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Original article

A disease predictive model based on epidemiological factors for the management of bacterial leaf blight of rice

Um modelo preditivo de doenças baseado em fatores epidemiológicos para o manejo da queima bacteriana das folhas do arroz

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Abstract

Rice is a widely consumed staple food for a large part of the world's human population. Approximately 90% of the world's rice is grown in Asian continent and constitutes a staple food for 2.7 billion people worldwide. Bacterial leaf blight (BLB) caused by Xanthomonas oryzae pv. oryzae is one of the devastating diseases of rice. A field experiment was conducted during the year 2016 and 2017 to investigate the influence of different meteorological parameters on BLB development as well as the computation of a predictive model to forecast the disease well ahead of its appearance in the field. The seasonal dataset of disease incidence and environmental factors was used to assess five rice varieties/ cultivars (Basmati-2000, KSK-434, KSK-133, Super Basmati, and IRRI-9). The accumulated effect of two year environmental data; maximum and minimum temperature, relative humidity, wind speed, and rainfall, was studied and correlated with disease incidence. Average temperature (maximum & minimum) showed a negative significant correlation with BLB disease and all other variables; relative humidity, rainfall, and wind speed had a positive correlation with BLB disease development on individual varieties. Stepwise regression analysis was performed to indicate potentially useful predictor variables and to rule out incompetent parameters. Environmental data from the growing seasons of July to October 2016 and 2017 revealed that, with the exception of the lowest temperature, all environmental factors contributed to disease development throughout the cropping season. A disease prediction multiple regression model was developed based on two-year data (Y = 214.3-3.691 Max T-0.508 Min T + 0.767 RH + 2.521 RF + 5.740 WS), which explained 95% variability. This disease prediction model will not only help farmers in early detection and timely management of bacterial leaf blight disease of rice but may also help reduce input costs and improve product quality and quantity. The model will be both farmer and environmentally friendly.

Keywords: BLB, environmental variables, prediction model, rice, *Xanthomonas oryzae*.

Resumo

O arroz é um alimento básico amplamente consumido por grande parte da população humana mundial. Aproximadamente 90% do arroz do mundo é cultivado no continente asiático e constitui um alimento básico para 2,7 bilhões de pessoas em todo o mundo. O crestamento bacteriano das folhas (BLB) causado por *Xanthomonas oryzae* pv. *oryzae* é uma das doenças devastadoras do arroz. Um experimento de campo foi realizado durante os anos de 2016 e 2017 para investigar a influência de diferentes parâmetros meteorológicos no desenvolvimento do BLB, bem como o cálculo de um modelo preditivo para prever a doença bem antes de seu aparecimento em campo. O conjunto de dados sazonais de incidência de doenças e fatores ambientais foi usado para avaliar cinco variedades/cultivares de arroz (Basmati-2000, KSK-434, KSK-133, Super Basmati e IRRI-9). O efeito acumulado de dados ambientais de dois anos; temperatura máxima e mínima, umidade relativa do ar, velocidade do vento e precipitação pluviométrica foram estudados e correlacionados com a incidência da doença. A temperatura média (máxima e mínima) apresentou correlação significativa negativa com a doença BLB e todas as outras variáveis; umidade relativa, precipitação e velocidade do vento tiveram uma correlação positiva com o desenvolvimento da doença BLB em variedades individuais. A análise de regressão *stepwise* foi realizada para indicar variáveis preditoras potencialmente úteis e para descartar parâmetros incompetentes. Os dados ambientais das safras de julho a outubro de 2016 e 2017 revelaram que, com exceção da temperatura mais baixa, todos os fatores ambientais contribuíram para o desenvolvimento da doença ao longo da safra. Um modelo de regressão múltipla de previsão de doença foi desenvolvido com base em dados de dois anos (Y = 214,3-3,691 Max T-0,508 Min T + 0,767 RH + 2,521 RF + 5,740 WS), que explicou 95% de variabilidade. Este modelo de previsão de doenças não só ajudará os agricultores na detecção precoce e gestão atempada da doença bacteriana das folhas do arroz, mas também pode ajudar a reduzir os custos de insumos e melhorar a qualidade e a quantidade do produto. O modelo será agricultor e ambientalmente amigável.

Palavras-chave: BLB, variáveis ambientais, modelo de previsão, arroz, *Xanthomonas oryzae*.

