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EFFECT OF SOWING DATES AND WEATHER PARAMETERS ON EPIDEMIOLOGY OF EARLY BLIGHT OF POTATO CAUSED BY *Alternaria solani* UNDER SUBTROPICAL CLIMATE

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ABSTRACT

Potato (*Solanum tuberosum* L.) is one of the most economically important food crops worldwide, but is very susceptible to different fungal diseases. Early blight is a common disease of potato caused by the necrotrophic fungus *Alternaria solani* which can cause up to 75% yield loss depending on weather and disease pressure. The present study was conducted to investigate the epidemiological parameters affecting the development of early blight of potato under field conditions. The experiment was conducted at the student's instructional farm, Chandra Sekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh (26.49 N latitude, 80.30 E longitude and at 126 msl) during the two successive *Rabi* seasons 2024-25 and 2025-26. The severity of the disease was evaluated weekly from 18 days after planting until harvest, and a standard 0-5 rating system was used. The disease severity and area under disease progress curve were observed on weekly intervals. Meteorological parameters, *viz.*, bright sunshine hours, maxi mum and minimum temperature, morning and evening relative humidity, rainfall, and wind speed, were collected from the Meteorology department of CSAUAT. Pearson's correlation coefficients were calculated to evaluate the association between the various weather parameters and the disease severity. Multiple regression models were developed to predict disease severity from weather parameters. Results across both seasons indicated that early-sown crops had consistently higher disease severity and higher AUDPC than late-sown crops. The maximum disease severity recorded was 33.3% (with an Area Under Disease Progress Curve value of 229) in the early sowing and 28% (with an Area Under Disease Progress Curve value of 191) in the late sowing in 2024–25. Similarly, during 2025-26, the maximum disease severity recorded was 38.7% (with an Area Under Disease Progress Curve value of 266) in the early sowing and 32% (with an Area Under Disease Progress Curve value of 214.7) in the late sowing. All the parameters, such as maximum temperature, minimum temperature, wind speed, and bright sunshine hours, were significantly and positively correlated with disease severity for all sowing dates and seasons by correlation analysis. However, the relative humidity in the morning and evening had a consistent negative relationship with disease progression. There was a poor, sporadic correlation between rainfall and disease severity. The weather factors that are most important for early blight development in potato are temperature, wind speed, and bright sunshine hours; whereas, increasing relative humidity slows disease development. The results provide an excellent epidemiological foundation for forecasting early blight occurrence and for developing weather-based integrated disease management programs.

***Keyword* :** Potato, Early blight, Disease severity, AUDPC, Weather parameter.

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important vegetable crop, which grows in temperate to subtropical parts of the world. It belongs to the family Solanaceae and originated from the hills of the Andes in Bolivia in South America. Later, it was introduced in Europe by Spaniards during the second half of 16th Century. It was introduced in India by the Portuguese during the 17th Century (Mehi *et al.*, 2018). It is the fourth most cultivated crop in the world after rice, wheat, and corn. In 2023, potatoes were cultivated on 17.8 million hectares with 376 million tonnes of production, and the average productivity was around 21 tonnes per hectare worldwide (Anonymous, 2023a). India is the second-largest producer of potato in the world after China. It contributes 54 million tonnes of production (Anonymous, 2023b). In India, the highest potato-producing state is Uttar Pradesh, followed by West Bengal, Bihar, Gujarat, Punjab, *etc*. Uttar Pradesh contributes about 30 % of the total potato production in India. In Uttar Pradesh, the highest potato-producing districts are Agra, Firozabad, Aligarh, Hathras, and Mathura (Anonymous, 2024). Potato is an economical food crop that provides low-cost energy for the human diet, so considered as "Poor man's food". Potato tubers are a rich source of starch, vitamins (C and B1) and minerals (P, Ca, Mg, K Fe, S and Cl). It also contains carbohydrates (20.6%), protein (2.1 %,) fat (0.3 %), crude fiber (1.1 %), and a good amount of amino acids, *viz*., leucine, tryptophan, isoleucine, etc. Potato tubers are also used as raw material for several industries such as alcohol, chips, and snacks industries (Chandrakala *et al*., 2012).

However, susceptibility of this tuber crop to plant pathogens, *viz*., fungi, bacteria, viruses, and nematodes during cultivation poses significant challenges, adversely affecting both the yield and quality of potatoes (Birch *et al*., 2012; Weng *et al*., 2024).

