



Influence of Weather Variables on Progression of Rust Disease (*Phakopsora gossypii*) in Cotton

Valarmathi Pandian^{1#}, Kanjana Duraisamy^{2#}, Sankaranarayanan Kaliyakonar³

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ABSTRACT

Background: To effectively manage the rust disease, it is crucial to understand how weather conditions impact both the host stage and disease development, as environmental factors significantly influence its severity and occurrence.

Methods: The effect of weather factors on the development of cotton rust in different varieties and Bt cotton hybrids were investigated during *kharif* 2021-2023 at ICAR- Central Institute for Cotton Research (CICR), Coimbatore under irrigated conditions.

Result: The development of rust during different years in the same varieties/hybrids showed similar trend. Correlation analysis of pooled data indicated strong correlations between rust intensity and maximum temperature, wind speed and relative humidity in both varieties and hybrids. Positive and significant correlation of wind speed was recorded both in varieties and hybrids. Multiple regression analysis of pooled data showed that weather parameters including RH I, SSH and windspeed significantly influenced the development of rust disease.

Key words: Correlation, Cotton, *Phakopsora gossypii*, Regression, T-test, Weather parameters.

INTRODUCTION

Cotton (*Gossypium spp.*) a key fiber crop essential to the textile industry, has experienced fluctuating production due to climate change-induced biotic stresses such as insects, diseases and weeds, as well as abiotic stresses including drought, salinity, heat and cold. Throughout the growing season, the cotton crop faces various foliar diseases such as leaf spots/blights, grey mildew and rust. Cotton crop is being affected by number of foliar diseases throughout the season. Among the fungal diseases, *Alternaria* leaf spot/blight, grey mildew and rust cause economic losses in the range of 26 to 34 per cent under congenial conditions (Monga *et al.*, 2013).

However, a new challenge has emerged in the form of an epidemic of cotton rust caused by the fungus *Phakopsora gossypii* (Arth.) Hirat. This disease has resulted in considerable losses, amounting to 30-40% of total yield, in the majority of Bt cotton hybrids cultivated in the region during 2009-2010 (Pindikur *et al.*, 2012). Cotton rust is prevalent in tropical and subtropical cotton-growing regions worldwide and has the potential to cause significant reductions in yield under favorable weather conditions. In some cases, it has been reported to reduce cotton yields by as much as 24%, as observed in Coimbatore (Johnston, 1963). The disease tends to appear during the dry season, spanning from December to March and has been observed in Karnataka andhra Pradesh and Gujarat, as reported by Puri *et al.* (1998). Currently, controlling tropical rust relies on the use of fungicides, which substantially raises production costs for growers, as resistant cotton cultivars are not yet available. This poses a significant challenge for the industry and highlights the importance of finding more sustainable solutions to combat this disease effectively (Kirkpatrick and Rothrock, 2001; Pindikur *et al.*, 2012). The rise in air and soil

¹Department of Plant Pathology, ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore-641 003, Tamil Nadu, India.

²Department of Soil Science, ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore-641 003, Tamil Nadu, India.

³Department of Agronomy, ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore-641 003, Tamil Nadu, India.

[#]These authors contributed equally to this work.

Corresponding Author: Valarmathi Pandian, Department of Plant Pathology, ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore-641 003, Tamil Nadu, India.

Email: valarpath@gmail.com

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temperature due to global climate changes has a notable impact on soil microbial activity, consequently affecting the prevalence of pathogens (Pregitzer, 1993). Pathogenic virulence mechanisms like fabrication of virulence proteins and toxins, and also spore germination and survival are governed by factors such as atmospheric carbon dioxide, temperature and humidity (Sharma and Verma, 2019).

Cotton leaf rust caused by *Phakopsora gossypii* poses a significant challenge in the southern region. The disease manifests as yellowish-brown uredia on the surfaces of leaves. Primary uredia, found on the upper leaf surface, penetrate deep into the tissues, while secondary uredia are shallower and present on the lower surface. Despite occurring later in the crop season, it still inflicts losses on late sown and extensively irrigated crops. In the past, the south zone experienced substantial losses due to early

instances of rust in 2009 and 2010. The estimated avoidable loss attributed to rust disease was approximately 21.7% in Bunny Bt and a significant 34.1% in RCH 2 BG II (Monga *et al.*, 2013; Bhattiprolu, 2015).

