.00	4.00
8	HPB-6-1	41.67	41.33	41.50	61.00	59.33	60.17	2.80	2.73	2.77	3.00	3.13	3.07
9	HPB-7	42.00	41.67	41.83	57.00	55.67	56.34	3.00	3.17	3.09	3.10	3.17	3.13
10	HPB-22	41.25	40.00	40.63	58.67	56.00	57.33	2.80	2.57	2.68	3.10	3.00	3.05
11	HPB-29	38.33	36.67	37.50	53.67	55.00	54.33	2.90	3.07	2.98	3.10	3.00	3.05
12	HPB-35	47.00	45.00	46.00	61.67	59.00	60.33	2.80	2.73	2.77	3.20	3.07	3.13
Testers													
13	HPB-39	37.33	35.67	36.50	50.00	51.33	50.67	2.80	2.83	2.82	3.30	3.10	3.20
14	California Wonder	40.67	40.33	40.50	56.67	59.00	57.84	2.67	2.93	2.80	3.63	3.67	3.65
15	HPB-39-CW (F_1)	41.67	43.33	42.50	55.00	56.33	55.67	2.67	2.53	2.60	3.17	3.33	3.25
Cross-combinations													
16	Kandaghat Selection × HPB-39	40.00	40.67	40.33	54.00	57.00	55.50	2.93	2.87 8	2.90	3.33	3.33	3.33
17	Kandaghat Selection × California Wonder	41.00	43.33	42.17	56.00	57.67	56.83	2.87	3.00	2.93	3.17	3.33	3.25
18	Kandaghat Selection × HPB-39-CW	42.67	41.00	41.83	57.33	56.00	56.67	2.87	2.87	2.87	3.50	3.17	3.33
19	HPB-HY-22 × HPB-39	43.34	42.00	42.67	59.67	58.00	58.83	2.65	2.53	2.59	3.00	3.17	3.08
20	HPB-HY-22 × California Wonder	42.84	42.00	42.42	59.67	56.33	58.00	2.67	2.67	2.67	3.50	3.33	3.42
21	HPB-HY-22 × HPB-39-CW	42.33	39.33	40.83	55.00	53.00	54.00	2.60	2.67	2.63	3.17	3.17	3.17
22	HPB-AC-48 × HPB-39	36.42	34.67	35.54	51.00	51.33	51.17	2.57	2.93	2.75	3.17	3.00	3.08
23	HPB-AC-48 × California Wonder	36.67	35.33	36.00	53.00	52.67	52.83	2.87	2.73	2.80	3.30	3.43	3.37
24	HPB-AC-48 × HPB-39-CW	37.67	35.67	36.67	52.00	52.67	52.33	2.80	2.93	2.87	3.20	3.17	3.18
25	HPB-AC-49 × HPB-39	39.42	37.67	38.54	56.00	55.33	55.67	2.53	2.60	2.57	3.17	3.20	3.18
26	HPB-AC-49 × California Wonder	38.33	35.67	37.00	53.00	52.67	52.83	2.87	2.73	2.80	3.57	3.43	3.50

