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RESEARCH ARTICLE

Development of interspecific tomato hybrid derivative lines resistant to peanut bud necrosis virus

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Abstract

A field screening of F_3 to F_6 generation interspecific tomato hybrid-derived lines for Peanut Bud Necrosis Virus (PBNV) resistance was conducted at the Department of Horticulture, Agricultural College and Research Institute, Madurai, Tamil Nadu Agricultural University, Tamil Nadu, from 2019 to 2021. PBNV is one of the most devastating and economically significant viruses affecting tomatoes, leading to yield losses of up to 80-100 %. This study aimed to develop PBNV-resistant tomato lines suitable for commercial cultivation and assess the inheritance of resistance in advanced generations. Three tomato lines were crossed with ten wild species, generating 30 interspecific hybrids. Among these, four interspecific crosses *viz.*, H4 (Arka Vikas × PSR 11668 - *Solanum pimpinellifolium*), H6 (Arka Vikas × EC 519809 - *S. peruvianum*), H17 (CO3 × EC 519791 - *S. habrochaites*) and H27 (PKM1 × EC 519791 - *S. hirsutum*) were screened in advanced generations under natural field conditions. No insecticide was applied throughout the entire crop production period. The disease incidence was evaluated on the 30th, 45th, 60th and 90th day after transplantation using the Percent Disease Incidence (PDI %) and disease reaction scale. Further in the F_4 generation, a total of seventeen lines from the above four crosses were evaluated. In F_5 and F_6, generation 10 lines and 3 lines, respectively, from two crosses-viz., H6 (Arka Vikas × EC 519809, *S. peruvianum*) and H27 (PKM-1 × EC 519791) were evaluated. The results indicated that PBNV infection was present at all stages of crop growth. Among the four interspecific hybrids, the highest level of field resistance was observed in two lines of H6 (Arka Vikas × EC 519809 - *S. peruvianum*), followed by one line of H27 (PKM-1 × EC 519791). The resistant plants will either be released as a PBNV-resistant variety or utilized as a source of PBNV resistance in tomato breeding programs.

Keywords: field screening; interspecific hybrids; resistance to PBNV; tomato

Introduction

India ranks as the worlds' second-largest producer of vegetables, followed by China. Among vegetable crops, tomatoes (*Solanum lycopersicum* L.) are the third most widely cultivated in the tropical and subtropical regions of the country (1). Fresh tomatoes and their processed products are rich in bioactive compounds, including carotenes (lycopene, β-carotene), ascorbic acid, tocopherol and phenolic compounds. In India, tomato cultivation spans 0.841 million hectares, with a total production of 19.7 million tonnes in the 2017-18 season. Approximately 11 % of the worlds' tomato production is grown in India (1). Over 15000 tomato cultivars can be found worldwide. India is home to an estimated 1200 to 1500 tomato varieties. However, only a few are commercially available and others are consumed locally. Several seed companies have further bred tomatoes, developing new varieties with specific traits such as disease resistance, improved yield, extended shelf life and enhanced flavour (2). Tomatoes are susceptible to over 40 different virus species, among which Peanut Bud Necrosis Virus (PBNV) is one of the most economically damaging. PBNV, a member of the *Tospovirus* genus (serogroup IV) in the Bunyaviridae family, poses a significant threat to tomato cultivation. The incidence of *Tospovirus* in vegetable crops, particularly tomatoes, has been increasing annually (3).The initial documented instance of *Tospovirus* in tomatoes took place in Australia in 1915, whereas in India, it was first identified in 1964 in the Nilgiris, Tamil Nadu (4). The disease is transmitted naturally by *Thrips palmi* Karny in a circulative and propagative manner. PBNV has a broad host range, affecting agricultural, horticultural and ornamental crops (5). In horticultural crops, it infects four different families of vegetable crops, namely Solanaceae, Fabaceae, Cucurbitaceae and Amaranthaceae (6). The characteristic symptoms of *Tospovirus* in tomatoes include necrosis of young, growing buds, bronzing of leaves with brown, necrotic lesions and, in severe cases, plant wilting. Ripened fruits develop circular markings, appearing as concentric bands of red and yellow broken rings approximately 1 cm in diameter (7). PBNV infection in tomatoes occurs year-round, with severity varying based on crop stage, season and location, potentially leading to yield losses of 80-100 % (8). Managing PBNV through cultural practices remains challenging and less effective due to the

virus and vectors' extensive host range (9). Additionally, prophylactic pesticide applications for thrips control are ineffective due to the continuous migration of thrips from surrounding areas. Wild relatives of tomato are well known for harbouring resistance genes against Tomato Spotted Wilt Virus (TSWV) (10, 11). The first identified source of TSWV resistance was in *Solanum pimpinellifolium*, with additional resistance sources recorded in *S. peruvianum* and *S. hirsutum*. Incorporating these resistance sources into tomato breeding programs enables the development of resistant hybrids, offering a strategic approach to mitigating PBNV infection. Based on this premise, the present study aimed to develop PBNV-resistant tomato lines through an interspecific hybridization program. In this context, to develop PBNV resistant tomato lines, an interspecific hybridization program was undertaken using wild tomato species such as *S. habrochaites* and *S. peruvianum*, which are known sources of viral resistance. The resulting hybrids were screened for resistance using mechanical inoculation with viruliferous thrips (*Frankliniella* sp.) under controlled conditions and resistance was assessed through symptom observation and an ELISA test (Enzyme-Linked Immunosorbent Assay) for PBNV detection (12, 13).

