



Effect of soybean yellow mottle mosaic virus (*Gammacarmovirus glycinis*) on growth, yield and seed quality of soybean (*Glycine max*) cultivars

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ABSTRACT

Gammacarmovirus glycinis [Soybean yellow mottle mosaic virus, (SYMMV)] is an important viral pathogen associated with mosaic and mottle symptoms in leguminous crops including soybean (*Glycine max* L.). The present study was carried out during the year 2022 at ICAR-Indian Agricultural Research Institute, New Delhi to understand the impact of SYMMV on various growth, seed yield and quality parameters in 18 soybean (*Glycine max* L.) cultivars through mechanical sap inoculation under controlled environmental conditions. SYMMV infection significantly influenced the plant height, number of pods and seed yield/plant, 100-seed weight, germination%, seedling length, seedling fresh weight and dry weight, seedling vigour index-I and II across all cultivars. Cultivars like SL-688 and SL-744 exhibited notable reduction in plant height whereas number of pods and seed yield/plant was recorded low in SL-744, SL-958, SL-1104 and JS-335. Great variation in 100-seed weight was observed for the cultivars MACS-450 and MACS 1281 compared to other cultivars. Seed germination was significantly reduced in cultivars SL-688 and SL-744 whereas seedling length was greatly influenced in the cultivars SL-744, JS-335, DSB-23 and MACS-57. Both seedling vigour index I and II were negatively affected particularly in SL-525, SL-688, SL-744, DSB-23, and JS-335. The soybean cultivars SL-525, SL-688, SL-744, SL-958, SL-1104, JS-335, DSB-23, MACS-57 and MACS-1281 exhibited the great reduction in growth and seed quality parameters confirming their high susceptibility to SYMMV infection. The study highlights that while all cultivars experienced some negative effects, the degree of impact varied significantly. The findings of this study points to the importance of monitoring and managing SYMMV infection in soybean crop to prevent significant agricultural losses and maintain seed quality and crop productivity.

Keywords: Germination percentage, Seed quality, Seed yield, Soybean, Soybean yellow mottle mosaic virus

Soybean (*Glycine max* L.), is a rich source of oil and high quality protein grown worldwide. Currently, India is the fifth largest producer of soybean in the world contributing to 3% of global production (USDA 2023). In India, soybean area has expanded with the adoption of high yielding varieties and use of plant protection measures. Despite the increased area, soybean production is being challenged by various biotic factors especially diseases caused by fungal, viral, bacterial and nematode pathogens (Wrather *et al.* 2001, Asad *et al.* 2006). The occurrence of more than 50 viruses has been reported to infect soybean regardless of growth stage (Bhat *et al.* 2002, Ramteke *et al.* 2007). Recently, a new virus soybean yellow mottle mosaic virus (SYMMV) has been reported to infect legumes including mungbean (*Vigna radiata*), soybean and urdbean (*Vigna mungo*) from various parts of the world (Li *et al.* 2009, Nam *et al.* 2009, Sandra *et al.* 2015 and 2019, Wei *et al.* 2020).

Soybean yellow mottle mosaic virus (*Gammacarmovirus glycinis*, SYMMV), member of Genus: *Gammacarmovirus* (Family: Tombusviridae), has positive sense single stranded RNA of 3974nt long encoding six ORF's required for replication (ORF1 and ORF2), short (ORF3 and 4) and long (ORF5) distance movement. Host range studies of SYMMV through mechanical sap inoculation and agro-inoculation with full length infectious clone revealed that SYMMV confined to only Leguminosae members (Sandra *et al.* 2017). The symptoms produced by SYMMV include chlorotic blotches, mosaic, mottling, and veinal necrosis in various leguminous crops and found to be seed transmitted in nature (Sandra *et al.* 2017 and 2020).

The development of effective management strategies against newly emerging plant viruses is crucial to limit their spread and minimize crop losses. Among the available disease management approaches, the deployment of host plant resistance is considered the most practical, sustainable, and eco-friendly option. Further, soybean seed quality is a key determinant of its market value, primarily governed by germination and vigour, which can be adversely affected

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by seed-borne viral infections, resulting in poor seed performance (Bellaloui and Mengistu 2007, Bellaloui *et al.* 2012). Despite the economic importance of soybean in India, there is currently no comprehensive information on the influence of SYMMV on national soybean production.