Among fungal diseases, early blight of potato caused by *Alternaria solani* is one of the most important and destructive diseases, which appears from seedling stage of crops to harvesting stage. This is the major cause of concern in potato production at present, suppressing the crop productivity in the field as well as affecting tuber quality in storage. The average annual yield loss of potatoes due to this disease was approximately 75% of total production, depending on the nature of the disease, weather conditions, and type of variety grown (Dey and Chakraborty, 2012).

Early blight of potato caused by *Alternaria solani* belongs to Phylum Ascomycota, Class Dothideomycetes, Order Pleosporales, Family Pleosporaceae. *Alternaria* is a necrotrophic pathogen that kills the host tissue and feeds on dead tissues and reproduce asexually through conidia. Early blight affects all plant parts, especially leaves and stems. The initial symptoms appear as spots begin as small, dark, dry papery flecks, which enlarge and become brown to black, circular to oval areas. A target board appearance due to the formation of concentric rings is often seen bordering the growing spots. Environmental factors such as temperature, relative humidity (moisture), wetness (rainfall), and BSS affect the development of early blight on potato crop (Adams and Stevenson, 1990; Vloutoglou and Kalogerakis, 2000). Water in the form of high relative humidity, rainfall, or dew accumulation can increase conidia germination and pathogen infection (Rotem, 2004). Alternating low and high humidity conditions have also been shown to favour disease development (Van der Waals *et al*., 2001). The young plants of potato show high resistance to early blight due to *Alternaria solani* as compared to older ones (Bambawale *et al*., 1978). Within the same plant, the lower leaves, which are physiologically different from the middle and top ones (Dowley *et al*., 1975), are more susceptible to certain pathogens, with resistance increasing in an acropetal direction.

In Uttar Pradesh, potato is the major cultivated crop; however, it faces a significant threat of yield loss due to the infestation of Early blight. Therefore, considering the devastating nature of this disease, a detailed investigation was undertaken to study the epidemiological parameters against early blight of potato.

Materials and Methods

Experimental site

The field experiment was conducted at SIF (Students' Instructional Farm) of Chandra Sekhar Azad University of Agriculture and Technology, Kanpur, situated at a latitude of 26.49ºN and longitude 80.30º E and at around 126 m MSL for two consecutive years. The general climate of this district is a humid subtropical climate, which is characterized by very hot summers and cold winters. The maximum temperature during summer goes up to 40ºC. Whereas, the minimum temperature during winter falls up to 5ºC and even below sometimes. The average annual rainfall is approximately 800-900 mm, of which 75-80 percent of the rainfall is received through the south-west monsoon during June to September.

Assessment of the progress of early blight disease intensity may be evaluated by three different dates of sowing at 10-day intervals. The experiment was conducted using a randomized block design with three replications during two rabi season, first experiment in *rabi* season 2024-25 (1st sowing date 10th November, 2nd sowing date was 20th November and 3rd sowing date was 30th November 2024) second experiment in *rabi* season 2025-26 (1st sowing date 8th November, 2nd sowing date was 18th November and 3rd sowing date was 28th November 2025) The potato variety chipsona-1was used for this experiment and plants were kept unsprayed with any chemicals for record the disease development under epiphytotic condition. The intention behind experimenting with three different planting dates is to expose the most vulnerable stage of crops to disease development.

Collection of Weather parameters data:

A collection of the weather parameters *viz.,* weekly mean of maximum temperature (ºC), minimum temperature(ºC), morning relative humidity (%), evening minimum relative humidity (%), rainfall (mm), and Bright sunshine hours (hr), was collected from the Meteorology unit of the Agronomy department, Chandra Shekhar Azad University of Agriculture &Technology, Kanpur during both cropping periods.

Disease observation:

Disease incidence was recorded from five randomly selected plants from each plot at a weekly interval, and those plants were tagged for further observation. The observation was recorded from 18 days after planting till the harvesting. The selected plants were scored according to the visible symptoms and their intensity by using the disease rating scale 0 to 5 (Horsefall and Barret, 1945). The disease rating scale according to Horsefall and Barret (1945):

Category	Grade/ Numerical rating	Description of the Symptoms
I	0	Leaves are free from infection
II	1	Small irregular spots covering 1-10% leaf area
III	2	Small irregular brown spots with concentric rings covering 11-25% leaf area
IV	3	Lesions enlarge to form irregular brown lesions with concentric rings covering 26-50% leaf area.
V	4	Lesions coalesce to form irregular and appears as a typical blight symptom covering 50-75% leaf area
VI	5	Lesions coalesce to form irregular and appears as a typical blight symptom covering >76% leaf area.

