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Seed priming and foliar application of GA_3 enhance disease control in tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Seed priming is an effective approach to control diseases in tomato. In this context, the current study was undertaken to confirm the effectiveness of seed priming. Treatments included (1) dry seeds; (2) seed priming with 1 mL of moringa leaf extract diluted with 30 mL of distilled water for 18 hr; (3) seed priming with 1% NaCl for 36 hr; (4) seed priming with 10% polyethylene glycol (PEG) for 12 hr; (5) 100 ppm GA_3; (6) 5% KNO_3 under dark conditions and (7) 1000 ppm thiourea for 24 hr; (8) distilled water for 12 hr and (9) 2% KH_2PO_4; and 0.5 mmol · L^{-1} NAA at 4°C for 6 hr. The treated seeds were immediately broadcasted in separate nursery beds; after that 21-day old seedlings were transplanted in main plots. Foliar application of GA_3 at 100 ppm was sprayed 25 days after the seedlings were transplanted. Two-year results revealed that tomato seeds primed with 2% KH_2PO_4 in combination with GA_3, significantly reduced bacterial wilt, leaf spot, early blight, late blight and leaf curl diseases. Additionally, the combination of 10% PEG with GA_3 has emerged as the most effective for controlling collar rot disease. While PEG decreased the incidence of collar rot, KH_2PO_4 strongly reduced bacterial wilt. Target leaf spot, early blight and late blight were less severe when KH_2PO_4, KNO_3 and moringa leaf extracts were used, indicating that seed priming was more crucial for prevention of disease severity. Application of GA_3 also enhanced the effect of nearly all priming agents.

Keywords: diseases, GA_3, moringa leaf extract, polyethylene glycol, seed priming, tomato

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.), a member of the Solanaceae family, is typically cultivated annually. It has a weak, woody stem that often scrambles over other plants. The tomato fruit is an edible berry characterised by its bright red colour due to the presence of lycopene. Tomatoes are nutritionally categorised as vegetables. Recent studies have shown that a significant portion of vegetable crops deteriorate each year, either during growth or postharvest storage. This deterioration is caused primarily by diseases caused by fungi, nematodes, bacteria and viruses, which have posed major challenges to food production and human development over millennia (Dun-Chun et al., 2016).

Tomato is the second most consumed vegetable crop globally after potato, contributing significantly to the farmer's income, processing industries and international trade (FAO, 2021). It is consumed both fresh and in processed forms such as sauces, soups, juices, purees, ketchups and canned products. Traditionally, tomato is valued for improving digestion and skin health, while medicinally its bioactive compounds like lycopene and β-carotene are linked to reduced risks of cardiovascular diseases and certain cancers, with vitamins A, C and E further enhancing immunity (Ali et al., 2020). In addition, tomato is a staple in diverse cuisines worldwide, ranging from Mediterranean sauces to Asian curries and chutneys, and is recognised as a 'protective food' for its nutritional benefits.

Tomato is highly susceptible to numerous diseases that significantly reduce yield. Over 200 insect pests and diseases have been identified in tomatoes, leading to both direct and indirect production losses (Nowicki et al., 2013). Among the most serious diseases are early blight, caused by *Alternaria solani*; late blight, caused by *Phytophthora infestans*; Fusarium wilt, caused by *Fusarium oxysporum*; bacterial wilt, caused by *Pseudomonas solanacearum*; and seedling damping-off, caused by *Pythium spp.* and *Rhizoctonia spp.* These pathogens predominantly impact both production and quality, whether in the field or during postharvest processing (Ramyabharathi et al., 2012; Chakraborty et al., 2022). To combat plant diseases, various fungicides and bactericides are used; however, these chemicals often leave residues on plant parts, posing health risks to humans. To mitigate these adverse effects, alternative measures should be considered. One effective approach is seed priming before sowing, which can produce vigorous seedlings and reduce the need for chemical treatments (Chakraborty and Bordolui, 2021).

In this context, various seed priming techniques have been evaluated, including hydropriming, biopriming, osmopriming, matrix priming and halopriming (Basra et al., 2011; Aliyu et al., 2016; Behra, 2016). Therefore, soaking the seeds in water for 8 hr before sowing significantly reduced downy mildew incidence in seedlings of a highly susceptible cultivar, decreasing it from approximately 80% to <60% (Harris et al., 2005). Nayaka et al. (2008) investigated the use of *Trichoderma harzianum* as a seed treatment to control maize ear rot and manage the accumulation of fumonisin, which is synthesised by *Fusarium verticillioides*, in maize seeds. Similarly, Nakaune et al. (2012) demonstrated that low-salt seed priming with sodium chloride enhances tomato plant germination and emergence, as well as subsequent growth and tolerance to *Ralstonia solanacearum*, the causative agent of tomato bacterial wilt, compared with hydroprimed and non-primed seedlings. Taken together, the present study evaluated the impact of different seed priming treatments on disease suppression and plant health during tomato cultivation. This study highlights the significant role of seed priming and foliar application of GA_3 in mitigating tomato disease by improving plant health and yield. This integrated approach offers a sustainable and ecofriendly alternative to chemical treatment, contributing to improving disease resistance and quality seed production in tomato cultivation.

MATERIALS AND METHODS

Location and experimental details

The research was conducted at Incheck Farm, Kalyani, Nadia, West Bengal, India, during November to March of 2019–2020 and 2020–2021. The treatment consisted of the tomato genotype BCT-25, sourced from the All India Coordinated Research Project (AICRP) on Vegetable Crops at Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India. After standardising the concentration and duration, various chemicals were used for seed priming, with dry seeds serving as the control (Table 1).

These treatments were evaluated with and without gibberellic acid (GA). Treated seeds were immediately

Table 1. Selected concentrations and durations of priming agents and GA.

Seed priming agent	Concentration	Duration (hr)
Control (T_0)		
Moringa leaf extract (T_1)	Leaf extract: water @ 1:30	18
NaCl (T_2)	1%	36
PEG 6000 (T_3)	10%	12
GA_3 (T_4)	100 ppm	24
KNO_3 (T_5)	5%	24
Thiourea (T_6)	1000 ppm	24
Distilled water (T_7)	-	12
KH_2PO_4 (T_8)	2%	6
NAA (T_9)	0.5 mmol · L^{-1}	6
Foliar application of GA_3 (G_1)		
No application of GA_3 (G_0)		

GA, gibberellic acid; PEG, polyethylene glycol.

broadcasted in separate nursery beds measuring 1 m × 1 m after priming. Standard agronomic practices were followed for raising seedlings in individual plots. At 21 days after sowing (DAS), the seedlings were transplanted into main plots (3 m × 1.2 m) with a spacing of 60 cm × 60 cm, which were arranged in a strip plot design with three replications. Each block or replication was further divided into 10 horizontal strips and 2 vertical strips.