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1. Introduction

Rice (*Oryzae sativa* L.) is a member of the family Poaceae and is one of the major food crops of the world, especially in most Asian countries like Pakistan, Bangladesh, China, Vietnam, and Korea. Rice is ranked second in cereal cultivation around the globe and occupies an important position in the economy of Pakistan as an export item as well as a staple food (Zahid et al., 2005). It is the predominant dietary energy source for 17 countries in Asia and the Pacific, 9 countries in North and South America, and 8 countries in Africa. Rice provides 20% of the world's dietary energy supply, while wheat supplies 19% and maize (corn) 5% (Juliano, 1993). After cotton, rice is Pakistan's second largest export commodity and accounts for 3.2 percent of the overall agricultural value added and 0.7 percent of GDP (Naseem et al., 2014). In exports, Pakistan ranks third in the world market. Rice is the main crop after wheat in Pakistan, grown on an area of 2.8 million hectares with a production of 7.5 million tonnes (Shabbir et al., 2020).

Among diseases present in rice crop, bacterial leaf blight of rice (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* also referred to as *Xoo*, is a major disease in Asia (Shah et al., 2009; Swings et al., 1990). The unfavorable environmental conditions can pose a serious risk for rice processing units in Pakistan by favouring BLB that has been progressed yearly in the field (Shah et al., 2009). *X. oryzae* pv. *oryzae* is recognized as an infectious pathogen of rice that causes more losses in temperate, rainfed, and hot areas, especially in regions cultivated with watered rice around the world (Frei and Becker, 2004). BLB is a destructive seed-borne disease causing up to 50 percent disease losses (Sharma et al., 2017). The seed-borne nature of the causal agent is a primary source of inoculum that can lead to a serious incidence of disease. The seed and the developing plant may be infected by the pathogen, leading to common infection (Hilaire et al., 2001; McGee, 1995). In Pakistan, BLB was reported on lucrative rice genotypes such as Basmati-198 and Palman at the Rice Research Institute, Kala Shah Kaku, and adjoining crop zones (Mew et al., 1993). In the "Kaller" areas of Punjab, Khyber Pakhtunkhwa (KPK), and Sindh the incidence of BLB rice disease was mainly found high, a potential threat to rice cultivation in these areas (Ahmad and Majid, 1980).

In Pakistan, the establishment of BLB into the stern, rice crop yield is affected badly. Currently, the disease is prevailing in Punjab with an incidence ranging between 49.23-70.12% (Shaheen et al., 2019). It has continued to diminish the produce. Weeds and stubbles infected plant fields, unavailability of resistant varieties, lack of knowledge about the disease prevailing conditions, pathogen disease cycle, and its effective control strategies is a major challenge to the crop (Akhtar and Rafi, 2007; Waheed et al., 2009). Cheema et al. (1998) and Aktar et al. (2009) recorded that nearly all of the lucrative basmati cultivars grown in the province are vulnerable to BLB disease.

Pesticides application is, to date, considered as a widespread practice of BLB control however this is a significant financial burden for growers, and there is a great deal of uncertainty in deciding when and how much to apply to commercial fields. Currently, when it comes to disease monitoring, producers frequently rely on easy visual identification, measuring incidence and severity using standard area diagrams (SADs), disease progress (AUDPC) curves, and weather/forecast conditions, among other methods (Nopsa and Pfender, 2014; Ojiambo et al., 2017). A calendar-based schedule is then used to apply pesticides either preventatively, or even if no disease has been diagnosed, according to the level of perceived risk (Carisse et al., 2009).

The epidemiological factors such as high temperatures, low and high errant rainfall, high humidity, and anomalies of wind, play a crucial role in the establishment of BLB, and therefore, rice yield is lower than its potential (Ali et al., 2017; Shakoor et al., 2015). Climatic conditions greatly influence the development of *X. oryzae* pv. *oryzae* infection on rice (Naqvi, 2019). The infection cycle is influenced by the dispersal of pathogen and transfer between host plant species. Environmental factors facilitating the pathogen dispersal may determine why susceptible crops in a region are regularly infected while others remain pathogen free (An et al., 2020). Minogue and Fry (1983) referred both pathogens and host plants may be studied together under a specific environmental setting termed a plant disease classic triangle. It is imperative to study epidemiological factors which generally lead to the epidemic of disease.

For the proper disease management, disease predictive models can assist by indicating the potentially useful environmental predictor variables in disease development and improving program evaluation and acceptance while also reducing pesticide use in areas where disease risk is minimal. The disease prediction models for the BLB disease of rice have been effectively constructed and validated (Naqvi, 2019).

