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### Research Article

## Enhancing Cabbage Resistance to Bacterial Leaf Spot through Plant Defense Activators and Epidemiological Analysis

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### ABSTRACT

Bacterial leaf spot of cabbage, caused by *Pseudomonas syringae* pv. *maculicola*, is a destructive disease that significantly reduces yield and market quality. Environmentally safe management strategies and reliable disease forecasting tools are needed to minimize reliance on synthetic bactericides. Therefore, the present study evaluated selected plant defense activators under greenhouse and *in vivo* conditions and developed a predictive model based on epidemiological variables. Under greenhouse conditions, salicylic acid exhibited the lowest mean disease incidence (24.76%), followed by citric acid (27.43%), benzoic acid (29.58%), and  $K_2HPO_4$  (33.32%), compared with the untreated control. Disease suppression was more pronounced at lower concentrations, with salicylic acid at 0.25% recording the minimum incidence (21.35%). Temporal analysis further confirmed that salicylic acid consistently reduced disease progression across observation intervals. Similar trends were observed under *in vivo* conditions, where salicylic acid resulted in the lowest disease incidence (27.73%) and maintained superior suppression over time. Environmental analysis revealed that peak disease incidence occurred at 26-30°C maximum temperature, 10-15°C minimum temperature, 69-73% relative humidity, 0.5-1.0 mm rainfall, and 1.5-2.0 km h<sup>-1</sup> wind speed. A multiple linear regression model developed using two-year data ( $R^2 = 0.804$ ) explained 80.4% of the variability in disease incidence. Diagnostic and validation analyses demonstrated strong agreement between predicted and observed values, confirming model reliability. In conclusion, salicylic acid proved to be the most effective defense activator, and the developed predictive model offers a robust decision-support tool for sustainable management of bacterial leaf spot in cabbage.

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### Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.), a member of the family Brassicaceae, is an economically important leafy vegetable cultivated worldwide. It originated along

the Atlantic and Mediterranean coasts of Europe and has since been widely disseminated across temperate and subtropical regions. Cabbage is highly valued for its nutritional composition, serving as a rich source of

vitamins (particularly vitamin C and K), carbohydrates, proteins, minerals, calcium, iron, and other essential nutrients (Shabir et al., 2024). In addition to its nutritional significance, *Brassica* species contain diverse bioactive phytochemicals, including polyphenols, phenolic acids, flavonoids, and carotenoids, which contribute to antioxidant activity and are associated with reduced risks of chronic diseases such as diabetes, ulcers, and hyperglycemia (Tripathi et al., 2017).

Globally, cabbage is cultivated on approximately 2.45 million hectares, with an annual production of about 71.70 million tons. In Pakistan, it is grown on nearly 5.8 thousand hectares, producing approximately 111.06 thousand tons annually (GOP, 2023-24), highlighting its importance in both global and national vegetable production systems.

Despite its economic value, cabbage is susceptible to numerous fungal and bacterial diseases. Among bacterial pathogens, *Pseudomonas syringae* pv. *maculicola* is one of the most destructive, causing bacterial leaf spot in cabbage. Under favorable environmental conditions, this pathogen can cause severe epidemics, resulting in yield losses of up to 80-100% (Schofield et al., 2012). *P. syringae* pv. *maculicola* is a gram-negative, rod-shaped bacterium possessing a polar flagellum (Katagiri et al., 2002). The pathogen can survive in infected crop residues and is disseminated through infected seeds, insect vectors, irrigation water, and rain splash (Kim et al., 2022). Characteristic symptoms include small, dark, water-soaked lesions that enlarge and become necrotic, leading to significant deterioration of marketable leaves (Zhao et al., 2000).

Several strategies are employed for the management of plant diseases, including the use of resistant cultivars, cultural practices, chemical bactericides, and biological control agents. During severe outbreaks, synthetic chemicals are often relied upon due to their rapid and broad-spectrum action. However, excessive and indiscriminate application of agrochemicals poses serious risks to human and animal health, promotes environmental contamination, and may lead to the development of pathogen resistance (Chhipa, 2019). Therefore, sustainable and environmentally safe alternatives are urgently needed.

Plant defense activators represent a promising alternative approach. These compounds enhance the innate defense capacity of plants by stimulating their immune responses rather than directly targeting the pathogen (Sun et al.,

2015). Plant activators induce systemic acquired resistance (SAR), a broad-spectrum and long-lasting defense response mediated primarily through the salicylic acid signaling pathway (Achuo et al., 2004; Ahmad et al., 2010). Key signaling molecules such as salicylic acid regulate defense-related gene expression, thereby strengthening resistance against diverse biotic and abiotic stresses (Simaei et al., 2012; Atiq et al., 2024).

Environmental factors such as temperature, relative humidity, and rainfall play critical roles in pathogen survival, infection, and disease progression, thereby influencing epidemic development. Understanding the relationship between environmental variables and disease dynamics is essential for developing reliable forecasting systems. Disease prediction models, based on environmental monitoring and disease incidence data, enable proactive implementation of management strategies and help minimize economic losses (McGuffie and Henderson-Sellers, 2014).

Therefore, the present study was undertaken to evaluate the role of plant defense activators in enhancing resistance against bacterial leaf spot of cabbage and to determine the key environmental factors associated with disease development caused by *P. syringae* pv. *maculicola*.

## Materials and Methods

### Isolation and purification of the bacterium

Symptomatic cabbage leaves showing typical bacterial leaf spot symptoms were collected from different localities of district Faisalabad, Punjab, Pakistan, including Samundri, Jaranwala, and the Ayub Agricultural Research Institute (AARI). Samples were placed in sterile brown paper bags (12 × 8 inches), properly labeled with collection site and date, and transported to the laboratory. Nutrient agar (NA) medium was prepared by dissolving 28 g of commercial NA powder in 1 L of distilled water, followed by sterilization in an autoclave (HV-1330-HA) at 121°C and 15 psi for 15 min.

Collected leaf samples were washed under running tap water to remove debris and air-dried at room temperature. Small sections (2-3 mm), including diseased tissue along with a small portion of adjacent healthy tissue, were excised using sterile forceps. Surface sterilization was performed with 1% sodium hypochlorite (NaOCl) for 30 sec (Singh et al., 2014; Asif et al., 2023), followed by rinsing with sterile distilled water and blot drying on sterile filter paper. The sterilized tissue pieces were aseptically placed on

solidified NA plates. Plates were sealed with parafilm and incubated at  $25 \pm 2^\circ\text{C}$ .

Emerging bacterial colonies were purified using the single-colony streaking technique. A well-isolated colony was streaked onto fresh NA plates using a sterile inoculating loop and incubated under the same conditions (Ranjan et al., 2021). Pure cultures were maintained for further characterization and experimentation.

#### Identification and preservation of the pathogen

Preliminary identification of the bacterial isolate was based on colony morphology (color, shape, elevation, margin, and growth pattern) and standard biochemical tests, including gram staining and the KOH solubility test (Sharma and Singh, 2019; Ali et al., 2024).

