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Impact of Weather Factors on the Severity of Rhizoctonia Aerial Blight Caused by *Rhizoctonia solani* in Soybean (*Glycine max* L.)

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ABSTRACT

The experiment was conducted during *kharif* (July–November), 2020 and 2021 at Instructional cum Research Farm, Assam Agricultural University, Jorhat, Assam, India to evaluate ten soybean cultivars to screen for resistance to Rhizoctonia aerial blight and to analyze disease severity in relation to weather variables. The onset of the disease in both years occurred from September 10th to 16th, coinciding with the flowering stage. In both the years of study, the highest PDI was recorded in the cultivar Punjab 1 (Moderately susceptible) and PK472 (Resistant) recorded the lowest PDI. Maximum temperature, minimum temperature, and afternoon relative humidity showed a negative correlation with Rhizoctonia aerial blight disease development, whereas morning relative humidity and rainfall exhibited a positive correlation. During two years of research, the minimum temperature of the current week and rainfall and bright sunshine hours of the preceding week were substantially associated with severity of the disease. The scatter chart plotted showed a negative correlation between minimum temperature (current week), rainfall (preceding week) and mean PDI with R^2 value of 0.63 and 0.59 respectively, while a positive correlation was observed between BSSH (preceding week) and mean PDI (R^2=0.57). Stepwise multiple regression analysis was conducted between pooled PDI (2020-2021) and weekly average weather variables showed an R^2 of 57.2–68.4% between minimum temperature (current week) and PDI. Furthermore, the preceding week's BSSH explained 66.9–58.4% variability in certain cultivars, while rainfall explained 60.5–69.2% variability in others.

KEYWORDS: Percent disease index, correlation, regression, prediction model, epidemiology

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1. INTRODUCTION

Soybean (*Glycine max* L.), known as the "miracle crop" or "yellow jewel", is a widely grown oilseed cum pulse crop. India holds fourth position globally in terms of soybean cultivation, spanning 12.14 m ha and making up 9.07% of the world's total soybean acreage. It ranks fifth in production with 12.99 mt in 2022. Among the states, Madhya Pradesh ranks first with 53.35 lakh hectares, followed by Maharashtra with 50.72 lakh hectares, Rajasthan with 11.44 lakh hectares, Karnataka with 4.11 lakh hectares, Gujarat with 2.66 lakh hectares, and Telangana with 1.89 lakh hectares during 2023–24 (Anonymous, 2022; Banerjee et al., 2022). Soybean productivity in India ranges from 1000 to 1200 kg ha^{-1} in recent years which is roughly 60% of the global average and one of the lowest among major soybean-producing countries (Anonymous, 2017). Soybean contributes 25% to global edible oil production and provides approximately two-thirds of the world's protein concentrate (Agarwal et al., 2013). It offers numerous health benefits, including improved bone health, cognitive function, visual memory, anti-cancer, cardio-protective, antimicrobial, anti-obesity, and cholesterol-lowering. Soybean is particularly beneficial for vegetarians and vegans due to its high protein content (40%), earning it the nickname "vegetarian meat" in India and so it has gained popularity rapidly throughout the country (Singh et al., 2022; Belobrajdic et al., 2023; Mishra et al., 2024). In India, soybean is mostly grown during kharif season when the weather is hot and humid making the crop more susceptible to disease and insect pest attack. Losses due to various diseases are one of the major causes of low productivity of the soybean. Hartman et al. (2015) estimated annual soybean yield losses in the U.S. due to diseases at around 11%, while Savary et al. (2019) reported that such losses in the Midwest U.S. and Canada reached approximately 25%. Rhizoctonia aerial blight (RAB) caused by the pathogen Rhizoctonia solani, is a significant disease, causing considerable yield losses globally, ranging from 40-50%, which can increase to as much as 80% under optimal conditions for disease development (Mathpal and Singh, 2017; Bhamra et al., 2022). In India, Rhizoctonia aerial blight disease was recorded for the first time from Pantnagar (Uttarakhand) in 1967 (Mukhopadhyay and Singh, 1984). Since then it has spread to other soybean-growing states like Rajasthan, Sikkim, Haryana, Punjab, Uttar Pradesh, Bihar, Madhya Pradesh, Chhattisgarh and Assam (Goyal and Ahmad, 1988; Ray et al., 2007; Sharma and Tripathi, 2001; Srivastava and Gupta, 1989).