Crop plants disease prediction modeling counts the main attributes of the disease development and focuses on the strategies for tactical disease management (Van Maanen and Xu, 2003). A comprehensive knowledge and detailed information regarding the pathogen, host, time, human and environmental parameters is necessary to make it possible to accurately forecast the disease and avoid heavy losses by arranging the plant protection measures. Stepwise regression model development techniques have been used extensively by the plant pathologists to describe the relationship of climatic factors with the disease intensity and severity and many successful regression models have been developed previously (Coakley et al., 1985; Jacobi et al., 1983).

Disease prediction models have the potential to improve the timeliness, effectiveness, and foresight for controlling crop diseases while minimizing economic costs environmental impacts, and yield losses. Therefore, the present research aimed to create a meteorological stepwise regression model to forecast bacterial leaf blight of rice disease.

2. Material and Methods

2.1. Experimental place

The study was conducted at the experimental area of Department of Plant Pathology, Bahauddin Zakariya University, Multan (Latitude: 30.0042. Longitude: 71.1625). The major crops of Multan include wheat, cotton, sugarcane, rice, maize, sunflower, and fodder crops. Although the region has a comparative advantage in producing cotton over rice and other crops however, rice is cultivated on an area of 379000 acres in this region. Multan features an arid climate and has a hot summer and a cold winter. The city has some of the country's hottest temperatures. Since rice requires a humid environment and grows best in humid climates with plenty of sunshine and water, Multan is a suitable place for rice cultivation. The crop planting time is marked by hot days and warm nights. The region is dominated by a humid subtropical climate where 57.5% rainfall is estimated during the summer monsoon season. Rainfall and the mean temperature are 534 mm and 31°C, respectively in the Central region. June and July are the prominent months that reduce moisture stress.

2.2. Nursery preparation and transplantation in the field

Germplasm of five different varieties/ cultivars (Basmati-2000, KSK-434, KSK-133, Super Basmati, and IRRI-9) collected from Kala Shah Kaku and the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan was sandwiched in a fine layer of farmyard manure (FYM) in forty small parcels (1-1 ft width and length) on raised beds with clayey loam soil for nursery preparation. After a week of sprouting, the nursery was flooded and covered with wheat straw. Water was applied three times a day. Forty-day-old plants were transplanted into the field in an RCBD with three duplicates. With two plants in each hole, the plant to plant and row to row spacing was nine inches. Standard cultural practices such as irrigation, hoeing, weeding, insect pest sprays, and so on were carried out to maintain a healthy crop stand. The plants of each variety were evaluated for disease development and regression model.

2.3. Disease assessment

Bacterial Leaf Blight (BLB) 0-9 disease rating scale described by Anon (1980) was used to record disease incidence (Equation 1). The magnitude of the infection was calculated as a percentage of the infected leaf area where; 0 = no infection (HR); 1 = < 1-10% (R); 3 = 11-30% (MR); 5 = 31-50% (MS); 7 = 51-75% (S); and 9 = 76-100% (HS) leaf areas infected. Based on symptoms, BLB disease was noted as yellowish-white, water soaked streaks at the margins of plant leaves (IRRI, 1996). The disease incidence was calculated on average 10 days interval after the appearance of the first leaf symptom using the following formula described by Gnanamanickam et al. (1999):

$$\text{\% Disease incidence} = \frac{\text{Lesion length}}{\text{Total leaf length}} \times 100 \quad (1)$$

2.4. Environmental variables

Weekly Data on environmental variables; rainfall, maximum and minimum air temperature, wind speed, and relative humidity for two years were collected from Ayub Agricultural Research Institute (AARI), Faisalabad.

2.5. Prediction model development & validation

The correlation and regression analysis determined the effect of each variable on disease development. All data pertaining to disease incidence and the effect of environmental variables on disease development were analyzed using IBM SPSS Statistics 22 and SAS 9.3 (SAS Institute Inc., 1990). A protocol determined by Myers et al. (2000) was followed for the stepwise regression model for PLB disease prediction the significance of environmental variables; maximum, minimum air temperature, rainfall, relative humidity, and wind speed conducive for disease development was determined. SAS with intercept model computed all possible regressions (SAS Institute Inc., 1990). The best model for predicting bacterial late blight disease incidence was chosen based on R2, MSE, and Mallows C (p) (p = number of regressor variables in the model).