In our previous study, 18 soybean cultivars were screened for their response to SYMMV, and none of them exhibited complete resistance to the virus (Srikant *et al.* 2025). Therefore, building upon that work, the present study was undertaken to quantify the impact of SYMMV infection on plant growth, seed yield, and seed quality parameters in these 18 soybean cultivars under controlled conditions through mechanical sap inoculation.

MATERIALS AND METHODS

Soybean seed material: The present study was carried out during the year 2022 at ICAR-Indian Agricultural Research Institute (28.6377°N, 77.1571°E; at an elevation of 228.61 m amsl), New Delhi. Total of 18 soybean cultivars were obtained from ICAR-Indian Agricultural Research Institute, New Delhi.

Virus source, maintenance and inoculation: The experiment was conducted under controlled environmental conditions at National Phytotron Facility (NPF), ICAR-Indian Agricultural Research Institute, New Delhi in a completely randomized design (CRD). Initially the SYMMV full length infectious clone placed under 35S promoter was maintained on French bean cv. Arka Sharat through agro-inoculation (Sandra *et al.* 2017). Healthy seeds of the soybean cultivars were sown in 6 inch pots (two seeds/pot) containing soilrite mixture and maintained with the conditions of 26±2°C, 16 h/8 h photoperiod and 70% relative humidity. French bean samples tested positive for SYMMV through reverse transcription polymerase chain reaction (RT-PCR) were macerated in 0.1 M phosphate buffer (pH-7.0, @1:2 w/v) with the help of pre-cooled mortar and pestle. The sap was applied to 10 seedlings of all the soybean cultivars in two replications at 2–4 leaves stage. Plants that were mock inoculated with only phosphate buffer served as control. Inoculated plants were confirmed for SYMMV infection through DAC-ELISA and RT-PCR with coat protein specific primers at 25 days of post inoculation as described previously (Sandra *et al.* 2020, Srikant *et al.* 2025).

Data collection and statistical analysis: Plant height (cm) was measured from base to tip at the time of harvesting in all the soybean cultivars. Yield parameters such as number of pods and seed yield per plant were also measured. The pods were manually harvested, dried and weighed with the aid of an electronic balance. A randomly selected seed sample of each soybean cultivar in 2 replicates was used for determining 100-seed weight. The seed quality was assessed for each cultivar by seed germination test using between paper method with four replications of 25 seeds in walk-in germinator (ISTA 2024). The seedling length [root length (cm) + shoot length (cm)], seedling fresh weight and dry weight were also recorded on randomly selected 10 seedlings

in four replicates from the germinated seedlings. Seedling vigour index I (SV-I) and II (SV-II) were calculated as per following formula (Abdul Baki and Anderson 1973),

$$\text{Seedling vigour index-I} = \text{Seed germination \%} \times \text{Seedling length (cm)}$$

$$\text{Seedling vigour index-II} = \text{Seed germination \%} \times \text{Seedling dry weight (g)}$$

Percentage data such as germination% was transformed via arcsine before analysis. The data was analyzed statistically for testing heterogeneity of means by adopting paired t-test with OPSTAT software package (<http://www.hau.ernet.in/opstat.html>). The probability was recorded at 5% level of significance.

RESULTS AND DISCUSSION

Effect of SYMMV on vegetative growth: Plant virus infection was reported to reduce the growth components by disrupting growth regulating hormone pathways of the plants (Zhao and Li 2021). In the present study, plant height was significantly reduced in the SYMMV infected cultivars SL-688 (33.92 cm), SL-744 (33.65 cm), SL-958 (41.05 cm) compared to control (49–54.70 cm) and other soybean cultivars. The mean plant height of control plants ranged from 42.88–61.5 cm whereas it was 33.65–59.02 cm in SYMMV infected plants (Table 1). Reduction of plant height was also reported for cucumber mosaic virus (CMV) infected cowpea (*Vigna unguiculata*), soybean mosaic virus (SMV) infected soybean and rice dwarf virus infected rice (*Oryza sativa*) plants (Arif *et al.* 2002, Mandhare and Gawade 2010, Jin *et al.* 2016, Babalola *et al.* 2018). The decrease of height in virus infected plants might be due to lowered photosynthetic activity and translocation efficiency resulting in reduced cell division, elongation and ultimately vegetative growth (Buhari *et al.* 2022).

