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Effect of Weather Parameters on the Severity of Bacterial Leaf Blight of Rice (cv. Basmati-370)

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ABSTRACT: Weather conditions significantly influence the plant disease incidence and development. Rainfall, temperature, relative humidity, flood and cyclonic conditions are the important factors for disease development. High humidity (>80%), rain and cloudy conditions accelerate the disease development in bacterial leaf blight of rice. A moderate and evenly distributed rainfall during the crop season can bring about an epidemic. Temperature is an important environmental factor influencing plant development in natural and diseased conditions in BLB. Disease appeared on 31st SWM during both the years with disease severity of 1.03 and 1.47 percent. Terminal severity of BLB was recorded as 44.13 and 45.45 per cent, when the crop was at harvest stage during 46th SMW during both the years of 2019 and 2020. During the epidemiological studies of BLB, maximum infection rate (r) of 0.175 (Basmati-370) was observed during 32nd standard week (2019) and, maximum infection rate (r) of 0.164 was observed during 33rd standard week (2020). AUDPC of BLB was 293.19 and 305.27 in 2019 and 2020, respectively. During 2019, temperature (Max. and Min.), relative humidity (evening), rainfall and bright sunshine hours showed significant but negative correlation with severity of BLB, whereas, relative humidity (morning), showed positive correlation with disease. Whereas, during 2020, temperature (Max. and Min.), relative humidity (morning), relative humidity (evening) and rainfall showed significant but negative correlation with severity of BLB and sunshine hours showed positive correlation with disease severity. On the basis of pooled data of both the years, a significantly negative correlation with maximum temperature, minimum temperature, evening relative humidity and rainfall but non-significantly negative correlation with morning relative humidity were observed. The generated model had coefficient of determination (R^2) of 0.95, which showed that 95 per cent of the variation in the severity of BLB was influenced by maximum and minimum temperature, maximum and minimum relative humidity and rainfall during 2019 and the same model had coefficient of determination (R^2) of 0.94 which showed 94% of the variation in the observed severity of bacterial leaf blight of rice was influenced by maximum and minimum temperature, morning and evening relative humidity, sunshine hours and rainfall during 2020. On the basis of pooled data, model had coefficient of determination (R^2) of (0.89) which showed that 89 per cent of the variation in the observed disease severity of BLB was influenced by maximum and minimum temperatures, morning and evening relative humidity, sunshine hours and rain fall.

Keywords: Weather, severity, disease, BLB, rice, blight, parameters.

INTRODUCTION

Rice is one of the most important food crops in the world. It is the staple food of about 60% of the world's population. More than 90% of the rice is produced and consumed in Asia (Singh *et al*., 2001). Rice is the staple food of the people of the eastern, northern and southern parts of the country (Zhu and Wu 2008). In India, rice is grown in an area of 437.8 lakh ha with a production of 118.4 million tonnes and productivity 2705 kg ha^{-1} (Anonymous, 2021). Whereas, in the UT of Jammu and Kashmir, rice is grown over an area of 262.01 thousand ha with the production of 6161 thousand q and productivity 23.51 q ha^{-1} (Anonymous, 2021). Bacterial leaf blight of rice, caused by *Xanthomonas oryzae* pv. *Oryzae* is one of the most destructive diseases of rice and was first noticed by the farmers of Japan in 1884 (Tagami and Mizukami 1962). The disease is known to occur in epidemic proportions in many parts of the world, incurring severe crop loss of up to 50%. In India, rice yield losses in severely infected fields generally range from 20 to 30 % and in some areas are reported up to 80 % depending upon the stage of crop and type of cultivar (Shanti *et al*., 2001). Crop loss assessment studies have revealed that this disease reduces grain yield to varying levels, depending on the stage of the crop, degree of cultivar susceptibility and to a great extent, the conduciveness of the environment in which it occurs (Swings *et al*., 1990). *Xanthomonas* *oryzae* pv. *oryzae* caused huge losses in form of quantitative and qualitative of rice. It can cause damage at vegetative and reproductive stages of rice plants (Shanti *et al*., 2001). In world, due to this disease yield loss was estimated approximately 50 per cent (Shekhar and Kumar 2020) and in India 81.3 per cent (Prasad *et al*., 2018; Swati *et al*., 2015). Several biotic and abiotic factors are the main constraint for reducing the production and productivity of rice. In tropical countries *viz*., India, Philippines, Indonesia, it is more destructive because of resulting kresek syndrome of bacterial leaf blight, which affects 3-4 weeks of transplanted seedling of rice and yield loss reached upto 60-75 per cent. This disease affects grain quality by interfering with maturation depends on weather, location and varieties. Crop losses of 10-20 per cent in moderate conditions or severe losses of up to 50 per cent in highly conducive conditions have been recorded in several Asian and Southeast Asian countries (Sharma *et al*., 2017; Mouria *et al*., 2017).

