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Influence of Climatic Factors on Sorghum Rust Severity in Dharwad, Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Sorghum rust, caused by *Puccinia purpurea*, significantly reduces crop yield, affecting plant growth and grain quality. Understanding the impact of weather parameters on disease incidence is crucial for timely disease management, to enhance crop resilience and yield stability. This study aims to

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identify and quantify the relationship between weather parameters and the incidence of sorghum rust, to inform decision-making on disease management strategies. A comprehensive analysis was conducted utilizing 17 years of secondary data (2006-2022) sourced from the All India Coordinated Research Project (AICRP) on Sorghum and the Department of Agrometeorology at the Climate Model Intercomparison Project (CMIP), University of Agricultural Sciences (UAS), Dharwad. The study employed statistical methods, including Multiple Linear Regression (MLR) and Step-wise Regression, to model the dependence of rust disease incidence on independent variables such as precipitation, temperature, relative humidity, wind speed, radiation, and heat flux. The results revealed the MLR model explains 65.45% of the variation and the Step-wise Regression model identifies four critical parameters- relative humidity, heat flux, wind speed, and radiation that together accounted for 65.09% of the variation without exhibiting multicollinearity (Variance Inflation Factor values below 10). These findings enhance the understanding of environmental impacts on sorghum rust and can inform future agricultural management strategies for disease prediction and control.

Keywords: Multiple Linear Regression (MLR); Step-wise Regression; rust incidence; Variance Inflation Factor (VIF).

1. INTRODUCTION

Sorghum, botanically known as *Sorghum bicolor* L., is a carbohydrate-rich crop of the Poaceae Gramineae family and originated in Africa. It was domesticated between 3,000 and 5,000 years ago [1], Sorghum ranks as the world's fifth-largest crop, following wheat, maize, rice, and barley. Nevertheless, sorghum plays a vital role in the fight against hunger and food insecurity and is essential to the food security of a large number of the world's poor, who reside in fragile agro-ecological zones [2]. Sorghum is popularly known as “King of Millets”, is highly significant in terms of carbohydrates and is a staple food source for millions of people living in semi-arid tropical regions. Although sorghum is mainly used as a staple food for humans, it is primarily grown as a fodder crop for animal feeding in some Western countries like the United States, Brazil and Australia. Because of its exceptionally low input tolerance, it is a vital component for regions with minimal rainfall. Sorghum can therefore play a critical role in feeding the most vulnerable people on the planet in the context of rising demand for scarce freshwater supplies, expanding use of marginal crop land, and shifting climate trends. Due to its thought-provoking characteristics, sorghum is a perfect plant species to investigate the evolutionary relationships among other grass species as well as to conduct diverse study under changing climate conditions to ensure food security [3].

Despite its robustness and adaptability to harsh environments, sorghum’s productivity is significantly compromised by a range of diseases. Among these, rust diseases caused by obligate biotrophic fungi pose a serious threat to sorghum production worldwide. The economic impact of the diseases is considerable, leading to reduced productivity and increased costs for disease management. Knowledge of disease epidemics and characterization of Patho systems is important for long term disease management [4]. Understanding the epidemiology, pathogenesis, and management of sorghum diseases is essential to reduce the impacts of diseases and to develop effective control measures and ensure the sustainability of sorghum production.

Sorghum rust is primarily caused by two major fungal pathogens: *Puccinia purpurea* and *Puccinia sorghi*. *Puccinia purpurea*, responsible for sorghum leaf rust, and *Puccinia sorghi*, which causes sorghum rust (also known as grain rust), can both lead to severe losses in yield and quality [5] The symptoms of these rust diseases include the formation of pustules on leaves, stems, and panicles, which disrupt photosynthesis and overall plant health. The impact of these diseases extends beyond immediate crop loss, affecting the economic stability of farming communities and the broader agricultural sector. The epidemiology of sorghum rust diseases is influenced by a complex interplay of host-pathogen-environment interactions Under favourable conditions, early infection and quick disease development might impact panicle exhaustion and result in yield losses of up to 65% [6].

Rust is known to predispose plants to other serious diseases such as *Fusarium* stalk rots, charcoal rot, and grain moulds [7]. If the climatic conditions are favourable, there will be early infection and quick disease development which impact panicle exhaustion and result in yield losses of up to 65% [6]. Yield losses ranging from 30% to 50% have been documented in the Philippines, India, and Puerto Rico [8].

The incidence and severity of rust diseases in sorghum are closely linked to weather parameters, which play a critical role in the development and spread of these fungal pathogens. Severe rust infection also results in lodging [9]. High rainfall and high relative humidity during crop growth are conducive for aggravation of disease severity [10,11]. Temperature, humidity, and rainfall are key factors influencing rust disease dynamics. Rust fungi are obligate biotrophs, meaning they require living host tissue to complete their life cycles, and their growth and sporulation are highly sensitive to environmental conditions.