For long-term preservation, nutrient broth (NB) was prepared and sterilized. A loopful of pure bacterial culture was inoculated into NB and incubated at  $28^\circ\text{C}$  for 24 h in a shaking incubator to obtain dense growth. Subsequently, 1 ml of bacterial suspension was mixed with 1 ml of sterile glycerol (1:1, v/v) in 2.5 ml microcentrifuge tubes and stored at  $-18^\circ\text{C}$  in a refrigerator (Model SI-207IZ).

#### Pathogenicity test

Pathogenicity was confirmed by fulfilling Koch's postulates. A bacterial suspension was prepared in sterile distilled water and adjusted to approximately  $1 \times 10^8$  CFU  $\text{ml}^{-1}$  using a spectrophotometer (Hitachi U-2001).

Cabbage seeds were procured from local seed suppliers in Faisalabad and sown in earthen pots ( $28 \times 14$  cm) filled with sandy loam soil in the research area of the Department of Plant Pathology, University of Agriculture Faisalabad (UAF). At 45 days after sowing, plants were inoculated by foliar spraying with the bacterial suspension using a hand sprayer (Planas-Marquès et al., 2018). Control plants were sprayed with sterile distilled water.

After symptom development, infected leaf tissues were re-isolated, and the recovered bacterium was compared morphologically and biochemically with the original culture to confirm pathogenicity.

#### Evaluation of plant defense activators under greenhouse conditions

Four plant defense activators, benzoic acid, citric acid, salicylic acid, and dipotassium phosphate ( $\text{K}_2\text{HPO}_4$ ), were evaluated at three concentrations (0.25%, 0.50%, and 0.75%) under greenhouse conditions. Solutions were prepared by dissolving 0.25, 0.50, and 0.75 g of each compound in 100 ml of distilled water.

Cabbage plants were grown in earthen pots containing sandy loam soil. At 45 days of age, plants were artificially

inoculated with a bacterial suspension ( $1 \times 10^8$  CFU  $\text{ml}^{-1}$ ). Following symptom appearance, the respective plant defense activators were applied as foliar sprays at the designated concentrations. Distilled water served as the untreated control.

The experiment was arranged in a Completely Randomized Design (CRD) with three replications per treatment. Disease incidence was recorded at 5-day intervals over 15 days using the formula described by Prasad et al. (2021):

$$\text{Disease incidence (\%)} = \frac{\text{Number of Infected Fruits}}{\text{Total Number of Plants}} \times 100$$

#### Evaluation of plant defense activators under field conditions

Field experiments were conducted at the research field of the Department of Plant Pathology, UAF. Cabbage plants were inoculated at 45 days of age with a bacterial suspension ( $1 \times 10^8$  CFU  $\text{ml}^{-1}$ ) using a hand sprayer during early morning hours to facilitate infection (Planas-Marquès et al., 2018).

After symptom development, the most effective concentration (0.75%) of each activator identified under greenhouse conditions was evaluated under field conditions. Distilled water served as the control treatment.

The experiment was conducted in a Randomized Complete Block Design (RCBD) with three replications. Disease incidence (%) was recorded at 5, 10, and 15 days after treatment application.

#### Characterization of epidemiological factors

Environmental factors conducive to bacterial leaf spot development were monitored under field conditions. Data on relative humidity (%), rainfall (mm), temperature ( $^\circ\text{C}$ ), and wind speed ( $\text{km h}^{-1}$ ) were obtained from the Agricultural Meteorology Cell, Department of Crop Physiology, UAF.

Weekly averages were calculated from October to December 2023. Disease incidence and infection periods were recorded weekly using a standard disease rating scale. Correlation and regression analyses were conducted to evaluate the relationship between environmental variables and disease development.

#### Regression and statistical analysis

Regression analysis was performed to determine the influence of environmental factors on disease development and to identify optimal conditions for bacterial leaf spot progression. Stepwise regression was used to develop a disease prediction model based on significant environmental variables.

Model selection was based on coefficient of determination ( $R^2$ ) and Mean Square Error (MSE). Analysis of variance (ANOVA) was conducted to assess treatment effects. The Least Significant Difference (LSD) test was applied for mean comparison (Steel et al., 1997). Greenhouse and field data were analyzed using SAS software under CRD and RCBD experimental designs, respectively.

## Results

### Evaluation of plant defense activators against bacterial leaf spot of cabbage under greenhouse conditions

Among the tested treatments, salicylic acid resulted in the lowest mean disease incidence (24.76%), followed by citric acid (27.43%), benzoic acid (29.58%), and  $K_2HPO_4$  (33.32%), compared with the untreated control (Figure 1). Analysis of the treatment  $\times$  concentration (T  $\times$  C) interaction revealed that disease incidence decreased at lower concentrations of the tested elicitors. The lowest disease incidence was recorded with salicylic acid at 0.25% (21.35%), followed by 0.50% (25.66%) and 0.75% (27.27%). A similar trend was observed for citric acid, which exhibited disease incidence values of 24.60%, 28.09%, and 29.61% at 0.25%, 0.50%, and 0.75%, respectively. Benzoic acid resulted in 27.43%, 30.00%, and 31.31% disease incidence, whereas  $K_2HPO_4$  showed comparatively higher values of 31.12%, 33.44%, and

35.39% at the corresponding concentrations (Figure 2). The treatment  $\times$  days (T  $\times$  D) interaction demonstrated temporal variation in disease development. The highest disease incidence across observation intervals was recorded with  $K_2HPO_4$  (36.21%, 32.87%, and 30.87%), followed by benzoic acid (32.18%, 29.47%, and 27.08%), citric acid (30.13%, 27.39%, and 24.77%), and salicylic acid (27.99%, 24.30%, and 21.99%) at 5, 10, and 15 days after treatment, respectively, relative to the control (Figure 3). Overall, salicylic acid consistently provided the greatest suppression of bacterial leaf spot under greenhouse conditions.

### Evaluation of plant defense activators against bacterial leaf spot of cabbage under in vivo conditions

Among the treatments tested, salicylic acid resulted in the lowest disease incidence (27.73%), followed by Citric acid (32.77%), Benzoic acid (38.32%), and  $K_2HPO_4$  (38.39%), compared to the untreated control (Figure 4). Analysis of the treatment  $\times$  time interaction (T  $\times$  D) revealed that Salicylic acid consistently provided the highest disease suppression, with disease incidence of 32.03%, 27.00%, and 24.17% at 5, 10, and 15 days post-treatment, respectively. This was followed by Citric acid (37.50%, 32.33%, and 28.47%), Benzoic acid (41.93%, 38.27%, and 34.77%), and  $K_2HPO_4$  (42.50%, 38.67%, and 34.00%) over the same period, relative to the control (Figure 5).