Nesur (2014) emphasized the significant positive influence of evening relative humidity on rust incidence in cotton crops when developing a decision support system for cotton. Correlation analysis of pooled data indicated strong correlations between rust intensity and sun shine hours and evaporation in Bunny BG II, Jadoo BG II and RCH 2 BG II hybrids (Bhattiprolu *et al.* 2016). Bhattiprolu and Monga (2018) further reported that minimum temperature, morning relative humidity and evening relative humidity were the critical parameters that contributed to the development of cotton rust in BG II hybrids, indicating the presence of genotypic differences in response to these environmental factors.

In their study, Singh and Ratnoo (2013) found that the temperature range of 28.8°C to 31°C and relative humidity between 86% and 93% were favorable conditions for the occurrence of *Alternaria* leaf spot in cotton with positive correlation was observed with maximum relative humidity. Furthermore, Johnson *et al.* (2013) observed that a temperature regime of 20°C to 30°C, along with prolonged high humidity exceeding 80% and frequent rainfall, promoted *A. macrospora* infection and facilitated disease development in cotton. Venkatesh *et al.* (2013) determined that the minimum temperature and afternoon relative humidity were crucial factors for predicting *Alternaria* blight disease in cotton genotypes. Similarly, Pankaj Baiswar *et al.* (2013) observed a significant negative correlation between the minimum temperature and the percentage disease index of soybean rust. Lasso *et al.* (2020) predicted the primary indicator of coffee rust incidence is monitoring, as it offers crucial insights into the current inoculum, which ultimately determines the potential for an increase or decrease in incidence. Temperature plays a decisive role during the germination and penetration phases of uredospore, specifically between 9 to 6 days and 4 to 1 day before the predicted date. Furthermore, the quantity of rainfall influences whether uredospore dispersal or washing conditions take place. The extended range weather forecast (ERWF) provides timely weather information and protects crops from weather-induced biotic and abiotic risks (Senbagavalli *et al.*, 2024).

Based on the current research, it was determined that the development of *Alternaria* blight, grey mildew and rust in the cotton crop is significantly influenced by specific weather parameters. These critical weather factors include maximum and minimum temperature, morning and evening relative humidity, as well as rainfall and the number of rainy days (Somasekhhar *et al.* 2023). Before effectively managing the disease, it is essential to have a comprehensive

understanding of how weather factors impact the host stage and the development of the disease. Environmental factors play a crucial role in influencing the severity and occurrence of the disease in any host plant. To effectively manage the disease, it is essential to comprehend the impact of weather conditions on its development. Hence, the present study aimed to evaluate the progression of cotton rust concerning various environmental factors.

MATERIALS AND METHODS

The effect of weather factors on the development of rust in cotton varieties viz., CCH 15, Suraksha, hybrids viz., RCH659 BG II and Suraj Bt was investigated during Kharif 2021 to 2023 at ICAR-CICR, Regional Station, Coimbatore under irrigated conditions. The crop was raised in a bulk plot with an area of 150 m². Twenty-five plants, in the middle rows, at random, were tagged and rust disease was scored on 0 to 4 scale (Sheo Raj, 1988) at weekly intervals on labelled plants, starting from the first appearance of the disease and expressed as Percent Disease Intensity (PDI) using Wheeler's formula:

$$PDI = \frac{\text{Sum of numerical ratings}}{\text{Total number of leaves scored} \times \text{maximum disease grade}} \times 100$$

Meteorological data (maximum temperature, minimum temperature, morning relative humidity (RH I), evening relative humidity (RH II), rain fall, sunshine hours (SSH), wind speed and rain days) was recorded daily from sowing onwards and weekly means were calculated while rainfall during the standard meteorological week was totaled. Correlation between progress of rust severity and weather factors was calculated and multiple regression equation was derived using Excel programme.

The disease progress with weather parameters such as rainy days, rainfall, temperature, relative humidity, sunshine hours and windspeed were recorded and obtained from the corresponding annual report of AICCP on cotton during the cropping season from August 2021 to February 2022 and August 2022 to February 2023.

Correlation

Correlation between disease and weather variables (mean temperature, mean rainfall and mean RH) was calculated using MS software.

Regression analysis

Regression equations and Coefficient of determination (R²) were derived by using step down regression analysis by using the SPSS software.

Soil nutrient status of field given as below.