The recommended fertiliser was applied to the main plots at a rate of N:P:K = 150:75:75 kg · ha^{-1}. Foliar application of 100 ppm GA_3 was applied 25 days after transplanting (Ray and Bordolui, 2020). Observations were recorded from standing crops to assess disease incidence and severity under natural conditions during November–March of 2019–2020 and 2020–2021.

Disease incidence (%)

The incidences of collar rot and bacterial wilt diseases were calculated as follows:

$$\text{Percent disease incidence} = \left(\frac{\text{Number of plants infected}}{\text{Total number of plants}}\right) \times 100$$

Percent Disease Index

The severity of different foliar diseases (target leaf spot, early blight, late blight and tomato leaf curl viral disease) was recorded from the entire individual plot via visual observation on different disease grading scales. Ten plants were selected randomly and tagged from each treatment to assess the disease severity from transplanting to harvest at 15-day intervals. Disease severity was calculated by using a 0–5 scale for target leaf spot and early blight (Mayee and Datar, 1986), late blight by a 0–5 scale (Akhtar et al., 2012) and tomato leaf curl viral disease by using a 0–4 scale (Friedmann et al., 1988). The percent disease index (PDI) was calculated as follows (McKinney, 1923):

$$\text{Percent disease index} = \left(\frac{\text{Sum of numerical ratings}}{\text{Total number of observations}}\right) \times \left(\frac{100}{\text{Maximum disease score}}\right)$$

Statistical analysis

This research was conducted via a two-factor strip plot design. All the analyses included in the manuscript were performed via OPSTAT version 1.0.2 (Sheoran et al., 1998), including angular transformation.

RESULTS AND DISCUSSION

Bacterial wilt disease

Compared with the control, all priming materials in combination with GA_3 and without GA_3 decreased bacterial wilt disease in tomatoes (Figure 1 and Figure S1 in Supplementary Materials) during both seasons. In the second-year trial, the disease incidence was slightly higher than that in the first year for all the treatments. Compared with the seed priming treatments, the exogenous application of GA_3 significantly influenced the incidence of bacterial wilt disease in tomatoes, and G_1 (15.96%, 17.45%) presented a lower disease

Figure 1. Bacterial wilt disease.

Table 2. Influence of different priming materials in combination with or without GA_3 on the incidence of bacterial wilt disease in tomato.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	22.07* (28.36)	14.41 (22.71)	18.55 (25.88)	14.24 (22.58)	18.68 (25.97)	15.03 (23.21)	18.21 (25.63)	21.54 (28.00)	13.60 (22.05)	18.11 (25.56)	17.44 (24.99)
G_1	20.37 (27.19)	13.07 (21.61)	17.05 (24.77)	12.67 (21.28)	16.98 (24.71)	13.96 (22.35)	16.62 (24.44)	20.12 (27.01)	11.98 (20.69)	16.78 (24.56)	15.96 (23.86)
Mean *T*	21.22 (27.78) a	13.74 (22.16) f	17.80 (25.32) c	13.46 (21.93) g	17.83 (25.34) c	14.49 (22.78) e	17.41 (25.03) d	20.83 (27.51) b	12.79 (21.37) h	17.45 (25.06) d	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.082	0.075	0.114				0.130				
LSD (0.05)	0.244	0.456	NS				NS				
CV (%)	0.823	1.680	0.802				0.802				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	23.12 (29.08)	15.57 (23.63)	19.67 (26.68)	15.22 (23.36)	19.68 (26.69)	16.58 (24.41)	19.50 (26.56)	22.99 (28.99)	14.52 (22.80)	19.58 (26.62)	18.64 (25.88)
G_1	21.85 (28.22)	14.33 (22.65)	18.44 (25.80)	14.01 (22.39)	18.41 (25.77)	15.46 (23.55)	18.26 (25.67)	21.74 (28.13)	13.63 (22.08)	18.35 (25.73)	17.45 (25.00)
Mean *T*	22.49 (28.65) a	14.95 (23.14) d	19.05 (26.24) b	14.62 (22.88) d	19.04 (26.23) b	16.02 (23.98) c	18.88 (26.11) b	22.36 (28.56) a	14.08 (22.44) e	18.96 (26.18) b	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.119	0.048	0.138				0.106				
LSD (0.05)	0.354	0.295	NS				NS				
CV (%)	1.147	1.043	0.679				0.679				

Note: G = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1 = with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 =10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PEG, polyethylene glycol; SEM: standard error of mean.

incidence than did G_0 (17.44%, 18.64%) during both years (Table 2). On average, with and without GA_3, T_8 (12.79%, 14.08%) had the minimum incidence, followed by T_3 and T_1 during the first and second years, although T_3 and T_1 were not significantly different from each other; it was the maximum for T_0 (21.22%, 22.49%) in both years. During both years, T_8, that is, KH_2PO_4 in combination with GA_3 (11.98%, 13.63%) and without GA_3 (13.60%, 14.52%), had the lowest disease incidence, followed by T_3 and T_1, although a statistically non-significant influence was observed for the performance of priming agents with and without GA_3 (Table 2).

There was no significant difference among the treatments with the application of foliar application of GA_3 to individual priming agents in either season. Disease reduction was also calculated for the control. The data revealed that the greatest degree of disease control was achieved with the combination of GA_3 and without GA_3 application during both years. The data revealed that the greatest degree of disease control was observed in T_8 in combination with GA_3 and without GA_3 application during both years.

Collar rot disease

The application of GA_3 as a foliar spray had a significant influence on the incidence of collar rot disease (Figure 2 and Figure S1 in Supplementary Materials) in tomatoes; during both seasons, the results revealed that G_1 had a lower disease incidence (11.20% and 12.51%) than did G_0 (12.53% and 13.82%) when the mean was made over seed priming. The trait varied significantly because of seed priming, with an average over with and without GA_3 application; minimum disease incidence was observed for T_3, that is, 10% polyethylene glycol (PEG) (8.68% and 10.04%) during both years, followed by T_8 and T_1; maximum disease incidence was observed after the control, that is, T_0 (14.78% and 16.18%) in 2 years (Table 3). Non-significant variation was observed for the influence of the seed priming agent either alone or in combination with GA_3 and for the influence of foliar GA_3 application on individual priming materials. The disease reduction was also calculated for the control (Table 3). The data revealed that the greatest degree of disease control, that is, PEG, was observed in T_3 during both years.