Materials and Methods

The germplasm used in this study was initially obtained from the National Bureau of Plant Genetic Resources (NBPGR), New Delhi and the Indian Institute of Horticultural Research (IIHR), Bangalore. A total of ten parental lines were selected for the hybridization program, as detailed in Table 1. In the F_1 generation, 30 hybrid combinations were evaluated for resistance to PBNV under natural field conditions. Among these, four hybrids exhibited resistance to PBNV, confirmed through both field screening and enzyme-linked immunosorbent assay (ELISA) at the Horticulture College and Research Institute, TNAU, Coimbatore. These resistant hybrids were subsequently advanced to the F_2 generation for further field evaluation. In the F1 generation, morphological screening along with ELISA testing was carried out to assess resistance. In the F_3 generation, 35 single plant progenies derived from the four resistant hybrids were further progressed to the F_4, F_5 and F_6 generations, as outlined in Table 2. The experiment was conducted at the Department of Horticulture, Agricultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Madurai, Tamil Nadu, India, from August 2019 to September 2021. The study was conducted using a Randomised Block Design (RBD) to ensure a reliable comparison among treatments by minimizing variability. The research site is characterized by a warm tropical climate and sandy loam soil, situated at an altitude of 158 m above mean sea level (MSL), with geographical coordinates of 09°58´30.5´N latitude and 078°12´27.4´E longitude. Tomato seedlings were raised in pots under an insect-proof net, followed by standard nursery protocols without pesticide application. At 25 days post sowing, seedlings were transplanted into the main field at a spacing of 30 × 30 cm. To establish a conducive environment for PBNV infection, one row of cowpea variety Co (CP)-7 was planted after every two rows of tomato, serving as a host crop. The recommended agronomic package of practices, as prescribed in the TNAU Crop Production Guide, was followed and no pesticides were applied throughout the crop cycle to facilitate natural PBNV infection (14). The disease incidence was assessed on 30, 45, 60 and 90 days after planting based on Per-cent disease incidence, calculated as,

$$\text{PDI (\%)} = \frac{\text{Number of plants affected with PBNV}}{\text{Total number of plants}} \text{ X } 100 \quad \text{(Eqn. 1)}$$

Table 1. Details of parents used for the crossing programme

	Name of the Parent	Special attributes	Notation
	Lines		
1	Arka Vikas	Medium round, oblate with light green shoulder	L_1
2	CO3	Medium size, determinate variety	L_2
3	PKM1	Determinate with green shoulder	L_3
	Testers		
1	KARS 425 (*S. pimpinellifolium)*	Small-sized fruit with an oval shape and indeterminate	T_1
2	BSBS 157(*S. pimpinellifolium)*	Higher number of fruits and small-sized fruits with an oval shape	T_2
3	BSBS 180 (*S. pimpinellifolium)*	Indeterminate and small-sized fruit with an oval shape	T_3
4	PSR 11668 (*S. pimpinellifolium)*	Semi-determinate and a large number of fruits	T_4
5	EC 514103 (*S. pimpinellifolium)*	Small fruits in spherical shape	T_5
6	EC 5198091 (*S. peruvianum)*	Medium fruits with high TSS	T_6
7	EC 519791 *(S. habrochaites)*	Spherical fruit shape with medium size	T_7
8	IIHR 2101 (*S. habrochaites)*	Very small-sized fruits with high ascorbic acid content	T_8
9	EC 631363 (*S. lycopersicum)*	High-yielding and potato leaf type	T_9
10	EC 617091 (*S. lycopersicum)*	Large fruited	T_{10}