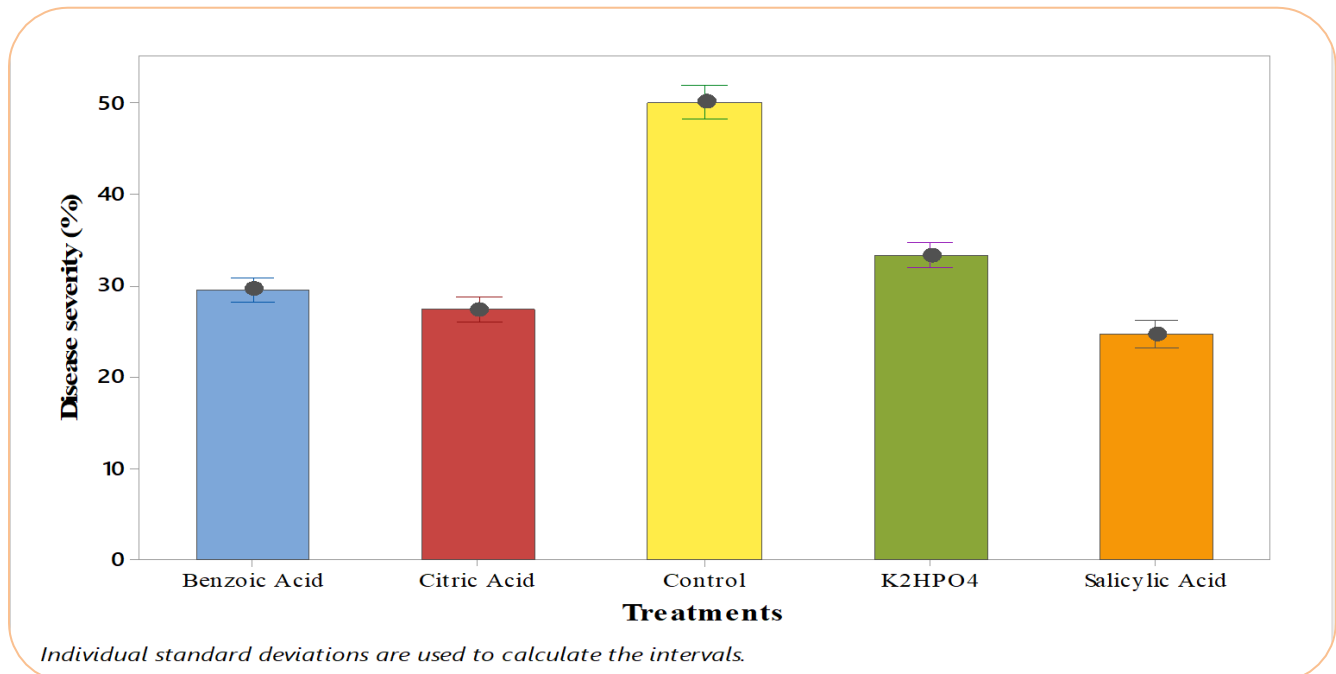


Figure 1. Evaluation of plant defense activators against bacterial leaf spot of cabbage under greenhouse conditions.

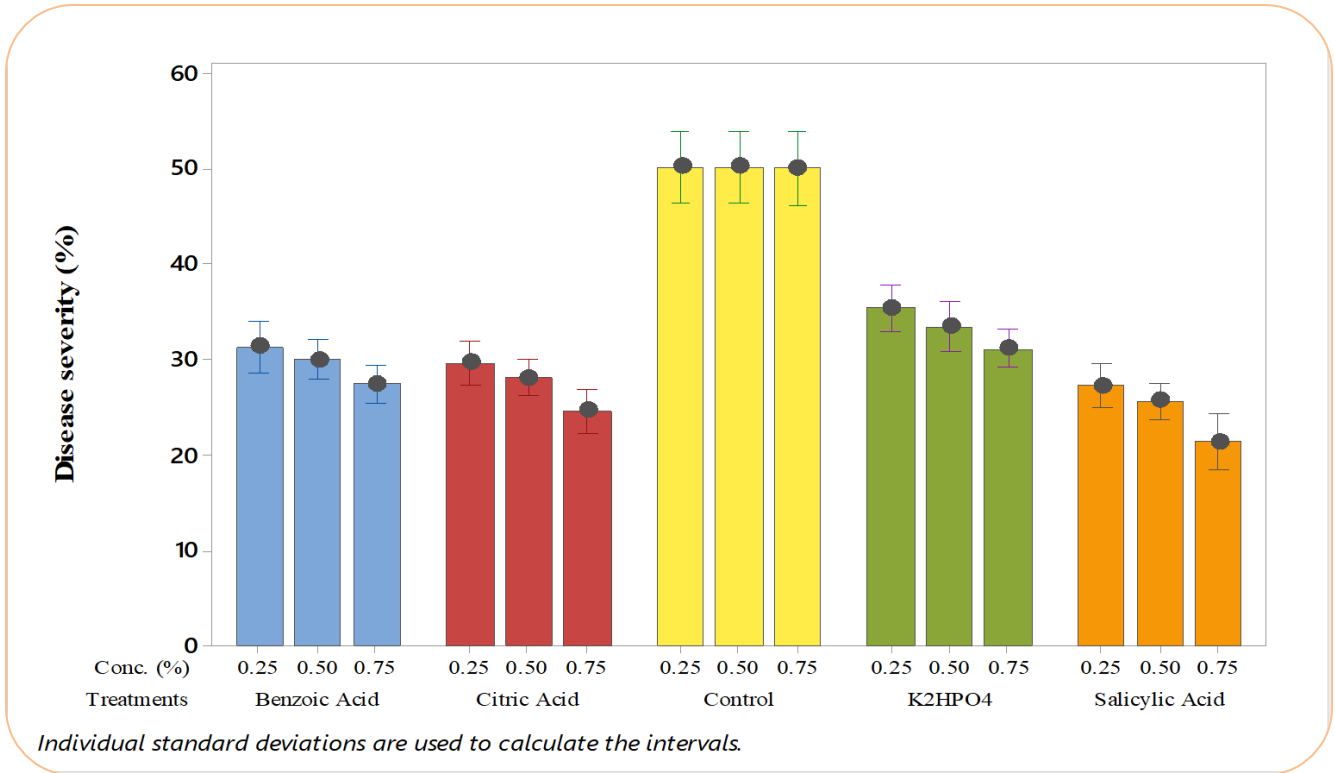


Figure 2. Interaction effects of treatments and concentrations (T × C) on bacterial leaf spot severity in cabbage under greenhouse conditions.