Figure 2. Collar rot disease.

Table 3. Influence of different priming materials in combination with or without GA_3 on the incidence of collar rot disease in tomato.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	15.65* (23.70)	10.38 (19.26)	13.27 (21.78)	9.24 (18.19)	14.02 (22.40)	11.04 (19.86)	12.35 (21.01)	15.17 (23.32)	9.90 (18.81)	14.30 (22.63)	12.53 (21.10)
G_1	13.91 (22.31)	9.00 (17.95)	11.86 (20.58)	8.11 (17.06)	12.69 (21.30)	9.62 (18.55)	11.06 (19.88)	13.87 (22.28)	8.65 (17.60)	13.20 (21.72)	11.20 (19.92)
Mean *T*	14.78 (23.00) a	9.69 (18.60) h	12.57 (21.18) e	8.68 (17.63) J	13.36 (21.85) d	10.33 (19.21) g	11.71 (20.44) f	14.52 (22.80) b	9.27 (18.21) i	13.75 (22.18) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.086	0.020	0.137				0.145				
LSD (0.05)	0.254	0.121	NS				NS				
CV (%)	1.020	0.530	1.282				1.282				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	16.70 (24.50)	11.81 (20.54)	14.39 (22.70)	10.66 (19.51)	15.25 (23.38)	12.17 (20.85)	13.70 (22.14)	16.53 (24.37)	11.23 (20.03)	15.72 (23.75)	13.82 (22.18)
G_1	15.66 (23.71)	10.33 (19.21)	13.12 (21.65)	9.43 (18.36)	13.89 (22.30)	11.00 (19.82)	12.23 (20.90)	15.19 (23.34)	9.94 (18.85)	14.28 (22.61)	12.51 (21.08)
Mean *T*	16.18 (24.10) a	11.07 (19.88) h	13.76 (22.18) e	10.04 (18.94)i	14.57 (22.84) d	11.58 (20.34) g	12.97 (21.52) f	15.86 (23.85) b	10.59 (19.44) i	15.00 (23.18) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.077	0.013	0.099				0.084				
LSD (0.05)	0.229	0.080	NS				NS				
CV (%)	0.873	0.331	0.701				0.701				

Note: G = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1 = with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 =10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PEG, polyethylene glycol; SEM: standard error of mean.

Figure 3. Target leaf spot disease.

Target leaf spot disease

In the case of target leaf spot disease in tomato (Figure 3 and Figure S2 in Supplementary Materials), all priming materials in combination with GA_3 and without GA_3 decreased the incidence of disease compared with the control in both seasons. The disease severity percentage was slightly greater from 2020 to 2021 than from 2019 to 2020 for all the treatments (Table 4). Foliar application of GA_3 significantly influenced the disease severity percentage or PDI when the average was greater than that of the seed priming treatments; G_1 (30.83%, 32.21%) presented a lower disease severity than did G_0 (33.11%, 34.48%) during both years. On average, with and without GA_3, treatment with 2% KH_2PO_4 (25.79%, 27.27%) resulted in the lowest degree of disease severity, followed by KNO_3 and the moringa leaf extract. The lowest PDI was obtained from 2% KH_2PO_4 (24.70%, 26.87% and 26.22%, 28.31%), followed by 5% KNO_3 and moringa leaf extract in combination with GA_3 and without GA_3 for both seasons. The highest disease severity was observed in the control (36.64%, 38.73% and 37.95%, 40.11%, respectively) (Table 4).

Disease reduction was also calculated for the control (Table 4). The data revealed that the greatest degree of disease control was observed. 2% KH_2PO_4, followed by 5% KNO_3 and moringa leaf extract in combination with GA_3 and without GA_3 for both seasons.

Early blight disease

Compared with the control, all priming materials in combination with GA_3 and without GA_3 decreased early blight disease (Figure 4 and Figure S2 in Supplementary Materials) during both seasons. In the first-year trial, the disease severity percentage was slightly lower than that in the second year in all the treatments. Significant variation was observed for the percent disease severity or PDI in the early blight stage of tomato plants after they were sprayed with GA_3, when the average was greater than that in the seed priming treatment group; G_1 (23.93%, 25.19%) presented a lower disease severity than did G_0 (25.23%, 26.58%) during both years (Table 5). On average, with and without GA_3, 2% KH_2PO_4 (18.61%, 19.91%) had the lowest disease severity, followed by 5% KNO_3 and moringa leaf extract in two consecutive seasons; the disease severity was greatest for T_0 (29.74%, 31.17%) in both years. During both seasons, 2% KH_2PO_4 (17.27%, 19.94% and 18.63%, 21.18%) in combination with GA_3 and without GA_3 had the lowest disease severity percentage or PDI, followed by 5% KNO_3 Moringa leaf extract.

The disease severity was greatest in the control (28.76%, 30.72%, and 30.08%, 32.26%, respectively) treatment. Disease reduction was also calculated for the control (Table 5). The data revealed that the greatest degree of disease control was associated with

Table 4. Influence of different priming materials in combination with or without GA_3 on the PDI of the target leaf spot.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	38.73* (38.78)	29.10 (32.96)	30.89 (34.07)	32.90 (35.30)	36.16 (37.26)	27.81 (32.15)	33.82 (35.86)	37.90 (38.29)	26.87 (31.55)	36.96 (37.74)	33.11 (35.40)
G_1	36.64 (37.55)	26.67 (31.42)	28.29 (32.45)	30.22 (33.66)	33.60 (35.73)	26.36 (31.22)	31.82 (34.64)	35.73 (37.01)	24.70 (30.13)	34.24 (36.12)	30.83 (33.99)
Mean *T*	37.69 (38.16) a	27.88 (32.19) h	29.59 (33.26) g	31.56 (34.48)f	34.88 (36.50) d	27.09 (31.68) i	32.82 (35.25) e	36.82 (37.65) b	25.79 (30.84) j	35.60 (36.93) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.050	0.032	0.066				0.066				
LSD (0.05)	0.147	0.195	0.194				0.244				
CV (%)	0.348	0.507	0.301				0.301				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	40.11 (39.59)	30.27 (33.69)	32.39 (35.00)	34.17 (36.08)	37.41 (38.00)	29.20 (33.02)	35.24 (36.71)	39.33 (39.13)	28.31 (32.46)	38.36 (38.56)	34.48 (36.22)
G_1	37.95 (38.32)	28.14 (32.35)	29.59 (33.27)	31.63 (34.53)	34.99 (36.57)	27.78 (32.12)	33.04 (35.39)	37.08 (37.81)	26.22 (31.13)	35.66 (36.96)	32.21 (34.85)
Mean *T*	39.03 (38.96) a	29.20 (33.02)h	30.99 (34.13) g	32.90 (35.30) f	36.20 (37.28) d	28.49 (32.57) i	34.14 (36.05) e	38.20 (38.47) b	27.27 (31.79) j	37.01 (37.76) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.055	0.014	0.079				0.077				
LSD (0.05)	0.165	0.085	0.235				0.237				
CV (%)	0.382	0.215	0.390				0.390				

Note: *G* = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1 = with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 = 10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = Distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PDI, percent disease index; PEG, polyethylene glycol; SEM: standard error of mean.