Disease severity and prevalence was calculated by using the Wheeler's formula (1996).

$$\text{Severity} = \frac{\text{Sum of Numerical ratings}}{\text{Total number of leaves observed} \times \text{Maximum disease rating}} \times 100$$

Area under disease progress curve

The amount of progress of disease is represented in a curve that show the progress of disease over period of time in a cropped area is called area under disease progress curve (AUDPC) which was calculated by following equation (Shaner and Finney 1977).

$$\text{AUDPC} = \sum_{k=0}^{n-1} \frac{[Yi + Y(i+1)]}{2} \times [t(i+1) - ti]$$

Where, Y_i is an assessment of a disease at the i^{th} observation, t_i is time (in days, hours etc.) at i^{th} observation and n is the number of observations.

Statistical analysis

Correlation coefficients were analysed using disease severity of early blight of potato with the weather parameters, *viz*., minimum temperature (ºC), maximum temperature (ºC), morning relative humidity (%), evening relative humidity (%), BSS (Hr) and rainfall (mm) during 2024-25 and 2025-26 for three different dates of sowing. The Pearson correlation coefficient (r) was calculated to find the effect of single as well as a combination of different weather parameters on the disease progression of early blight.

Multiple regression analysis predicts the disease severity of early blight of potato on three different dates of sowing.

$$Y = a + b_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6$$

Where,

Y is predicted disease severity, 'a' is the intercept, 'b1' to 'b6' are partial regression coefficients, X1 is maximum temperature (ºC), X2 is minimum temperature (ºC), X3 is morning relative humidity (%), X4= evening relative humidity (%), X5 = BSS (Hr), and X6=rainfall (mm).

Results and Discussion

The influence of weather factors on disease development of early blight in potato was made to correlate the disease severity and Area Under Disease Progress Curve (AUDPC) with weather parameters *viz*., maximum temperature (Tmax), minimum temperature (Tmin), morning relative humidity (RH-1) evening relative humidity (RH-2), rainfall, Wind speed and Bright sunshine hours (BSS) during rabi season 2024-25 and 2025-26. Weekly data of mean temperature (Tmax and Tmin), relative humidity (RH-1 and RH-2), rainfall, wind speed, BSS and disease severity as well as area under disease progress curve are recorded and presented in Tables 1 and 2

Disease severity and Area Under Disease Progress Curve (AUDPC)

The table 1 and 2 show that the lowest disease severity was recorded in the late sowing crop (3rd date of sowing) of 28%, with an AUDPC of 191, while the highest maximum disease severity was recorded in early sowing crop (1st date of sowing) of 33.3% with an AUDPC of 229, during the rabi season 2024-25. Similarly, during 2025-26, late sowing crop (3rd date of sowing) recorded minimum disease severity of 32.0% and AUDPC of 214.7, while the early sowing crop (1st date of sowing) recorded maximum disease severity of 38.7% and AUDPC of 266. These results clearly indicate that early planting exposed crops to more favourable weather conditions for disease development, resulting in higher disease severity and AUDPC values. The progressive increase in the severity of the disease with the age of the crop corroborates the observations made by Dey and Chakraborty (2012) that the lower and physiologically older leaves are more vulnerable than the upper leaves, leading to an increase in disease severity as the crop matures. The higher AUDPC values of the early sown crops indicate that the disease was present for long periods of time, in line with the findings of Bambawale (1978).

