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Unravelling Relationship of Weather Factors with Rice Blast Disease Severity and Development of Prediction Equations

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Abstract

Magnaporthe oryzae causes rice blast disease, which is one of the most devastating and widespread rice diseases. The present study explores the effects of weather factors (temperature, relative humidity, rainfall and bright sunshine hours) on paddy blast severity. During *kharif* 2019-20 at Zonal Agricultural Research Station, V. C. Farm, Mandya, seven genotypes were studied *viz.,* Jyothi, Jaya, IR 64, PAC 837, PAC 837+, CO 39 and HR 12, all of which showed distinct responses to blast disease. The disease started in the 42nd standard meteorological week of 2019 with a mean severity of 1.29 per cent, gradually increasing to a peak in the 3rd standard meteorological week of 2020 (46.14 %). The HR12 (highly susceptible) genotype showed the highest mean disease severity (64.12 %), whereas the PAC837+ hybrid which is moderately resistant, showed the lowest mean blast severity (3.48 %). The optimal weather conditions for disease development were determined to be maximum temperature (26.75-29.50^{0}C), minimum temperature (16.50-19.25^{0}C), morning relative humidity (80.50 - 94%), evening relative humidity (60.10 - 80.50%) and sunshine (2.50 - 9.50 hours). According to a correlation study between meteorological factors and disease severity, all the variables interacted to play a role in the development of rice blast disease. Further more, the disease development was influenced by the maximum temperature and evening relative humidity. The prediction equations were developed using multiple regression analysis for all seven genotypes, with coeucients of determination (R^2) varying from 66 to 79.70 per cent, indicating that 66 to 77.0 per cent of the total variation in the per cent disease index can be explained by the predicted value of disease severity (PDI).

Keywords : Rice blast, Disease severity, Weather parameters, Correlation, Regression, Prediction equation

Rice (*Oryza sativa* L.) is the most important staple food for more than half of the human population, providing approximately 19 per cent of the daily calories consumed worldwide. Rice is the main food for most countries in Asia and about 90 per cent of the global rice area, production and consumption are concentrated in Asia. The fast growth of the world population demands an increase of 26 per cent in rice production to fulfill the requirement (Dean *et al.,* 2012; Mahesh *et al.,* 2016 and Bhavya & Shivakumar, 2018). India is the world's second largest rice producer and consumer next to China. In India, it is cultivated in 44.44 million hectares and with a total production of 122.0 million tons and productivity of 4.1 metric tons per hectare during 2020-21 (Deepak *et al.,* 2021).

The primary constraints in rice production are biotic and abiotic factors. Among these challenges, fungal diseases result in considerable yield loss every year. Amongst the fungal diseases, rice blast disease caused by an ascomycete *Magnaporthe oryzae* (Hebert) Barr is considered as the highest loss causing one in the world among the top 10 fungal diseases that threaten global food security (Dean *et al.,* 2012 and Jagadeesh *et al.,* 2020). Yield loss due to blast disease can be ranging from 30 to 100 per cent when the disease occurs in epidemic proportions (Wang *et al.,* 2015; Nalley *et al.,* 2016 and Sahana *et al.,* 2018). To minimize this damage, most farmers use resistant varieties, fungicides or avoid excessive use of fertilizer. Despite these precautions, rice blast causes severe losses under certain environmental conditions. This is due to the interactive influences of weather on the pathogen's reproductive ability and the rice plant's resistance.

Management of blast disease is essential and early prediction of its occurrence will be very helpful in reducing yield loss. Since, weather plays a very important role in the appearance, multiplication and spread of the rice blast fungus, a weather based forewarning system may provide the desired prediction accuracy. Hence, an attempt has been made to elucidate the effect of weather parameters on rice blast disease severity and to develop a prediction model that could guide the management decisions.

MATERIAL AND METHODS

Field Experiment

To explicate the influence of weather parameters on the development of rice blast disease, the field experiment was conducted during the *kharif* 2019-20 at V.C. Farm, Mandya (12°34' N latitude, 76°50' E longitude and at an altitude of 695.0 m above mean sea level).