Figure 4. Early leaf blight disease.

2% KH_2PO_4, 5% KNO_3 and Moringa leaf extract in combination with GA_3 and without GA_3 was used for both seasons (Table 5).

Late blight disease

While observing the influence of all priming agents in combination with GA_3 and without GA_3, a reduction in late blight disease in tomato (Figure 5 and Figure S2 in Supplementary Materials) was noted over the control in both seasons.

Significant variation was noted for the percent disease severity or PDI after GA_3 application when the average was performed over the seed priming treatments; disease severity was lower in the treatments with GA_3 (20.10%, 21.35%) than in the treatments without GA_3 (21.05%, 22.40%) during both years (Figure 5). Among the seed priming treatments, 2% KH_2PO_4 (15.74%, 17.08%) resulted in the lowest disease severity, followed by 5% KNO_3 and moringa leaf extract during both seasons. When the mean disease severity was greater than that of *G* (with and without GA_3), it was highest for the control (25.15%, 26.40%) in both years (Table 6). The minimum disease severity percentage or PDI was noted for 2% KH_2PO_4 (14.92%, 16.56% and 16.20%, 17.95%), followed by 5% KNO_3 and moringa leaf extract in combination with GA_3 and without GA_3 for both seasons. The maximum disease severity was found control (24.67%, 25.63%, and 25.87%, 26.92%, respectively) (Table 6). The reduction in disease incidence was also greater than that of the control. The maximum reduction was observed. 2% KH_2PO_4 followed by 5% KNO_3 and T_1, that is, moringa leaf extract in combination with GA_3 and without GA_3, for both seasons.

Tomato leaf curl viral disease

In the case of tomato leaf curl disease (Figure 6 and Figure S2 in Supplementary Materials), all priming materials in combination with GA_3 and without GA_3 decreased the incidence of disease compared with the control in both seasons. The percent disease severity or PDI for this disease significantly varied after foliar application of GA_3, with an average over seed priming treatments during both years; lower disease severity was detected with GA_3 (14.14%, 15.48%) than without GA_3 (15.84%, 17.15%). In terms of the performance of the seed priming agents, the average over with and without GA_3, the trait varied significantly in both years; 2% KH_2PO_4 (11.94%, 13.31%) had the lowest disease severity, followed by 10% PEG and moringa leaf extract during the year and, in the second year, that they interchanged, although T_1 and T_3 were not significantly different from each other in either season. T_0 (19.15%, 20.54%) was highest in both years. The lowest disease severity percentage or PDI was obtained at 2% KH_2PO_4 (10.71%, 13.17% and 12.06%, 14.57%) in combination with GA_3 and without GA_3 for both seasons; 2% KH_2PO_4 was followed by 10% PEG and Moringa leaf extract, with slight changes in their position over the years; the highest disease severity was observed in the control (18.51%, 19.78% and 19.91%, 21.18%, respectively) (Table 7).

The results clearly demonstrate that both GA_3 application and seed priming treatments contributed to a reduction in bacterial wilt and collar rot incidence,

Table 5. Influence of different priming materials in combination with or without GA_3 on the PDI of early blight.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	30.72* (33.97)	21.46 (27.94)	23.19 (29.13)	24.29 (29.86)	27.58 (32.00)	20.95 (27.59)	25.98 (30.97)	29.83 (33.42)	19.94 (26.88)	28.31 (32.47)	25.23 (30.42)
G_1	28.76 (32.75)	21.09 (27.69)	21.98 (28.30)	23.51 (29.34)	26.55 (31.34)	20.16 (27.03)	24.96 (30.31)	27.97 (32.25)	17.27 (24.93)	27.00 (31.63)	23.93 (29.56)
Mean *T*	29.74 (33.36) a	21.28 (27.82) h	22.59 (28.72) g	23.90 (29.60) f	27.06 (31.67) d	20.55 (27.31) i	25.47 (30.64) e	28.90 (32.83) b	18.61 (25.91) j	27.66 (32.05) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.037	0.021	0.055				0.059				
LSD (0.05)	0.109	0.128	0.162				0.197				
CV (%)	0.299	0.385	0.331				0.331				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	32.26 (34.92)	22.69 (28.79)	24.64 (30.09)	25.58 (30.71)	28.97 (32.88)	22.33 (28.54)	27.37 (31.86)	31.22 (34.28)	21.18 (27.75)	29.60 (33.27)	26.58 (31.31)
G_1	30.08 (33.58)	22.29 (28.52)	23.13 (29.09)	24.86 (30.24)	27.93 (32.22)	21.40 (27.91)	26.18 (31.10)	29.18 (33.01)	18.63 (25.94)	28.21 (32.40)	25.19 (30.40)
Mean *T*	31.17 (34.25) a	22.49 (28.65) h	23.89 (29.59) g	25.22 (30.48) f	28.45 (32.55) d	21.87 (28.23) i	26.77 (31.48) e	30.20 (33.64) b	19.91 (26.84) j	28.91 (32.84) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.034	0.018	0.041				0.035				
LSD (0.05)	0.102	0.114	0.124				0.138				
CV (%)	0.274	0.332	0.184				0.184				

Note: G = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1, with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 = 10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = Distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PDI, percent disease index; PEG, polyethylene glycol; SEM: standard error of mean.