3. Results

3.1. Bacterial leaf blight disease assessment

The magnitude of the infection was calculated as a percentage of the infected leaf area. The 0-9 scale was used to assess BLB disease incidence on the field. Based on symptoms, the disease was noted as yellowish-white, water soaked streaks at the margins of plant leaves (IRRI, 1996). In each variety, lesions developed uniformly downward from the point of inoculation. However, the length of the leaf infection varied in all genotypes. The average weekly data on environmental variables and disease incidence on individual genotype is given in Table 1. Overall, during the two growing seasons, maximum mean disease incidence was recorded on Super Basmati (52.5%) followed by KSK-434 (50.1%), KSK-133 (35.9%) and Basmati-2000 (30.1%) while minimum mean disease incidence was recorded on IRRI-9 (22.9%) as shown in Table 2. Whereas maximum disease incidence was recorded on Super Basmati (70.0%) followed by KSK-434 (68.0%), KSK-133 (51.2%) and Basmati-2000 (45.0%) while minimum disease incidence was recorded on IRRI-9 (33.6%) as shown in Table 2.

3.2. Correlation between disease incidence and environmental variables

The accumulated effect of two-year environmental data was correlated with disease incidence. There was a significant correlation of environmental variables i.e., temperature maximum, minimum, relative humidity, rainfall, and wind speed with the BLB disease incidence observed on individual genotype which showed a highly significant effect for the disease development in the field during the years 2016 (Table 3). A similar trend was observed during the years 2017 except Basmati-2000 and Super Basmati showed a non-significant effect in relative humidity and minimum temperature, respectively (Table 4). It was observed that temperature (Maximum & minimum) has a negative significant correlation with BLB disease and other variables including relative humidity, rainfall, and wind speed had a positive highly significant correlation with the BLB disease incidence on all genotypes however,

Table 1. Average weekly data on environmental variables and disease incidence on individual genotype.

Weeks	Max T	Min T	RH	RF	WS	Basmati-2000	KSK-434	KSK-133	Super Basmati	IRRI-9
week1	36.0	26.4	74.9	2.1	3.0	16.4	33.0	21.0	34.0	10.0
week2	35.5	26.5	75.9	2.2	3.2	18.0	37.2	23.2	36.5	12.2
week3	35.1	26.0	76.6	2.85	3.8	19.8	38.3	26.4	39.5	14.0
week4	34.0	25.7	76.7	3.0	4.3	22.0	42.5	28.0	45.0	18.4
week5	33.8	24.3	77.6	4.6	5.0	24.1	46.0	33.1	49.34	20.0
week6	33.0	23.6	81.9	6.0	5.4	27.0	49.1	35.4	52.0	22.3
week7	35.0	25.7	76.4	2.0	6.4	32.0	52.2	38.0	57.0	25.1
week8	35.0	23.4	76.5	2.1	6.9	36.0	55.0	39.6	59.55	27.1
week9	34.4	21.6	78.0	2.4	7.2	38.0	59.5	42.2	60.0	30.0
week10	33.6	21.4	78.7	2.6	8.8	41.8	62.0	45.0	63.3	31.2
week11	33.1	21.0	79.0	3.0	9.0	42.1	65.0	49.2	65.0	32.0
week12	32.0	18.1	81.0	4.6	9.8	45.0	68.0	51.2	70.0	33.6

Table 2. Response of rice genotypes to bacterial leaf blight disease.

Genotype	Mean disease incidence (%)	Max. disease incidence (%)	Scale for infection rate	Response
KSK-434	50.1	68.0	7	S
Basmati-2000	52.5	45.0	5	MS
KSK-133	35.9	51.2	7	S
Super Basmati	52.5	70.0	7	S
IRRI-9	22.99	33.6	5	MS

Table 3. Correlation of environmental factors with BLB incidence on Rice varieties during the year 2016.

Varieties/lines	Maximum T	Minimum T	Relative Humidity	Rainfall	Wind velocity
	2016	2016	2016	2016	2016
KSK-434	-0.9520*	-0.9340*	0.9650*	0.9720*	0.9740*
	0.0000	0.0000	0.0000	0.0000	0.0000
Basmati-2000	-0.9400*	-0.9320*	0.9470*	0.9690*	0.9580*
	0.0001	0.0001	0.0000	0.0000	0.0000
KSK-133	-0.9350*	-0.8550*	0.9740*	0.9100*	0.9470*
	0.0000	0.0000	0.0000	0.0001	0.0000
Super Basmati	-0.9370*	-0.8930*	0.9730*	0.9420*	0.9660*
	0.0002	0.0000	0.0000	0.0003	0.0000
IRRI-9	-0.9580*	-0.9190*	0.9810*	0.9610*	0.9750*
	0.0001	0.0003	0.0000	0.0000	0.0000

Upper values indicate Pearson's correlation coefficient; *Highly Significant at P = 0.05. Lower values indicate level of probability at P = 0.05; NS = Nonsignificant.

genotype KSK-434 showed a positively significant effect in rainfall and Basmati-2000 showed a non-significant effect in relative humidity (Table 5).