27	HPB-AC-49 × HPB-39-CW	36.92	35.33	36.13	52.00	52.33	52.17	2.67	2.67	2.67	3.23	3.37	3.30
28	HPB-2-16 × HPB-39	40.33	37.00	38.67	53.00	52.67	52.83	2.67	2.67	2.67	3.03	3.00	3.02
29	HPB-2-16 × California Wonder	40.92	37.67	39.29	54.00	53.33	53.67	3.07	3.23	3.15	3.17	3.33	3.25
30	HPB-2-16 × HPB-39-CW	42.17	41.00	41.58	54.00	54.00	54.00	2.67	2.47	2.57	3.03	3.00	3.02
31	HPB-3-10 × HPB-39	38.09	36.00	37.05	53.00	52.67	52.83	2.67	2.67	2.67	3.00	3.17	3.08
32	HPB-3-10 × California Wonder	40.09	39.00	39.55	55.67	54.00	54.84	2.80	2.87	2.83	3.13	3.17	3.15
33	HPB-3-10 × HPB-39-CW	41.67	38.67	40.17	57.33	54.67	56.00	2.93	3.07	3.00	3.00	2.93	2.97
34	HPB-1 × HPB-39	43.33	42.33	42.83	58.67	56.33	57.50	2.80	2.93	2.87	3.67	3.67	3.67
35	HPB-1 × California Wonder	42.17	40.67	41.42	58.00	56.33	57.17	3.00	3.03	3.02	3.00	3.33	3.17
36	HPB-1 × HPB- 39-CW	44.33	42.33	43.33	56.00	55.00	55.50	3.13	2.80	2.97	3.50	3.33	3.42
37	HPB-6-1 × HPB-39	43.00	41.33	42.17	56.33	54.00	55.17	2.73	2.67	2.70	3.00	3.17	3.08
38	HPB-6-1 × California Wonder	39.67	37.67	38.67	55.67	53.33	54.50	2.97	3.20	3.08	3.13	3.40	3.27
39	HPB-6-1 × HPB- 39-CW	38.25	36.00	37.13	55.00	53.67	54.33	2.87	2.87	2.87	3.00	3.17	3.08
40	HPB-7 × HPB-39	37.42	36.33	36.88	52.67	52.67	52.67	2.73	2.70	2.72	3.00	3.17	3.08
41	HPB-7 × California Wonder	37.09	36.00	36.55	51.33	53.33	52.33	2.47	2.73	2.60	3.67	3.33	3.50
42	HPB-7 × HPB- 39-CW	38.59	38.00	38.30	53.67	52.67	53.17	3.03	2.93	2.98	3.00	3.00	3.00
43	HPB-22 × HPB- 39	40.67	41.00	40.83	55.67	58.67	57.17	2.40	2.60	2.50	3.17	3.33	3.25
44	HPB-22 × California Wonder	44.00	43.00	43.50	57.00	59.33	58.17	3.23	3.20	3.22	3.17	3.23	3.20
45	HPB-22 × HPB- 39-CW	41.67	44.33	43.00	56.00	58.67	57.33	2.60	2.53	2.57	3.00	3.10	3.05
46	HPB-29 × HPB- 39	37.33	37.00	37.17	48.00	52.00	50.00	2.93	2.77	2.85	3.17	3.07	3.12
47	HPB-29 × California Wonder	40.00	43.00	41.50	53.33	57.00	55.17	2.60	2.97	2.78	3.50	3.50	3.50
48	HPB-29 × HPB- 39-CW	39.00	39.33	39.17	50.67	54.00	52.34	2.93	3.07	3.00	3.67	3.50	3.58
49	HPB-35 × HPB- 39	40.67	39.33	40.00	56.33	56.33	56.33	3.23	3.00	3.12	2.67	2.67	2.67
50	HPB-35 × California Wonder	42.67	44.00	43.33	57.00	56.33	56.67	2.80	2.93	2.87	3.03	2.83	2.93

51	HPB-35 × HPB-39-CW	44.33	43.67	44.00	58.00	56.33	57.17	2.60	2.67	2.63	2.33	2.63	2.48
Checks													
52	Bomby	45.00	43.67	44.33	58.00	55.00	56.50	2.50	2.67	2.58	4.00	3.67	3.83
53	Capsicum Hybrid (Novel Seed Ltd.)	40.75	39.00	39.88	56.92	54.33	55.63	3.23	3.07	3.15	4.00	4.00	4.00
	SE (m)	0.82	1.39	0.79	0.54	0.51	0.55	0.10	0.10	0.07	0.17	0.16	0.11
	CV (%)	3.49	6.08	4.82	1.70	1.61	2.43	6.22	6.14	6.32	8.92	8.42	8.21
	CD (5%)	2.30	3.91	2.20	1.53	1.44	1.53	0.28	0.28	0.20	0.47	0.44	0.30
	Grand mean	40.67	39.70	40.19	55.53	55.28	55.41	2.81	2.83	2.82	3.22	3.22	3.22

check 'Capsicum Hybrid' (3.15), whereas none of the hybrid was superior to best check over pooled environments.