The epidemiology of the disease is critical in understanding yield losses. 'Epidemiological triad' or 'disease cycle' states that the alignment of a susceptible host, a virulent pathogen, and favourable environmental conditions is essential for a disease outbreak. Hence, modifying/changing any one of the factors would help in disease escape. Researchers have noted the significant influence of weather variables such as temperature, relative humidity, sunshine hours, and rainfall on disease development and yield loss (Yang et al., 1990; Stetina et al., 2006; Surbhi and Singh, 2020; Amrate et al., 2021). Figure 1(A-B) depicts characteristic symptoms of soybean aerial blight caused by Rhizoctonia solani Kuhn which include water-soaked necrotic lesions, pale yellow to tan brown leaf lesions, stem and petiole lesions, pod spots, leaf defoliation, matting/sticking together of the infected leaves, appearance of web-like mycelium and sclerotia on infected plant parts (Rodriguez et al., 2023; Arya, 2020). Typically, field symptoms develop during the late vegetative

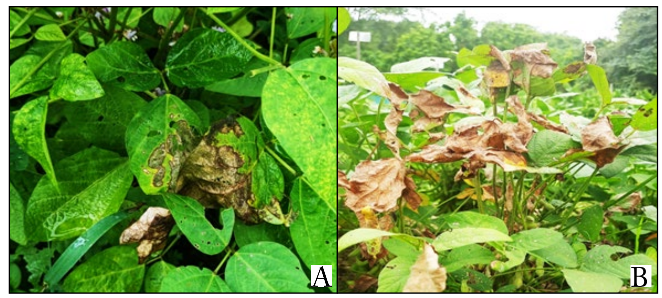

Figure 1 (A-B): Typical symptoms of rhizoctonia aerial blight on soybean plant

or early reproductive stages on the lower portions of the plant following canopy closure. (Rodriguez et al., 2023). The alignment of favourable weather conditions with the susceptible growth stage of the plant is essential for disease development, regulating mycelial growth and sclerotia formation (Sinclair, 1982; Ram and Trikha, 1997). This study aims to examine the severity of RAB disease in relation to weather parameters for ten soybean cultivars under Assam conditions.

2. MATERIALS AND METHODS

2.1. Experimental site and treatment details

The experiment was conducted for two seasons during *kharif*, 2020 and 2021 (July to November) at Instructional cum Research Farm, Assam Agricultural University, Jorhat (Latitude: 26°71' N, Longitude: 94°18' E, Altitude: 96.24 m), Assam, India to understand the epidemiology of aerial blight of soybean. Ten cultivars i.e. JS 95-60, JS 93-05, Bragg, PK 262, Monetta, JS 335, Shivalik, PK 472, NRC 7 and Punjab 1 were sown in a plot size of 4×1.2 m^2 $cultivar^{-1}$ with row to row distance of 45 cm and plant to plant distance of 10 cm following Randomized Block Design (RBD) with three replications. The disease severity was recorded at weekly intervals starting from first week of September to third week of November, in both the years. For calculating disease severity, randomly ten plants were selected and tagged in each treatment (plot) and these tagged plants were graded as per the following disease assessment key of Mayee and Datar (1986) based on the per cent leaf area infected (0 to 9 scales) (Table 1).

Table 1: Disease severity rating scale used to grade leaves of the soybean plant (Mayee and Datar, 1986)

Grades	Percent foliage covered
0	No lesions
1	1.1% of the leaf area covered with lesions
3	1.1 to 10% of the leaf area covered with lesions
5	10.1 to 25% of the leaf area covered no defoliation-and little damage.
7	25.1 to 50% of the leaf area covered, dropping some leaves, death of a few plants, damage conspicuous.
9	>50.1 % of the leaf area covered, lesions very common on all plants, defoliation common, death of plants common, damage more than 50%

2.2. Observations

Per cent disease index and area under disease progress curve

Furthermore, Per cent Disease Index (PDI) (Wheeler, 1969) and Area Under Disease Progressive Curve (AUDPC) (Shaner and Finney, 1977) were calculated using the following formulas:

$$\text{Per cent disease index (PDI)}=\frac{\text{Sum of all ratings}}{\text{No. of ratings}\times\text{Maximum grade}}\times 100 \quad \text{(Eq.1)}$$

$$\text{AUDPC}=\sum_{i-1}^{k}\frac{1}{2}\ (Si+(Si+1)(Ti-(Ti+1)) \quad \text{(Eq.2)}$$

Here, Si represents the per cent disease index at the end of time i, k denotes the number of successive evaluations, Ti-(Ti+1) is the time interval between two evaluations, i and i-1 of the disease.