Plant Material, Nursery Sowing and Transplanting

The planting materials of seven selected genotypes *viz.,* Jyothi, Jaya, IR 64, PAC 837, PAC 837+, CO 39 and HR12 were collected from Zonal Agricultural Research Station (ZARS), Mandya and nursery was prepared on raised beds with seeds of each genotypes in individual small plots (1 x 1 ft width and length). One month old rice seedlings of individual cultivars were transplanted into the plot of 3m x 3m size. A recommended fertilizer dose of N: P: K at the rate of 58:23:25 kg / acre and routine cultural practices were performed to sustain a vigorous crop stand.

Disease Severity

After transplanting, the onset time of disease was monitored as the appearance of first symptoms and rice blast severity was assessed in the field. The disease severity was scored using a 0-9 disease rating scale (IRRI, 1996). Twenty plants per plot were selected randomly in the 'Z' pattern for recording the disease severity under natural epiphytotic conditions. The whole plant was assessed at 3 days intervals upto 15 days before harvest. Per cent disease index (PDI) was calculated following the standard formula (Mckinney, 1923).

$$\text{PDI} = \frac{\text{Sum of the score}}{\text{Number of observations x highest number in rating scale}} \times 100$$

Correlation and Regression

To study the epidemiology of the rice blast pathosystem, correlation and linear regression among the metrological factors and disease severity were determined. For this, Standard meteorological week (SMW) wise weather variables *i.e.,* maximum temperature (^{0}C), minimum temperature (^{0}C), morning and evening humidity (%), rainfall (mm) and sunshine hours were obtained from the Meteorological Observatory, V.C. Farm, Mandya for the period of investigation. Meteorological factors significantly affecting the disease severity were identified and established by the correlation and linear regression analysis. The meteorological factors were set as independent variables and disease severity served as the dependent variable.

Statistical Analysis

All the collected data sets were statistically subjected to the correlation of disease severity with the weather factors and linear regression analysis to identify the responsive variable using the software R version 4.1.0 (R Core Team, 2020).

RESULTS AND DISCUSSION

Response of Various Rice Genotypes to Blast Disease

Conducive environmental conditions facilitated early disease initiation, rapid disease development and the highest disease pressure in the highly susceptible genotypes (HR 12 and CO 39). In susceptible (Jyothi, Jaya, IR 64 and PAC 837) and moderately resistant

TABLE 1

0-9 severity scale for scoring leaf blast disease (IRRI, 1996)

0-9	Disease severity
0	No lesion observed
1	Small brown specks of pinpoint size
2	Small roundish to slightly elongated, necrotic grey spots, about 1-2 mm in diameter, with a distinct brown margin. Lesions are mostly found on the lower leaves
3	Lesion type same as in 2, but significant number of lesions on the upper leaves
4	Typical susceptible blast lesions, 3 mm or longer infecting less than 4 % of leaf area
5	Typical susceptible blast lesions of 3 mm or longer infecting 4-10 % of the leaf area
6	Typical susceptible blast lesions of 3 mm or longer infecting 11-25 % of the leaf area
7	Typical susceptible blast lesions of 3 mm or longer infecting 26-50 % of the leaf area
8	Typical susceptible blast lesions of 3 mm or longer infecting 51-75 % of the leaf area many leaves are dead
9	Typical susceptible blast lesions of 3 mm or longer infecting more than 75 % leaf area affected

genotypes (PAC 837+), delayed disease initiation, slower disease development rates and lower mean disease severities were recorded. HR 12 showed mean maximum disease severity (64.12%) followed by CO39 (55.30 %), indicating the highly susceptible response. Similarly, the mean disease severity was recorded minimum on Jaya (22.84 %), Jyothi (18.36 %), PAC 837 (13.94 %) and IR 64 (12.51%), which showed susceptible response to rice blast disease, whereas PAC 837+ (3.48 %) exhibited moderately resistant response (Fig.1). The findings are in accordance with the results of Manojkumar *et al.* (2020) conducted a phenotypic evaluation of blast disease reaction, which indicated that the rice varieties such as IR 64, Jaya and Jyothi were susceptible to leaf and neck blasts.