Table 2. Details of materials evaluated in different generations are given below

Sl No	Name of interspecific hybrids	Lines evaluated in F_3 progenies	Lines evaluated in F_4 progenies	Lines evaluated in F_5 progenies	Lines evaluated in F_6 progenies
1.	H4 – Arka Vikas (*S. lycopersicum*) × PSR 11668 (*S. pimpinellifolium*)	10, 13, 25, 43, 99, 105, 115, 120 (8 lines)	H4-115-18 (1line)		
2.	H6 – Arka Vikas (*S. lycopersicum*) × EC 519809 (*S. peruvianum*)	42, 48, 53, 71, 77, 100, 148, 152, 169, 212 (10 lines)	H6-48-16, H6-48-44, H6-100-3, H6-100-11, H6-100-23, H6-100-31, H6-100-36, H6-100-39, H6-212-91 (9 lines)	H6-48-44-17, H6-100-11-11, H6-100-11-10, H6-212-91-6, H6-212-91-12, H6-212-91-16, H6-212-91-26, H6-212-91-28, H6-212-91-37(9 lines)	H6- 48-44 – 17 – 16 H6-212-91- 28 - 21 (2 lines)
3.	H17 - CO3 (*S. lycopersicum*) ×	2, 18, 28, 38, 44, 63, 110, 141(8 lines)	H17-2-5, H17-2-6, H17-2-23, H17-44-18(4 lines).		
4.	H27 - PKM1 (*S. lycopersicum*) ×	66, 88, 91, 112, 122, 168, 173, 218, 212(9 lines)	H27-173-8, H27-173-10, H27-173-22(3 lines)	H27-173-22-23 (1line)	H 27-173-22 – 23- 6 (1 line)
	Total lines selected	**35**	**17**	**10**	**3**

The disease severity was categorized into six different disease rating grades as per the standard scale (15). The percentage of disease incidence data, shown in Table 3, was statistically analyzed using ANOVA and significance was determined based on the corresponding p-values (≤ 0.05).

Thirty F_1 hybrids were evaluated, along with parental lines and a check variety, to assess their performance. Among the thirty hybrids evaluated, four hybrids were selected and forwarded for F_2 and F_3 progeny evaluation.

1. H6 ($L_1 \times T_6$) Arka Vikas × EC 519809 (*S. peruvianum)*
2. H17 ($L_2 \times T_7$) - CO3 × EC 519791 (*S. habrochaites*)
3. H4 ($L_1 \times T_4$) - Arka Vikas × PSR 11668 (*S. pimpinellifolium*)
4. H27 ($L_3 \times T_7$)- PKM1 × EC 519791 (*S. hirsutum*)

Population of each progeny: 250 plants

Disease reaction scale

A disease reaction scale was employed to evaluate the resistance level of each strain. Symptom severity was categorized into numerical grades ranging from 0 to 4, based on visual assessment (1). To quantify disease severity, calculations were performed using the formula as detailed in Table 3 (16).

Table 3. Disease reaction scale

Scale	Percent incidence	Disease reaction
0	0 to 1 % infection	Highly resistant (HR)
1	1.1 to 5 % infection	Resistant (R)
2	5.1 to 10 % infection	Moderately resistant (MR)
3	10.1 to 25 % infection	Moderately susceptible (MS)
4	25.1 to 50 % infection	Susceptible (S)
5	50.1 % and above	Highly susceptible (HS)

Results and Discussion

Interspecific hybrid progenies were evaluated in F_3, F_4, F_5 and F_6 generations for growth, yield and resistance to PBNV.

Performance of interspecific progenies in F_3 generation evaluation

Based on F_2 generation yield and resistance towards PBNV, thirty -five superior-performing progenies were evaluated in the F_3 generation. The highest plant height was observed in the cross H4-13 (171 cm) followed by H4-10 (169 cm), while the lowest plant height was exhibited in the cross H17- 2 (107 cm). The highest number of fruits per plant was recorded in the cross H4-115 (178 fruits), followed by H4-10 (160 fruits). The highest single fruit weight was observed in the cross H6-48 (68.3 g), followed by H6-100 (67.3 g).

The highest yield per plant was observed in the cross H6-100 (4.40 kg/plant) followed by H6-48 (4.20 kg/plant), while the lowest yield per plant was observed in the cross H4-99 (1.22 kg/ plant) (Table 4). H6-100 and H6-48 likely exhibited higher yields due to a combination of favourable genetic characteristics inherited from their parent lines and adaptive responses to environmental conditions. Genetically, these lines may possess improved resistance genes, better plant vigour and enhanced physiological traits such as fruit set and nutrient use efficiency.

Resistance to PBNV

Among the four interspecific hybrids, the cross H6 (Arka Vikas × EC 519809 - *S. Peruvianum*) exhibited the highest level of field resistance, with three resistant lines namely H6-48, H6-100 and

