



Role of Salicylic Acid in Enhancing Resistance and Metabolic Stability in Moth bean Against Cercospora Leaf Spot

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Abstract: The present study investigates the role of salicylic acid (SA) in inducing systemic resistance and biochemical modulation in moth bean (*Vigna aconitifolia*) against *Cercospora* leaf spot disease caused by *Cercospora canescens*. *In vitro* assays confirmed a dose-dependent inhibition of *C. canescens* mycelial growth, with 200 $\mu\text{g mL}^{-1}$ SA achieving 95% inhibition. Moth bean seeds (var. RMO-2251) were treated with varying concentrations of SA (50, 100, 150, and 200 $\mu\text{g mL}^{-1}$) through seed soaking and foliar application under pot conditions. The 200 $\mu\text{g mL}^{-1}$ concentration of SA was found most effective, recording the lowest disease intensity (17.55%) and highest disease control (63.02%). Biochemical analyses revealed significant enhancement in phenol and protein contents in SA-treated plants, particularly under disease stress, indicating an activated defense mechanism. Diseased tissues treated with 200 $\mu\text{g mL}^{-1}$ SA showed the highest phenol (6.11 mg g^{-1}) and protein content (20.53 mg g^{-1}). In contrast, infection led to a reduction in total sugars and malic acid; however, higher SA concentrations mitigated this decline, supporting improved metabolic stability. These results underscore the potential of salicylic acid, particularly at 200 $\mu\text{g mL}^{-1}$, as an effective chemical elicitor for enhancing disease resistance and physiological resilience in moth bean under biotic stress. The findings suggest that SA could be explored as a component of sustainable disease-management strategies for moth bean.

Key words: *Vigna aconitifolia*, *Cercospora canescens*, Salicylic acid, Induced resistance.

Moth bean [*Vigna aconitifolia* (Jacq.) Marechal], also known as matki, moth bean, or Turkish gram, is a hardy, drought-resistant legume predominantly grown in the arid and semi-arid regions of India. Well-suited to sandy soils and low-input conditions, moth bean plays a vital role in ensuring food and nutritional security in dryland agriculture (Heuze *et al.*, 2020; Tomooka *et al.*, 2011). Rajasthan remains the principal state in terms of both area and production of this crop (Anonymous, 2023-24). However, despite its adaptability, moth bean is vulnerable to a range of biotic stresses, particularly foliar

diseases such as *Cercospora* leaf spot (CLS), caused by *Cercospora canescens* Ellis and Martin. This disease first reported by Munjal *et al.* (1962), leads to the development of necrotic, angular to circular spots on leaves, premature defoliation, and significant yield reductions-sometimes as high as 70% under severe infestations (Kumar *et al.*, 2023; Kumari *et al.*, 2025). The pathogen's production of the phytotoxin cercosporin and its ability to survive in crop debris, soil, and seeds make management extremely challenging (Daub and Ehrenshaft, 2000; McKay *et al.*, 1918). Conventional disease management strategies such as fungicide application and cultural practices often yield inconsistent results due to environmental variability and the genetic diversity of the pathogen. Therefore, there is an urgent need for alternative, sustainable approaches that enhance the plant's intrinsic defence mechanisms. In this context, the use of plant defence inducers like salicylic acid (SA) has gained increasing attention. SA is a naturally occurring phenolic compound that plays a central role in the activation of systemic acquired resistance (SAR) in plants. It regulates a cascade of defence responses, including the accumulation of pathogenesis-related (PR) proteins, activation of antioxidative enzymes, and increased synthesis of phenolic compounds, thereby strengthening the plant's ability to resist pathogenic attack (Kumar *et al.*, 2011). Although the protective role of exogenous SA has been demonstrated in various crops against fungal and bacterial pathogens, its specific potential in managing *Cercospora* leaf spot in moth bean remains largely unexplored, particularly under field conditions in arid regions. The present study aims to evaluate the efficacy of salicylic acid in inducing resistance against CLS in moth bean, with a focus on disease suppression and activation of plant defense responses. This research seeks to contribute to the development of cost-effective and eco-friendly disease management strategies, promoting sustainable cultivation of pulses in challenging agro-ecological zones.