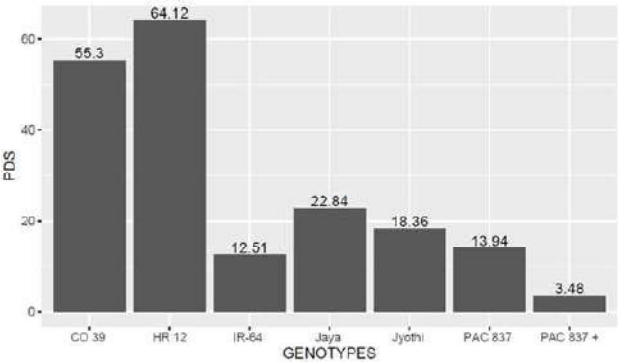

Fig.1: Mean blast disease severity of different rice genotypes

Progress of Rice Blast Disease under Natural Condition

In the present investigation, disease development in relation to weather parameters was studied as described in 'Material and Methods'. This study depicts the relationship between the weather parameters like maximum and minimum temperature (TMAX and TMIN), morning and evening relative humidity (RHI and RHII), total rainfall (RF) and bright sunshine hour (SSH) with blast severity. The frequency of disease intensity (PDI) was scored from 42nd SMW of 2019 to 3rd SMW of 2020 at 3 days interval for seven genotypes were worked out at weekly intervals and represented in Table 2.

Different rice genotypes showed varying responses to rice blast disease under the influence of significant meteorological conditions. During the period of investigation, disease progress in relation to weather parameters revealed that initially, at 42nd standard meteorological week (SMW 2019) mean disease severity was very low (1.29 %), that increased gradually to 46.14 % (3rd SMW 2020). The blast disease incidence initiated at 42th SMW in highly susceptible genotypes (HR 12 and CO 39) and from 43rd SMW in susceptible (Jyothi, Jaya, IR 64 and PAC 837) and moderately resistant (PAC 837+) genotypes. In all the seven genotypes studied, there was linear

TABLE 2

Weather parameters during assessment weeks and rice blast disease severity

	Weather Parameters						Per cent Disease Index (PDI)							
SMW	Tmax (°C)	Tmin (°C)	RHI (%)	RHII (%)	RF (mm)	SSH (Hours)	Jyothi	Jaya	IR64	PAC 837	PAC 837+	CO39	HR12	Mean
42	32.00	18.00	95.00	85.20	54.00	1.00	0.00	0.00	0.00	0.00	0.00	4.00	5.00	1.29
43	31.50	19.50	95.00	76.90	0.00	7.50	5.00	8.00	0.00	0.00	1.00	15.00	20.00	7.00
44	33.00	19.00	95.00	77.40	0.00	10.00	10.00	12.00	0.00	1.00	1.00	22.00	25.00	10.14
45	31.50	17.83	92.00	76.13	0.67	8.07	10.90	15.00	3.67	4.00	1.67	37.00	40.00	16.03
46	31.25	18.25	85.00	77.15	0.00	6.25	14.00	18.50	8.25	7.50	2.17	40.22	49.00	19.95
47	30.75	18.25	86.50	72.30	0.00	6.60	17.25	20.50	9.50	8.50	2.65	43.00	54.00	22.20
48	28.50	17.75	93.00	80.70	0.00	2.50	18.50	23.60	12.75	14.00	3.17	51.50	66.00	27.07
49	28.00	17.75	90.50	70.40	0.00	6.50	19.95	25.50	14.17	16.45	3.45	60.00	80.50	31.43
50	27.50	16.50	90.00	77.30	0.00	6.75	22.00	26.75	15.79	17.50	3.75	65.00	86.50	33.90
51	28.00	17.00	89.50	74.25	0.00	6.60	25.15	29.25	19.00	19.78	4.75	70.00	91.00	36.99
52	26.75	17.25	90.00	78.90	0.00	5.25	27.00	31.67	21.00	23.00	5.00	86.50	94.00	41.17
1	29.50	18.50	94.00	72.00	9.00	8.00	28.00	34.00	22.00	25.00	5.60	90.00	95.00	42.80
2	29.00	19.25	92.00	70.85	0.00	8.00	29.25	36.00	24.00	28.50	6.50	95.00	95.73	45.00
3	29.50	17.00	94.00	60.10	0.00	9.50	30.00	39.00	25.00	30.00	8.00	95.00	96.00	46.14
				Mean PDI			18.36	22.84	12.51	13.94	3.48	55.30	64.12	27.22