Correlation Between Weather Parameters and Disease Severity

Pearson's correlation coefficients (r) were analysed to assess the relationship between weather parameters and early blight disease severity for both seasons and all three dates of sowing (Tables 2 and 3). Maximum temperature had a positive relationship that is gradually increasing with the severity of the disease for all planting dates for both seasons. During 2024-25, the correlation coefficient (r) ranged from 0.355 (D1) to 0.582 (D2) and 0.740 (D3). During 2025-26, the values were higher at r = 0.379 (D1), 0.719 (D2), and 0.833 (D3). Minimum temperature showed a consistently positive correlation with disease severity, which was relatively stronger than the maximum temperature. The r values during 2024-25 were 0.524 (D1), 0.669 (D2) and 0.742 (D3), while during 2025-26 the correlations were even more pronounced at r = 0.704 (D1), 0.821 (D2), and 0.859 (D3). Rainfall showed a negative correlation with disease severity during 2024-25, with r values of -0.13 (D1), -0.22 (D2), and -0.31 (D3). During 2025-26, rainfall showed a slight positive but weak correlation (r = 0.209, 0.103, and 0.083 for D1, D2, and D3, respectively). Morning (RH-1) and evening (RH-2) relative humidity were negatively correlated with disease severity for both planting dates and seasons. During 2024-25, RH-1 ranged from r = -0.346 (D1) to -0.433 (D2) and -0.593 (D3), while RH-2 ranged from -0.183 (D1) to -0.305 (D2) and -0.495 (D3). During 2025-26, stronger negative correlations were observed for RH-1 (r = -0.383 to -0.724) and RH-2 (r = -0.216 to -0.648). The initial wetness in the early season could have led to initial infection, and the low humidity at peak disease times is more in line with the later growth stages of the crop. Van der Waals *et al.* (2001) found that the early blight development was promoted by alternate humidity conditions of high and low, which is consistent with the present study.

Wind Speed: In both seasons, there was a consistent positive correlation between wind speed and disease severity. During 2024-25, r values were 0.576 (D1), 0.579 (D2), and 0.552 (D3), while during 2025-26 they were 0.571 (D1), 0.477 (D2), and 0.603 (D3). The wind can spread conidia of *A. solani* from infected to healthy plant tissues to enhance secondary infection and worsen the disease. These findings are in agreement with other investigators who have reported that wind speed is an important epidemiological parameter for the spread of Alternaria blight

Table 1: Relationship between disease severity, AUDPC, and different weather parameter under three different dates of sowing during rabi season 2024-25.

Sr. No.	SMW	1st date of sowing		2nd date of sowing		3rd date of sowing		Abiotic factor						
		Disease severity	AUDPC	Disease severity	AUDPC	Disease severity	AUDPC	Tmax	Tmin	rainfall	RH-1	RH-2	WS	BSS
1	48	0.0						26.7	9.8	0	92	45.8	1.6	6.6
2	49	1.3	5	0.0				26.8	10	0	80	34	3	6.2
3	50	6.7	28	0.0	0	0.0		23.4	7.3	0	80	33	4.4	4.9
4	51	9.3	56	5.3	19	2.7	9	24.4	7.9	0	90	45.5	1.5	8.9
5	52	10.7	70	8.0	47	5.3	28	22.4	11.7	1.6	91.4	66.8	4.1	0
6	1	13.3	84	9.3	61	6.7	42	15.2	7.3	0	91	79	3.4	0
7	2	16.0	103	12.0	75	9.3	56	19.1	6.6	2.2	95	61.1	3.3	0
8	3	17.3	117	13.3	89	10.7	70	21.7	9.2	0	90	60	5.3	2.7
9	4	20.0	131	17.3	107	14.7	89	24.5	8.2	0	83	36	5	7.7
10	5	24.0	154	20.0	131	17.3	112	27.2	9.2	0	91	39	2.7	5.5

11	6	25.3	173	22.7	149	18.7	126	25.8	10.1	0	75	38	6.4	8.7
12	7	29.3	191	25.3	168	21.3	140	28.1	11.8	0	80	38	5.8	9.2
13	8	32.0	215	28.0	187	25.3	163	27.8	11.7	0	84	39	3.8	7.3
14	9	33.3	229	30.7	205	26.7	182	29.4	14.9	0	80	41	4.7	5.5
15	10			30.7	215	28.0	191	29.7	11.9	0	70	31	7.5	8.8

Table 2: Relationship between disease severity, AUDPC, and different weather parameter under three different dates of sowing during rabi season 2025-26.