Materials and Methods

A laboratory and pot experiment was conducted during the kharif seasons of 2023 and 2024 at the Department of Plant Pathology and the Experimental Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner.

In vitro evaluation

An *in vitro* experiment was conducted using a completely randomized design (CRD) with four replications to evaluate the inhibitory effect of salicylic acid (SA) on the mycelial growth of *Cercospora canescens*. The poisoned food technique described by Nene and Thapliyal (1973) was employed, using malt extract agar (MEA) medium supplemented with streptomycin sulphate ($30 \mu\text{g mL}^{-1}$) to suppress bacterial contamination.

Salicylic acid was tested at concentrations of 50, 100, 150, and $200 \mu\text{g mL}^{-1}$. MEA medium was prepared, autoclaved, and amended with the respective SA concentrations before being poured into sterilized 90 mm Petri plates. A 5 mm mycelial disc taken from a 15-day-old culture of *C. canescens* was aseptically placed in the centre of each plate (inverted side down). Plates were sealed with parafilm and incubated at $27 \pm 1^\circ\text{C}$. Plates without SA served as the untreated control. Radial mycelial growth was measured at two-day intervals until the control plates achieved full growth (15 days). The percentage of mycelial growth inhibition was calculated using the formula by Tiru *et al.*, 2013.

Pot culture study

Prior to sowing of moth bean seeds of RMO-2251 variety were surface sterilized by sodium hypochlorite 1% solution and were soaked in different concentration (50, 100, 150 and $200 \mu\text{g mL}^{-1}$) of salicylic acid ($\text{C}_7\text{H}_6\text{O}_3$) for 30 minutes while for control, sterilized distilled water was used. The pathogen was mass multiplied on sterilized sorghum grains, and 20 g of inoculum was incorporated per pot at the time of sowing. At 45 days after sowing (DAS), foliar application of SA was carried out using the same concentrations (50, 100, 150, and $200 \mu\text{g mL}^{-1}$), following the method of Jabnoun-Khiareddine *et al.* (2015). Pots were maintained under controlled conditions. Observations on percent disease intensity (PDI) were recorded at 45 DAS during both kharif 2023 and 2024 seasons. PDI was calculated using the following formula: $\text{Px}100$

Biochemical analysis

Biochemical analysis viz., phenol, protein, total sugar and malic acid were also done on healthy and infected plants, which show

different reactions when treated with salicylic acid.

Estimation of total phenol content

The total phenol content was estimated by the method described by Bray and Thorpe (1954). One gram of leaf sample was weighed by electric balance and grind in mortar and pestle with 10 mL 80% ethanol. The homogenate was centrifuged at 10,000 rpm for 20 minutes. The supernatant was filtered and the residue was re-extracted with five-time volume of 80% ethanol; supernatant was cooled and evaporated to dryness in water bath. The residue was dissolved in 5 mL of distilled water. An aliquot of 0.2 mL was transferred in test tube and volume was made to 3 mL with distilled water, Folin-ciocalteu reagent (0.5 mL) was added in each test tube. After three minutes, 2 mL of 20% sodium carbonate was added in each tube and was mixed thoroughly. All test tubes were then placed in water bath for one minute. After cooling, the absorbance was measured at 650 nm against a blank reagent. The standard curve was prepared by taking different concentrations of catechol. The phenol content was express as mg g^{-1} of fresh tissue.