Tmax= Maximum temperature, Tmin= Minimum temperature, RHI= Morning relative humidity, RHII= Evening relative humidity, SSH= Sunshine hours, RF= Rainfall progress of the per cent disease severity (PDS) with the advancement of SMW throughout the crop season (Fig. 2). From Table 2, it is evident that gradual progress in mean disease severity was observed from 48th SMW onwards, which coincided with favourable weather conditions *viz.,* maximum temperature (26.75 - 29.50ºC), minimum temperature (16.50 - 19.25ºC), morning relative humidity (80.50 - 94 %), evening relative humidity (60.10 - 80.50 %) and sunshine (2.50 - 9.50 h). The maximum mean disease severity of rice blast occurred at 3rd SMW with the temperature (17 - 29.50ºC), relative humidity (60.10 - 94 %) and sunshine (9.50 h).

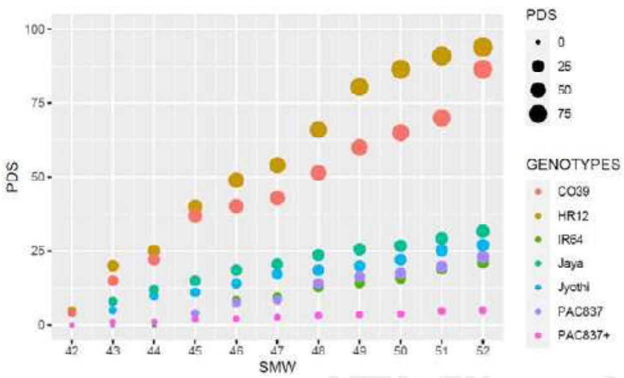

Fig. 2 : Progress of blast disease severity over standard meteorological week

An increase in disease severity is mainly attributed to weather conditions predominating in an area or particular year. This is because, reproduction and propagation of the rice blast fungus are greatest at high humidity (>90 %) and comparatively low temperature (21-24°C). The propagating capacity decreases if the temperature varies. When temperatures are above 31°C during the growth stage, the rice plants showed a resistant reaction to the disease. During long periods of cloudiness, the resistance of rice plants is diminished. The results are in agreement with the findings of Kapoor *et al.* (2004) reported that temperature (18 - 28°C), relative humidity (more than 9 h > 90 %) and cloudiness during the crop season were the most critical factors in the development of rice blast epidemics. Bhatt (1992) reported that the congenial factors for blast development include a minimum temperature between 15-20°C with an average temperature between 22-25 °C and more days with RH > 90 per cent, with an average of >50 per cent RH.

Correlation of Rice Blast with Weather Parameters

The leaf blast disease severity of all seven genotypes and overall mean disease severity were separately correlated with weather variables *i.e.,* maximum temperature (°C), minimum temperature (°C), morning and evening humidity (%), rainfall (mm) and sunshine hours during the investigation period. The correlation coefficients in relation to weather parameters of seven genotypes are presented in Table 3.

The per cent disease severity correlated negatively and was highly significant with maximum temperature in all seven genotypes under study with correlation coefficient (r) ranging from -0.632 to -0.828 in PAC837+ and HR12, respectively. Whereas, in relation to evening relative humidity, per cent disease severity of all seven genotypes showed significantly negative correlation with correlation coefficient (r) ranging from -0.438 (HR12) to -0.605 (PAC837+). In all seven genotypes under study minimum temperature, morning relative humidity and rainfall showed a negative correlation, whereas bright sunshine hours showed positive correlation and remained irresponsive in disease progression (Table 3).