On the basis of PDI soybean cultivars were categorized into different Resistance category as given below:

2.3. Correlation and regression

To assess the effect of meteorological parameters on development of the disease, daily maximum temperature (Max T), minimum temperature (Min T), rainfall (RF)and relative humidity during morning (RH-I) and afternoon (RH-II) and bright sunshine hours (BSSH) data were collected from the Agro-meteorological observatory located within a radius of 200 m from the experimental site , Department of Agro-meteorology, Assam Agricultural University, Jorhat from first week of September to third week of November. PDI data on all the dates of observations were calculated individually for all the varieties and for the two seasons separately. The correlation between the disease severity index of RAB and environmental variables was estimated for these two consecutive growing seasons of soybean. Stepwise regression analysis was also performed for the development of multiple linear regression models for the prediction of Rhizoctonia aerial blight (RAB) severity. The model is defined as follows:

$$Y=ß_0+ß_1X_1+ß_2X_2+ß_3X_3+\ldots\ldots\ldots ß_4X_4 \quad \text{(Eq.3)}$$

Where Y=RAB severity (Increased PDI), $ß_0$=Intercept (constant), $ß_1$ to $ß_4$=regression Coefficient, X=weather variables i.e. maximum temperature (Max T), Minimum temperature (Min T), rainfall (RF), morning relative humidity (RH-I), afternoon relative humidity (RH-II) Bright Sunshine hours (BSSH). All the requisite data, for correlation coefficient and stepwise multiple linear regressions, were analyzed by using SPSS 26.0 statistical software.

3. RESULTS AND DISCUSSION

3.1. Per cent disease index and area under disease progress curve

The Percent Disease Index (PDI) quantifies the proportion of diseased plant parts in a sample, providing an overview of the affected plant area. The Area Under Disease Progress Curve (AUDPC) measures disease intensity over time, useful for comparing disease intensity across different intervals. Disease progression was plotted graphically, with the area under the curve representing disease advancement. Table 3 and Figure 2 shows the data on PDI and AUDPC of aerial blight on soybean cultivars recorded during the maturity initiation stage of the crop i.e. 79 days after sowing (DAS). The initiation of disease symptoms started from 37th DAS (10th Sept– 16th September) during 2020 and 2021. During this period the crop was at the beginning to bloom stage (flowering initiation) and the average maximum temperature ranged from 33–35°C, minimum temperature from 24.9–25.4°C and relative humidity from 76.4–87.64%. Surbhi and Singh (2020) similarly reported that the initiation of RAB disease symptoms started during the first and second week of September in 2016 and 2017

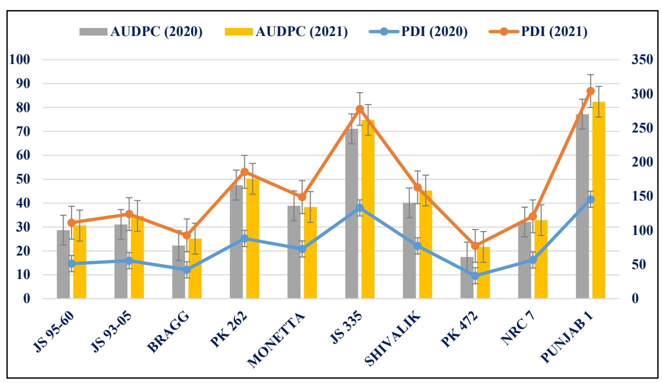

Figure 2: Fluctuations of PDI and AUDPC of aerial blight disease during *kharif*, 2020 and 2021

respectively when the weather was warm and humid (maximum temperature of 32–34°C and average minimum temperature of 25°C, relative humidity of 86 to 90% and rainfall about 2.4 mm) which encouraged the initiation aerial blight in the field. Amrate et al. (2021) reported that the RAB disease appeared in the field between first to second week of August, corresponding to bloom initiation to full bloom stages. They found that the PDI varied across different genotypes reaching values of 21.8%, 42.3% and 46.8% in 2017, 2018 and 2019 respectively.