Lobes per fruit

The mean performance of lobes per fruit varied from 2.48 to 4.00 with a grand mean of 3.22 in pooled over environments. Among parents, HPB-1 (4.00) showed a maximum number of lobes per fruit, whereas minimum numbers of lobes per fruit were exhibited by HPB-HY-22 (3.00) and HPB-AC-48 (3.00) (Table 2). None of the cross-combination was found superior or statistically at par with best check 'Capsicum Hybrid' (4.00). However, the maximum number of lobes per fruit were exhibited by HPB-29 × HPB-39-CW (3.58), HPB-1 × HPB-39 (3.67), HPB-7 × California Wonder (3.50), HPB-29 × California Wonder (3.50) and HPB-AC-49 × California Wonder (3.50) hybrids.

Marketable fruit yield per plant (g)

In the current study, parent, HPB-39 (658.48 g) was found to exhibit maximum marketable green fruit yield per plant among the parents, whereas California Wonder (104.66 g) was reported to exhibit minimum marketable fruit yield per plant (Table 3). All the cross-combinations were found to be significantly superior over best check 'Capsicum Hybrid'. However, cross-combinations, HPB-7 × California Wonder (1124.35 g), HPB-7 × HPB-39-CW (980.26 g), HPB-2-16 × HPB-39 (953.15 g), HPB-6-1 × California Wonder (917.86 g) and HPB-29 × HPB-39 (820.47 g) were placed at top five amongst rest in having maximum marketable green fruit yield per plant.

Capsanthin content (ASTA units)

In the present investigation, maximum capsanthin content among the parents is exhibited by HPB-39 (106.79 ASTA units), whereas HPB-35 (39.96 ASTA units) recorded the minimum capsanthin content. The mean value for this trait ranged from 39.96 to 112.31 ASTA units with grand mean of 82.61 ASTA units in pooled over environments (Table 3). The best check 'Capsicum Hybrid' (87.74 ASTA units) was found statistically at par with seven cross-combinations, while ten cross-combinations viz., Kandaghat Selection × HPB-39 (112.31 ASTA units), HPB-3-10 × HPB-39-CW (110.45

ASTA units), HPB-HY-22 × HPB-39 (105.62 ASTA units), HPB-35 × HPB-39 (102.77 ASTA units), Kandaghat Selection × HPB-39-CW (101.30 ASTA units), HPB-6-1 × California Wonder (98.89 ASTA units), Kandaghat Selection × California Wonder (97.03 ASTA units), HPB-35 × HPB-39-CW (95.61 ASTA units), HPB-HY-22 × HPB-39-CW (95.42 ASTA units) and HPB-HY-22 × California Wonder (94.71 ASTA units) were found superior over it.

TSS content (°Brix)

Among the parents, TSS content was reported maximum in parent, HPB-3-10 (4.58), whereas minimum TSS was found in parent, California Wonder (3.24) (Table 3). The mean performance for the trait ranged from 2.98 to 5.45 with grand mean of 4.32. In pooled data analysis, only four cross-combinations were found statistically at par with best check 'Capsicum Hybrid' (3.58), while the rest of the crosses were observed superior over it. Cross-combinations, HPB-3-10 × HPB-39-CW (5.45), HPB-1 × California Wonder (5.40), HPB-1 × HPB-39 (5.27), HPB-2-16 × HPB-39-CW (5.10) and HPB-22 × HPB-39-CW (5.02) were placed at top five amongst rest in having maximum TSS content.