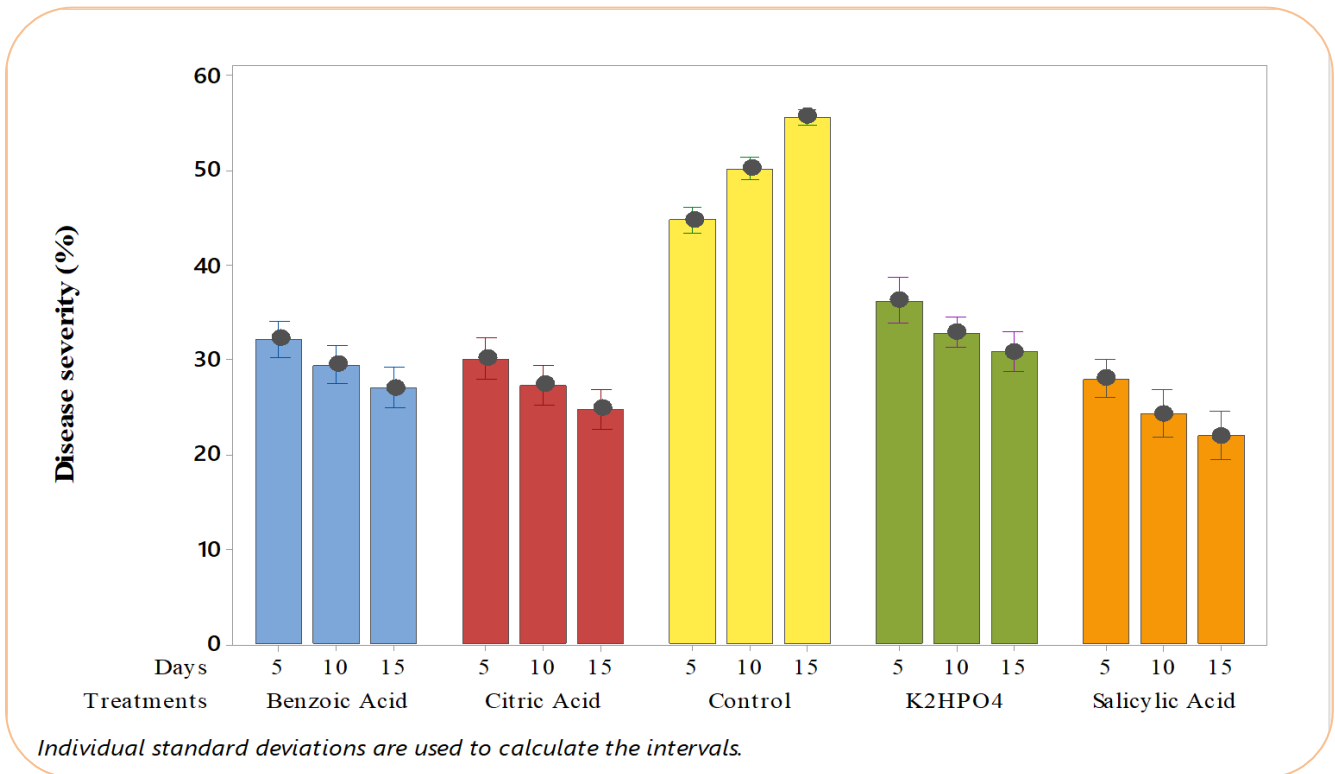


Figure 3. Interaction effect of treatments and time (T × D) on bacterial leaf spot severity in cabbage under greenhouse conditions.

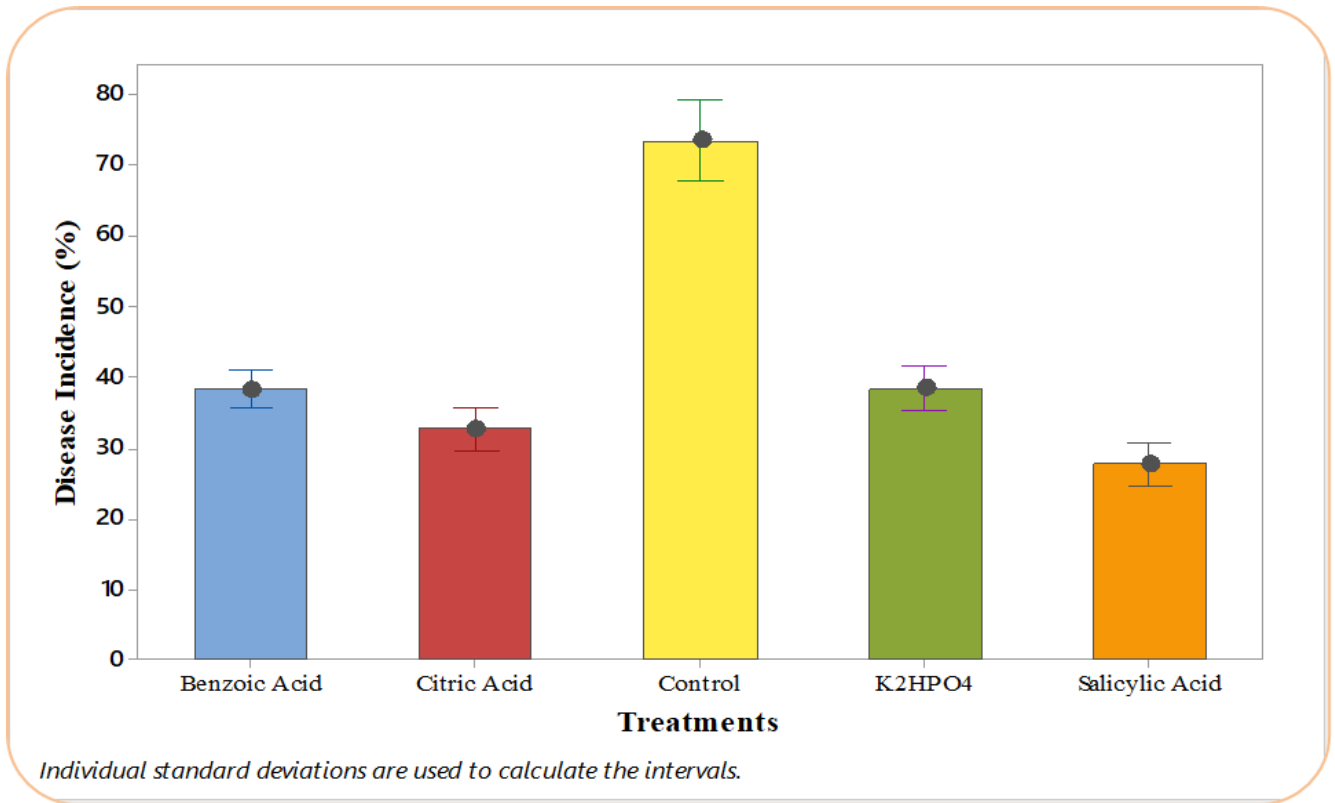


Figure 4. Evaluation of plant defence activators for controlling bacterial leaf spot in cabbage under field conditions.