Table 4. Mean performance of interspecific hybrid progenies in F_3 generation

	H4 - Arka Vikas × PSR11668 (*S. pimpinellifolium*)					H6 - Arka Vikas × EC519809 (*S. peruvianum*)					H17 - CO3 × EC 519791(*S. habrochaites*)					H27 - PKM1 × EC 519791 (*S. hirsutum*)				
P.No	Plt. Ht (cm)	No. of fruits/ plt.	Fruit wt. (g)	Yield / plt. (kg)	PBNV disease reaction	Progeny No	Plt. Ht (cm)	No. of fruits / plt.	Fruit wt. (g)	Yield / plt. (kg)	PBNV disease reaction	Progeny No	Plt. Ht (cm)	No. of fruits / plt.	Fruit wt. (g)	Yield / plt. (kg)	PBNV disease reaction
10	169	160	10.6	1.68	R	42	130.1	46.60	61.7	2.85	MS	2	107.0	114	28.8	3.3	**R**	66	149.0	92.60	26.34	2.41	MR
13	171	143	10.8	1.55	MS	48	151.8	66.00	68.3	4.20	**R**	18	114.5	92	28.3	2.6	MR	88	110.3	108.20	27.40	2.95	MS
25	145	153	10.9	1.60	MS	53	130.1	49.60	64.5	3.20	MR	28	130.9	81	25.9	2.1	MS	91	136.6	85.50	26.96	2.25	**MR**
43	115	149	10.3	1.54	MR	71	116.7	50.60	62.6	3.15	MR	38	126.9	90	28.2	2.5	MR	112	112.5	71.20	25.84	1.80	MS
99	125	130	9.70	1.22	S	77	132.2	57.80	63.2	3.60	MR	44	141.4	105	27.3	2.8	**R**	122	109.0	117.80	27.54	3.22	MS
105	143	153	9.48	1.43	MR	100	123.8	65.40	67.3	4.40	**R**	63	143.8	101	26.8	2.7	S	168	140.2	81.20	26.14	2.12	**S**
115	133	178	12.5	2.20	R	148	142.6	48.80	60.9	2.95	S	110	115.7	93	28.8	2.6	MS	173	118.0	119.80	29.80	3.57	**R**
120	131	135	10.2	1.35	MS	152	128.0	50.60	63.1	3.19	MR	141	134.8	98	27.3	2.6	MS	218	124.5	75.00	26.22	1.95	**S**
Mean	142	150	10.5	1.57	-	169	116.4	56.80	66.3	3.76	MS	**Mean**	126.9	97	27.7	2.7	–	212	150.5	101.60	25.94	2.61	**MS**
SEd	8.2	10.7	4.28	0.16	–	212	116.0	60.40	60.2	3.60	**R**	**SEd**	5.07	3.3	0.54	0.1		**Mean**	127.8	94.8	26.9	2.5	
CD (0.05)	17.0	22	8.83	0.33		M	128.8	55.3	63.8	3.5		**CD (0.05)**	10.44	6.9	1.12	0.27		SEd	5.86	5.17	0.50	0.18	
						SEd	4.21	2.17	1.1	0.16								CD (0.05)	12.07	10.65	1.02	0.38	
						CD (0.05	8.67	4.48	2.3	0.33													

H6-212. The assessment of field resistance in the four interspecific hybrids, particularly in the cross H6 (Arka Vikas × EC 519809 - *S. peruvianum*), involved both a scoring technique and symptom observation, which together reliably identified resistant lines such as H6-48, H6-100 and H6-212. Additionally, the lines H6-53, H6-71, H6-77 and H6-152 were classified as moderately resistant. In the cross H4 (Arka Vikas ×PSR 11668 - *S. pimpinellifolium*), out of eight lines screened for PBNV resistance, H4-10 and H4-115 displayed resistance, while H4-43, H4-105 and H4-120 exhibited moderate resistance. For the cross H17 (CO3× EC 519791 - *S. habrochaites*), among the eight lines screened, H17 -2 and H17-44 demonstrated resistance, whereas H17-18 and H17-38 were categorized as moderately resistant. In the cross H27 (PKM1 × EC 519791 - *S. habrochaites*), out of nine lines evaluated, H27-173 was identified as resistant while H27-66 and H27-91 showed moderate resistance.

Performance of interspecific progenies in F_4 generation evaluation

Morphological and yield characters

Based on F_3 generation yield and resistance towards PBNV, seventeen superior progenies were evaluated in F_4 generation. The highest plant height was observed in the cross H6-48-44 (152.50 cm), followed by H4-48-61 (147.70 cm), while the shortest plant height was observed in the cross H17-2-6 (105.50 cm). The earliest flowering, with 50 % of plants in bloom, was observed in the cross H6-48-61 (28.48 days), followed closely by H6-48-44 (28.56 days). The cross H4-115-18 (5.30) had the most fruits per cluster followed by H6-48-61 (4.50); similarly, the cross H6-212-91 (78.36) had the highest fruit set percentage followed by H4-115-18 (74.64). The maximum number of fruits per plant was recorded in the cross H4-115-18 (175.20), followed by H27-173-22 (128.60). The highest single fruit weight was observed in the cross H6-100-11 (67.98 g), followed by H6-48-44 (67.45 g). The highest yield per plant was recorded in the cross H6-212-91 (4.78 kg) followed by H6-100-11 (4.67 kg), while the lowest yield per plant was exhibited in the cross H4-115-18 (1.97 kg). The highest titrable acidity was observed in the cross H6-100-23 (0.54 %) followed by H6-148-61 and H27-173-22 (0.49 %), while the lowest titrable acidity was observed in the cross H17-2-23 (0.39 %). The highest ascorbic acid was observed in the cross H4-115-18 (25.23 mg 100 g^{-1}) followed by H6-212-91 (25.21 mg 100 g^{-1}), while the lowest ascorbic acid was observed in the cross H6-100-3 (23.18 mg 100 g^{-1}). The total phenol content in the cross H6-48-44 and H6-212-91 (0.98 µg/g) was recorded as high followed by H6-100-11 (0.97 µg/g), while the lowest total phenol was recorded in the cross H17-2-5 (0.83 µg/g) (Table 5 & Fig. 1).