Rust developed between 16 and 28 °C, with the optimum temperature being 20 °C [12]. Deviations from these temperatures can either inhibit pathogen development or accelerate its progression, depending on the specific conditions. Similarly, high humidity and frequent rainfall create favourable conditions for rust spore germination and infection, as moisture is essential for the formation and dispersal of rust pustules [13].

Seasonal variations and climate change further complicate the interaction between weather parameters and rust disease incidence. Changes in temperature and precipitation patterns can alter the timing and severity of rust outbreaks, potentially leading to increased frequency of disease incidents and expanded geographic ranges of rust pathogens. For instance, warmer winters and increased rainfall in the growing season can enhance the survival and proliferation of rust fungi, leading to more severe infections in susceptible sorghum varieties.

2. MATERIALS AND METHODS

For this study, disease incidence data spanning seventeen years (2006 to 2022) was collected from the All-India Coordinated Research Project (AICRP) on Sorghum at the Dharwad center, where disease scoring was performed using a zero to nine-point scale [14]. The rust severity on sorghum was recorded according to the following scale:

- **0:** No symptoms on the leaves
- **1:** Small, brown, powdery pustules covering 1% or less of the leaf area
- **3:** Typical rust pustules covering 1% or less of the leaf area
- **5:** Typical rust pustules covering 2% to 25% of the leaf area
- **7:** Typical rust pustules covering 26% to 50% of the leaf area
- **9:** Rust pustules covering 51% or more of the leaf area, with yellowing and withering of leaves

All the leaves of a sorghum plant were observed for recording rust severity in the present study. Weather data, including precipitation, temperature, relative humidity, wind speed, radiation, and heat flux, was collected from the Department of Agrometeorology, Climate Model Intercomparison Project (CMIP) at UAS, Dharwad.

2.1 Descriptive Statistics

Descriptive statistics, including minimum, maximum, mean, standard deviation, variance, skewness, kurtosis, and coefficient of variation (CV), were calculated for rust scores and weather parameters. The effect of weather parameters on disease scores and its component traits was examined by correlating these with the weather parameters using linear functional forms.

2.2 Multiple Linear Regression

Multiple Linear Regression (MLR) is a statistical method that employs several explanatory variables to predict the value of a response variable. MLR aims to model the linear relationship between the explanatory (independent) variables and the response (dependent) variable.

The multiple linear regression model for the disease (Y) and the weather parameters (Xi) is given as,

$$Y' = X\beta' + \varepsilon$$

Where, $Y' = (Y_1, Y_2, \dots, Y_n)$ is the vector of values of the dependent variable which is disease incidence. X is a matrix of order (nXp) containing independent variables i.e., weather parameters. $\beta' = \beta_1, \beta_2, \dots, \beta_k$ is the vector of parameters and $\varepsilon' = (\varepsilon_1, \varepsilon_2, \dots, \varepsilon_k)$ is the error vector.

The error vector is ε is assumed to be normally distributed with $N[0,\sigma^2]$. The least square estimator of the parameter vector β is $\hat{\beta} = b = (X'X)^{-1}\, X'Y$ and $V(b) = (X'X)^{-1}\sigma^2$

The fitted equation is $\hat{Y} = Xb$.

In this study y is disease incidence (Rust Scores) and x_i 's are independent variables that is precipitation, temperature, relative humidity, wind speed, radiation and heat flux. The significance of the model is tested by F-test.

2.3 Step-Wise Regression

Stepwise regression is one of the most regularly used algorithms for variable selection and it was given by Efroymson. This method was an improvement over the forward selection and backward elimination. In this method, all the regress or variables entered into the model previously were re-verified at each stage by using their partial F- statistics. The elimination of the variable from the model was done when the partial F- statistics value was less than the $F_{OUT.}$

2.4 Multiple Coefficient of Determination (R^2)

Multiple coefficient of determination (R^2) was used to assess the adequacy of the model, which was used to know the percentage contribution of the independent variable on the dependent variable. The quantity is defined as follows

$$R^2 = \frac{RSS}{TSS}$$

Where, RSS= Regression sum of squares and TSS= total sum of squares. F test was used to test of significance of the R^2.

3. RESULTS AND DISCUSSION

The descriptive statistics of the weather variables reveal that the mean temperature is 25.07°C, with a relatively low standard deviation of 0.84. The data is positively skewed (0.51) and exhibits platykurtic characteristics. Precipitation shows a higher mean value of 206.72 mm and a considerable standard deviation of 63.02, reflecting significant variability in precipitation levels. The skewness of -1.02 indicates that the precipitation data is skewed toward lower values, while the positive kurtosis (1.67) suggests a distribution with heavier tails, implying occasional extreme precipitation events.

Relative Humidity (RH) has a mean value of 78.9% with a standard deviation of 4.06, pointing to relatively consistent humidity levels. Wind Speed has a mean of 4.70 m/s and a standard deviation of 0.57, indicating moderate variability in wind speeds. The skewness of -2.06 reflects a notable skew toward lower wind speeds, while the high kurtosis of 6.09 highlights a distribution with very heavy tails, suggesting that extremely high wind speeds are relatively common. Radiation and Heat Flux exhibit moderate variability, with mean values of 233.12 and 58.86, respectively. Both variables show a high degree of dispersion, as indicated by their standard deviations. Temperature and Heat Flux have relatively high coefficient of variation (CV) values, suggesting greater variability in these measures relative to their means. Conversely, RH and Wind Speed show lower CV values, indicating more stability in these variables.