3.3. *Stepwise linear regression model for BLB disease of rice*

The data on environmental variables for growing two seasons, July to October 2016-17 correlated with disease incidence on individual genotypes using stepwise linear regression indicated that except the minimum temperature, all variables contributed to the development of the disease during the whole cropping season. All the stepwise regression model parameters were significant at $P < 0.05$. The coefficient of determination (r^2) of 0.95 proved the significance of the overall regression prediction model accuracy (Table 6).

Table 4. Correlation of environmental factors with BLB incidence on Rice varieties during the year 2017.

Varieties/lines	Maximum T	Minimum T	Relative Humidity	Rainfall	Wind velocity
	2017	2017	2017	2017	2017
KSK-434	-0.9200*	-0.9140*	0.9020*	0.9260*	0.9730*
	0.0000	0.0000	0.0000	0.0000	0.0000
Basmati-2000	-0.9670*	-0.9870*	0.8620NS	0.9620*	0.9710*
	0.0000	0.0000	0.0621	0.0000	0.0000
KSK-133	-0.9670*	-0.9780*	0.8880*	0.9670*	0.9870*
	0.0000	0.0000	0.0000	0.0000	0.0000
Super Basmati	-0.9650*	-0.9790NS	0.8840*	0.9690*	0.9890*
	0.0000	0.0521	0.0000	0.0000	0.0000
IRRI-9	-0.9670*	-0.9770*	0.8780*	0.9700*	0.9880*
	0.0000	0.0001	0.0000	0.0000	0.0000

Upper values indicate Pearson's correlation coefficient; *Highly Significant at P = 0.05. Lower values indicate a level of probability at P = 0.05; NS = Nonsignificant.

Table 5. Correlation of environmental factors with BLB incidence on Rice varieties in response of two year interaction during 2016&2017.

Varieties/lines	Max. Temperature (°C)	Min. Temperature (°C)	R. Humidity (%)	Rain fall (mm)	Wind speed (Km/hr)
KSK-434	-0.9040**	-0.9060**	0.9210**	0.8620*	0.9600**
	0.0000	0.0000	0.0005	0.0420	0.0000
Basmati-2000	-0.7850**	-0.9500**	0.8420NS	0.9600**	0.8880**
	0.0020	0.0000	0.0520	0.0000	0.0000
KSK-133	-0.6690**	-0.8700**	0.7880**	0.9260**	0.8260**
	0.0001	0.0000	0.0000	0.0000	0.0000
Super Basmati	-0.7390**	-0.9110**	0.8410**	0.9520**	0.8670**
	0.0000	0.0000	0.0000	0.0000	0.0010
IRRI-9	-0.8690**	-0.9500**	0.8910**	0.9210**	0.9610**
	0.0000	0.0000	0.0000	0.0002	0.0000

Upper values indicate Pearson's correlation coefficient; * Significant at P = 0.05. Lower values indicate level of probability at P = 0.05; ** Highly significant at P = 0.01. NS = Nonsignificant.

Table 6. Analysis of variance for stepwise regression model of BLB of rice during July-Oct 2016-17.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	10155.6	2031.11	224.28	0.0000*
Max T	1	259.3	259.29	28.63	0.0000*
Min T	1	65.8	65.81	7.27	0.009*
RH	1	72.3	72.3	7.98	0.006*
RF	1	172.9	172.95	19.1	0.0000*
WS	1	444.1	444.11	49.04	0.0000*
Error	58	525.2	9.06		
Lack-of-Fit	26	488.3	18.78	16.26	0.0000*
Pure Error	32	37	1.15		
Total	63	10680.8			

* Highly significant at P = 0.01.

3.4. Prediction model development & validation

The multiple regression model based on two-year data (Y=214.3 - 3.691 Max. T - 0.508 Min. T + 0.767 RH + 2.521 RF + 5.740 WS) explained 95% variability (Table 7). The normal probability plot showed (Figure 1) that most points were present on the reference line at different points. In the residual verses fitted value, all the points were distributed within the range -8 to +8. Only four points were present along the reference line (Figure 2).