Ascorbic acid (mg/100g)

Among the parents, maximum ascorbic acid content was recorded in HPB-AC-48 (106.62 mg/100g), whereas the minimum ascorbic acid content was reported in parent, HPB-35 (74.01) and has been presented in (Table 3). The mean performance for the character varied from 37.98 to 113.32 mg/100g with grand mean of 87.02 mg/100g in pooled over environments. Ten cross-combinations were found statistically at par with best check 'Capsicum Hybrid' (90.61 mg/100g), whereas nine cross-combinations viz., Kandaghat Selection × HPB-39 (113.32 mg/100g), HPB-2-16 × HPB-39-CW (113.20 mg/100g), HPB-2-16 × California Wonder (111.16 mg/100g), Kandaghat Selection × California Wonder (106.52 mg/100g), HPB-7 × California Wonder (106.38 mg/100g), HPB-HY-22 × HPB-39 (99.38 mg/100g), HPB-HY-22 × California Wonder (98.32 mg/100g), HPB-AC-49 × HPB-39-CW (98.64 mg/100g), and HPB-7 × HPB-39-CW (98.34 mg/100g) were reported superior over best check.

Table 3: Mean performances of 15 parents, their 36 cross-combinations along with standard checks under three environments viz., Kharif2021 (E_1), Kharif2022 (E_2) and in pooled over environments

S. No.	Genotypes/ Treatments	Marketable green fruit yield per plant (g)			Capsanthin content (ASTA units)			TSS ($^{\circ}$ Brix)			Ascorbic acid (mg/100g)		
		E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled	E_1	E_2	Pooled
Line													
1	Kandaghat Selection	325.67	362.07	343.87	86.09	82.66	84.37	3.43	4.10	3.77	99.40	101.91	100.65
2	HPB-HY-22	482.32	520.67	501.49	79.16	75.60	77.38	3.57	3.83	3.70	92.74	97.53	95.14
3	HPB-AC-48	487.77	502.80	495.29	67.56	74.95	71.25	3.37	3.63	3.50	112.73	100.51	106.62
4	HPB-AC-49	356.34	382.80	369.57	79.51	70.33	74.92	3.70	4.17	3.93	98.18	105.00	101.59
5	HPB-2-16	538.03	575.73	556.88	71.61	75.99	73.80	4.27	4.35	4.31	106.79	101.67	104.23
6	HPB-3-10	559.32	594.73	577.03	79.38	74.62	77.00	4.50	4.67	4.58	90.06	95.00	92.53
7	HPB-1	533.35	551.07	542.21	82.93	73.86	78.39	4.57	4.23	4.40	77.58	73.33	75.45
8	HPB-6-1	384.21	424.67	404.44	109.41	103.38	106.39	4.53	4.40	4.47	84.36	76.67	80.52
9	HPB-7	541.51	574.13	557.82	76.92	83.15	80.03	4.07	3.67	3.87	103.03	108.60	105.82
10	HPB-22	373.23	380.00	376.62	66.31	70.03	68.17	3.63	4.73	4.18	78.79	80.42	79.61
11	HPB-29	423.32	465.87	444.60	85.99	81.73	83.86	3.40	3.67	3.53	77.38	70.77	74.07
12	HPB-35	368.95	407.13	388.04	38.81	41.11	39.96	4.67	3.73	4.20	72.76	75.27	74.01
Testers													
13	HPB-39	646.73	670.23	658.48	103.59	109.99	106.79	4.13	4.37	4.25	101.82	98.79	100.31
14	California Wonder	100.40	108.92	104.66	86.87	80.96	83.91	3.27	3.22	3.24	76.36	71.92	74.14
15	HPB-39-CW (F_1)	500.44	543.93	522.19	101.19	107.69	104.44	4.33	3.97	4.15	64.24	56.67	60.45
Cross-combinations													
16	Kandaghat Selection \times HPB-39	418.70	450.87	434.78	111.19	113.43	112.31	3.27	4.07	3.67	109.13	117.50	113.32
17	Kandaghat Selection \times California Wonder	348.16	389.07	368.61	100.42	93.64	97.03	3.57	3.77	3.67	103.03	110.00	106.52
18	Kandaghat Selection \times HPB-39-CW	391.36	412.27	401.81	104.58	98.02	101.30	4.50	4.13	4.32	89.70	92.24	90.97
19	HPB-HY-22 \times HPB-39	688.91	720.40	704.66	102.72	108.51	105.62	4.67	4.40	4.53	95.76	103.00	99.38
20	HPB-HY-22 \times California Wonder	693.33	741.87	717.60	97.03	92.39	94.71	4.60	4.50	4.55	99.39	97.24	98.32
21	HPB-HY-22 \times HPB-39-CW	679.36	704.93	692.15	92.72	98.13	95.42	4.23	4.35	4.29	86.06	75.48	80.77
22	HPB-AC-48 \times HPB-39	597.80	634.87	616.33	81.51	84.95	83.23	4.60	5.15	4.88	78.19	80.28	79.24