The mean per cent disease severity correlated negatively with maximum temperature and evening relative humidity with correlation coefficient (r) -0.763 and -0.478, respectively. With other weather parameters *viz.,* minimum temperature, morning relative humidity and rainfall showed a negative correlation whereas, bright sunshine hours depicted a positive correlation with mean per cent disease severity, however, remained non-significant in contributing to the disease development (Fig. 3). The results of this study conform with findings of Shafaullah *et al.* (2011), reported that the maximum temperature and incidence of paddy blast was negatively correlated *i.e.,* -0.88, -0.80, -0.95, -0.84, respectively, with 4 lines / varieties. Similar observations were made by Naqvi and Perveen (2015), where maximum temperature and evening relative humidity were negatively correlated

TABLE 3

Correlation of weather parameters with rice blast disease severity recorded on seven genotypes

Weather Parameters	Correlation coefficient (r)							
	Jyothi	Jaya	IR64	PAC 837	PAC 837+	CO39	HR12	Mean
X_1	-0.724 **	-0.707 **	-0.759 **	-0.734 **	-0.632 **	-0.713 **	-0.828 **	-0.763 **
X_2	-0.208	-0.217	-0.235	-0.209	-0.147	-0.21	-0.331	-0.252
X_3	-0.121	-0.095	-0.069	-0.002	0.026	-0.045	-0.134	-0.081
X_4	-0.488 *	-0.528 *	-0.466 *	-0.469 *	-0.605 **	-0.477 *	-0.438 *	-0.478 *
X_5	-0.456	-0.485	-0.300	-0.282	-0.337	-0.387	-0.434	-0.403
X_6	0.168	0.198	0.073	0.100	0.173	0.180	0.100	0.140

** : Correlation is significant at the 0.01 level (2-tailed); * : Correlation is significant at the 0.05 level (2-tailed).
X_1= Maximum temperature (°C), X_2= Minimum temperature (°C), X_3= Morning relative humidity (%),
X_4= Evening relative humidity (%), X_5= Rainfall (mm) and X_6= Bright sunshine hours (Hours).

with rice blast disease severity (-0.892 and -0 .576, respectively). Pattanayak and Das (2020), also analysed the correlation of PDI with weather variables and observed a significant negative correlation with Tmin = -0.486, RH1 -0.853, RH2 -0.744 and RF - 0.713.

The relationship of maximum temperature with disease severity on most genotypes was negatively correlated (Fig.4a). A decrease in temperature resulted in increased disease severity and vice versa (Table 2). When the temperature decreased from 30.75 p C (47th SMW) to 28.50 p C (48th SMW), the mean

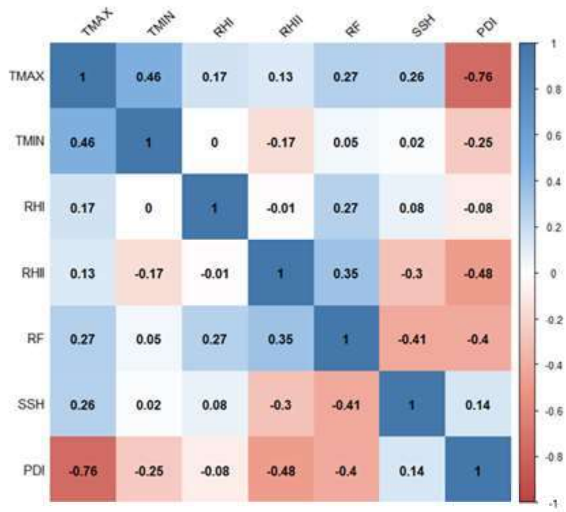

Fig.3 : Heatmap depicting the correlation between mean blast disease severity with weather parameters

disease severity was increased. In parallel with maximum temperature, the correlation of evening relative humidity with disease severity on most genotypes was negative (Fig. 4b). Though morning relative humidity and rainfall play a significant role in rice blast epidemics, they were non-significant in contributing to blast severity in the present study. A possible reason could be the presence of autocorrelation within these two independent variables. Most of the data points lies within 90-95 per cent (Morning relative humidity) and rainfall remains zero in most cases (Fig. 4c and Fig. 4d). Although these parameters contribute to blast severity at field conditions, there was no significant difference observed within these variables between time intervals, making them statistically irresponsive to rice blast severity.