The environmental variables maximum and minimum temperature, relative humidity, rainfall, and wind speed were biologically important in the development of BLB disease on five rice varieties. The models with significantly important variables were developed by stepwise regression on five rice varieties separately to predict BLB disease incidence for two years (Figure 3).

During epidemiological investigations, the maximum temperature ranged from 32 to 36 ºC and minimum

Table 7. Coefficient estimates of stepwise regression model for BLB of rice during July-Oct 2016-17.

Term	Coefficients	Standard error	t Stat	P-Value
Constant	-214.3	38.7	-5.54	0.000*
Max T	3.691	0.69	5.35	0.000*
Min T	0.508	0.189	2.7	0.009*
RH	0.767	0.272	2.83	0.006*
RF	2.521	0.577	4.37	0.000*
WS	5.74	0.82	7	0.000*

*Highly significant at P = 0.01.

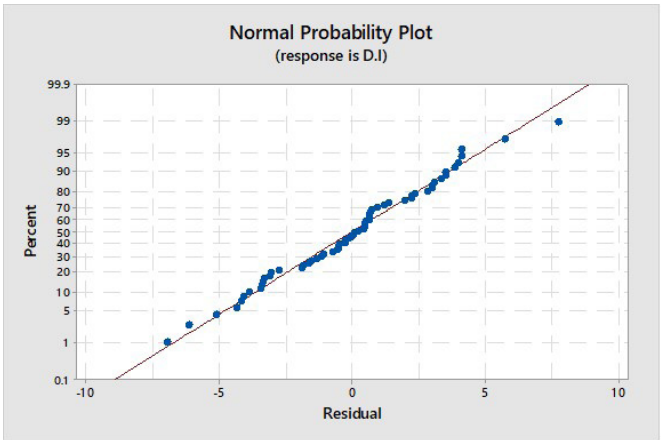

Figure 1. Normal Probability plot.

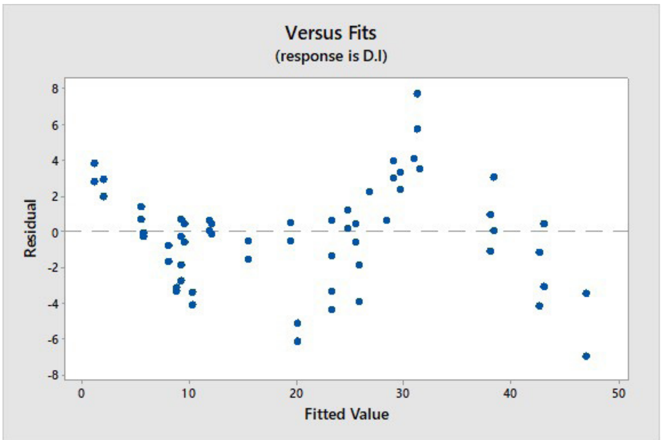

Figure 2. Residual versus Fitted value plot.

temperature ranges from 18 to 26 ºC showed a significant negative correlation with BLB development while with the relative humidity of 76 to 81% coupled with rainfall (1-6mm) and wind speed (3-10 km/h) for disease development and showed a significant positive correlation with BLB development (Figures 4-8).

4. Discussion

The environmental variables responsible to cause epiphytotic are temperature, relative humidity, wind speed, rainfall, and the presence of inoculums with virulence. Climatic change effect might be positive, negative, or may

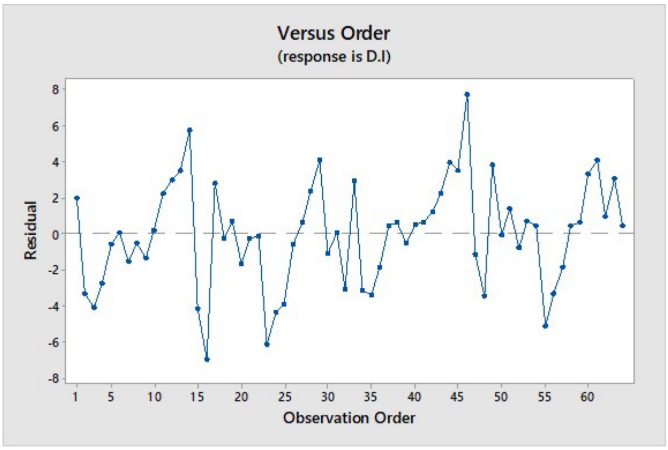

Figure 3. Residual versus observation order plot.