Soil nutrient status	Surface (0-30 cm depth)				Sub surface (30-60 cm depth)			
	OC (g/kg)	AN (mg/kg)	AP (mg/kg)	AK (mg/kg)	OC (g/kg)	AN (mg/kg)	AP (mg/kg)	AK (mg/kg)
	6.1	105	19.2	494	4.4	90	14.3	446

RESULTS AND DISCUSSION

Correlation analysis

The disease occurred at 31.5°C maximum temperature, 22.0°C minimum temperature, 87% RH I, 50% RH II, 4.5 SSH, 5.9 km/h wind speed and reached maximum intensity at 30.0°C maximum temperature, 21.1°C minimum temperature, 84% RH I, 52.0% RH II, 4.7 SSH, 5.7km/h wind speed in Bt hybrids (RCH659 BG II and Suraj Bt). In the hybrids (RCH659 BG II and Suraj Bt) the rust disease intensity starts by 44th meteorological week (i.e. first week of November) with 10.8 and 8.8 PDI and attains its peak intensity by 52nd meteorological week (i.e. last week of December) with 54.1 and 42.7 PDI respectively. In the varieties (CCH 15 and Suraksha) the disease intensity initiates by 47th meteorological week (i.e. third week of November) and reaches its peak intensity by 52nd meteorological week (i.e. last week of December) with 27.3 and 15.3 PDI respectively.

The disease progress with respect to different meteorological week and weather parameters such as rainy days, rainfall, temperature, relative humidity, sunshine hours and windspeed were recorded during the two-cropping seasons from August 2021 to January 2023 in accordance with hybrids and varieties were depicted in Fig 1. Simple correlation showed that disease intensity has

positive correlation with maximum temperature (0.257,0.323,0.118 and 0.215), relative humidity I (0.294,0.293,0.171 and 0.208) and windspeed (0.575,0.550,0.505 and 0.552) whereas, negative correlation was observed with rainfall, minimum temperature, relative humidity II and sunshine hours during the two cropping years respectively (Table 1). The Correlation values 'r=0.545' for windspeed was found to be significantly correlated with the disease. Literature on cotton rust epidemiology is inadequate. In case of soybean rust caused by *P. pachyrhizii*, temperature, RH and leaf wetness duration played critical role for infection (Archana Nunkumar, 2006). Significant negative correlation of minimum temperature with per cent disease index of soybean rust was observed by Pankaj Baiswar *et al.* (2013). Bhattiprolu *et al.* (2016) conducted studies on different varieties and hybrids of cotton such as Narasimha, L 604, NSPHH 5, Bunny, Jaadoo BG II and RCH 2 BG II to investigate the factors influencing rust progression. They concluded that for Bunny hybrid, both relative humidity (RH I) and sunshine hours (SSH) were influential in rust development. In Bunny BG II, rust severity was primarily driven by SSH. Jaadoo BG II and RCH 2 BG II hybrids showed rust severity influenced by SSH, either independently or in combination with evaporation. Specific cultivars exhibited distinct factors affecting rust

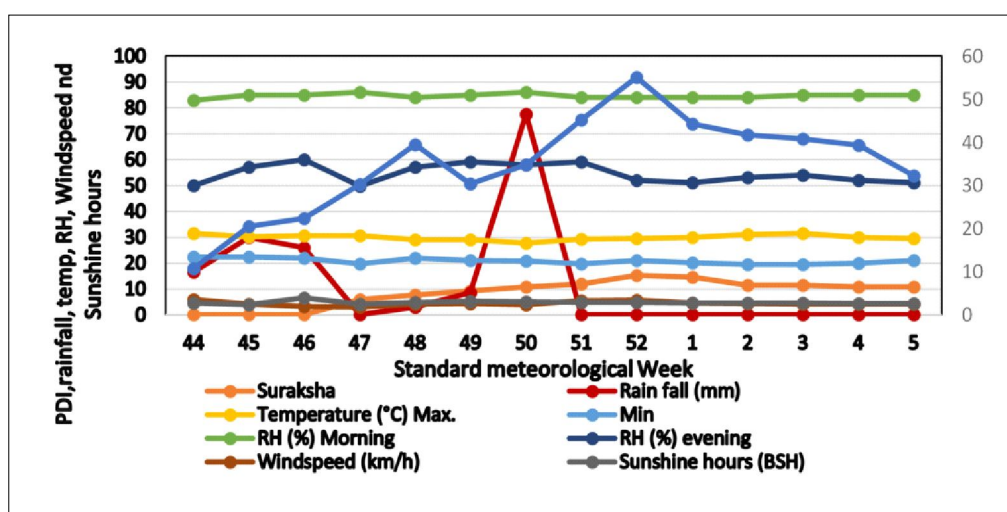


Fig 1: Incidence of rust disease (%) in relation to weather parameters in RCH659 BGII and Suraksha.