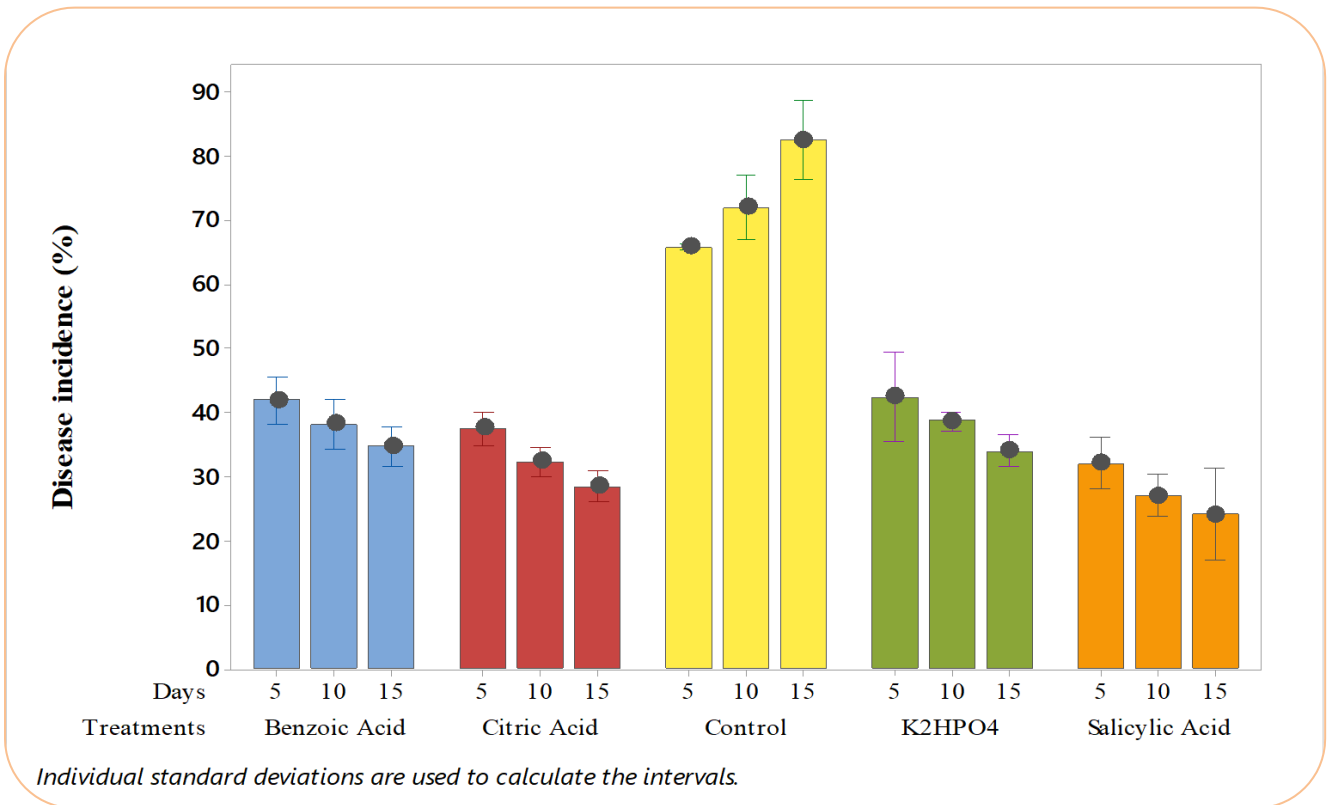


Figure 5. Effect of treatment × day interaction (T × D) on bacterial leaf spot of cabbage under field conditions.

**Correlation and characterization of environmental factors conducive to the development of bacterial leaf spot of cabbage**

Three cabbage lines (V201, V205, and V209) were evaluated to determine the influence of environmental factors, maximum temperature, minimum temperature, rainfall, relative humidity, and wind speed, on the development of bacterial leaf spot (Table 1).

Analysis of the relationship between disease incidence and maximum temperature indicated that the highest disease incidence occurred within the temperature range of 26-30°C (Figure 6). Similarly, with respect to minimum temperature, peak disease incidence was observed within the range of 10-15°C (Figure 7). Correlation analysis revealed an inverse relationship between maximum and minimum temperatures, indicating that as one variable increased, the other decreased.

Relative humidity showed a positive but statistically non-significant correlation with disease incidence. The highest disease incidence was recorded at 69-73% relative humidity (Figure 8). Rainfall also exhibited a positive but non-significant association with disease incidence, with maximum disease levels observed at 0.5-1.0 mm rainfall (Figure 9). Likewise, wind speed demonstrated a positive yet non-significant correlation across all tested lines, with peak disease incidence occurring at wind speeds of 1.5-2.0 km h<sup>-1</sup> (Figure 10). Overall, the results suggest that relative humidity, rainfall, and wind speed are positively associated with disease severity, although these relationships were not statistically significant. Increasing levels of these environmental factors tended to coincide with increased disease severity, indicating their potential contributory role in the epidemiology of bacterial leaf spot in cabbage.

Table 1. Correlation and characterization of environmental factors favouring the development of bacterial leaf spot in cabbage.

Lines	Max. Temperature (°C)	Min. Temperature (°C)	(%) Relative Humidity	Rainfall (mm)	Wind Speed (km/h)
V201	0.000**	0.001**	0.011*	0.049*	0.003**
V202	0.002**	0.030**	0.003*	0.009**	0.008**
V203	0.003**	0.006**	0.002*	0.014*	0.003**
V204	0.000**	0.002**	0.012*	0.006*	0.001**
V205	0.000**	0.009**	0.005*	0.039*	0.000**
V206	0.001**	0.013**	0.022*	0.005*	0.005**
V207	0.003**	0.033*	0.003*	0.008*	0.006**
V208	0.001**	0.015*	0.003*	0.019*	0.001**
V209	0.001**	0.0312*	0.001*	0.003*	0.002**
V210	0.001**	0.012*	0.011*	0.006*	0.003**

\*\* = Highly Significant at P < 0.05; \* = Significant at P < 0.05.

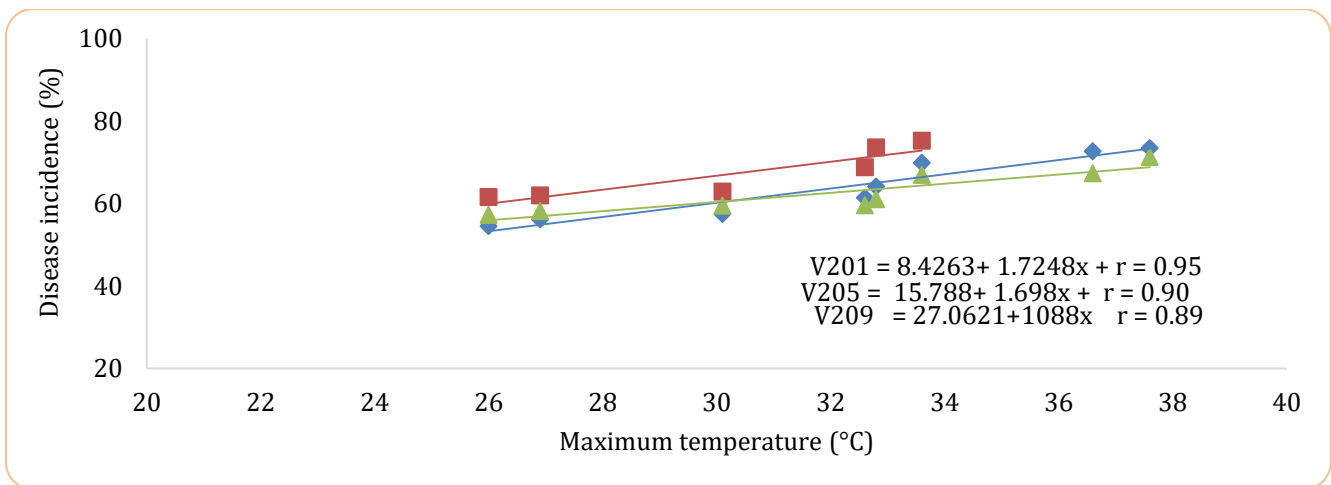


Figure 6. Effect of maximum temperature on the incidence of bacterial leaf spot in cabbage.