Overall, from Table 2 it is observable that when, weather conditions *viz.,* maximum temperature (26.75-29.50ºC), minimum temperature (16.50 - 19.25ºC), morning relative humidity (80.50 - 94 %), evening relative humidity (60.10 - 80.50 %) and sunshine (2.50 - 9.50 hrs) prevails in an area result in rice blast severity.

Multiple Regression Analysis

The multiple regression analysis was performed for six independent weather variables to identify critical and much contributing weather variable(s) separately

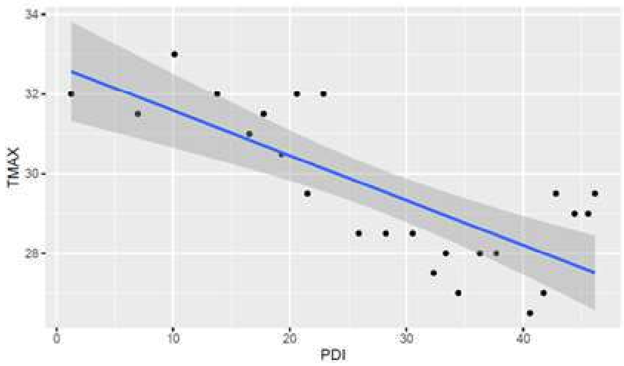

Fig. 4a : Relationship of maximum temperature with mean rice blast disease severity

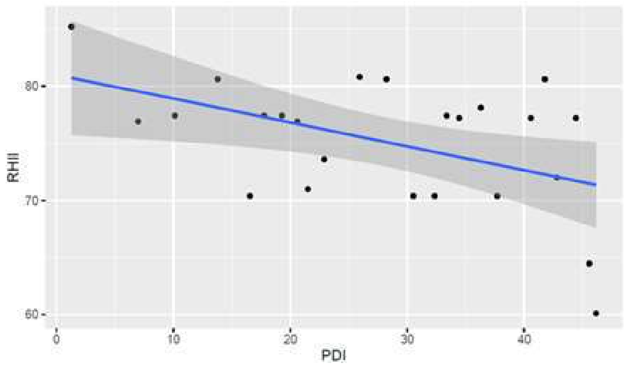

Fig. 4b : Relationship of evening relative humidity with mean rice blast disease severity

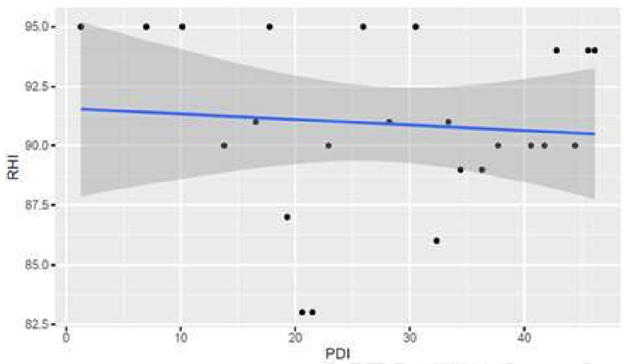

Fig. 4c : Relationship of morning relative humidity with mean rice blast disease severity