Effect of SYMMV on seed yield: Number of pods/plant was significantly reduced in all the SYMMV infected soybean cultivars compared to the control plants. The mean number of pods/plant recorded for control was 38 whereas 28 for diseased plants. More significant reduction in number of pods/plant due to SYMMV was observed for cultivars JS-335, SL-1104, DSB-23 compared to control and other cultivars (Table 1). This was mainly attributed to two factors i.e. interference of SYMMV infection in physiological processes such as photosynthesis and flower abortion which ultimately resulted in less number of pods which was already reported to occur in other virus pathosystems like bean pod mottle virus-soybean and paprika mild mottle virus-*Nicotiana benthamiana* (Rahoutei *et al.* 2000, Byamukama *et al.* 2015, Cao *et al.* 2019). Seed yield/plant was significantly reduced in SYMMV infected soybean cultivars when compared to control plants. The mean seed yield/plant was recorded as 10.59 g in control plants whereas 8.50 g in diseased plants. Significant reduction in seed yield/plant due to SYMMV was observed for cultivars SL-744 (7.77) compared to control (12.0) (Table 1). Reduction in seed yield might be due to reduction in pod number of SYMMV

Table 1 Effect of soybean yellow mottle mosaic virus on seed yield attributes in soybean cultivars

Cultivar	Plant height (cm)				No. of pods/plant				Seed yield/plant (g)			
	Control	Diseased	Diff	% Reduction	Control	Diseased	Diff	% Reduction	Control	Diseased	Diff	% Reduction
SL-525	61.85	55.22	6.63	10.71	40.55	30.00	10.55	26.01	11.60	8.75	2.85	24.56
SL-688	49.00	33.92	15.08	30.77	44.00	32.10	11.90	27.04	12.50	9.20	3.30	26.40
SL-744	49.70	33.65	16.05	32.29	42.25	27.97	14.28	33.79	12.00	7.77	4.23	35.25
SL-958	54.70	41.05	13.65	24.95	33.70	27.71	5.99	17.77	10.85	7.52	3.33	30.69
SL-979	46.87	38.19	8.68	18.51	36.95	31.05	5.90	15.96	11.43	8.90	2.53	22.13
SL-1028	54.10	45.90	8.20	15.98	27.35	23.90	3.45	12.61	9.20	7.05	2.15	23.36
SL-1104	50.49	45.45	5.04	9.98	43.11	22.49	20.62	47.83	9.34	7.45	1.89	20.23
DSB-23	43.50	36.50	7.00	16.09	37.75	22.95	14.80	39.20	8.00	7.15	0.85	10.62
DSB-34	47.25	39.67	7.58	16.04	35.65	22.64	13.01	36.49	9.57	6.94	2.63	27.48
JS-335	55.54	46.85	8.69	15.64	44.50	23.08	21.42	48.13	8.52	7.01	1.51	17.72
MACS-13	54.20	47.16	7.04	12.98	36.85	25.71	11.14	30.23	10.84	8.29	2.55	23.52
MACS-57	50.09	44.03	6.06	12.09	33.03	24.99	8.04	24.34	10.35	8.51	1.84	17.77
MACS-58	50.05	42.44	7.61	15.20	34.75	29.29	5.46	15.71	10.00	9.02	0.98	9.80
MACS-124	45.55	41.34	4.21	9.24	33.20	30.78	2.42	7.28	10.90	9.61	1.29	11.83
MACS-450	57.75	53.44	4.31	7.46	45.00	34.96	10.04	22.31	12.25	11.06	1.19	9.71
MACS-1188	46.70	42.38	4.32	9.25	39.10	28.79	10.31	26.36	10.31	9.21	1.10	10.66
MACS-1281	61.50	59.02	2.48	4.03	46.85	32.42	14.43	30.80	12.00	9.97	2.03	16.91
MACS-1407	42.88	38.93	3.95	9.21	35.75	29.89	5.86	16.39	11.00	9.59	1.41	12.81
Mean	51.21	43.62			38.37	27.82			10.59	8.50		
MSD at 5%	8.08				11.29				1.97			
SE(d)	5.97				8.31				1.61			
SEM	4.22				5.87				1.14			

MSD, Minimum significant difference.