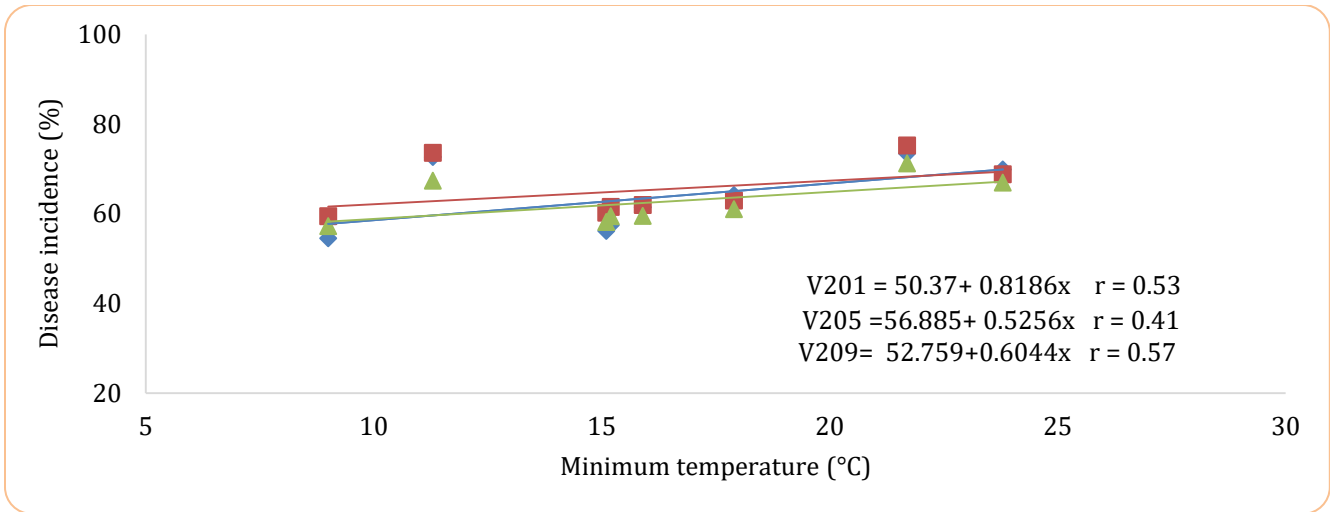


Figure 7. Effect of minimum temperature on the incidence of bacterial leaf spot in cabbage.

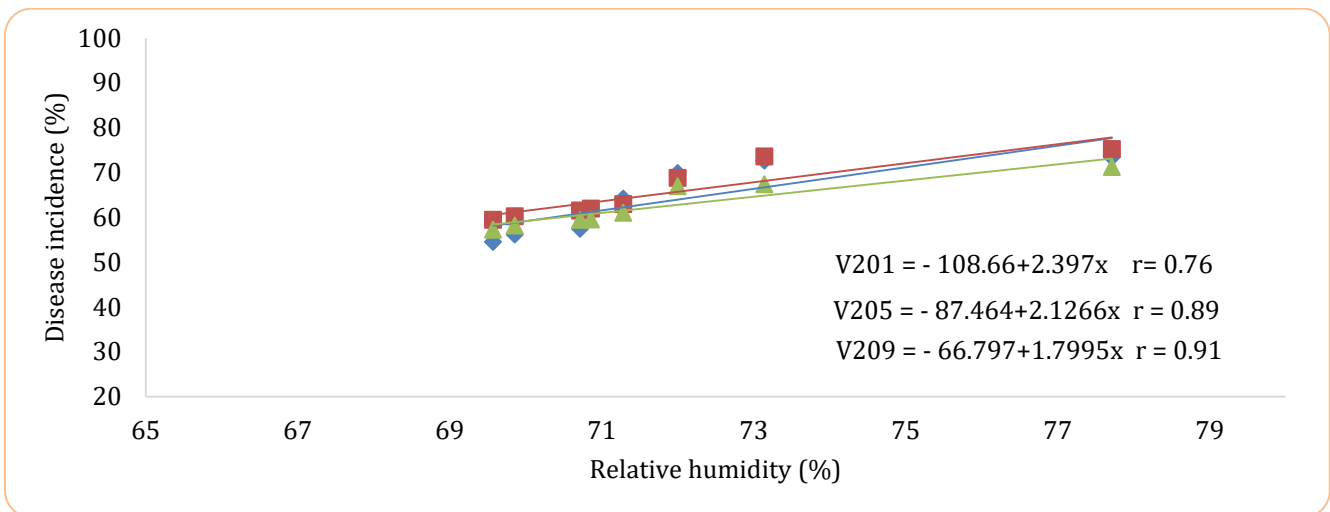


Figure 8. Effect of relative humidity on the incidence of bacterial leaf spot in cabbage.

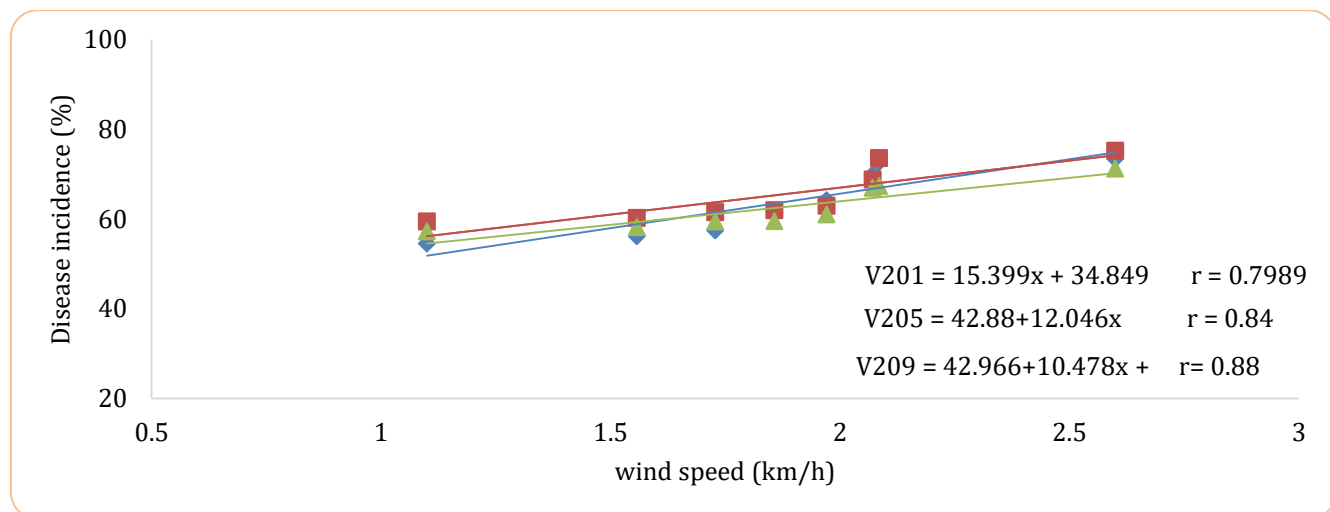


Figure 9. Effect of wind speed on the incidence of bacterial leaf spot in cabbage.