Figure 5. Late blight disease.

although the magnitude of their effects varied between diseases and years. In the case of bacterial wilt, priming treatments (particularly T_1, T_3, and T_5) were consistently more effective than GA_3 alone, while the significant $T \times G$ interaction highlighted that genotype-specific responses played an important role in disease suppression. Similarly, for collar rot, seed priming emerged as the major factor driving disease reduction, with GA_3 acting mainly as a supportive enhancer by improving plant vigour and tolerance rather than directly suppressing pathogen activity. The interaction effects in collar rot also indicated that certain genotypes performed better under specific priming treatments when combined with GA_3, suggesting a synergistic benefit in some cases. Overall, while both factors contributed, the priming materials were the principal drivers of disease suppression in this study, and GA_3 primarily complemented their effect by enhancing plant growth and resilience.

The present study demonstrated that seed priming with 10% PEG and 2% KH_2PO_4 effectively decreased the incidence and severity of several tomato diseases. Specifically, KH_2PO_4 substantially reduced bacterial wilt, while PEG was more effective in reducing collar rot incidence. Furthermore, the application of KH_2PO_4, KNO_3 and moringa leaf extract lowered the severity of target leaf spot, early blight and late blight, suggesting that these treatments can enhance plant defence mechanisms. Although GA_3 application led to a marginal reduction in disease severity, its effect was statistically comparable to that of the non-GA_3 treatments, indicating that seed priming had a more pronounced role in disease suppression than GA_3 supplementation.

Our findings are consistent with earlier reports highlighting the disease-suppressive potential of KH_2PO_4 and other salt-based compounds. For instance, Reuveni et al. (1994) observed a 79% reduction in disease incidence in roses treated with KH_2PO_4 in combination with KOH, K_2HPO_4, $NaHCO_3$ or topiramate, while Ehret et al. (2002) reported that foliar applications of KCl, $MgSO_4$ and K_2HPO_4 significantly reduced powdery mildew in tomato. Similarly, Ata et al. (2008)

Table 6. Influence of different priming materials in combination with or without GA_3 on the PDI of late blight.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	25.63* (30.74)	17.80 (25.33)	19.03 (26.23)	19.91 (26.86)	23.04 (29.02)	17.25 (24.92)	22.39 (28.58)	24.92 (30.28)	16.56 (24.39)	23.91 (29.61)	21.05 (27.60)
G_1	24.67 (30.11)	16.92 (24.67)	18.48 (25.83)	19.16 (26.32)	22.29 (28.52)	16.38 (24.26)	20.93 (27.58)	23.92 (29.61)	14.92 (23.12)	23.32 (29.21)	20.10 (26.92)
Mean *T*	25.15 (30.43) a	17.36 (25.00) h	18.76 (26.03) g	19.54 (26.59) f	22.67 (28.77) d	16.82 (24.59) i	21.66 (28.08) e	24.42 (29.94) b	15.74 (23.76) j	23.62 (29.41) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.013	0.008	0.018				0.019				
LSD (0.05)	0.040	0.054	0.048				0.062				
C.V. (%)	0.121	0.180	0.083				0.083				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	26.92 (31.58)	19.12 (26.29)	20.37 (27.18)	21.33 (27.85)	24.31 (29.87)	18.69 (25.98)	23.76 (29.51)	26.21 (31.12)	17.95 (25.44)	25.32 (30.54)	22.40 (28.54)
G_1	25.87 (30.90)	18.16 (25.59)	19.78 (26.76)	20.37 (27.18)	23.66 (29.44)	17.56 (25.15)	22.16 (28.42)	25.11 (30.40)	16.20 (24.12)	24.59 (30.06)	21.35 (27.80)
Mean *T*	26.40 (31.24) a	18.64 (25.94) h	20.07 (26.97) g	20.85 (27.52) f	23.99 (29.66) d	18.12 (25.56) i	22.96 (28.97) e	25.66 (30.76) b	17.08 (24.78) j	24.96 (30.30) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.053	0.029	0.077				0.081				
LSD (0.05)	0.156	0.179	0.228				0.273				
C.V. (%)	0.457	0.573	0.485				0.485				

Note: *G* = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1, with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 = 10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PDI, percent disease index; PEG, polyethylene glycol; SEM: standard error of mean.

Figure 6. Tomato leaf curl viral disease.

demonstrated that KH_2PO_4 application effectively suppressed rust disease in wheat, and Abo-Elyousr et al. (2022) reported that foliar sprays of KH_2PO_4, K_2HPO_4 and $MgSO_4$ reduced powdery mildew in sunflower with efficacy comparable to conventional fungicides. Moreover, Reuveni et al. (1996) found that regular foliar applications of K_2HPO_4 or KH_2PO_4 were highly effective in controlling powdery mildew in cucumber. These results support the proposition that phosphate-based compounds act as alternative eco-friendly disease management tools.

The role of GA_3 in disease reduction has also been documented across multiple crops. In grapevines, GA_3 applications at bloom significantly reduced *Botrytis* and sour rot, with greater efficacy than two specific fungicide applications (Spring and Viret, 2010). Hed et al. (2011) further confirmed GA_3-mediated reductions in bunch rot severity in Vignoles and Chardonnay grapes. Similarly, da Silva et al. (2018) reported that GA_3 treatment in grapevines decreased *Botrytis cinerea* infection and enhanced cluster and rachis length. Other studies have shown GA_3-induced suppression of foliar pathogens, such as *Alternaria dauci* in carrot (Santos et al., 2000). The black spot of persimmon, caused by *Alternaria alternata,* was reduced by the application of GA, which reduced the relative humidity around the infection site due to increased calyx erectness (Perez et al., 1995). Janisiewicz et al. (2005) and Percival et al. (2009) noted that foliar application of KH_2PO_4 may protect against various pathogens via several host–pathogen interactions. Dibasic potassium phosphate was applied as a foliar spray to evaluate its ability to induce resistance against rust disease in sugar beet caused by *Uromyces betae,* which reduces both disease incidence and severity, as observed by Ata et al. (2008). Khalifa and Thabet (2014) reported that spraying KH_2PO_4 suppressed leaf rust disease in the sensitive wheat cultivar Sids-1, as indicated by reduced disease severity. These results collectively suggest that GA_3 influences both plant architecture and disease development, though in the present study its effect was not superior to seed priming. Phosphate priming with KH_2PO_4 not only supplies readily available phosphorus that enhances plant vigour but also induces systemic resistance by activating defence-related enzymes, strengthening cell walls and modulating oxidative stress responses, thereby limiting pathogen establishment. On the other hand, GA_3 influences plant architecture by loosening cell walls and reducing cluster compactness, which lowers humidity within the canopy and diminishes pathogen colonisation; it is also known to interact with

Table 7. Influence of different priming materials in combination with or without GA_3 on the PDI of tomato leaf curl viral disease.