Sr. No.	SMW	1st date of sowing		2nd date of sowing		3rd date of sowing		Abiotic factor						
		Disease severity	AUDPC	Disease severity	AUDPC	Disease severity	AUDPC	Tmax	Tmin	rainfall	RH-1	RH-2	WS	BSS
1	48	0.0						26.2	7.9	0	93	37	1.8	3.6
2	49	1.3	4.7	0.0				25.1	7.8	0	84	36	3.4	4.9
3	50	4.0	18.7	2.7	9.3	0.0		24.5	7.3	0	92	46	2.2	3.7
4	51	9.3	46.7	5.3	28.0	0.0	0.0	18	7.7	0	96	72	2.4	0.6
5	52	14.7	84.0	6.7	42.0	2.7	9.3	17.4	7.2	0	95	69	2.5	1
6	1	17.3	112.0	9.3	56.0	5.3	28.0	17	6.6	0	94	69	3	0.8
7	2	20.0	130.7	13.3	79.3	8.0	46.7	20.4	5.6	0	94	46	2	4
8	3	22.7	149.3	17.3	107.3	10.7	65.3	23.1	6.1	0	95	42	2.4	5.4
9	4	26.7	172.7	20.0	130.7	16.0	93.3	22.9	10.2	6.7	90	56	4.2	2.6
10	5	28.0	191.3	22.7	149.3	18.7	121.3	19.9	10.8	10.3	95	70	3.3	0.8
11	6	33.3	214.7	26.7	172.7	24.0	149.3	25.2	10.2	0	86	40	4.2	7.9
12	7	36.0	242.7	29.3	196.0	25.3	172.7	26.9	10.1	0	89	36	2.8	0.6
13	8	37.3	256.7	33.3	219.3	28.0	186.7	29.1	13.1	0	89	37	2.8	8.7
14	9	38.7	266.0	36.0	242.7	29.3	200.7	30.7	14.2	0	78	30	4.6	9.1
15	10			36.0	252.0	32.0	214.7	33.1	17.7	0	89	44	3.1	7.3

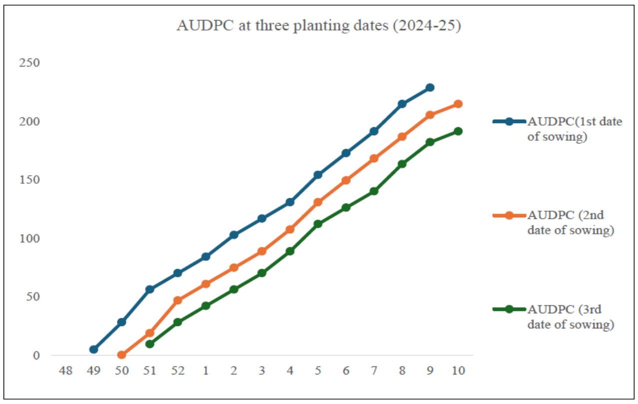

Fig. 1: Area Under Disease Progress Curve of three different date of sowing during rabi season 2024-25

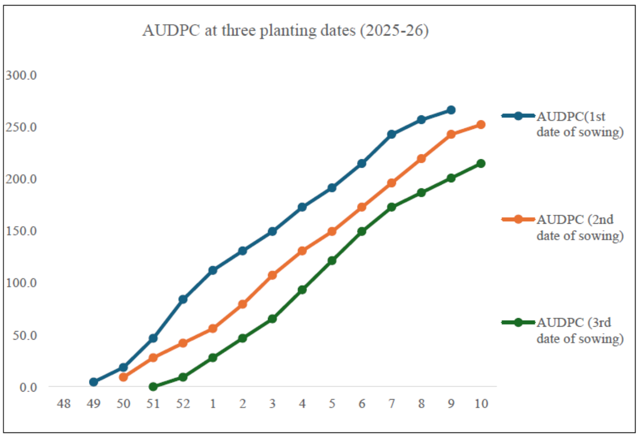

Fig. 2 : Area Under Disease Progress Curve of three different date of sowing during rabi season 2025-26

Table 3 : Pearson Correlation Coefficients between Weather Parameters and Disease Severity of Early Blight during Rabi season 2024-25

Weather parameter	1st date of sowing	2^{nd} date of sowing	3rd date of sowing
Tmax (°C)	0.36	0.58	0.74
Tmin (°C)	0.52	0.67	0.74
Rainfall (mm)	-0.13	-0.22	-0.31
RH-Morning (%)	-0.35	-0.43	-0.59
RH-Evening (%)	-0.18	-0.31	-0.50
Wind Speed (km/h)	0.58	0.58	0.55
BSS (hr)	0.25	0.42	0.51