Resistance to PBNV

In the cross H6 Arka Vikas × EC 519809 (*S. peruvianum)*, nine hybrid-derived lines were evaluated for PBNV resistance and the mean PDI (%) ranged from 3.75 to 14.47 %. Out of nine assessed lines, five lines were found to be resistant (R), namely H6-48-44, H6-100-11, H6-100-23, H6-100-36 and H6-212-91. In the cross H17 -CO3 × EC 519791 (*S. habrochaites)*, out of four lines evaluated, one line was found to be resistant (R) *viz.,* H17-2-6. In the H27-PKM-1 × EC 519791 (*S. habrochaites*) cross, three hybrid-derived lines were evaluated for PBNV resistance and one line was found to be resistant (R), namely H27-173-22.

Table 5. Mean performance of interspecific hybrid progenies in F_4 generation

Sl. No	Progeny No	Plt. ht (cm)	Days to 50 % flr.	No. of fruits /cl.	Fruit set %	No. of fruits /pt.	Single fruit wt. (g)	Yield /plt. (kg)	Acidity (%)	Ascorbic acid (mg 100 g^{-1})	Total phenol (µg/g)	PBNV
1	H4-115-18	140.20	37.40	5.30	74.64	175.20	11.74	1.97	0.45	25.23	0.93	R
2	H6-48-44	152.50	28.56	4.40	69.73	66.20	67.45	4.40	0.43	24.89	0.98	R
3	H6-48-61	147.70	28.48	4.50	65.69	63.70	66.89	4.23	0..49	24.41	0.94	MR
4	H6-100-3	120.50	34.50	3.23	55.88	63.10	64.58	3.97	0.46	23.18	0.94	MR
5	H6-100-11	122.40	34.00	3.70	57.09	66.40	67.98	4.49	0.48	24.87	0.97	R
6	H6-100-23	123.10	34.10	3.50	56.45	68.10	65.37	4.38	0.54	23.21	0.95	R
7	H6-100-31	115.70	35.60	3.50	52.47	62.50	64.35	3.99	0.41	23.58	0.93	MR
8	H6-100-36	120.50	34.50	3.50	54.68	65.80	62.87	4.10	0.43	24.25	0.96	R
9	H6-100-39	118.70	35.30	3.60	55.90	63.20	63.72	4.00	0.41	24.78	0.92	MS
10	H6-212-91	123.40	36.60	4.60	78.36	70.30	66.78	4.59	0.46	25.21	0.98	R
11	H17-2-5	110.20	40.10	3.78	67.02	117.60	26.80	3.15	0.42	24.35	0.83	MS
12	H17-2-6	105.50	41.30	3.70	70.47	126.20	27.60	3.39	0.40	24.16	0.87	R
13	H17-2-23	118.60	40.10	3.82	68.82	120.45	27.30	3.25	0.39	24.00	0.85	MR
14	H17-44-18	123.30	43.50	3.70	70.34	122.70	34.50	4.20	0.42	24.58	0.87	MS
15	H27-173-8	119.70	43.00	3.78	72.00	125.50	25.98	3.25	0.46	24.78	0.85	MR
16	H27-173-10	123.30	40.00	3.70	71.15	121.10	27.88	3.27	0.43	23.55	0.87	MR
17	H27-173-22	126.50	39.00	3.79	73.87	128.60	28.78	3.69	0.49	24.75	0.89	R
	Mean	125.57	37.33	3.99	67.46	99.87	44.90	3.73	0.45	24.40	0.90	
	SEd	3.68	0.91	0.14	2.14	7.31	4.10	0.17	0.01	0.19	0.02	
	CD(0.05)	7.58	1.87	0.30	4.40	15.05	8.45	0.35	0.03	0.39	0.04	