23	HPB-AC-48 × California Wonder	482.67	517.07	499.87	64.56	60.08	62.32	4.57	4.37	4.47	74.55	83.78	79.16
24	HPB-AC-48 × HPB-39- CW	593.09	633.20	613.15	87.08	80.47	83.78	4.43	4.17	4.30	82.42	75.00	78.71
25	HPB-AC-49 × HPB-39	716.77	747.33	732.05	67.84	71.67	69.75	4.57	4.28	4.43	71.24	74.39	72.82
26	HPB-AC-49 × California Wonder	698.61	735.93	717.27	91.79	86.26	89.02	4.40	4.42	4.41	65.46	56.40	60.93
27	HPB-AC-49 × HPB-39- CW	782.35	813.40	797.87	70.09	75.71	72.90	4.13	4.20	4.17	100.61	96.67	98.64
28	HPB-2-16 × HPB-39	933.50	972.80	953.15	73.14	77.57	75.36	4.70	4.73	4.72	85.15	89.58	87.36
29	HPB-2-16 × California Wonder	740.29	786.20	763.24	70.90	67.02	68.96	4.63	4.47	4.55	115.15	107.16	111.16
30	HPB-2-16 × HPB-39- CW	590.22	606.60	598.41	66.97	60.95	63.96	5.33	4.87	5.10	111.39	115.00	113.20
31	HPB-3-10 × HPB-39	684.65	704.53	694.59	67.57	73.31	70.44	3.90	4.02	3.96	72.73	81.87	77.30
32	HPB-3-10 × California Wonder	562.64	538.87	550.75	83.31	79.05	81.18	4.63	4.72	4.68	70.30	78.61	74.46
33	HPB-3-10 × HPB-39- CW	655.92	673.73	664.83	108.51	112.40	110.45	5.80	5.10	5.45	88.49	85.71	87.10
34	HPB-1 × HPB-39	492.61	463.13	477.87	82.93	79.60	81.26	5.20	5.33	5.27	90.91	91.43	91.17
35	HPB-1 × California Wonder	636.00	665.60	650.80	80.09	83.86	81.97	5.30	5.50	5.40	79.82	85.71	82.77
36	HPB-1 × HPB-39- CW	498.92	459.23	479.08	68.50	74.62	71.56	5.13	5.03	5.08	72.43	65.64	69.03
37	HPB-6-1 × HPB-39	723.72	760.73	742.23	87.63	79.60	83.61	4.50	4.43	4.47	83.64	80.00	81.82
38	HPB-6-1 × California Wonder	888.44	947.27	917.86	96.43	101.35	98.89	4.23	4.20	4.22	97.30	93.68	95.49
39	HPB-6-1 × HPB-39- CW	688.96	732.80	710.88	89.54	81.45	85.50	4.50	4.17	4.33	90.91	91.43	91.17
40	HPB-7 × HPB-39	677.64	721.47	699.56	71.92	77.90	74.91	4.97	4.47	4.72	87.58	91.50	89.54
41	HPB-7 × California Wonder	1097.99	1150.70	1124.35	71.40	78.78	75.08	4.13	4.21	4.17	102.42	110.33	106.38