Table 4 : Pearson Correlation Coefficients between Weather Parameters and Disease Severity of Early Blight during *Rabi* season 2025-26

Weather parameter	1st date of sowing	2^{nd} date of sowing	3rd date of sowing
Tmax (°C)	0.38	0.72	0.83
Tmin (°C)	0.70	0.82	0.86
Rainfall (mm)	0.21	0.10	0.08
RH-Morning (%)	-0.38	-0.47	-0.72
RH-Evening (%)	-0.22	-0.47	-0.65
Wind Speed (km/h)	0.57	0.48	0.60
BSS (hr)	0.38	0.56	0.64

Bright sunshine hours were positively correlated with disease severity, and an increasing trend was observed with the sowing dates from early to late sowing. During 2024-25, r values ranged from 0.248 (D1) to 0.421 (D2) and 0.507 (D3). During 2025-26, the correlations were stronger at r = 0.379 (D1), 0.563 (D2), and 0.638 (D3). These results corroborate those of Adams and Stevenson (1990), who found that bright sunshine and moderate temperatures are conducive to epidemics of early blight

Regression Analysis for Prediction of Disease Severity

Multiple regression analysis was performed to predict the disease severity of early blight of potato based on the seven weather parameters (Tmax, Tmin, Rainfall, RH-1, RH-2, Wind Speed, and BSS) for three different dates of sowing during both Rabi seasons. The regression statistics are presented in Table-5.

Table 5 : Multiple Regression Statistics for Disease Severity Prediction across Sowing Dates and Seasons.

	Rabi season 2024-25			Rabi season 2025-26		
Statistic	**1st date of sowing**	**2nd date of sowing**	**3rd date of sowing**	**1st date of sowing**	**2nd date of sowing**	**3rd date of sowing**
Multiple R	0.78	0.83	0.84	0.94	0.97	0.99
R Square	0.60	0.69	0.70	0.88	0.94	0.99
Adjusted R Square	0.14	0.33	0.29	0.74	0.88	0.97
Standard Error	10.05	8.71	7.92	6.79	4.39	1.87
Observations	14	14	13	14	14	13

During the Rabi season 2024-25, the multiple regression models explained 78%, 83% and 84% of the variance in disease severity for D1, D2 and D3, respectively (R^2 = 0.603, 0.693, 0.703), showing greater accuracy in prediction for later sowing dates.

In Rabi Season 2025-26, the regression model showed remarkably improved fit as compared to the year 2024-25. Multiple R values were 0.94 (D1), 0.97 (D2), and 0.99 (D3), with corresponding R^2 values of 0.882, 0.944 and 0.989, which explained a very high proportion of the variation in disease severity, particularly for the third sowing date.

These models can be used as early warning systems to support timely management of early blight in potato-growing areas. Dey and Chakraborty (2012) also developed a similar regression-based forecasting model for *Alternaria* blight, with the advantage of using the combined temperature and humidity parameters in improving the forecasting accuracy.

Discussion

The results of both correlation and regression analyses clearly indicated that minimum temperature, maximum temperature, wind speed, and bright sunshine hours contributed most consistently and significantly to the development of early blight, whereas the relative humidity (morning and evening) had a negative correlation with the development of early blight as the season progressed. A higher R^2 value for the 2025-26 Rabi season than the 2024-25 Rabi season showed closer synchrony between weather conditions and disease development, which can be explained by the favorable weather conditions in the 2025-26 Rabi season. An increasing trend of higher disease incidence was observed with crops planted at earlier sowing dates, supporting the epidemiological concept that the duration of crop exposure to favourable weather windows is associated with the increased disease progress; the same was reported by Vloutoglou and Kalogerakis (2000).

Conclusion

It was observed that the weather-based epidemiological analysis carried out over the two Rabi seasons on three different dates of sowing clearly concluded that minimum temperature, maximum temperature, wind speed, and bright sunshine hours were positively correlated with the disease severity of early blight in potato, while relative humidity showed a negative correlation during the progress of the disease. Multiple regression models, especially for 2025-26, showed good predictive power (R^2 up to 0.989), which serves as a good platform for the disease forecasting model of early blight of potato.

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Competing interests:

Authors have declared that no competing interests exist.

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