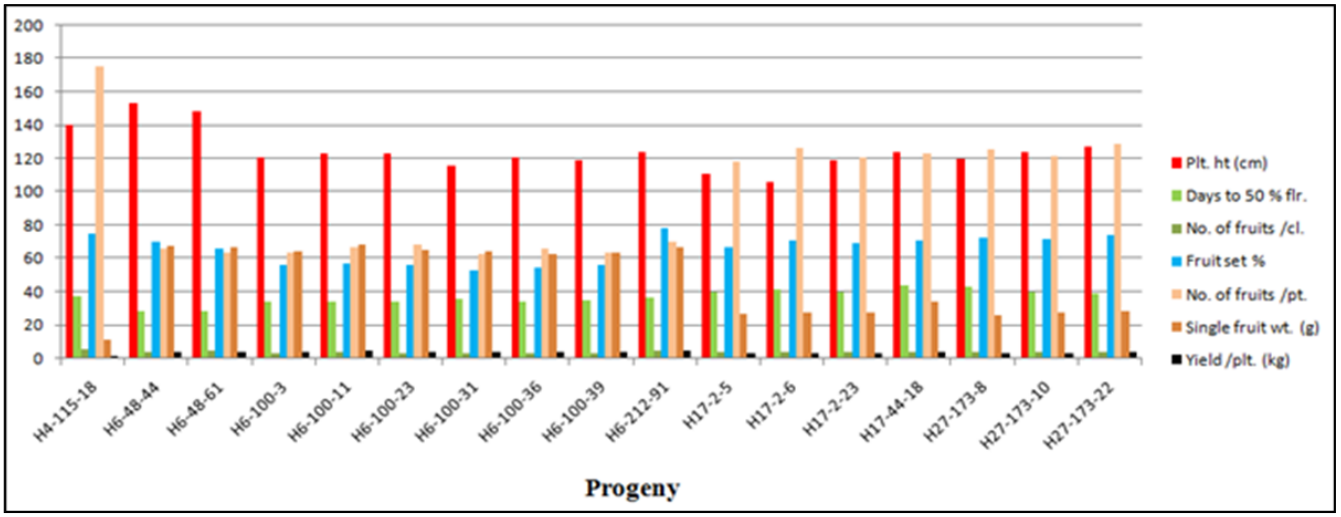

Fig. 1. Mean performance of interspecific hybrid progenies in F_4 generation.

Performance of interspecific progenies in F_5 generation evaluation

Morphological and yield characters

Based on F_4 generation yield and resistance to PBNV, ten superior-performing progenies were evaluated in the F_5 generation. Among the ten lines evaluated the highest plant height was observed in the cross H6-48-44-17 (172.50 cm) followed by H6-212-91-16 (170.50 cm). Earliness in terms of days taken for 50 % flowering was observed in the cross H6-48-44 -17 (32.50 days) followed by H6-212 -91-16 (33.40 days). The maximum number of fruits per cluster was exhibited in the cross H6-48-44 -17 (4.50), followed by H6-212-91-16 and H6-212-91-26 (4.20). Similarly, the highest fruit set percentage was observed in the cross H6-212-91 (78.36), followed by H4-115-18 (74.64). The cross H27-173-22-23 had the most fruits per plant (121.50), followed by H6-212-91- 28. The cross H6-100-11 had the heaviest single fruit weight (67.98 g), followed by H6-48-44 (67.45 g). The cross H6-212-91 had the highest yield per plant (4.78 kg), followed by H6-100-11 (4.67 kg) and the cross H4-115-18 had the lowest yield per plant (1.97 kg). The highest titrable acidity was observed in the cross H6-100-23 (0.54 %) followed by H6-148-61 and H27-173-22 (0.49 %), while the lowest titrable acidity was observed in the cross H17-2-23 (0.39 %). The highest ascorbic acid was observed in the cross H4-115-18 (25.23 mg 100 g^{-1}) followed by H6-212-91 (25.21 mg 100 g^{-1}), while the lowest ascorbic acid was observed in the cross H6-100-3 (23.18 mg 100 g^{-1}). The highest total phenol was recorded in the cross H6-48-44 and H6-212-91 (0.98 µg/g) followed by H6-100-11 (0.97 µg/g), while the lowest total phenol was recorded in the cross H17-2-5 (0.83 µg/g) (Table 6 & Fig. 2).

Resistance to PBNV

In the cross H6 (Arka Vikas × EC 519809 - *S. peruvianum)*, nine hybrid derived lines were evaluated for PBNV resistance and the mean PDI per cent ranged from 3.75 to 14.47 %. Out of nine lines evaluated, five lines are found to be resistant (R), namely H6-48-44, H6-100-11, H6-100-23, H6-100-36 and H6-212-91. In the cross H17-CO3 × EC 519791 (*S. habrochaites)*, out of four traits evaluated, one line was found to be resistant (R), namely H17-2-6. In H27-PKM-1 × EC 519791 (*S. habrochaites)* cross, three hybrid derived lines were evaluated for PBNV resistance and one line was found to be Resistance (R) *viz.,* H27-173-22.