GA_3	2019–2020										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	19.78* (26.77)	13.66 (22.11)	17.09 (24.80)	13.51 (21.98)	17.04 (24.76)	14.27 (22.60)	15.70 (23.74)	17.51 (25.11)	13.17 (21.70)	16.62 (24.44)	15.84 (23.80)
G_1	18.51 (25.85)	11.15 (19.96)	15.94 (23.92)	11.06 (19.88)	14.89 (23.10)	11.85 (20.57)	14.66 (22.92)	17.76 (25.30)	10.71 (19.56)	14.88 (23.09)	14.14 (22.41)
Mean *T*	19.15 (26.31) a	12.41 (21.03) f	16.52 (24.36) c	12.29 (20.93) f	15.96 (23.93) c	13.06 (21.59) e	15.18 (23.33) d	17.63 (25.20) b	11.94 (20.63) f	15.75 (23.77) c	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.058	0.033	0.063				0.048				
LSD (0.05)	0.173	0.198	0.190				0.213				
CV (%)	0.616	0.773	0.286				0.286				
GA_3	2020–2021										
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean *G*
G_0	21.18 (27.75)	14.85 (23.06)	18.51 (25.85)	14.79 (23.02)	18.18 (25.61)	15.75 (23.78)	17.14 (24.83)	18.74 (26.01)	14.57 (22.84)	17.80 (25.33)	17.15 (24.81)
G_1	19.91 (26.86)	12.44 (21.08)	17.22 (24.90)	12.50 (21.14)	16.11 (24.05)	13.13 (21.66)	16.13 (24.06)	19.13 (26.30)	12.06 (20.75)	16.20 (24.12)	15.48 (23.49)
Mean *T*	20.54 (27.30) a	13.64 (22.07) g	17.87 (25.37) c	13.65 (22.08) g	17.15 (24.83) d	14.44 (22.72) f	16.63 (24.45) e	18.93 (26.16) b	13.31 (21.80) h	17.00 (24.73) d	
	T	*G*	*T* at same level of *G*				*G* at same level of *T*				
SEM (±)	0.058	0.006	0.077				0.070				
LSD (0.05)	0.170	0.042	0.228				0.207				
CV (%)	0.581	0.157	0.519				0.519				

Note: *G* = with GA_3 and without GA_3 treatment, G_0 = without GA_3, G_1, with GA_3, *T* = priming treatment, T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 = 10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm thiourea, T_7 = distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 mol/L NAA.

*In brackets, the arcsine value is given.

CV, coefficient of variation; GA, gibberellic acid; LSD, least significant difference; NAA, 1-Naphthaleneacetic acid; NS, Non-significant; PDI, percent disease index; PEG, polyethylene glycol; SEM: standard error of mean.

defence signalling pathways such as salicylic acid and jasmonic acid, leading to enhanced resistance. Together, these mechanisms provide a plausible basis for the reduced disease incidence observed in this study.

Despite these encouraging results, certain limitations warrant consideration. Environmental conditions such as temperature, humidity and soil type, which strongly influence disease progression, were not systematically monitored. Additionally, the absence of molecular validation, such as pathogen DNA quantification or biochemical markers of induced defence, restricts the extrapolation of these findings to diverse agroclimatic regions. Future research should therefore incorporate pathogen quantification, biochemical assays for plant defence responses, and detailed climatic data to strengthen the scientific basis for integrating seed priming and salt-based treatments into tomato disease management strategies.

CONCLUSIONS

Across both seasons, the 2% KH_2PO_4 treatment significantly reduced the incidence of bacterial wilt disease, whereas the 10% PEG treatment effectively minimised the occurrence of collar rot. Furthermore, 2% KH_2PO_4 consistently had the lowest severity in the management of several key foliar diseases of tomato, including target leaf spot, early blight, late blight and leaf curl. The foliar application of GA_3 also contributed to reduced disease infection, achieving the minimum PDI among the treatments. Overall, a combined approach that includes seed priming with 2% KH_2PO_4 and 10% PEG, together with the exogenous foliar application of GA_3, effectively mitigates the incidence and severity of multiple diseases affecting tomato plants. This integrated strategy holds promise for enhancing disease resistance and improving crop health in tomato cultivation.

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AUTHOR CONTRIBUTIONS

J.R., P.K.G., S.K.B. and R.D. conceptualisation. J.R., P.K.G., S.K.B., R.D. and V.V.K. methodology and visualisation. V.B., M.B., A.G. and A.H. software. J.R., P.K.G., S.K.B., R.D. and V.V.K. validation. V.B., M.B., A.G. and A.H. formal analysis. J.R., P.K.G., S.K.B., R.D. and V.V.K. investigation. P.K.G. resources. V.B., M.B., A.G. and A.H. data curation. P.K.G., V.B., M.B., A.G. and A.H. supervision. P.K.G., V.B., M.B., A.G. and A.H. project administrator, writing—original draft preparation.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

Abo-Elyousr, K., Ahmed, H. A. M., Hassan, M. A. E., and Abd El-Fatah, B. E. S. (2022). Influence of foliar application of some salts, phyto-extracts and essential oils for contolling powdery mildew disease of *Helianthus annuus*. *Journal of Plant Pathology, 104*, 735–747, https://doi.org/10.1007/s42161-022-01092-4

Akhtar, K. P., Muhammad, Y. S., Muhammad, A., Ali, S., Nighat, S., and Muhammad, T. E. (2012). Resistance of solanum species to *Phytophthora infestans* evaluated in the detached-leaf and whole-plant assays. *Pakistan Journal of Botany, 44*(3), 1141–1146.

Ali, M. Y., Sina, A. A., Khandker, S. S., Neesa, L., Tanvir, E. M., Kabir, A., Khalil, M. I., and Gan, S. H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods (Basel, Switzerland), 10*(1), 45, https://doi.org/10.3390/foods10010045.

Aliyu, U., Jamilu, S., Alassan, J., Muhammad, A., and Mohammed, I. U. (2016). Germination and early growth of tomato (*Lycopersicon esculentum* L.) as influenced by different hydropriming regimes. *International Journal of Agriculture and Environmental Research, 2*(5), 1249–1255.

Ata, A. A., El-Samman, M. G., Maysa, A. M., and Mostafa, M. H. (2008). Inducing resistance against rust disease of sugar beet by certain chemical compounds. *Egyptian Journal of Phytopathology, 36*(1–2), 113–132.