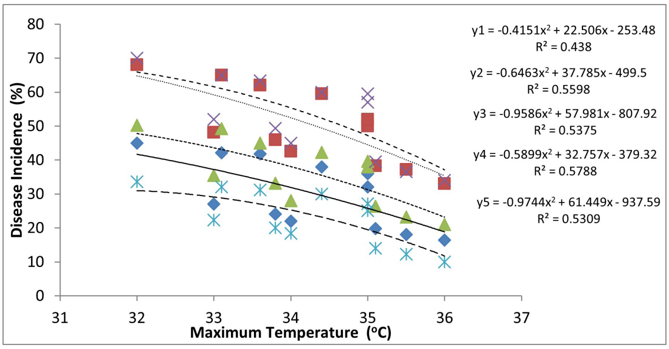

Figure 4. Relationship of maximum temperature with BLB. Varieties y1 = Basmati-2000, y2 = KSK-434, y3=KSK-133, y4=Super Basmati and y5=IRRI-9.

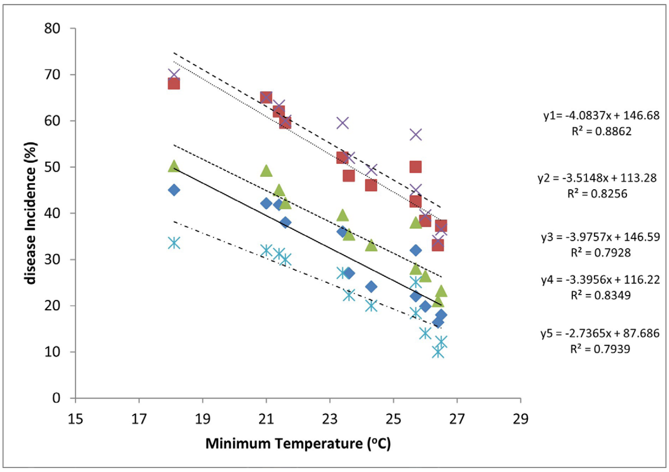

Figure 5. Relationship of minimum temperature with BLB. Varieties y1 = Basmati-2000, y2 = KSK-434, y3=KSK-133, y4=Super Basmati and y, 5=IRRI-9.

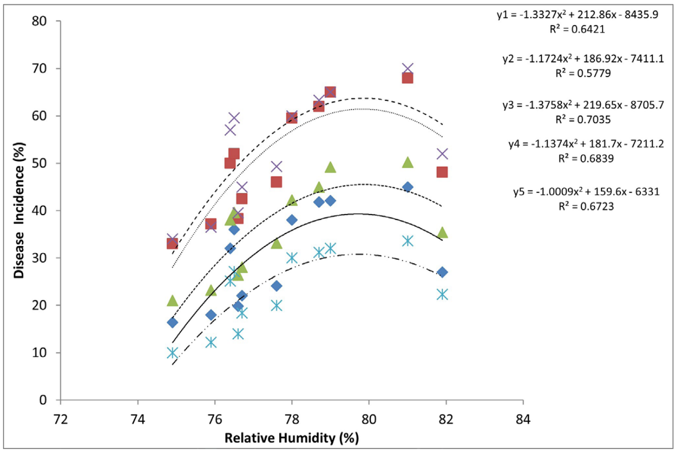

Figure 6. Relationship of relative humidity with BLB. Varieties y1 = Basmati-2000, y2 = KSK-434, y3=KSK-133, y4=Super Basmati and y5=IRRI-9.

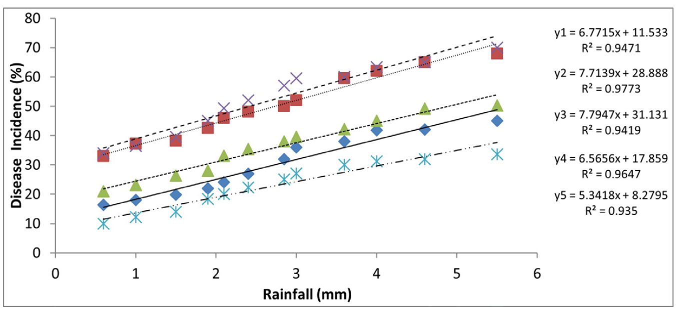

Figure 7. Relationship of rainfall with BLB. Varieties y1 = Basmati-2000, y2 = KSK-434, y3=KSK-133, y4=Super Basmati and y5=IRRI-9.