Performance of interspecific progenies in F_6 generation evaluation

Based on F_5 generation yield and resistance to PBNV, three superior performing progenies were evaluated in F6 generation. Among the three lines evaluated, the highest plant height was observed in the cross H6-48-44-17-16 (170.50 cm) followed by H6 -212-91-28-21 (162.00 cm). Earliness in terms of days taken for 50 % flowering was observed in the cross H6-48-44-17-16 (30.50 days) followed by H6-212-91-28 -21 (35.00 days). The highest number of fruits per cluster was observed in the cross H6-48-44-17-16 (4.20), followed by H6-212-91-28-21 (4.10). Similarly, the highest fruit set percentage was observed in the cross H27-173-22-23-6 (74.00). The highest number of fruits per plant was recorded in the cross H27-173-22-23-6 (115.50), followed by 110.0 in the cross H6-48-44-17-16. The highest single fruit weight was exhibited in the cross H6-48-44-17-16 (37.00 g), followed by H6-212-91-28- 21 (32.00 g). The highest yield per plant was observed in the cross H6-48-44-17-16 (3.8 kg) followed by H27-173-22-23-6

Table 6. Mean performance of interspecific tomato hybrid derived lines in F_5 generation

Sl. No	Progeny No	Plt. ht (cm)	Days to 50 % flr.	No. of fruits /cl.	Fruit set %	No. of fruits /pt.	Single fruit wt. (g)	Yield /plt. (kg)	PBNV
1	H6-48-44 - 17	172.50	32.50	4.50	68.00	112.00	37.45	3.00	R
2	H6-100-11- 11	158.60	34.50	3.80	59.00	98.50	28.50	2.95	R
3	H6-100- 11 - 10	168.40	34.10	3.50	56.50	105.60	32.60	3.50	R
4	H6-100-36 - 10	153.70	34.50	3.50	54.50	99.30	35.40	3.30	R
5	H6-212-91- 12	165.78	35.50	4.00	55.50	100.25	33.40	3.40	R
6	H6-212-91- 16	170.50	33.40	4.20	60.50	99.80	28.70	2.85	R
7	H6-212-91- 26	123.40	36.60	4.20	62.30	120.50	30.15	3.65	R
8	H6-212-91- 28	168.25	37.50	3.50	61.50	117.60	27.90	3.30	R
9	H27-173-22 - 23	126.50	40.05	3.50	73.87	121.50	28.78	3.50	R
	MEAN	155.04	35.41	3.84	61.30	108.34	31.43	3.27	
	SEd	3.62	1.21	0.17	1.98	5.95	3.95	0.17	
	CD (0.05)	7.24	2.40	0.34	4.00	11.90	7.90	0.35	

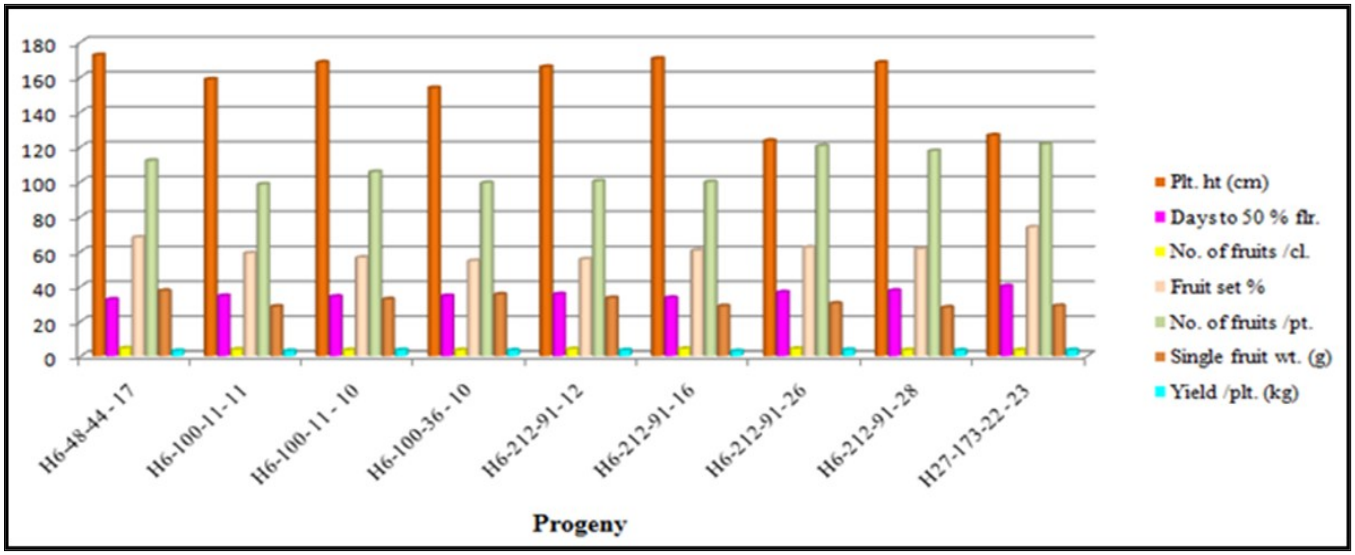

Fig. 2. Mean performance of interspecific hybrid progenies in F_5 generation.