42	HPB-7 × HPB-39-CW	959.98	1000.53	980.26	76.04	70.90	73.47	4.37	4.34	4.35	95.29	101.38	98.34
43	HPB-22 × HPB-39	507.93	542.87	525.40	72.54	77.79	75.17	4.60	4.63	4.62	90.61	81.91	86.26
44	HPB-22 × California Wonder	399.73	435.13	417.43	82.66	78.61	80.63	4.83	4.27	4.55	72.73	80.00	76.36
45	HPB-22 × HPB-39-CW	480.27	448.33	464.30	85.66	80.64	83.15	5.00	5.03	5.02	79.76	85.71	82.74
46	HPB-29 × HPB-39	804.01	836.93	820.47	71.70	78.06	74.88	4.37	4.60	4.48	91.82	92.86	92.34
47	HPB-29 × California Wonder	569.83	581.93	575.88	74.13	69.59	71.86	4.17	4.02	4.09	88.37	81.89	85.13
48	HPB-29 × HPB-39-CW	794.61	746.27	770.44	64.67	60.35	62.51	3.47	4.13	3.80	109.09	116.19	112.64
49	HPB-35 × HPB-39	602.35	630.67	616.51	105.89	99.66	102.77	4.37	4.40	4.38	78.79	70.67	74.73
50	HPB-35 × California Wonder	630.34	663.27	646.80	83.31	88.67	85.99	4.83	4.57	4.70	72.42	65.95	69.19
51	HPB-35 × HPB-39-CW	523.40	574.67	549.04	98.29	92.93	95.61	4.93	4.47	4.70	60.61	66.82	63.71
Checks													
52	Bomby	206.40	187.33	196.87	87.96	82.12	85.04	2.80	3.17	2.98	37.58	38.38	37.98
53	Capsicum Hybrid (Novel Seed Ltd.)	238.33	257.93	248.13	84.57	87.74	86.15	3.77	3.40	3.58	94.54	86.67	90.61
	SE (m)	20.43	21.14	14.17	1.35	1.18	1.48	0.16	0.18	0.14	2.08	2.39	1.99
	CV (%)	6.19	6.13	5.94	2.82	2.49	4.37	6.50	7.06	7.74	4.14	4.76	5.59
	CD (5%)	57.29	59.28	39.47	3.79	3.32	4.11	0.46	0.49	0.38	5.83	6.71	5.53
	Grand mean	571.72	597.27	584.50	82.89	82.34	82.61	4.33	4.32	4.32	87.01	87.02	87.02

Table 4: Top five potential hybrids compared to best check for fruit yield and related traits in bell pepper on the basis of overall mean performance

S. No.	Traits	Best check	Superior hybrids	Statistically at par
1	Days to 50 per cent flowering	Capsicum Hybrid	HPB-AC-48 × HPB-39, HPB-AC-48 × California Wonder, HPB-AC-49 × HPB-39-CW HPB-7 × California Wonder, HPB-AC-48 × HPB-39-CW	HPB-7 × HPB-39-CW HPB-AC-49 × HPB-39, HPB-2-16 × HPB-39, HPB-6-1 × California Wonder, HPB-29 × HPB-39-CW
2	Days to first picking	Capsicum Hybrid	HPB-29 × HPB-39, HPB-AC-48 × HPB-39, HPB-AC-49 × HPB-39-CW, HPB-AC-48 × HPB-39-CW HPB-7 × California Wonder	HPB-6-1 × HPB-39-CW HPB-6-1 × California Wonder, HPB-3-10 × California Wonder, HPB-6-1 × HPB-39, HPB-29 × California Wonder
3	Primary branches per plant	Capsicum Hybrid	-	HPB-22 × California Wonder, HPB-2-16 × California Wonder, HPB-35 × HPB-39, HPB-6-1 × California Wonder, HPB-1 × California Wonder
4	Lobes per fruit	Capsicum Hybrid	-	-