Similarly, the descriptive statistics of rust scores reveal that the mean rust score was found to be 3.13, with a standard deviation of 0.75. This indicates a moderate level of rust severity across the observed sorghum plants, with scores ranging from 2.20 to 4.50.

Table 1. Summary of statistics for rust score and weather parameters

Descriptive statistics	Rust	Temperature	Precipitation	RH	Wind Speed	Radiation	Heat Flux
Mean	3.13	25.07	206.72	78.9	4.70	233.12	58.86
Standard Deviation	0.75	0.84	63.02	4.06	0.57	9.73	8.37
Skewness	0.51	-0.14	-1.02	-0.73	-2.06	0.33	0.91
Kurtosis	-0.95	-0.77	1.67	1.45	6.09	0.91	1.89
Minimum	2.20	23.52	49.33	68.94	2.96	216.95	45.88
Maximum	4.50	26.38	289.58	85.05	5.30	255.02	79.02
CV	23.96	3.35	30.49	5.15	12.13	4.17	14.22

Table 2. Results of Multiple linear regression and stepwise regression

Weather parameters	Coefficients of Multiple Linear Regression	Coefficients of Stepwise regression
Intercept	57.14*	58.82**
RH	0.12	0.11*
Wind Speed	0.71	0.74
Radiation	-0.14*	-0.15**
Heat Flux	-0.13	-0.14**
Temperature	-0.02	-
Precipitation	0.001	-
R^2	0.6545	0.6509
F- value	2.56	4.66

*** Significant @1%, *Significant @5%*

The results from the Multiple Linear Regression (MLR) and Stepwise Regression models, as shown in Table 2, indicate that weather parameters such as temperature, precipitation, relative humidity, wind speed, radiation, and heat flux collectively explain 65.45% of the variation in rust incidence. However, the MLR model has an F-value of 2.56, which is not statistically significant, suggesting a moderate fit. This implies that while the predictors contribute to explaining rust incidence, there may be room for improvement in capturing the full variability of rust occurrence.

The stepwise regression model reveals that wind speed and relative humidity has a positive impact. In contrast, radiation and heat flux have a highly significant negative impact. Collectively, these four parameters account for 65.09% of the variation in rust incidence. Despite this slight decrease in explanatory power compared to the MLR, the F-value increases to 4.66, indicating that the stepwise model provides a better overall fit and highlights the most significant predictors. Radiation and heat flux, with coefficients of -0.14 and -0.15 respectively, play a crucial role in rust incidence. Increased radiation and heat flux contribute to environmental conditions that can influence rust growth. Elevated radiation can significantly affect rust disease in sorghum crops by inducing physiological stress, which can either increase the plants' vulnerability to rust or promote growth that helps resist infection. Specifically, high light intensity, combined with high relative humidity, cooler temperature, heavy dews and rainfall, supports the development of the sorghum rust caused by an obligate fungal pathogen *Puccinia purpurea* [15]. Biotic stress such as sorghum rust combined with abiotic heat stress stimulates maximum decreases in floret fertility, leading to a poor seed set ultimately lead to severe yield loss [16].

Sorghum rust can be economically detrimental in warm, moist climates where late-planted. Thus, the disease often develops late in the season at high temperatures; if infection occurs earlier, yield reductions are more evident. It is characterized by the formation of tiny, brown uredinia pustules that occur on the upper and lower leaf surface [17].

Heat flux, which represents the rate of heat transfer per unit area, also impacts rust incidence. High heat flux can weaken plant defences and make them more susceptible to infections, particularly when combined with high humidity levels that favour fungal growth. The stepwise regression model is free from multicollinearity with all the variation inflation factor values less than 10 [18].

4. CONCLUSION

This study provides a comprehensive analysis of the influence of weather parameters on the incidence of rust disease in sorghum, specifically caused by the pathogen *Puccinia purpurea*. The descriptive statistics reveal meaningful insights into the climate conditions surrounding rust outbreaks, with recognized variability in temperature, precipitation, relative humidity, wind speed, radiation, and heat flux. Notably, the results from the Multiple Linear Regression (MLR) model explain 65.45% of the variation in rust incidence, while the improved Stepwise Regression model highlights the significance of specific predictors, accounting for 65.09% of the variation and demonstrating a more favorable statistical fit.

Key findings suggest that increasing relative humidity and wind speed positively influence rust incidence, whereas both radiation and heat flux exert a significant negative impact. The elevated radiation and heat flux can create environmental stress conditions that may enhance the susceptibility of sorghum plants to rust disease. Additionally, the absence of multicollinearity was effectively addressed in the stepwise model, ensuring the reliability of the findings.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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