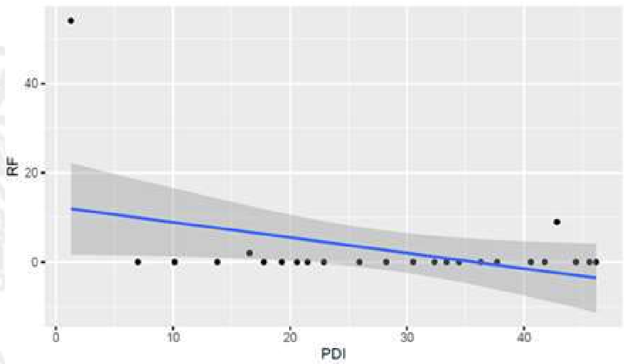

Fig. 4d : Relationship of total rainfallwith mean rice blast disease severity

towards the dependent variable *i.e.,* blast disease severity, for all the seven genotypes. In multiple regression analysis except for the maximum temperature and evening relative humidity, other parameters were non-significant in contributing to the disease severity. This is attributed to the multicollinearity factor that existed in between the independent variables. Further data was subjected to stepwise regression analysis to find significant contributing variables. Results revealed that maximum temperature and evening relative humidity were the parameters that contributed more to disease severity. Based on this results, prediction equations were formulated for all seven genotypes by employing significant variables *viz.,* maximum temperature and evening relative humidity.

The regression coefficient based on stepwise regression analysis for per cent disease severity of rice blast with respect to significant weather parameters *viz.,* maximum temperature and evening relative humidity have been worked out and presented in Table 4.

TABLE 4

Stepwise multiple linear regression equations for the prediction of rice blast severity

Genotypes	Regression equation	R	R^2
Jyothi	$Y=147- 2.872X_1 -0.582X_2$	0.826	68.20
Jaya	$Y=176.349- 3.254X_1 -0.755X_2$	0.833	63.30
IR64	$Y=143.143-3.033X_1 -0.541X_2$	0.845	71.30
PAC 837	$Y=162.820- 3.401X_1 -0.641X_2$	0.825	68.00
PAC 837+	$Y=35.082- 0.588X_1 -0.189X_2$	0.823	67.80
CO39	$Y=461.073-9.06X_1 -1.81X_2$	0.812	66.00
HR12	$Y=532.752-11.515X_1 -1.67X_2$	0.893	79.70
Mean	$Y=236.952-4.818X_1 -0.886X_2$	0.853	72.80

X_1= Maximum temperature (°C),
X_2= Evening relative humidity (%)

The results indicated the multiple linear regression equation, with R value ranging from 0.812 - 0.893 in all seven genotypes, indicating a strong association between per cent disease severity with maximum temperature and evening relative humidity. The co-efficient of determination value (R^2) was found to be, 66 - 79.70 per cent indicating that 66 - 79.70 per cent of the variation in blast disease severity was explained by the function of the weather parameters *viz.,* maximum temperature and evening relative humidity. Using these multiple regression models makes it is possible to predict disease in advance and the epidemic nature of the disease could be prevented by timely application of the management measures. Our results support earlier findings of Pradhan *et al.* (2018), who developed the multiple regression equation in variety Khandagiri, for blast disease severity (R^2 = 97 %). Kapoor *et al.* (2004) also developed a multiple regression model for rice blast disease for the Kangra district of Himachal Pradesh with a model efficiency of 72 - 98 per ecnt.

The dynamic process of plant disease depends upon the interactions among the host, pathogen and the environment. The variation in any one of the factors influences disease development. Meteorological conditions during rice cultivation periods are subject to change annually and on hour basis. It is difficult to determine when and how meteorological conditions influence the outbreak of rice blast. Rice blast epidemics differ from field to field even under the same meteorological conditions as the cultivation methods (varieties, amount of fertilizer etc.) are different. This human factor increases the difficulty of analyzing the relationship between epidemics of the disease and specific meteorological conditions. The present investigation suggested that change in climatic conditions attributed to an increase in rice blast disease severity. The disease management strategies according to changing climatic conditions with the amalgamation of new strategies will be useful for sustainable food production. Thus, if a sound forewarning system is developed, the epidemic nature of the disease could be prevented by the timely application of the management measures. Such a system will help to reduce the cost of production and promote environmental safety by reducing chemical usage.

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