Table 1: Correlation values between weather parameters and rust of cotton (Correlation coefficient -r), (2021-2023).

Entry	PDI	Rainfall	Rainy days	Temp. (°C)		Relative humidity (%)		Sunshine hours (km/h)	Wind speed
				Max.	Min	Morning I	Evening II (BSH)		
RCH659 BG II	54.1	-0.249	-0.437	0.257	-0.870	0.294	-0.383	-0.379	0.575
Suraj Bt	41.7	-0.199	-0.403	0.323	-0.859	0.293	-0.368	-0.359	0.550
CCH 15	25.8	-0.340	-0.478	0.118	-0.828	0.171	-0.404	-0.326	0.505
Suraksha	15.3	-0.484	-0.485	0.215	-0.850	0.208	-0.405	-0.350	0.552

development. For example, maximum temperature notably impacted L 604, while minimum temperature played a significant role in NSPHH 5. RH I was a key factor in Narasimha, L 604 and Bunny, whereas evaporation was significant in Bunny BG II. In our study it was observed that simple correlation showed the disease intensity has positive correlation with maximum temperature, relative humidity I and windspeed whereas, negative correlation was observed with rainfall, minimum temperature, relative humidity II and sunshine hours during these cropping years (2021-2022 and 2022-2023 respectively) in both hybrids (RCH 659 BG II and Suraj Bt) and varieties (CCH 15 and Suraksha).

Independent t test analysis

Independent t test analysis were carried for all the weather parameters against per cent disease intensity (PDI) using data analysis pack in Excel. The results obtained from the analysis were depicted in Table 2. The weather parameters such as min temp, RH (Morning and Evening), Windspeed which seems to be significant against PDI were discussed in detail. Other weather parameters such as rainfall, max temp and sunshine hours seems to be non-significant against PDI. For the minimum temperature, the test statistic turns out to be 4.536 and the corresponding p-value is 0.0002 for RCH659 BG II. For Suraj Bt- t value (-2.263) with p-value is 0.032. t value for CCH15 is -3.780 and p-value

(0.0008). For Suraksha, t value (2.990) and p-value (0.0099). Since this p-value is less than 0.05, it is evident to say that the correlation between the two variables is statistically significant. The Chi-square test of Independence is a statistical method used to evaluate the relationship between two or more categorical variables. It is commonly employed in various research fields to determine if there are significant associations between variables. The Chi-Square analysis resulted in a Chi-Square statistic (χ^2) of 19.43, with 10 degree of freedom. The associated p-value was 0.04, below the alpha level of 0.05, suggesting a statistically significant association between weather variables and PDI for cotton rust.

Regression analysis

Study the effect of weather on the disease development regression equations were derived and coefficient of determination (R^2) were calculated. Typically, a regression analysis is done for one of two purposes: In order to predict the value of the dependent variable for individuals where some information concerning the explanatory variables are available, or in order to estimate the effect of some explanatory variables (*i.e.* weather variables) on the dependent variable (*i.e.* PDI). The coefficient of determination is a statistical measurement which examines how differences in one variable (*i.e.* PDI) can be explained by the difference in a second variable (*i.e.* weather

Table 2: Independent t test results for PDI Vs Weather parameters.

Genotypes	t value	df	n	p value (CI 95%)	Significance
PDI Vs Min. Temp					
RCH659	4.536	13.15	14	0.0002	S*
Suraj Bt	1.765	13.24	14	0.044	S*
CCH15	-3.668	13.24	14	0.0005	S*
Suraksha	-8.599	12.14	14	0.0002	S*
PDI Vs RH morning					
RCH659	1.770	13.12	14	0.002	S*
Suraj Bt	1.659	13.22	14	0.002	S*
CCH15	1.563	13.11	14	0.002	S*
Suraksha	1.761	14.12	14	0.002	S*
PDI Vs Windspeed					
RCH659	9.8848	13.142	14	0.001	S*
Suraj Bt	-2.2634	25.541	14	0.032	S*
CCH15	-3.7809	25.633	14	0.0008	S*
Suraksha	2.9908	13.689	14	0.0099	S*

Table 3: Regression equations developed at CICR, RS, Coimbatore (2021-2023).