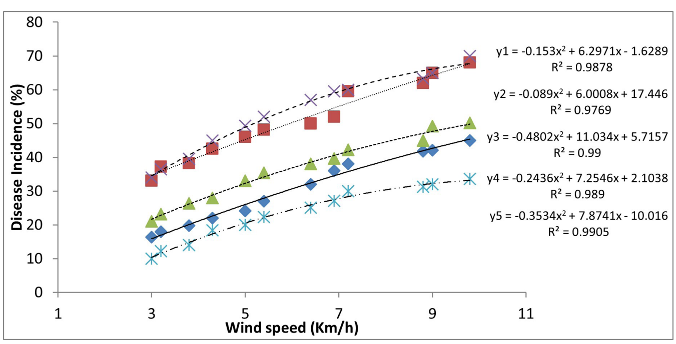

Figure 8. Relationship of Wind speed with BLB. Varieties y1 = Basmati-2000, y2 = KSK-434, y3=KSK-133, y4=Super Basmati and y5=IRRI-9.

pose no effect on diseases of plants (Chakraborty, 2005). The development and survival of plants are based on many abiotic environmental variables like temperature, relative humidity, wind velocity, and rainfall that play an important role in disease development, dissemination, and cause infection. Plant-pathogen interaction, host plant growth, susceptibility, as well as pathogen reproduction, dispersal, survival, and activity may all be influenced by these environmental factors (Kang et al., 2010).

Overall correlation clearly described the relationship of rice varieties sown for the study of epidemiological influences. The correlation was regarded as an important component of the description of the results because it revealed the resistivity, immunity, and susceptibility reactions of each variety as they were influenced by various environmental factors. Maximum and minimum temperature showed a negative highly significant correlation on the other hand relative humidity, rainfall, and wind speed formed a positive highly significant correlation with rice varieties during the years 2016 and 2017. Now coming towards maximum and minimum temperature and BLB disease relationship, it was concluded on the basis of the correlation presented which showed a negatively significant trend for the disease i.e. BLB incidence was increased by decreasing the maximum and minimum temperature. In addition to relative humidity, there were other epidemiological factors under investigation that had a significant impact on rice varieties, as they all showed an increase in disease incidence. Different disease incidence values resulted from the relationship between heavy rains, crop duration, and crop pattern. During epidemiological investigations, the maximum temperature ranged from 32ºC to 36ºC and minimum temperature ranges from 18 to 26ºC showed a significant negative correlation with BLB development while with the relative humidity of 76 to 81% coupled with rainfall (1-6mm) and wind speed (3-10 km/h) for disease development and showed a significant positive correlation with BLB development.

Our findings are in agreement with the results of (Khalid et al., 2010) as he reported the similar result as maximum BLB disease expected at 35-38 maximum temperature and 26-27 °C minimum temperature, 61-72% relative humidity, 1-12 mm total rainfall and 3-5 km/h wind speed, while at some locations maximum BLB may occur at 33-37°C and 20-23°C max and min air temp, 35-59% relative humidity, 0.73-13 mm total rainfall and 3-5 km/h wind speed.

Similarly, Pal et al. (2017) investigated that maximum temperature and bacterial blight disease severity was positive was similar 2013-2014 Kharif season but it was negative in Kharif 2016, in other environmental factors like minimum temperature, relative humidity, rainfall was negatively correlated with bacterial blight disease severity in all three dates of sowing in Kharif season of 2013-2014 and 2016 and contrary result with current finding. A similar response was described by the finding of Swati and Roy (2015) and Kiran and Singh (2015) as they reported the disease develops without rainfall. Biswas et al. (2011) also discussed a similar result about weather parameters as reported that maximum temperature and rainfall involved in disease development. A maximum temperature around 34 degrees and a minimum temperature around 26 degrees were found to be favourable for the spread of sheath blight after its establishment in the field.

Environmental variables effect disease development and may be used to forecast diseases of crop plants and their onset. Thus, to quantify BLB disease incidence in relation to environmental variables, regression analysis was employed. The model has been verified with two years of data and has shown good results in predicting BLB illness. The model has good forecasting potential and may help in making accurate predictions of the BLB disease of rice.

5. Conclusion

Two years bacterial leaf blight disease predictive model, based on five environmental variables i.e. maximum and minimum temperatures, relative humidity, rainfall, and wind speed explained 95% variability positive significance with disease incidence. Maximum and minimum temperature showed a negative significant while relative humidity, rainfall, and wind speed during two growth seasons (2016–2017) exhibited a positive significant correlation with the development of bacterial leaf blight disease of rice.

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