Estimation of soluble protein content

The soluble protein content of the samples was estimated following the method of Lowry *et al.* (1951). One gram of fresh leaf sample was macerated in a mortar and pestle with 5 mL of 0.1 M sodium phosphate buffer (pH 7.0). The homogenate was centrifuged at 16,000 rpm for 20 min, and the supernatant was used for estimation of soluble protein content. For this purpose, 2% sodium carbonate (anhydrous) in 0.1 N NaOH (Solution A) was prepared. Similarly, 0.5% copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) in 1% sodium potassium tartrate was freshly prepared (Solution B). Solution C (alkaline copper sulphate) was prepared immediately before use by mixing 50 mL of Solution A with 1 mL of Solution B. An aliquot of 0.1 mL of the supernatant was taken in a test tube, and the volume was made up to 1 mL with distilled water. Subsequently, 5 mL of Solution C was added, mixed thoroughly, and incubated at room temperature for 10 min. Then, 0.5 mL of Folin-Ciocalteu reagent, diluted 1:1 with distilled water, was added, mixed thoroughly, and incubated at room temperature in the dark for 30 min. The absorbance was measured at 660

nm against a reagent blank. The protein content was calculated from a standard curve prepared using different concentrations of bovine serum albumin (BSA) and expressed as mg g^{-1} fresh weight (FW).

Estimation of total sugars

Total sugar content was determined using the colorimetric anthrone method described by Dubois *et al.* (1956). Briefly, 100 mg of fresh plant tissue was placed in a boiling tube, and 5 mL of 2.5 N HCl was added. The sample was hydrolysed in a boiling water bath for 3 h and then cooled to room temperature. The hydrolysate was neutralized with solid sodium carbonate until effervescence ceased. The volume was made up to 100 mL with distilled water, and the contents were centrifuged. The resulting supernatant was collected, and 0.5 and 1.0 mL aliquots were used for analysis for preparation of the standard curve, 0, 0.2, 0.4, 0.6, 0.8 and 1.0 mL of the working glucose standard (0.1 mg mL^{-1}) were taken in separate tubes, and the volume was made up to 1.0 mL with distilled water. The same final volume was maintained for the sample aliquots. Subsequently, 4 mL of anthrone reagent was added to each tube, followed by heating in a boiling water bath for 8 min. The tubes were then rapidly cooled, and the intensity of the green to dark-green colour was measured at 630 nm using a spectrophotometer. The sugar concentration was determined from a standard curve prepared using glucose as the reference standard. Total sugar content was expressed as mg g^{-1} fresh weight (FW).

Estimation of malic acid

The acidity of leaf exudates of crop was estimated by the procedure suggested by Koundal and Sinha (1981). Twenty tender leaves were randomly detached from each pot at 8.00 h when copious acid exudates are available for harvest; these were placed in 50 mL conical flask and washed with 25 mL distilled water. The water containing acid was then titrated as to sub samples of 10 mL each for acidity against 0.01 N sodium hydroxide (NaOH) solution using phenolphthalein as indicator. The samples were dried for two days at 60°C and the dry weight was determined. The mean of two titration values, adjusted for

Table 1. Efficacy of salicylic acid against *C. canescens* in *in vitro*

Salicylic acid ($\mu\text{g mL}^{-1}$)	mycelial growth (mm)	Per cent mycelial growth inhibition
50	29.55 (33.31)*	66.46
100	20.00 (26.50)	77.77
150	9.66 (18.09)	89.26
200	4.50 (12.19)	95.00
Control	90.00 (71.53)	0.00
S.Em $\pm$	0.48	-
CD ($p = 0.05$)	1.56	-

*Figures in parenthesis are angular transformed values

sample weight, were then used to calculate milli equivalents of acidity for each sample.

Statistics: The experimental data were subjected to analysis of variance (ANOVA) according to the appropriate experimental design. Percentage disease intensity data were subjected to arcsine square-root transformation before statistical analysis, while biochemical data were analysed using their original values. For factorial experiments, the main effects of salicylic acid concentration and disease status, as well as their interaction (SA concentration $\times$ disease status), were analysed. Treatment means were compared using the critical difference (CD) at the 5% level of significance.