infected plants as compared to control plants. Recent work on SYMMV showed the seed transmission nature which indicated that the virus can move systemically through the plant thereby could influence the seed yield through interfering photosynthesis and flower formation (Sandra *et al.* 2020). Similar reports of decline in seed yield/plant have been observed for mungbean yellow mosaic India virus (MYMIV), cowpea mild mottle virus (CPMMV) in cowpea and for turnip yellow virus in canola by Akhtar *et al.* (2011), Congdon *et al.* (2020) and Da silva *et al.* (2020), respectively. SYMMV infection significantly influenced the 100-seed weight in infected soybean cultivars compared to the control plants. Higher variation due to virus infection was observed for the cultivars MACS-450 and MACS-1281. The mean 100-seed weight recorded was 7.33 g in control plants whereas 4.89 g in diseased plants. Further there was a significant difference in 100-seed weight among the soybean cultivars. Low 100-seed weight was recorded in cultivars MACS-1281 (3.60 g), DSB-23 (4.14 g), MACS-58 (4.20 g), MACS-13 (4.31 g) and SL-688 (4.47 g) (Table 2). Reduction in seed weight might be due to virus interference with the carbohydrate metabolism in the leaf cells ultimately resulting in the disruption of source-sink relationship. The similar results were observed in CMV infected peanut

(*Arachis hypogaea*) and *Arabidopsis* plants (Shalitin *et al.* 2002, de Breuil *et al.* 2012, Bueso *et al.* 2017).

Effect of SYMMV on seed quality: The SYMMV infection greatly influenced the seed quality parameters of all soybean cultivars tested in the present study. Germination percentage was substantially reduced in SYMMV infected soybean cultivars compared to the control plants. The mean germination in SYMMV diseased plants recorded was 72% compared to 88% in control plants. Great variation in germination percentage due to SYMMV was observed for the cultivars SL-744, SL-525, and SL-688 (Table 2). In the present investigation, low germination might be due to influence of virus infection on metabolic process including synthesis of various enzymes like amylase and protease required for germination process (Escalante *et al.* 2024). The seedling length (cm) was notably decreased in SYMMV inoculated soybean cultivars compared to control plants. The mean seedling length was very low in infected soybean cultivars (20.22 cm) compared to control plants (28.71 cm) without infection. Remarkable variation in seedling length was noticed for the cultivars SL-744, DSB-23, JS-335 and MACS-57 due to SYMMV infection (Table 2). This can be attributed to the fact that virus infection can slow down various metabolic processes and steps involved in

Table 2 Effect of Soybean yellow mottle mosaic virus on 100-seed weight, germination and seedling length of soybean cultivars

Cultivar	100-seed weight (g)				Germination (%)				Seedling length (cm)			
	Control	Diseased	Diff	% Reduction	Control*	Diseased*	Diff	% Reduction	Control	Diseased	Diff	% Reduction
SL-525	6.48	5.29	1.19	18.36	91 (72.54)	64 (53.13)	27	29.67	27.60	21.67	5.93	21.48
SL-688	5.56	4.47	1.09	19.60	93 (74.66)	68 (55.55)	25	73.11	25.40	18.77	6.63	26.10
SL-744	5.57	4.55	1.02	18.31	89 (70.63)	55 (47.87)	34	38.20	26.90	12.97	13.93	51.78
SL-958	6.04	4.73	1.31	21.68	90 (71.57)	66 (54.33)	24	26.66	27.30	22.19	5.11	18.71
SL-979	6.23	4.91	1.32	21.18	87 (68.87)	76 (60.67)	11	12.64	25.80	19.53	6.27	24.30
SL-1028	7.48	5.67	1.81	24.19	86 (68.03)	70 (56.79)	16	18.60	28.95	20.64	8.31	28.70
SL-1104	8.58	5.85	2.73	31.81	87 (68.87)	78 (62.03)	09	10.34	29.25	20.77	8.48	28.99
DSB-23	6.55	4.14	2.41	36.79	88 (69.73)	70 (56.79)	18	20.45	31.25	18.86	12.39	39.64
DSB-34	7.60	5.44	2.16	28.42	86 (68.03)	72 (58.05)	14	16.27	29.00	18.71	10.29	35.48
JS-335	7.93	4.92	3.01	37.95	85 (67.21)	64 (53.13)	21	24.70	31.90	18.81	13.09	41.03
MACS-13	7.56	4.31	3.25	42.98	88 (69.73)	74 (59.34)	14	15.90	28.00	23.27	4.73	16.98
MACS-57	7.19	4.72	2.47	34.35	87 (68.87)	74 (59.34)	13	14.94	32.00	20.17	11.83	36.96
MACS-58	7.50	4.20	3.30	44.00	88 (69.73)	70 (56.79)	18	20.45	29.10	19.32	9.78	33.60
MACS-124	7.46	6.00	1.46	19.57	85 (67.21)	68 (55.55)	17	20.00	26.85	19.76	7.09	26.40
MACS-450	9.52	5.11	4.41	46.32	85 (67.21)	82 (64.90)	03	3.52	30.90	22.65	8.25	26.69
MACS-1188	7.46	5.00	2.46	32.97	89 (70.63)	80 (63.43)	09	10.11	28.25	21.20	7.05	33.25
MACS-1281	9.04	3.60	5.44	60.17	90 (71.57)	78 (62.03)	12	13.33	29.25	25.34	3.91	13.36
MACS-1407	8.15	5.11	3.04	37.30	91 (72.54)	88 (69.73)	03	3.29	29.00	19.39	9.61	33.13
Mean	7.33	4.89			88 (69.73)	72	27		28.71	20.22		
MSD at 5%		2.52			23.63				6.24			
SE(d)		1.91			12.61				6.16			
SEM		1.35			8.91				4.36			