Basra, S. M. A., Iftikhar, M. N., and Afzal, I. (2011). Potential of moringa (*Moringa oleifera*) leaf

extract as priming agent for hybrid maize seeds. *International Journal of Agriculture and Biology, 13*, 1006–1010.

Behra, S. (2016). A study on the effect of micronutrient ($ZnSO_4$) priming on seed quality parameters of solanaceous vegetables. *International Journal of Agriculture and Environmental Research, 6*(3), 321–336.

Chakraborty, A., and Bordolui, S. K. (2021). Impact of seed priming with ag-nanoparticle and ga_3 on germination and vigour in green gram. *International Journal of Current Microbiology and Applied Sciences, 10*(3), 941–950.

Chakraborty, A., Bordolui, S. K., Nandi, D., and Das, R. (2022). Effect of seed priming with silver nanoparticles (AgNPs) and gibberellic acid (GA_3) against mungbean yellow mosaic virus and cercospora leaf spot diseases in green gram (*Vigna radiata* L.). *Scientist, 1*(3), 3446–3456.

Da Silva, P. S., Barreto, C. F., Kirinus, M. B. M., Schiavon, A. V., Malgarim, M. B., and Mello-Farias, P. C. (2018). Effects of gibberellic acid (GA_3) on reduction of rot disease and physico-chemical quality of "Pinot Noir" grape. *Australian Journal of Crop Science, 12*(8), 1363–1369, https://doi.org/10.21475/ajcs.18.12.08.PNE1282.

Dun-Chun, H. E., Zhan, J., and Xie, L. (2016). Problems, challenges and future of plant disease management: From an ecological point of view. *Journal of Integrative Agriculture, 15*(4), 705–715, https://doi.org/10.1016/S2095-3119(15)61300-4.

Ehret, D. L., Utkhede, R. S., Frey, B., Menzies, J. G., and Bogdanoff, C. (2002). Foliar applications of fertilizer salts inhibit powdery mildew on tomato. *Canadian Journal of Plant Pathology, 24*(4), 437–444, https://doi.org/10.1080/07060660209507031.

Fao. (2021). The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses. Rome: Food and Agriculture Organization of the United Nations.

Friedmann, M., Lapidot, M., Cohen, S., and Pilowsky, M. (1988). A novel source of resistance to Tomato yellow leaf curl virus exhibiting a symptomless reaction to viral infection. *Journal of the American Society for Horticultural Science, 123*(6), 1004–1007, https://doi.org/10.21273/JASHS.123.6.1004.

Harris, D., Breese, W. A., and Rao, J. V. K. (2005). The improvement of crop yield in marginal environments using 'on-farm' seed priming: Nodulation, nitrogen fixation, and disease resistance. *Australian Journal of Agricultural Research, 56*(11), 1211–1218, https://doi.org/10.1071/AR05079.

Hed, B., Ngugi, H. K., and Travis, J. W. (2011). Use of gibberellic acid for management of bunch rot on chardonnay and vignoles grape. *Plant Disease, 95*(3), 269–278, https://doi.org/10.1094/PDIS-05-10-0382.

Janisiewicz, W. J., Peterson, D. L., Yoder, K. S., and Miller, S. S. (2005). Experimental bin drenching system for testing biocontrol agents to control postharvest decay of apples. *Plant Disease, 89*(5), 487–490, https://doi.org/10.1094/PD-89-0487.

Khalifa, W., and Thabet, M. (2014). Efficacy of mono potassium phosphate (KH_2PO_4) to enhance the resistance of wheat against leaf rust disease. *Middle East Journal of Applied Sciences, 4*(4), 1212–1224.

Mayee, C. D., and Datar, V. V. (1986). *Phytopathometry. Technical bulletin. 1 (special bul. 3)* (p. 218). Maharashtra, India: Marathwada Agricultural University Parbhani.

McKinney, H. H. (1923). Influence of soil temperature and moisture on infection of wheat seedling by *Helminthosporium sativum*. *Journal of Agricultural Research, 26*(5), 195–217.

Nakaune, M., Tsukazawa, K., Uga, H., Asamizu, E., Imanishi, S., Matsukura, C., and Ezura, H. (2012). Low sodium chloride priming increases seedling vigor and stress tolerance to *Ralstonia solanacearum* in tomato. *Plant Biotechnology, 29*(1), 9–18, https://doi.org/10.5511/plantbiotechnology.11.1122a

Nayaka, S. C., Niranjana, S. R., Uday Shankar, A. C., Niranjan Raj, S., Reddy, M. S., Prakash, H. S., and Mortensen, C. N. (2008). Seed biopriming with novel strain of *Trichoderma harzianum* for the control of toxigenic *Fusarium verticillioides* and fumonisins in maize. *Archives of Phytopathology and Plant Protection, 43*(3), 264–282, https://doi.org/10.1080/03235400701803879.

Nowicki, M., Kozik, E. U., and Foolad, M. R. (2013). Late blight of tomato. In R. K. Varshney and R. Tuberosa (Eds.), *Translational genomics for crop breeding, volume I: biotic stress* (1st ed.). Hoboken: Wiley, pp. 241–265. https://doi.org/10.1002/9781118728475.ch13.

Percival, G. C., Noviss, K., and Haynes, I. (2009). Field evaluation of systemic inducing resistance chemicals at different growth stages for the control of apple (*Venturia inaequalis*) and pear (*Venturia pirina*) scab. *Crop Protection, 28*(8), 629–633, https://doi.org/10.1016/j.cropro.2009.03.010.

Perez, A. V., Ben-Arie, R., Dinoor, A., Genizi, A., and Prusky, D. B. (1995). Prevention of black spot disease in persimmon fruit by gibberellic acid and iprodione treatments. *Phytopathology, 85*, 221–225, https://doi.org/10.1094/Phyto-85-221.

Ramyabharathi, S. A., Meena, B. L., and Raguchander, T. (2012). Induction of chitinase and β-1,3-glucanase PR proteins in tomato through liquid formulated *Bacillus subtilis* EPCO 16 against Fusarium wilt. *Journal of Today's Biological Sciences: Research and Review, 1*(1), 50–60.

Ray, J., and Bordolui, S. K. (2020). Effect of GA_3 on marigold seed production in Gangetic Alluvial Zone. *Journal of Crop and Weed, 16*(1), 120–126, https://doi.org/10.22271/09746315.2020.v16.i1.1281.