Result and Discussion

Salicylic acid was evaluated against *C. canescens* *in vitro* at concentrations of 50, 100, 150 and 200 $\mu\text{g mL}^{-1}$. The data are presented in Table 1. The results showed that the efficacy of salicylic acid increased with increasing concentration (Fig. 1). All four concentrations of salicylic acid significantly inhibited the mycelial growth of *C. canescens*. Among the tested concentrations, 200 $\mu\text{g mL}^{-1}$ showed the highest efficacy, with 95.00% inhibition of mycelial growth, followed by 150 $\mu\text{g mL}^{-1}$ (89.26%) and 100 $\mu\text{g mL}^{-1}$ (77.77%). The minimum inhibition of mycelial growth (66.46%) was observed at 50 $\mu\text{g mL}^{-1}$ concentration of salicylic acid.

Efficacy of salicylic acid against leaf spot disease of moth bean under pot study

The efficacy of salicylic acid against leaf spot disease of moth bean was evaluated under pot conditions using the RMO-2251 variety. Salicylic acid was applied at 50, 100, 150 and 200 $\mu\text{g mL}^{-1}$. The data on per cent disease intensity and per cent disease control are presented in Table 2. All the tested concentrations of salicylic acid were significantly superior to the untreated control in reducing disease intensity. The 200 $\mu\text{g mL}^{-1}$ concentration was most effective, recording the lowest disease intensity (17.55%) and the highest disease control (63.02%), followed by 150 $\mu\text{g mL}^{-1}$ (20.69% disease intensity and 56.41% disease control) and 100 $\mu\text{g mL}^{-1}$ (26.61% disease intensity and 43.94% disease control). The 50 $\mu\text{g mL}^{-1}$ concentration was least effective, with the highest disease intensity (32.31%) and lowest disease control (31.93%).

Effect of salicylic acid on biochemical changes in the leaf tissues of moth bean response to leaf spot disease infection: Biochemical analysis viz., phenol, protein, total sugar and malic acid were done on healthy and infected plants, which show different reactions when treated with salicylic acid.

Effect on total phenol: The data presented in Table 3 revealed that phenol content of moth bean leaf tissues significantly increased due to

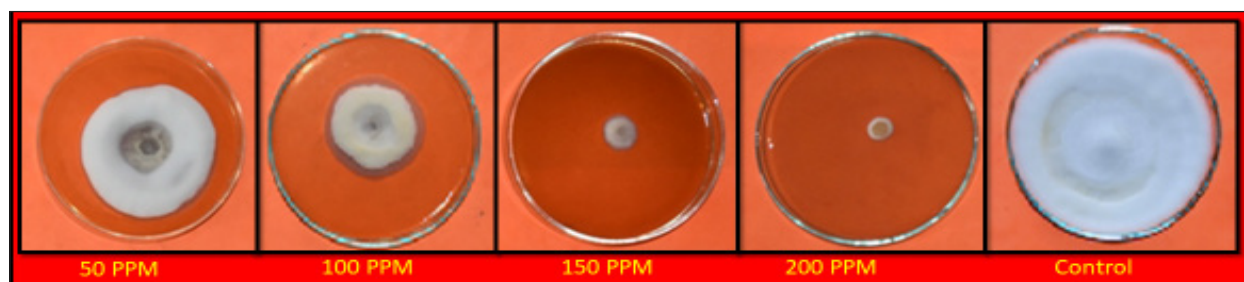


Fig.1. Efficacy of salicylic acid against *C. canescens* in *in vitro*

Table 2. Efficacy of salicylic acid against leaf spot disease of moth bean in pot condition

Salicylic acid ($\mu\text{g mL}^{-1}$)		Per cent disease intensity	Per cent disease control
Seed soaking	Foliar application		
50	50	32.31 (34.62)*	31.93
100	100	26.61 (30.99)	43.94
150	150	20.69 (27.04)	56.41
200	200	17.55 (24.74)	63.02
Control		47.47 (43.53)	0.00
S.Em $\pm$		0.85	-
CD (p = 0.05)		2.84	-

*Figures in parenthesis are angular transformed values.