MSD, Minimum significant difference; *, Arcsine transformed values.

germination ultimately results in reduced seedling length. Similar trend of reduction in germination and seedling length was reported for soybean infected with SMV (Mandhare and Gawade 2010). Seedling fresh weight and dry weight were found to be inversely related to SYMMV infection. The mean fresh weight recorded for control was 4.53 cm whereas 4.23 cm for diseased plants. However, among the cultivars significant variation was observed for SL-979 (0.51 g), DSB-23 (0.53 g), and MACS-13 (0.54 g). The mean dry weight observed for control plants was 0.46 g whereas 0.41 g for SYMMV infected soybean cultivars. There was a significant difference in seedling dry weight among the cultivars SL-744, SL-958 and SL-525 (0.06 g) due to SYMMV infection (Table 3). Reduction of these parameters might be due to decrease in the enzyme levels involved in reserve mobilization from seeds to seedlings at higher infection level. Similar results were reported by other workers (Chand and Varma 1983).

Seedling vigour: Seedling vigour index-I and seedling vigour index-II were highly influenced in all the SYMMV infected soybean cultivars compared to the control plants. The mean seedling vigour index-I recorded for control was

2525.71 whereas 1467.12 for SYMMV infected cultivars. Higher significant variation was observed for the cultivars SL-744 (1680.75), JS-335 (1507.66) and DSB-23 (1429.80) due to SYMMV infection when compared with the control plants (Table 4). The mean vigour index-II recorded for control was 40.41 whereas 29.94 for SYMMV infected cultivars. There was a significant variation in vigour index-II due to SYMMV infection in cultivars SL-744, SL-525 and SL-958 (Table 4). Reduction of seed germination and vigour in SYMMV infected plants might be due to reduced transportation and accumulation of photosynthates to developing pods resulted in poor development of seeds. Similarly, CMV infection in peanut plants resulted in significant reduction of seed yield and quality especially when infection occurs at seedling stage (de Breuil *et al.* 2012).

The findings of the present study demonstrated that SYMMV infection leads to considerable reductions in growth, seed yield, and seed quality traits in soybean cultivars, with particularly severe effects observed in SL-525, SL-688, SL-744, SL-958, JS-335, DSB-23, and MACS-1281. These results highlight the urgent need to

Table 3 Effect of soybean yellow mottle mosaic virus on seedling fresh and dry weight in soybean cultivars