Reuveni, M., Agapov, V., and Reuveni, R. (1996). Controlling powdery mildew caused by *Sphaerotheca fuliginea* in cucumber by foliar sprays of phosphate and potassium salts. *Crop Protection, 15*(1), 49–53, https://doi.org/10.1016/0261-2194(95)00109-3.

Reuveni, R., Agapov, V., Reuveni, M., and Raviv, M. (1994). Effects of foliar sprays of phosphates on powdery mildew (*Sphaerotheca pannosa*) of roses. *Journal of Phytopathology, 142*(4), 331–337, https://doi.org/10.1111/j.1439-0434.1994.tb00030.x.

Santos, P., Nunez, J. J., and Davis, R. M. (2000). Influence of gibberellic acid on carrot growth and severity of Alternaria leaf blight. *Plant Disease, 84*(5), 555–558, https://doi.org/10.1094/Pdis.2000.84.5.555.

Sheoran, O. P., Tonk, D. S., Kaushik, L. S., Hasija, R. C., and Pannu, R. S. (1998). Statistical software package for agricultural research workers. In D. S. Hooda and R. C. Hasija (Eds.), *Recent advances in information theory, statistics & computer applications* (pp. 139–143). Hissar: Department of Mathematics Statistics, CCS HAU.

Spring, J. L., and Viret, O. (2010). Influence of thinning methods on yield, bunch morphology, grey and sour rot, and wine quality of Pinot noir. *Revue Suisse de Viticulture, Arboriculture et Horticulture, 41*(2), 95–101.

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SUPPLEMENTARY MATERIALS

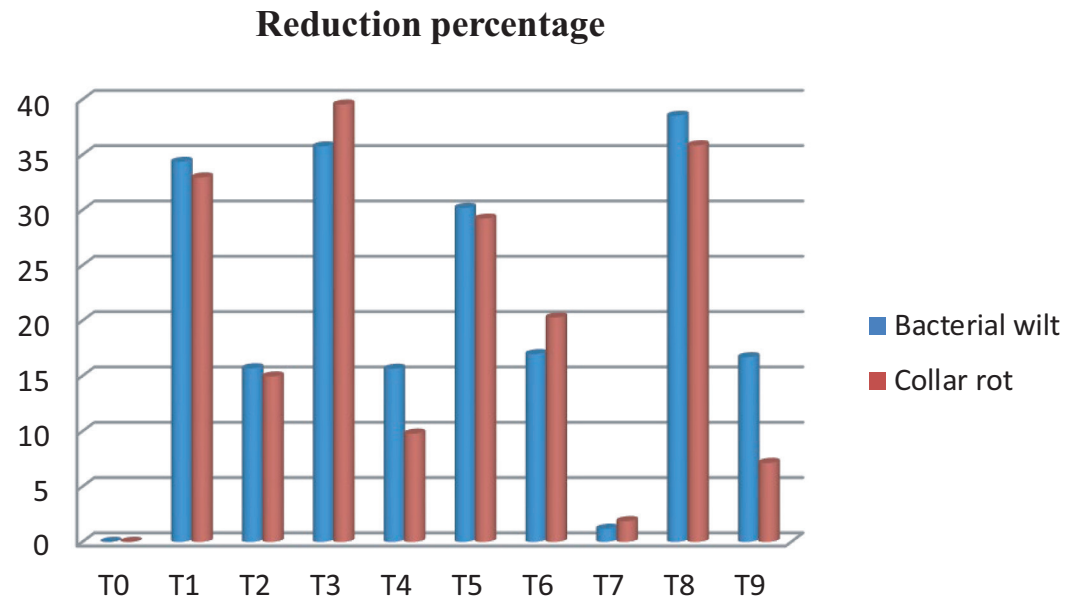

Figure S1. Reduction (%) in disease incidence after seed priming (average over 2 years).

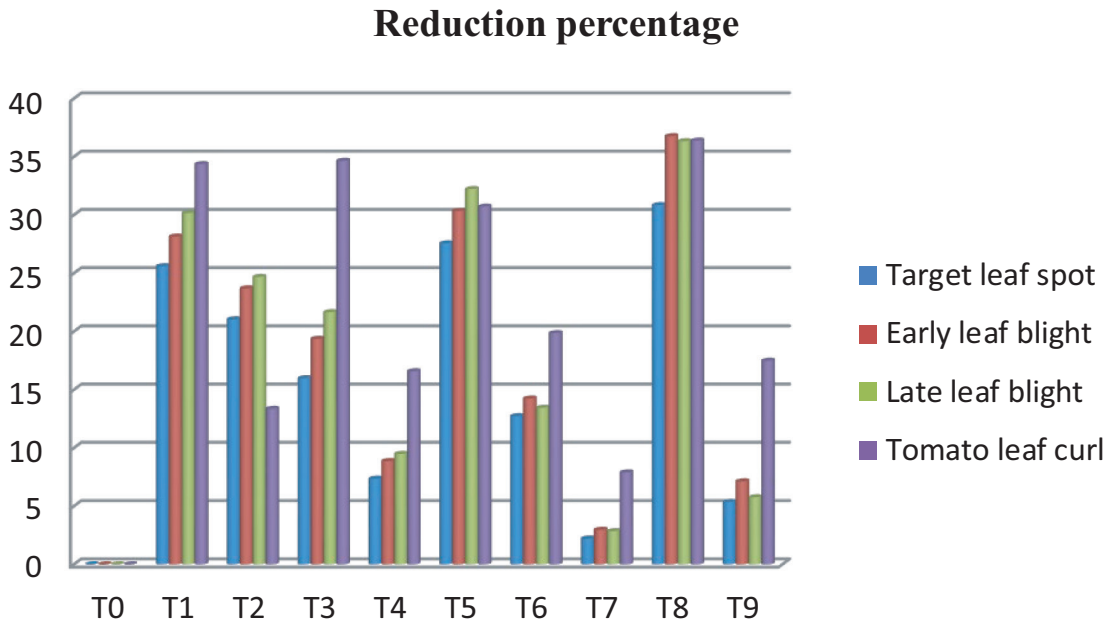

Figure S2. Reduction (%) in disease severity after seed priming (average over 2 years). *Note:* T_0 = control, T_1 = moringa leaf extract, T_2 = 1% NaCl, T_3 = 10% PEG, T_4 = 100 ppm GA_3, T_5 = 5% KNO_3, T_6 = 1000 ppm Thiourea, T_7 = distilled water, T_8 = 2% KH_2PO_4, T_9 = 0.5 m mol · L^{-1} NAA. PEG, polyethylene glycol.