Table 3. Effect of salicylic acid on phenol content in the leaf tissues of moth bean response to leaf spot disease infection

Salicylic acid ($\mu\text{g mL}^{-1}$)	Phenol (mg g^{-1} of fresh wt.)	
	Healthy	Infected
50	4.24 (11.87)*	4.44 (12.15)
100	4.47 (12.19)	4.75 (12.58)
150	4.88 (12.75)	5.13 (13.08)
200	5.56 (13.63)	6.11 (14.30)
Control	3.25 (10.38)	3.55 (10.85)
S.Em $\pm$	0.019	0.030
CD (P = 0.05)	0.061	0.095

*Figures in parenthesis are angular transformed values.

infection of *C. canescens* in all the four tested concentrations of salicylic acid, as well as in the untreated conditions. The phenol content varied significantly among the leaf tissues under different treatments. Diseased leaf tissues treated with 200 $\mu\text{g mL}^{-1}$ salicylic acid exhibited the highest phenol content (6.11 mg g^{-1} fresh weight), followed by those treated with 150 $\mu\text{g mL}^{-1}$ (5.13 mg g^{-1} FW) and 100 $\mu\text{g mL}^{-1}$ (4.75 mg g^{-1} FW). In comparison, healthy leaf tissues treated with the same concentrations of salicylic acid showed slightly lower phenol contents, with 5.56 mg g^{-1} FW at 200 $\mu\text{g mL}^{-1}$,

4.88 mg g^{-1} FW at 150 $\mu\text{g mL}^{-1}$, and 4.47 mg g^{-1} FW at 100 $\mu\text{g mL}^{-1}$.

The lowest phenol content among the salicylic acid treatments was recorded in healthy leaf tissues treated with 50 $\mu\text{g mL}^{-1}$ SA (4.24 mg g^{-1} FW), whereas diseased leaf tissues receiving the same concentration showed a slightly higher phenol content (4.44 mg g^{-1} FW). Under untreated conditions, phenol levels were at their minimum, with healthy leaf tissues showing 3.25 mg g^{-1} and diseased leaf tissues exhibiting a marginally higher value of 3.55 mg g^{-1} fresh weight.

Table 4. Effect of salicylic acid on soluble protein content in the leaf tissues of moth bean response to leaf spot disease infection

Salicylic acid ($\mu\text{g mL}^{-1}$)	Protein (mg g^{-1} of fresh wt.)	
	Healthy	Infected
50	14.50 (22.37)	15.27 (22.99)
100	15.47 (23.14)	16.43 (23.90)
150	17.01 (24.35)	18.53 (25.48)
200	18.23 (25.26)	20.53 (26.93)
Control	13.21 (21.30)	14.10 (22.04)
S.Em $\pm$	0.118	0.086
CD (p = 0.05)	0.378	0.273

Figures in parenthesis are angular transformed values.

Table 5. Effect of salicylic acid on total sugar content in the leaf tissues of moth bean response to leaf spot disease infection

Salicylic acid ($\mu\text{g mL}^{-1}$)	Total sugar (mg g^{-1} of fresh wt.)	
	Healthy	Infected
50	14.11 (22.05)	10.55 (18.94)
100	15.13 (22.88)	12.68 (20.85)
150	16.64 (24.06)	13.10 (21.21)
200	17.88 (25.00)	14.77 (22.59)
Control	11.19 (19.53)	8.24 (16.67)
S.Em $\pm$	0.033	0.032
CD ($p = 0.05$)	0.104	0.104

Figures in parenthesis are angular transformed values.

Effect on soluble protein

The soluble protein content in moth bean leaf tissues showed a significant increase following infection by *C. canescens* across all the four tested concentrations of salicylic acid, as well as in untreated conditions, when compared to healthy tissues (Table 4). The soluble protein content was observed to be highest in diseased leaf tissues treated with 200 $\mu\text{g mL}^{-1}$ salicylic acid (20.53 mg g^{-1} FW), followed by treatments with 150 $\mu\text{g mL}^{-1}$ (18.53 mg g^{-1} FW) and 100 $\mu\text{g mL}^{-1}$ (16.43 mg g^{-1} FW). In contrast, healthy leaf tissues treated with the same concentrations of salicylic acid showed lower protein levels, with 200 $\mu\text{g mL}^{-1}$ yielding 18.23 mg g^{-1} , 150 $\mu\text{g mL}^{-1}$ producing 17.01 mg g^{-1} and 100 $\mu\text{g mL}^{-1}$ resulting in 15.47 mg g^{-1} fresh weight.