In the year 2020, the highest PDI was recorded in the cultivar Punjab 1 (41.6) followed by JS 335 (38.0). The same trend was followed in the following year with the highest PDI recorded in Punjab 1 (45.3) followed by JS 335 (41.4). PK472 recorded the lowest PDI in both 2020 (9.6) and 2021 (12.5). Similarly, during both years of study, highest AUDPC was recorded in Punjabi 1 followed by JS 335. The cultivars were also categorized based on their resistance/susceptibility to the disease (Table 2). PK 472 was categorized as Resistant (R), JS95-60, JS93-05, Bragg, PK262, Monetta and Shivalik as Moderately Resistant (MR) and JS 335, Punjab 1 as Moderately susceptible (MS) cultivars. In their study, Amrate et al. (2023) evaluated one hundred twenty one soybean genotypes and found that only six namely JS 20-30, JS 20-57, JSM 222, MACS 1407, PS 1611and Cat 2126 B were found to be highly resistant against aerial blight disease of soybean. Whereas, fifty genotypes reacted as moderately resistant and rest were found to be moderately susceptible to susceptible. Similarly, Surbhi et al. (2021) evaluated 48 genotypes during 2016 and 2017 and found that only Glycine soja exhibited resistance to aerial blight, while five genotypes viz., DS-3101, SL-983, PS-1572, MAC-1460 and SL-982 exhibited minimum disease index and eighteen genotypes exhibited a moderately resistant response to aerial blight during both the years of study.

Table 2: Categorization of soybean cultivars based on PDI

PDI	Resistance category
0.0	Highly resistant (HR)
0.01–11.11	Resistant (R)
11.12–33.33	Moderately resistant (MR)
33.34–55.55	Moderately susceptible (MS)
55.56–77.77	Susceptible (S)
77.78–100.0	Highly susceptible (HS)

Table 3: Percent disease index (PDI) and Area under disease progress curve (AUDPC) of aerial blight on soybean cultivars recorded for the years 2020 and 2021

Cultivar	Resistance category	PDI (2020)	PDI (2021)	AUDPC (2020)	AUDPC (2021)
JS 95-60	MR	14.7	17.1	100.3	107.1
JS 93-05	MR	15.9	19.5	108.7	121.1
BRAGG	MR	12.1	14.4	77.8	88.0
PK 262	MR	25.2	27.9	166.4	175.6
MONETTA	MR	20.8	21.7	136.1	134.3
JS 335	MS	38.0	41.4	248.8	261.8
SHIVALIK	MR	22.1	24.5	140.5	158.4
PK 472	R	9.6	12.5	61.0	75.7
NRC 7	MR	16.2	18.3	112.3	115.0
Punjab 1	MS	41.6	45.3	270.3	288.4

3.2. Correlation analysis

The weather variables viz., maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, rainfall and bright sunshine hours were correlated with the per cent disease index of the ten cultivars for the two years of study. The weekly mean of weather parameters during the current week and preceding week throughout the period of observation (3rd Sept–28th Oct) were taken into consideration. The correlation analysis with the current week averages indicated that maximum temperature, minimum temperature, and afternoon relative humidity were negatively correlated with the percent disease index, whereas morning relative humidity and rainfall exhibited a positive correlation in the years 2020 and 2021. The correlation was significant and negative with minimum temperature of the current week with 'r' value ranging from -0.866 to -0.758 in 2020 and -0.832 to -0.754 in 2021 (Table 4). The correlation of the PDI with the weather variable of the preceding week showed that minimum temperature was negatively correlated with PDI in the years 2020 and 2021. In case of preceding week, minimum temperature showed the highest negative correlation (-0.806 to -0.24) with the PDI in the years 2020 and 2021. Similar to our findings, Surbhi and Singh (2020) reported that minimum temperatures were significantly negatively correlated with RAB disease development during the critical period. Amrate et al. (2021) reported that the increased PDI was positively correlated with current week's mean relative humidity (RH) and negatively with maximum temperature, while the previous week's number of rainy days and mean RH had the highest positive correlation with disease severity. In their study, Sinha et al. (2021) reported that low soil moisture predisposes field-grown chickpea plants to dry root rot (DRR) disease caused by Rhizoctonia bataticola

Table 4: Correlation coefficients of disease index of rhizoctonia aerial blight in relation to weather variables during *kharif*, 2020 and 2021