Variety/Hybrid	Multiple regression equation	Coefficient of determination (R^2)
RCH659 BG II	$Y=530-6.32524MT-2.17389RHI*+1.51131WS^{**}+1.78934SSH^{**}$	0.72
Suraj Bt	$Y=276.1-6.38107MT+0.602538RHI*+4.66145WS^{**}+3.58543SSH^{**}$	0.87
CCH 15	$Y=328.12-2.81029MT-1.17244RHI*+2.72941WS^{**}+2.18532SSH^{**}$	0.72
Suraksha	$Y=213.74-3.18157MT-0.41903RHI*+1.41519WS^{**}+1.40152SSH^{**}$	0.84

** Significant at 1%; *Significant at 5%

Y- Mean disease incidence; MT-Max temperature; RH I- Morning relative humidity; WS-Windspeed; SSH- Sunshine hours.

variables) when predicting the outcome of a given event. In other words, this coefficient assesses how strong the linear relationship is between two variables and is heavily relied on by investors when conducting trend analysis. The coefficient of determination (R^2) revealed that weather variables contributed 72, 87, 72 and 84 per cent effect on

the disease incidence (Table 3) in 2021-2022 and 2022-2023 cropping years respectively. The regression equations derived for all the hybrids (RCH659 BGII and Suraj Bt) and varieties (CCH 15 and Suraksha) for two cropping seasons showed that windspeed and sunshine hours are the most important factor for the disease development. Multiple