5	Marketable green fruit yield per plant (g)	Capsicum Hybrid	HPB-7 × California Wonder, HPB-7 × HPB-39-CW HPB-2-16 × HPB-39, HPB-6-1 × California Wonder, HPB-29 × HPB-39	-
6	Capsanthin content (ASTA units)	Capsicum Hybrid	Kandaghat Selection × HPB-39, HPB-3-10 × HPB-39-CW, HPB-HY-22 × HPB-39, HPB-35 × HPB-39, Kandaghat Selection × HPB-39-CW	HPB-6-1 × HPB-39-CW HPB-6-1 × HPB-39, HPB-22 × HPB-39-CW HPB-AC-48 × HPB-39-CW
7	TSS (°Brix)	Capsicum Hybrid	HPB-3-10 × HPB-39-CW, HPB-1 × California Wonder, HPB-1 × HPB-39, HPB-2-16 × HPB-39-CW, HPB-22 × HPB-39-CW	HPB-3-10 × HPB-39, HPB-29 × HPB-39-CW Kandaghat Selection × HPB-39, Kandaghat Selection × California Wonder
8	Ascorbic acid (mg/100g)	Capsicum Hybrid	Kandaghat Selection × HPB-39, HPB-2-16 × HPB-39-CW, HPB-2-16 × California Wonder, Kandaghat Selection × California Wonder, HPB-7 × California Wonder	HPB-6-1 × California Wonder, HPB-29 × HPB-39, HPB-6-1 × HPB-39-CW HPB-1 × HPB-39, Kandaghat Selection × HPB-39-CW

Discussion

Based on the mean performance, it is revealed that sufficient amount of variability is existed among hybrids and parents for all the traits. Hybrid bell peppers are highly popular over open-pollinated varieties due to their superiority in terms of fruit yield and component traits. Early flowering is desirable for any crop, particularly multiple-harvest crops like vegetables since it allows for an earlier harvest and helps in getting higher market prices. Similarly, days to first picking are also important criteria for earliness. In the present study, based on mean values, hybrid HPB-AC-48 × HPB-39 was earliest among all in bearing 50% flowering and hybrid HPB-29 × HPB-39 took minimum days to first harvest in pooled environments. Tremendous variability with respect to earliness was also reported by Devi *et al.* (2015), Rana *et al.* (2015), Sharma *et al.* (2017) and Aditika *et al.* (2018). The number of primary branches influences the fruit yield of a plant. The more the primary branches, higher will be the marketable fruit yield. On the basis of overall performance, hybrid, HPB-22 × California Wonder had maximum number of primary branches followed by HPB-2-16 × California Wonder and HPB-35 × HPB-39. Large numbers of variations ranging from 2.43 to 3.70 for this character also reported by Aditika *et al.* (2018). Generally, 3 to 4 lobes are desirable to give fruits a blocky appearance. Among hybrids, HPB-29 × HPB-39-CW (3.58), exerted maximum number of lobes per fruit followed by HPB-1 × HPB-39, HPB-7 × California Wonder, HPB-29 × California Wonder and HPB-AC-49 × California Wonder. Earlier, Afroza *et al.* (2013) and Thakur *et al.* (2019) also reported similar results with different material in their studies. The primary goal of all crop improvement programmes is to increase the yield. The mean values for marketable fruit yield per plant portrayed that the highest marketable fruit yield was reported in cross-combination, HPB-7 × California Wonder followed by HPB-7 × HPB-39-CW, HPB-2-16 × HPB-39, HPB-6-1 × California Wonder and HPB-29 × HPB-39. Mahmoud and El-Eslamboly (2015) and Aditika *et al.* (2018) also reported variation in marketable green fruit