Cultivars	Year	Max T	Min T	RH-I	RH-II	RF	BSSH	Max T	Min T	RH-I	RH-II	RF	BSSH
		Current week						Preceding week					
JS 95-60	2020	-0.47	-0.783*	0.40	-0.32	0.09	0.49	0.304	-0.724	0.04	-0.73	-.769*	.794*
	2021	-0.911**	-0.782*	0.22	-0.01	0.49	-0.12	-0.112	-0.32	0.146	0.252	0.508	-0.302
JS 93-05	2020	-0.46	-0.765*	0.34	-0.36	0.04	0.53	0.333	-0.673	0.003	-0.718	-.772*	.773*
	2021	-0.56	-0.762*	0.55	0.00	0.16	-0.04	-0.096	-0.33	0.083	0.253	0.468	-0.254
BRAGG	2020	-0.56	-0.839*	0.38	-0.26	0.16	0.42	0.374	-0.735	0.018	-.768*	-.795*	.812*
	2021	-0.63	-0.804*	0.59	0.02	0.22	-0.14	-0.038	-0.285	0.135	0.175	0.551	-0.246
PK 262	2020	-0.43	-0.766	0.39	-0.37	0.02	0.55	0.252	-0.666	-0.021	-0.656	-0.729	0.715
	2021	-0.60	-0.764*	0.59	0.06	0.20	-0.12	-0.094	-0.315	0.099	0.179	0.491	-0.254
Monetta	2020	-0.50	-0.776*	0.41	-0.25	0.15	0.47	0.211	-0.746	0.045	-0.683	-0.742	0.723
	2021	-0.65	-0.832*	0.61	-0.02	0.24	-0.16	-0.002	-0.24	0.114	0.186	0.549	-0.24
JS 335	2020	-0.51	-0.778*	0.39	-0.28	0.11	0.48	0.252	-0.701	-0.017	-0.692	-.759*	0.731
	2021	-0.60	-0.762*	0.57	0.06	0.21	-0.13	-0.083	-0.321	0.132	0.169	0.517	-0.249
Shivalik	2020	-0.63	-0.842*	0.34	-0.17	0.23	0.35	0.35	-0.731	-0.067	-.782*	-.834*	.761*
	2021	-0.44	-0.754*	0.51	0.11	0.32	-0.12	-0.077	-0.298	0.135	0.139	0.501	-0.241
PK 472	2020	-0.58	-0.866*	0.43	-0.19	0.25	0.35	0.353	-0.806*	0.094	-.782*	-.780*	.829*
	2021	-0.62	-0.799*	0.57	-0.01	0.20	-0.12	-0.024	-0.278	0.114	0.193	0.53	-0.228
NRC 7	2020	-0.44	-0.758*	0.37	-0.37	0.03	0.53	0.324	-0.68	-0.002	-0.732	-.780*	.799*
	2021	-0.60	-0.769*	0.60	0.04	0.24	-0.13	-0.055	-0.28	0.069	0.181	0.462	-0.22
Punjab 1	2020	-0.52	-0.783*	0.37	-0.30	0.10	0.49	0.285	-0.679	-0.031	-0.692	-.760*	0.734
	2021	-0.61	-0.758*	0.62	0.11	0.26	-0.19	-0.025	-0.251	0.063	0.116	0.46	-0.187

Note: *Correlation significant $p<0.05$ level (2-tailed), ** Correlation significant $p<0.01$ level (2-tailed)

and developed an artificial neural network (ANN)-based model that allows for location-specific prediction of DRR incidence. A negative correlation between disease incidence and rainfall was observed in the case of both the genotypes and soil types, indicating that rainfall negatively influences disease incidence, irrespective of genotype or soil type. Additionally, a positive correlation between the average maximum temperature in October and DRR incidence was found, which could be due to the influence of increased temperature on R. bataticola infectivity or its impact on soil moisture status. Figodia et al. (2022) studied the impact of weather parameters on Alternaria leaf spot on soybean incited by Alternaria alternata and found that the disease severity was positively correlated with maximum temperature, while it is negatively correlated with minimum temperature, minimum and maximum relative humidity and rainfall of *kharif*, 2018.