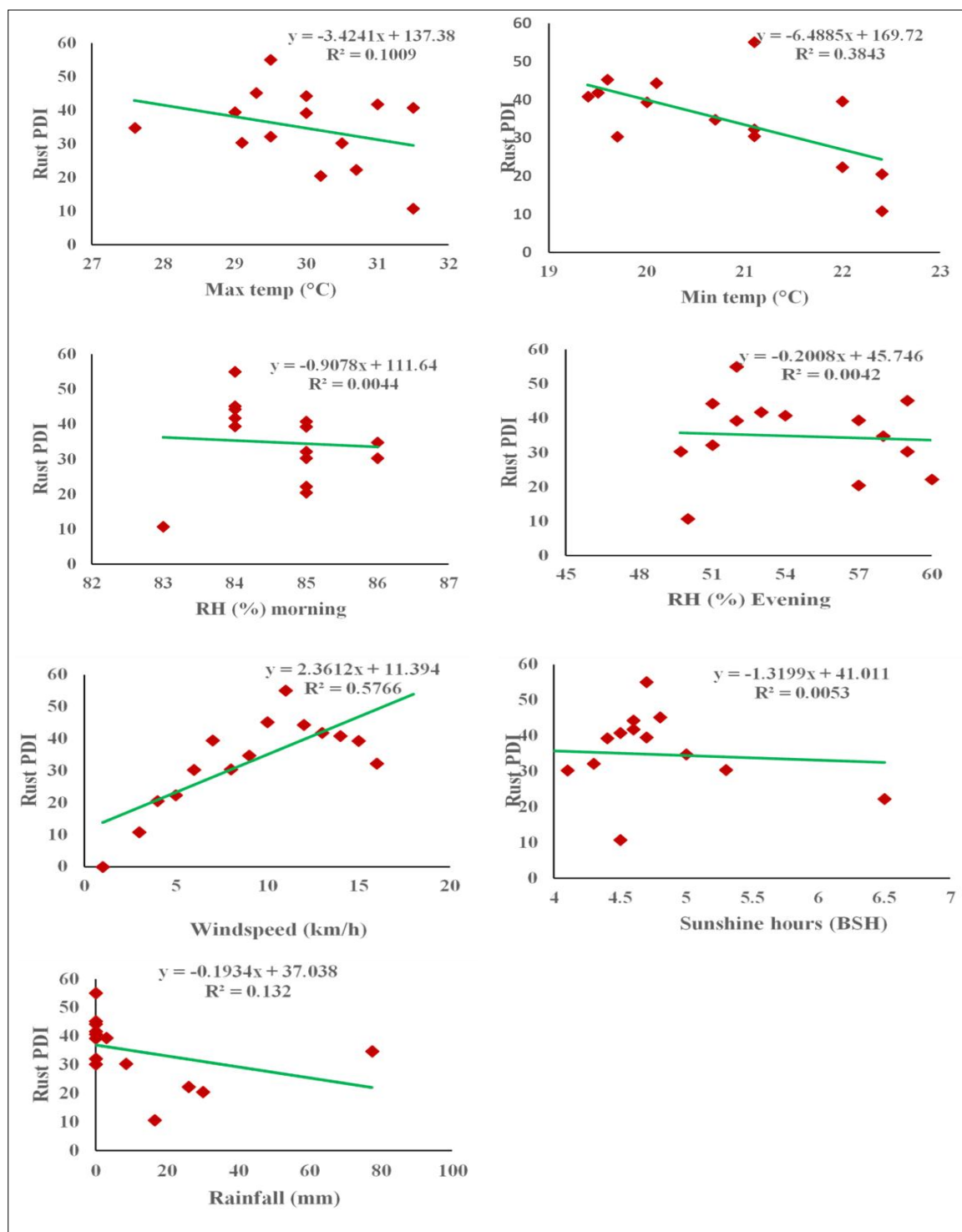


Fig 2: Trend line of rust disease of cotton in RCH659 BG II during Kharif - (2021-2023).

regression analysis of pooled data showed that weather parameters including RH I, SSH and windspeed significantly influenced the development of rust disease. Multiple regression analysis of pooled data showed that weather parameters including RH I, SSH and windspeed significantly influenced the development of rust disease. Independent t-test analysis indicates that as p-value is less than 0.05, it is sufficient to prove with evidence that the correlation between the two variables (*viz.*, max temp, RH morning, RH evening and windspeed against PDI) were found to be statistically significant.

The goodness of fit in a statistical model is crucial for assessing its accuracy and effectiveness. Various measures evaluate how well a regression model represents the data, commonly known as “regression errors.” Coefficient of Determination (R^2) measures how well a regression model replicates observed outcomes. Ranging from 0 to 1, a higher R^2 indicates a better fit. From our study, R^2 values for the weather variables are 0.72, 0.87, 0.72, 0.74 which indicates better fit. The weather variables, windspeed and minimum temperature showed positive trend line against PDI for RCH659BGII and Suraksha while rest of the weather variables showed negative trend line (Fig 2). The choice of goodness-of-fit measure depends on the context and goals of the analysis. R^2 serves as an interpretable percentage indicating the explained variability. A balance of these measures ensures a comprehensive evaluation of regression model performance.

Variation in rust intensity to the tune of 20.4% to 55.0% in different hybrids can be explained by weather factors. For every one-degree Celsius decrease in maximum temperature there was corresponding increase of rust intensity from 1.0% to 10.1% in different hybrids. With respect to increase in windspeed and sunshine hours, the disease intensity also increases. These observations indicate the importance of varieties/hybrids in developing prediction models for the disease. Guidance for farmers on control measures can be formulated by analysing disease onset and observations across various different meteorological weeks for cotton rust disease. The correlation of weather parameters with PDI of *Fusarium* wilt in pigeon pea indicated that significant and positively correlation with maximum and minimum temperature and negative correlation with evening relative humidity (Nagaraju *et al.*, 2022).

Similar observations were made by various researchers showed that the correlation analysis showed a positive correlation with sunshine hours (SSH) wherein significant negative correlation between rust incidence and maximum temperature, minimum temperature, rainfall (Rf) and rainfall days (Rd) in hybrids. On the other hand, varieties showed a significant negative correlation of PDI with maximum temperature, minimum temperature, RH II, Rf and Rd. The results of multiple regression analysis indicated that maximum and minimum temperatures had a significant influence on the

progression of rust in all entries. Rf and Rd had partial influence across all entries and SSH showed partial influence in the case of L 1060, NDH 1938 and RCH 2 BG II. (Anonymous, 2023). In recent times, the effects of global climate change have intensified the focus on weather-based disease prediction models to mitigate the sudden onset of crop diseases (Nath *et al.*, 2023). Despite taking precautions such as utilizing resistant varieties and applying fungicides, rust still inflicted significant damage under specific meteorological conditions.

CONCLUSION

The research conducted underscores the need for more extensive and in-depth studies utilizing an automated station network. Such endeavors would facilitate the assessment of how daily variations in weather conditions impact cotton rust infection triggered by this pathogen. Therefore, further epidemiological studies are needed to identify and understand the key factors essential for forecasting and predicting cotton rust disease accurately. These studies aim to minimize the yield losses associated with this disease. Climate change and its variability are important factors in the epidemiology of plant diseases. Enhanced epidemiological investigations are essential for the development of a weather-based forecasting model, which can be integrated into the Appropriate Integrated Management System.

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Disclaimers

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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