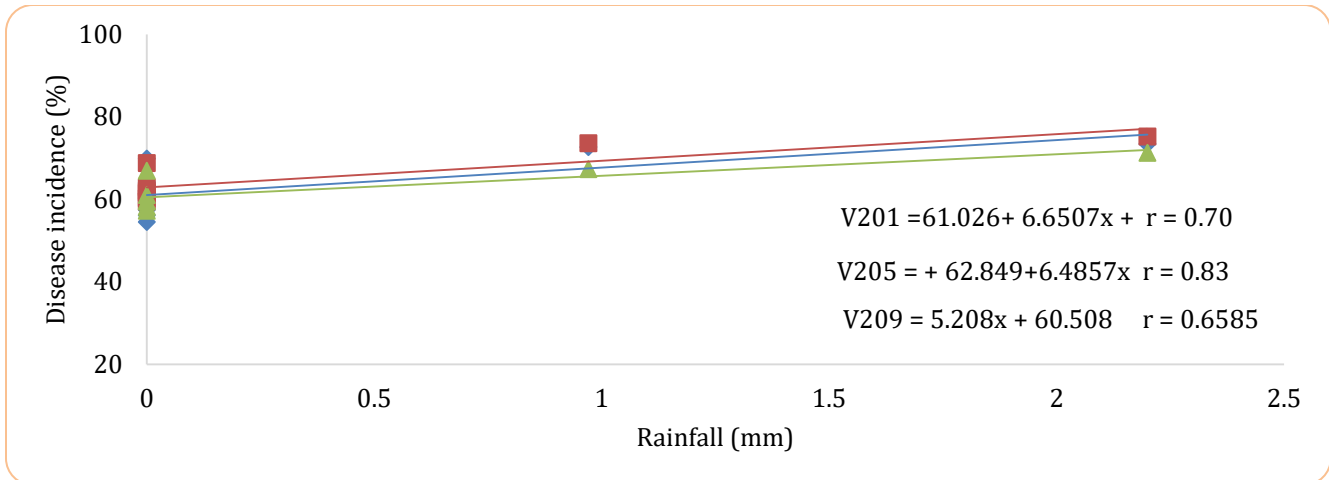


Figure 10. Effect of rainfall on the incidence of bacterial leaf spot in cabbage.

### Development and evaluation of a bacterial leaf spot predictive model based on two-year data

A multiple linear regression model was developed to predict bacterial leaf spot incidence using two years of epidemiological and meteorological data. The derived regression equation is:

$Y = 194 - 2.32X_1 + 1.14X_2 + 0.774X_3 - 7.81X_4 - 0.827X_5$   
 where Y represents disease incidence (%), and  $X_1$ ,  $X_2$ ,  $X_3$ ,  $X_4$ , and  $X_5$  denote maximum temperature ( $^{\circ}\text{C}$ ), minimum temperature ( $^{\circ}\text{C}$ ), rainfall (mm), wind speed ( $\text{km h}^{-1}$ ), and relative humidity (%), respectively.

The coefficient of determination ( $R^2 = 0.804$ ) indicates that 80.4% of the variation in disease incidence was explained by the selected environmental variables, demonstrating strong model performance under the prevailing agro-climatic conditions. The negative coefficients for maximum temperature, wind speed, and relative humidity suggest an inverse relationship with disease incidence, whereas minimum temperature and rainfall showed positive associations.

Diagnostic plots further supported model adequacy. The normal probability plot of residuals (Figure 11) showed that most data points closely followed the reference line, indicating approximate normality of residuals. The residuals versus fitted values plot revealed a random distribution around zero, suggesting homoscedasticity and absence of systematic bias. Although a few observations deviated slightly from the reference line, with residual values ranging from -7.5 to +5, these deviations were minor and did not substantially affect overall model validity. The modeling approach followed the statistical procedures described by Chattefuee and

Haddi (2006), ensuring methodological rigor in model development and evaluation.

### Assessment of the disease predictive model through regression analysis based on physical principles

The performance of the disease prediction model was evaluated by examining the relationships between the dependent variable (disease development) and the independent environmental variables using regression analysis grounded in underlying physical and epidemiological principles. Analysis of variance (ANOVA) of the regression model demonstrated that maximum and minimum temperature ( $T_{\text{max}}$  and  $T_{\text{min}}$ ), relative humidity (RH), rainfall (RF), and wind speed (WS) significantly contributed to disease development.

The coefficient of determination ( $R^2 = 80.4\%$ ) indicates that 80.4% of the variability in disease incidence is explained by the selected environmental variables, confirming that the model provides a strong statistical fit under the prevailing environmental conditions. The estimated regression coefficients for cabbage are presented in Table 2.

### Estimation of model performance based on predicted and observed values

Model performance was evaluated by comparing predicted values with the corresponding observed data points. Discrepancies between observed and predicted values were analyzed to assess the reliability and predictive accuracy of the model. Five observed data points deviated from the reference line (standard error = 2.83139), indicating the presence of experimental error. The graphical analysis demonstrated strong concordance between predicted and observed values,

reflecting a good overall model fit. Notably, 10 out of 30 predictions exhibited discrepancies of less than 5 units and were confined within both the 95% confidence interval (CI) and the 95% prediction interval (PI)

(Figure 12). These results indicate that the majority of predictions were statistically robust and fell within acceptable uncertainty bounds, thereby confirming the dependability of the model.

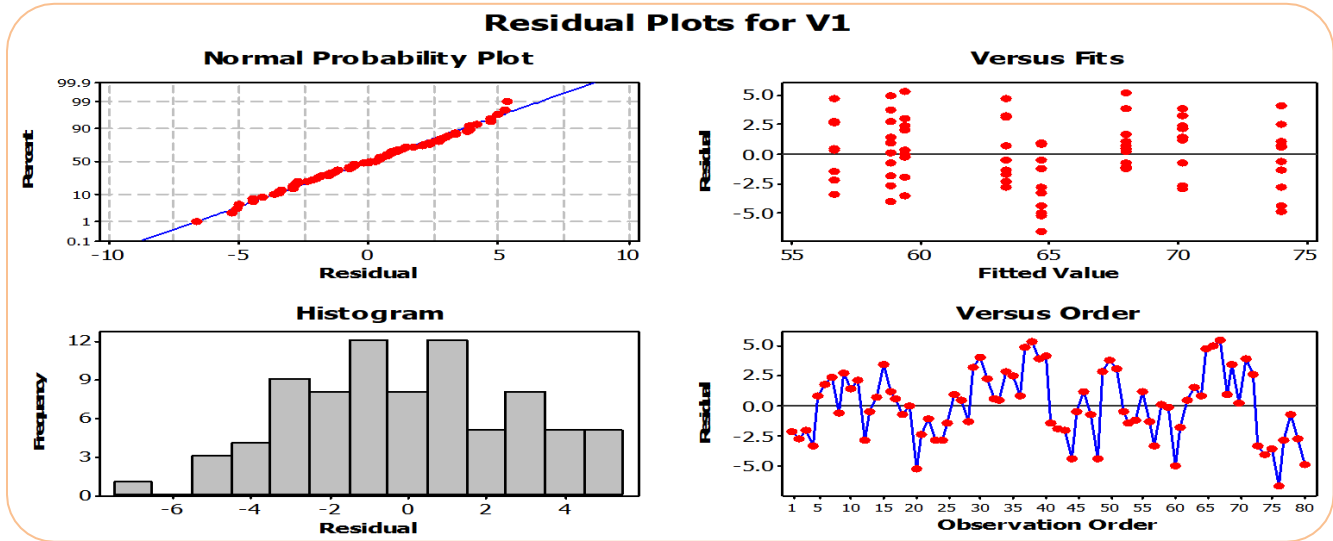


Figure 11. Residual plots of observed disease incidence for the bacterial leaf spot predictive model based on two years of data.