yield per plant. Among quality traits, maximum capsanthin and ascorbic acid content was exhibited by Kandaghat Selection × HPB-39 cross-combination. Capsanthin, a natural pigment, is gaining popularity worldwide as it is extensively utilized in the food, cosmetic and dye sectors. It is metabolized in human body and has antioxidative, anti-tumor, and anti-cancer properties, whereas ascorbic acid (vitamin C) contains antioxidant properties and aids in the immune system's defense against sickness. In addition to other horticultural aspects, the concentration of ascorbic acid in vegetables is recognized as an important quality attribute. Ascorbic acid is required to form and repair tissues throughout the human body. These results are in agreement with the findings of Anuradha and Sood (2019), Thakur *et al.* (2019) and Sood (2022) who also reported significant variation for these traits in their experimental material. Bell pepper with a TSS of 3.3 oBrix or more is typically preferred for producing numerous processed products in processing industries. In the current study, HPB-3-10 × HPB-39-CW had maximum TSS followed by HPB-1 × California Wonder and HPB-1 × HPB-39. Earlier, tremendous variation with respect to TSS was reported by Anuradha and Sood (2019) and Thakur *et al.* (2019). The trait-wise performances of top-ranking cross-combinations in comparison to best check for different traits are given in Table 4.

Conclusion

Based on the overall mean performance in all the environments, cross-combinations *viz.*, HPB-7 × California Wonder, HPB-7 × HPB-39-CW, HPB-2-16 × HPB-39, HPB-6-1 × California Wonder and HPB-29 × HPB-39 were found top highest yielders. Besides highest yielders, they were also better in performance for related traits such as days to 50 per cent flowering, days to first harvesting, primary branches per plant, lobes per fruit, capsanthin content, TSS and ascorbic acid content. Therefore, it is concluded that these cross-combinations can be directly released as hybrids after testing or can be used in further breeding programmes.

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सारांश

संकीर्ण अनुवांशिक आधार वाले जींस के जनकों के बीच संकरण परिवर्तनशीलता उत्पन्न करने का एक उत्तम तरीका है। ट्रिपल टेस्ट क्रॉस मेटिंग डिजाइन के माध्यम से वर्ष 2021-22 (खरीफ) के दौरान, 15 विविध जनकों (12 पंक्तियों और तीन परीक्षकों) और उनके 36 संकरों के 8 उपज और गुणवत्ता घटकों का दो मानक नियंत्रकों के साथ मूल्यांकित किया गया। शोध में वांछित गुणों के लिए सभी प्रभेदों के बीच महत्वपूर्ण विभिन्नता पायी गयी। वातावरण में समग्र माध्य प्रदर्शन से एकलित आंकड़ों के आधार पर संकरण संयोज्य जैसे-एच.पी.बी.-7 ग कैलिफोर्निया वंडर, एच.पी.बी.-7 ग एच.पी.बी.-39-सी.डब्ल्यू., एच.पी.बी.-2-16 ग एच.पी.बी.-39, एच.पी.बी.-6-1 ग कैलिफोर्निया वंडर और एच.पी.बी.-7 ग एच.पी.बी.-29-सी.डब्ल्यू.-29 शीर्ष अधिक उपज वाले पाये गये। अधिक उपज देने के अलावा पुष्प और तुड़ाई में अग्रेसीव पाया गया साथ ही साथ अधिक प्राथमिक शाखाएं और अच्छी मात्रा में कैप्सेथिन, कुल विलेय ठोस और एस्कार्बिक एसिड भी सर्वोपरी पाया गया। इसलिए इन संकर-संयोजनों को बहु-स्थानीय तथा किसानों के क्षेत्र परीक्षण के बाद सीधे तौर पर संकर के रूप में जारी किया जा सकता है या आगे के प्रजनन कार्यक्रमों में उपयोग किया जा सकता है।