Cultivar	Seedling fresh weight (g)				Seedling dry weight (g)			
	Control	Diseased	Mean	Diff	Control	Diseased	Mean	Diff
SL-525	4.70	4.53	4.61	0.17	0.52	0.46	0.49	0.06
SL-688	4.15	3.99	4.07	0.16	0.41	0.37	0.39	0.04
SL-744	3.25	3.04	3.15	0.21	0.43	0.37	0.40	0.06
SL-958	4.70	4.44	4.57	0.26	0.47	0.41	0.44	0.06
SL-979	4.65	4.14	4.39	0.51	0.49	0.44	0.46	0.05
SL-1028	4.75	4.58	4.67	0.17	0.54	0.52	0.53	0.02
SL-1104	5.25	4.90	5.08	0.35	0.59	0.55	0.57	0.04
DSB-23	4.65	4.12	4.39	0.53	0.40	0.35	0.37	0.05
DSB-34	4.75	4.32	4.53	0.43	0.43	0.40	0.41	0.03
JS-335	4.75	4.49	4.62	0.26	0.52	0.48	0.50	0.04
MACS-13	5.15	4.61	4.88	0.54	0.43	0.41	0.42	0.02
MACS-57	4.20	3.90	4.05	0.30	0.40	0.35	0.37	0.05
MACS-58	4.35	4.01	4.17	0.34	0.44	0.39	0.41	0.05
MACS-124	4.30	4.08	4.19	0.22	0.52	0.48	0.50	0.04
MACS-450	4.85	4.68	4.76	0.17	0.40	0.37	0.38	0.03
MACS-1188	5.15	4.84	4.99	0.31	0.48	0.44	0.46	0.04
MACS-1281	4.15	3.99	4.07	0.16	0.36	0.31	0.33	0.05
MACS-1407	3.85	3.57	3.71	0.28	0.44	0.39	0.41	0.05
Mean	4.53		4.23		0.46		0.41	
CD ($p=0.05$)			0.485				0.067	
SE(d)			0.229				0.032	
SEM			0.162				0.022	

Table 4 Effect of soybean yellow mottle mosaic virus on seedling vigour indices in various soybean varieties

Cultivar	Seedling vigour index-I				Seedling vigour index-II			
	Control	Diseased	Diff	% Reduction	Control	Diseased	Diff	% Reduction
SL-525	2511.60	1386.88	1124.72	44.78	47.32	29.44	17.88	37.78
SL-688	2362.20	1276.36	1085.84	45.96	38.13	25.16	12.97	34.01
SL-744	2394.10	713.35	1680.75	70.20	38.27	20.35	17.92	46.82
SL-958	2457.00	1464.54	992.46	40.39	42.30	27.06	15.24	36.02
SL-979	2244.60	1484.28	760.32	33.87	42.63	33.44	9.19	21.55
SL-1028	2489.70	1444.80	1044.90	41.96	46.44	36.40	10.04	21.61
SL-1104	2544.75	1620.06	924.69	36.33	51.33	42.90	8.43	16.42
DSB-23	2750.00	1320.20	1429.80	51.99	35.20	24.50	10.70	30.39
DSB-34	2494.00	1347.12	1146.88	45.98	36.98	28.80	8.18	22.12
JS-335	2711.50	1203.84	1507.66	55.60	44.20	30.72	13.48	30.49
MACS-13	2464.00	1721.98	742.02	30.11	37.84	30.34	7.50	19.82
MACS-57	2784.00	1492.58	1291.42	46.38	34.80	25.90	8.90	25.57
MACS-58	2560.80	1352.40	1208.40	47.18	38.72	27.30	11.42	29.49
MACS-124	2282.25	1343.68	938.57	41.12	44.20	32.64	11.56	26.15
MACS-450	2626.50	1857.30	769.20	29.28	34.00	30.34	3.66	10.76
MACS-1188	2514.25	1696.00	818.25	32.54	42.72	35.20	7.52	17.60
MACS-1281	2632.50	1976.52	655.98	24.91	32.40	24.18	8.22	25.37
MACS-1407	2639.00	1706.32	932.68	35.34	40.04	34.32	5.72	14.28
Mean	2525.71	1467.12			40.41	29.94		
MSD at 5%	4116.14					21.43		
SE(d)	760.80				5.60			
SEM	537.96				2.40			

MSD, Minimum significant difference.

screen a broader range of soybean germplasm to identify and introduce resistance genes into high-yielding cultivars through targeted breeding programmes. Since the durability of resistance often depends on pathogenic variability and the prevalence of different viral strains, incorporating multiple resistance genes would provide a more robust and sustainable strategy for effective management of SYMMV in leguminous crops.

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