The lowest soluble protein content among all salicylic acid treatments was recorded in healthy leaf tissues treated with 50 $\mu\text{g mL}^{-1}$ (14.50 mg g^{-1} FW), which increased to 15.27 mg g^{-1} under diseased conditions. Among untreated samples, healthy leaf tissues of moth bean exhibited the minimum protein content (13.21 mg g^{-1} FW), which rise to 14.10 mg g^{-1} under diseased conditions.

Effect on total sugar

The data presented in Table 5 revealed a significant reduction in the total sugar content in both salicylic acid treated and untreated diseased samples of moth bean leaf compared to the healthy ones.

The total sugar content (mg g^{-1} of FW) was observed to be consistently higher in healthy tissues compared to infected tissues across all salicylic acid (SA) treatments. The maximum total sugar content in healthy tissues was recorded at 200 $\mu\text{g mL}^{-1}$ SA (17.88 mg g^{-1}),

followed by 150 $\mu\text{g mL}^{-1}$ (16.64 mg g^{-1}), 100 $\mu\text{g mL}^{-1}$ (15.13 mg g^{-1}), and 50 $\mu\text{g mL}^{-1}$ (14.11 mg g^{-1}). The lowest sugar content in healthy tissues was observed in the control group (11.19 mg g^{-1}).

In infected tissues, a similar trend was noted, with the highest sugar content at 200 $\mu\text{g mL}^{-1}$ SA (14.77 mg g^{-1}), followed by 150 $\mu\text{g mL}^{-1}$ (13.10 mg g^{-1}), 100 $\mu\text{g mL}^{-1}$ (12.68 mg g^{-1}) and 50 $\mu\text{g mL}^{-1}$ (10.55 mg g^{-1}). The control group showed the lowest sugar content under infected conditions (8.24 mg g^{-1}).

Effect on malic acid

The malic acid content in the moth bean leaf tissues significantly reduced following *C. canescens* infection, across all the four tested concentrations of salicylic acid and in the untreated samples. This decrease was observed when compared to the levels found in the healthy control samples (Table 6). The maximum malic acid content was observed in healthy leaf tissues treated with 200 $\mu\text{g mL}^{-1}$ salicylic acid (6.87 $\mu\text{g 100 g}^{-1}$), followed by 150 $\mu\text{g mL}^{-1}$ (5.49 $\mu\text{g 100 g}^{-1}$), 100 $\mu\text{g mL}^{-1}$ (4.83 $\mu\text{g 100 g}^{-1}$) and 50 $\mu\text{g mL}^{-1}$ (4.09 $\mu\text{g 100 g}^{-1}$). After *C. canescens* infection, these values decreased to 6.02, 4.95, 4.10 and 3.78 $\mu\text{g 100 g}^{-1}$, respectively. In healthy and untreated condition, the malic acid content was found 3.56 $\mu\text{g 100 g}^{-1}$ and it decreased to 3.14 $\mu\text{g 100 g}^{-1}$ in the diseased condition.

These findings are in agreement with earlier reports of Abdel Aal *et al.* (2019) and Malik *et al.* (2023), who demonstrated the effectiveness of salicylic acid and other defense activators in reducing disease incidence and severity and improving crop performance. These findings support the potential of salicylic acid as an effective inducer of resistance against

Table 6. Effect of salicylic acid on malic acid content in the leaf tissues of moth bean response to leaf spot disease infection

Salicylic acid ($\mu\text{g mL}^{-1}$)	Malic acid ($\mu\text{g g}^{-1}$ of fresh wt.)	
	Healthy	Infected
50	4.09 (11.66)*	3.78 (11.20)
100	4.83 (12.68)	4.10 (11.67)
150	5.49 (13.54)	4.95 (12.85)
200	6.87 (15.18)	6.02 (14.19)
Control	3.56 (10.87)	3.14 (10.20)
S.Em $\pm$	0.219	0.220
CD (p = 0.05)	0.699	0.703

*Figures in parenthesis are angular transformed values.