(3.20 kg). In the cross H6 -Arka Vikas × EC 519809 (*S. peruvianum)*, two hybrid-derived lines were evaluated for PBNV resistance. In H27-PKM-1 × EC 519791 (*S. habrochaites)* cross, one hybrid-derived lines were evaluated for PBNV resistance and all three lines were found to be resistant (Table 7 & Fig. 3). Among the nine different tomato species, only *S. chilense* and *S. peruvianum* involved in advanced breeding lines derived from them exhibited resistance or moderate resistance to GBNV. The resistant lines identified in this study can be utilized for genetic studies on PBNV resistance and for developing molecular markers associated with the trait. These markers will facilitate the incorporation of resistance genes into elite tomato varieties, enhancing their disease resistance (17-19).

Conclusion

In conclusion, resistant genes were successfully introgressed into cultivated tomato, resulting in the development of interspecific tomato lines that exhibit strong resistance to PBNV. These lines produce large, red-coloured fruits with the desired shape, making them highly attractive to both growers and consumers. The enhanced resistance reduces the need for chemical controls, lowering production costs and minimizing environmental impact. These developed lines hold significant potential for commercial cultivation, offering more stable yields even under high disease pressure and can also serve as valuable parental material in hybridization programs aimed at further improving tomato resilience, fruit quality and overall agricultural sustainability.

Table 7. Mean performance of interspecific tomato hybrid-derived lines in F_6

Sl. No	Progeny No	Plt. ht (cm)	Days to 50 % flowering	No. of fruits / cl.	Fruit set %	No. of fruits / pt.	Single fruit wt. (g)	Yield /plt. (kg)	PBNV
1.	H6-48-44 – 17 – 16	170.50	30.50	4.20	65.00	110.00	37.00	3.80	R
2.	H6-212-91- 28 - 21	162.00	35.00	4.10	58.00	100.00	32.00	2.95	R
3.	H27-173-22 – 23-6	130.50	40.00	3.20	74.00	115.50	28.00	3.20	R
	Mean	154.33	35.17	3.83	65.67	108.50	32.30	3.20	
	SEd	3.50	1.40	0.19	2.20	6.00	4.00	0.17	
	CD(0.05)	7.20	2.79	0.40	4.40	12.05	8.10	0.35	

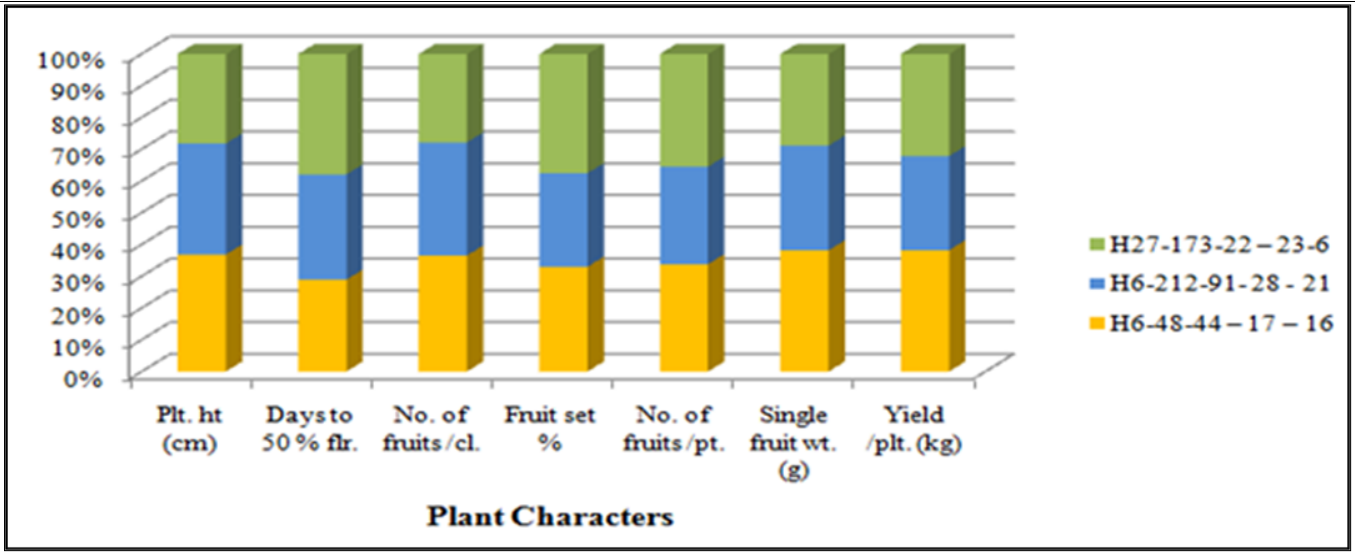

Fig. 3. Mean performance of interspecific hybrid progenies in F_6 generation.

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Authors' contributions

AB carried out the writing of original draft and conceptualization. KR did the revision of draft. KK contributed to the inclusion of tables and figures as well as proof reading. SS provided the technical support for writing the review article. AB carried out the revision, formatting and supervision. All the authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflicts of Interest: The authors declared no conflict of interest.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

For paraphrasing few sentences, I have used only the Chat GPT-AI tool.

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