3.2. Correlation analysis

Stepwise multiple regression analysis was performed between pooled PDI (2020 and 2021) and the current and preceding weekly average of weather variables (Table 5). Prediction equations developed for the current week suggested an R^2 statistic of 57.2–68.4% between the minimum temperature and the per cent disease index. For the development of RAB disease, the preceding week variable BSSH explained 66.9–58.4% of the variability in JS 95-60, JS 93-05, Bragg, PK 262, Monetta, PK 472, and NRC 7, while rainfall explained 60.5–69.2% of the variability in JS 335, Shivalik, and Punjab 1. The scatter chart plotted showed a negative correlation between minimum temperature (current week), rainfall (preceding week) and mean PDI with R^2 value of 0.63 and 0.59 respectively, while a positive correlation was observed between BSSH (preceding week) and mean PDI (R^2=0.57) (Figure 3). Similar finding was also reported by Kumar and Dubey (2002) that weather variables accounted for over 80% of the variation in web blight of winged bean caused by *R. solani*. Surbhi and Singh (2020) through multiple regression analysis of the disease severity with weather parameters found that the coefficient R^2 varied

Table 5: Stepwise multiple linear regression equations for prediction of rhizoctonia aerial blight (RAB) on different cultivars of soybean during the *kharif*, 2020 and 2021

Cultivar	Prediction equation for current week	R^2	Prediction equation for preceding week	R^2
JS 95-60	Y=65.019-0.783MinT	0.614	Y=66.011+0.815BSSH	0.664
JS93-05	Y=70.046- 0.764MinT	0.583	Y=68.575+0.765BSSH	0.584
BRAGG	Y= 64.056-0.819MinT	0.671	Y=64.058+0.809BSSH	0.654
PK 262	Y=105.074-0.762MinT	0.581	Y=75.836+0.758BSSH	0.610
Monetta	Y=87.705-0.776MinT	0.603	Y=114.738+0.788BSSH	0.621
JS 335	Y=164.915-0.765MinT	0.585	Y=416.336-0.780RF	0.608
Shivalik	Y=91.028-0.791MinT	0.626	Y=127.377-0.832RF	0.692
PK 472	Y=55.297-0.827MinT	0.684	Y=47.677+0.818BSSH	0.669
NRC 7	Y=71.394-0.756MinT	0.572	Y=79.377+0.781BSSH	0.610
Punjab 1	Y=189.646- 0.766MinT	0.586	Y=562.720-0.778RF	0.605

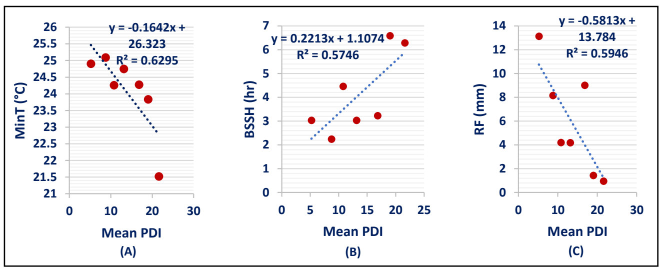

Figure 3: Linear relation of mean per cent disease index of RAB with minimum temperature of current week (A), Bright sunshine hours (B) and rainfall (C) of preceding week

from 41–70% indicating the association of weather factors with disease severity. Amrate et al. (2021) reported 94.6% variability of RAB severity with three weather variables viz., mean RH, rainfall and minimum temperature which could be increased upto 97.9% by adding one more variable i.e. sun shine hours. Nainwal et al. (2024) developed weather based statistical models for RAB disease of soybean in the Tarai region of Uttrakhand and found that weather variables viz., maximum air temperature, maximum relative humidity, rainfall, and sunshine hours played a pivotal role in RAB disease prevalence and spread collectively accounting for 56 to 75% of the variability in disease index. Ali et al. (2022) analyzed the environmental variables and Fusarium wilt of lentil disease severity data of two years (2017–2018) to develop a disease predictive model using a stepwise multiple regression analysis. They found that maximum and minimum temperatures, rainfall, and relative humidity significantly contributed to disease development and explained 94.39% variability in disease severity.

4. CONCLUSION

The disease onset occurred under warm and humid conditions during the flowering stage, with Punjab 1 and JS 335 being most susceptible, while PK 472 was resistant. Correlation and regression analysis revealed that weather factors, particularly minimum temperature, rainfall and bright sunshine hours, explained a substantial portion of the variability in RAB disease Rhizoctonia aerial blight (RAB) on soybean development.

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