Cercospora leaf spot through activation of plant defense mechanisms.

The present findings are also consistent with El-Shazly *et al.* (2018) and Ahmed *et al.* (2019), who reported that salicylic acid, alone or in combination with other disease-management treatments, reduced disease severity and enhanced crop performance. These studies further support the role of salicylic acid in inducing resistance against fungal pathogens.

Phenolic compounds play an important role in plant defense through mechanisms such as lignification, hypersensitive responses, phytoalexin production, and direct toxicity against pathogens (Nicholson and Hammerschmidt, 1992). Shukla *et al.* (2014) and Sunil *et al.* (2009) similarly reported higher phenol accumulation in resistant or moderately resistant mungbean cultivars following infection with *C. truncatum* and *Cercospora* leaf spot, respectively. The increased phenol content observed in the present study, particularly with SA treatment, therefore suggests enhanced defense activation in moth bean against *C. canescens*.

The increased protein content observed following SA application is also consistent with the proposed role of pathogenesis-related proteins in plant defense (Antoniw *et al.*, 1980; Boller, 1985). Gupta *et al.* (2010) and Adesh (2008) also reported biochemical changes, including increased protein and phenolic contents, associated with induced resistance against plant pathogens. These observations support the role of SA in strengthening biochemical defense responses in moth bean.

The reduction in sugar content in diseased tissues observed in the present study agrees with previous reports of reduced sugar

accumulation following *Cercospora* and anthracnose infections (Ghosh *et al.*, 2003; Kulkarni and Benagi, 2013). Such depletion may be associated with increased utilization of host sugars by the pathogen during infection (Jyothi *et al.*, 2018). The present findings further suggest that SA treatment may help maintain sugar metabolism under disease stress.

The significant reduction in malic acid content in *C. canescens*-infected moth bean leaves indicates disruption of host metabolism during disease development. A similar pattern of changes in malic acid content during disease progression was reported by Kiran *et al.* (2020) in *Calotropis procera*. The partial restoration of malic acid content at higher SA concentrations observed in the present study suggests that SA may contribute to maintaining metabolic stability and enhancing host defense under pathogen stress. Salicylic acid is known to regulate several physiological and defense-related processes and to contribute to plant tolerance against biotic and abiotic stresses (Radwan *et al.*, 2008; Sytar *et al.*, 2019; Khan *et al.*, 2020).

Conclusions

The study demonstrated that salicylic acid treatments effectively inhibited the mycelial growth of *C. canescens* in a concentration-dependent manner, with 200 $\mu\text{g mL}^{-1}$ achieving the greatest growth inhibition (95%). Additionally, salicylic acid reduced disease intensity in moth bean, with 200 $\mu\text{g mL}^{-1}$ showing the highest efficacy, resulting in the lowest disease intensity and the greatest disease control. Lower concentrations (50 $\mu\text{g mL}^{-1}$) were less effective, leading to higher disease intensity. These findings highlight the potential of salicylic acid, particularly at higher

concentrations, as an effective tool for disease management in moth bean crops.

Salicylic acid treatment significantly influenced the biochemical responses of moth bean plants to fungal infection. It enhanced phenol and protein contents, indicating an improved defense mechanism, particularly at 200 $\mu\text{g mL}^{-1}$ concentration. Diseased tissues exhibited higher phenol and protein levels compared to healthy ones, emphasizing the role of these compounds in plant defense. Although infection reduced sugar and malic acid levels, higher salicylic acid concentrations helped mitigate this decline. Overall, salicylic acid plays a crucial role in boosting the plant's defense and metabolic stability, improving tolerance to fungal infections and enhancing crop resilience.

Declarations

The authors have no competing interests.

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