Table 2. Regression coefficients of variables affecting bacterial leaf spot in cabbage.

Parameter	Coefficient	Standard Error	t-Stat	P-value
Intercept	487.9	154.3	3.16	0.002*
Max. temp. (°C)	3.0268	0.5803	5.22	0.000*
Min. temp. (°C)	1.5642	0.4142	3.78	0.000*
Rain fall (mm)	21.799	6.364	3.43	0.001*
Wind Speed (km/h)	17.693	5.751	3.08	0.003*
Relative Humidity (%)	7.252	2.394	3.03	0.003*

\* = Significant at P < 0.05; NS = Non-Significant at P > 0.05.

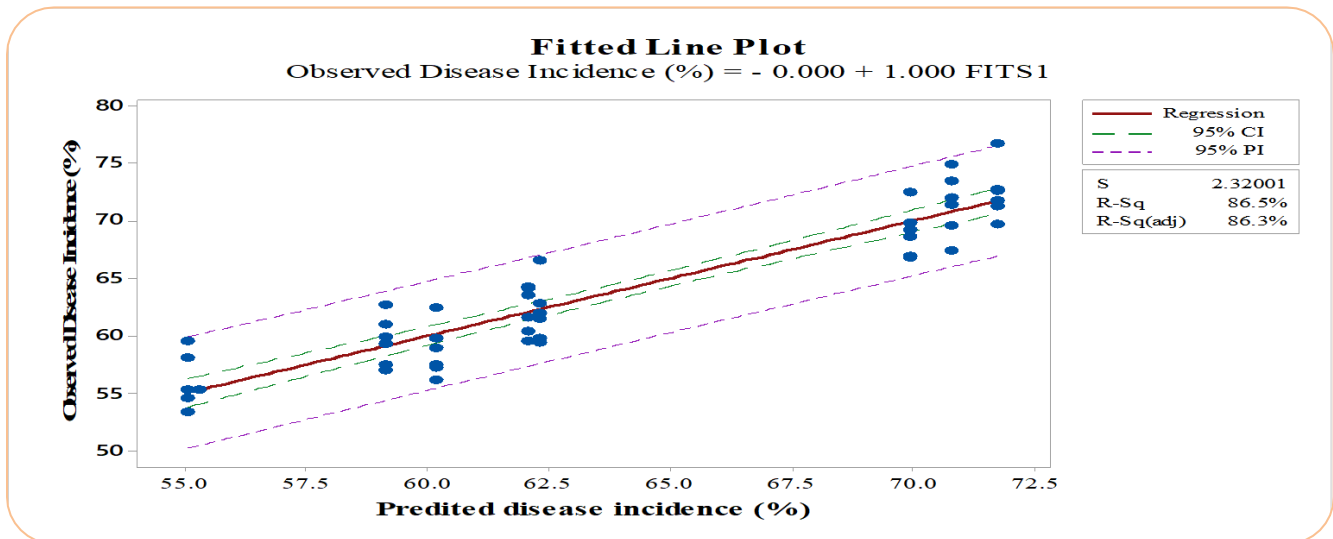


Figure 12. Fitted line plot showing observed and predicted data points for cabbage bacterial leaf spot.

## Discussion

Cabbage (*Brassica oleracea* var. *capitata* L.) is an important vegetable crop cultivated worldwide. Its production is constrained by several fungal and bacterial pathogens that cause substantial annual yield losses. Among these, bacterial leaf spot caused by *Pseudomonas syringae* pv. *maculicola* is one of the most destructive diseases of cabbage. Although various management strategies are available, synthetic bactericides are commonly used because of their rapid action and easy availability. However, their indiscriminate use poses serious risks to human and animal health and may lead to environmental contamination and pathogen resistance. Therefore, the development of eco-friendly and sustainable disease management approaches is imperative (Zahid et al., 2022). In this context, the present study evaluated selected plant defense activators for the management of bacterial leaf spot of cabbage and assessed key environmental factors to develop a disease predictive model.

Under greenhouse conditions, four plant defense activators, benzoic acid, citric acid, salicylic acid, and dipotassium phosphate ( $K_2HPO_4$ ), were evaluated at three concentrations. Among the tested treatments, salicylic acid consistently resulted in the lowest disease incidence under both greenhouse and field conditions. These findings corroborate earlier reports. For example, Li et al. (2020) demonstrated the antibacterial efficacy of plant defense activators against *X. oryzae* pv. *oryzae*. Similarly, Sun et al. (2015) reported strong antibacterial activity of plant activators against *P. syringae*, while Choi et al. (2014) documented their effectiveness against bacterial leaf spot of pepper.

Plant defense activators offer an environmentally sound alternative to conventional bactericides. They function by stimulating host defense mechanisms, activating defense-related genes, and inducing systemic resistance through signal transduction pathways, thereby providing prolonged protection against a broad spectrum of pathogens (Ahmad et al., 2010; Yaqoob et al., 2024). Salicylic acid plays a central role in plant growth regulation and defense signaling. It mediates the oxidative burst and modulates antioxidant systems, partly by interacting with catalase (CAT) activity and increasing hydrogen peroxide ( $H_2O_2$ ) accumulation in plant tissues. This controlled accumulation of reactive oxygen species enhances the expression of antioxidant enzymes and strengthens

plant tolerance to biotic and abiotic stresses (Tahir et al., 2023). Such biomolecular interactions are pivotal in plant-pathogen dynamics.

Environmental factors significantly influenced disease development. Maximum and minimum temperatures, rainfall, relative humidity, and wind speed exhibited significant ( $p < 0.05$ ) positive correlations with disease incidence. Pohronezny et al. (1990) highlighted the role of wind and windstorms in the dissemination of bacterial leaf spot pathogens. Diab et al. (1982) reported that fluctuations in relative humidity markedly affect the development of bacterial leaf spot of spinach. Extended periods of high relative humidity and the presence of free moisture on leaves favor infection and symptom development. Although *P. syringae* pv. *maculicola* does not require prolonged high humidity, exposure of inoculated plants to relative humidity above 85% for several hours over one or two days was sufficient to induce disease symptoms.

## Conclusions

Salicylic acid was the most effective plant defense activator under both greenhouse and field conditions, resulting in the lowest disease incidence, followed by citric acid, benzoic acid, and  $K_2HPO_4$ . Relative humidity was identified as a critical environmental factor influencing disease development. Therefore, the application of salicylic acid, integrated with consideration of prevailing environmental conditions, is strongly recommended as an eco-friendly strategy for managing bacterial leaf spot of cabbage.

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## Authors' Contributions

MI and MA designed, formulated and laid out the study. NA, JS and MA conducted the experiments. SS, MJM and AK collected, arranged and analyzed the data. MA and MU provided technical assistance. MA, AHK and NA supervised the work. MI, MA and MR wrote the manuscript. MI, MA and NA proofread the paper.

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**Conflict of Interest**

The authors declare no conflict of interest.

**Sustainable Development Goals Targeted**

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

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