Weather conditions significantly influenced the plant disease incidence and development. The most important factors for disease development are rainfall, temperature, relative humidity, flood and cyclonic conditions. High humidity (>80%), rain and cloudy condition accelerate the disease development. A moderate amount of rainfall evenly distributed during the crop season can bring about an epidemic. Temperature is an important environmental factor influencing plant development in natural and diseased conditions. The growth rate of plants grown at 27°C is more rapid than for plants grown at 21°C (Suzuki *et al*., 2014; Ashoub *et al*., 2015). Temperature influences crop growth and development through its impact on enzyme and membrane controlled processes. Carbon acquisition by photosynthesis typically has a temperature optimum close to the normal growth temperature for a given crop, while the carbon loss via respiration increases with temperature (Lambers *et al*., 2008). Therefore, crop growth will be indirectly controlled by temperature due to the balance between photosynthesis and respiration rates (Atkinson and Porter 1996). Thus, temperature affects the rate of pathogenesis progression in individual plants. A moderate temperature of 28-30°C coupled with high humidity helps in the build-up of the disease. High humidity favours development of majority of leaf diseases caused by bacteria. Moisture is generally needed for spore germination, the multiplication and penetration of bacteria, and the initiation of infection (Sharma *et al*., 2007).

In bacterial leaf blight of rice, flooding and water logging conditions, rains or strong winds not only cause wounds that hasten up infection and enhance severity of the disease but also aid in dissemination of the pathogen. Reduced duration of sunshine or cloudy conditions favours the disease development. The intensity of the disease was more in the field which is under shade (Laha *et al*., 2016). It is commonly observed when strong winds and continuous heavy rains occur, allowing the disease-causing bacteria to easily spread through ooze droplets on lesions of infected plants (Sharma *et al*., 2007). The pathogenic bacterium invades the rice crop plants through the water pores using the fresh wounds of 24 hours (Mukoo, 1957). The lesions normally start on one or both margins of leaves or can be observed on the fresh infected leaf veins under humid conditions. The environment played a key role for the development of the disease and the appearance of the symptoms in the field. The disease could be characterized mainly into two distinct phases; leaf blight phase, and the "Kresek phase" which is the destructive one for the epidemic of disease (Reddy and Ou 1976; Ou, 1985). The role of initial inoculum, rate (r) of pathogen or disease development (infection) and period of time (t) that the pathogen and host populations interact during the cropping period is revisited in modelling plant disease epidemics (Ashoub *et al*., 2015).

The importance of weather parameters and the relationship between initial inoculum and the rate of disease development represent key elements for identification of the most useful disease models to be used (Guan and Nutter, 2001). Since the epidemiological factors like temperature, relative humidity, rainfall and sunshine hours etc. have significant role on the occurrence and spread of bacterial leaf blight caused by *X. oryzae* pv. *oryzae (Xoo)*, it is important to understand these epidemiological parameters to manage the disease efficiently. Therefore, the present study aimed to study the effect of weather parameters on the development of bacterial leaf blight of rice caused by *Xanthomonas oryzae* pv. *oryzae*.

MATERIALS AND METHODS

The bacterial blight severity was recorded to its progress during the entire crop season. Highly susceptible rice cultivar (Basmati 370) was planted at Research Farm, to study the role of different weather parameters (minimum temperature (°C), maximum temperature (°C), average temperature (°C), maximum relative humidity (%), minimum relative humidity (%), average relative humidity (%), rainy days (nos.), rainfall (mm)), in relation to disease occurrence. Metrological data was collected from the division of Agro-Meteorology, SKUAST-J, Chatha. The experiment was conducted for two *kharif* season 2019-2020 and 2020-2021. The seeds of highly susceptible variety Basmati-370 was obtained from the Division of plant breeding and genetics and were sown in nursery on 28th of May 2019 and 30th of May 2020. After one month on 1st July 2019 and 2nd July 2020 transplanting was done in experimental plots that were laid out with plot size of 1.5m × 3.5min randomize block design (RBD) with three replications having row to row distance of 20 cm and 15-20 cm within the rows by adopting all standard agronomical practices. The field was kept free from any spray and seed treatment. Inocualtion was done at tillering stage by clipping method (Kauffman *et al.,* 1973). For recording the bacterial blight severity and its development ten plants were selected randomly from each line and labeled. The observations on bacterial leaf blight of rice, disease severity were recorded (at 7 days interval) right from disease initiation till the crop attained maturity.

Observations to be recorded: Disease severity shall be recorded on 1-9 scale (IRRI, 2004).

$$\text{Disease severity} = \frac{n(1)+n(3)+n(5)+n(7)+n(9)}{tn}$$

where, n = Number of leaves showing severity score of 1,3,5,7,9

tn= Total number of leaves score

Rate of infection (r). Infection rate is the amount of increase of the disease per unit time (per day/week/year) in a particular plant population (Vander Plank, 1963).

Rate of disease progress shall be calculated:

$$r = 2.3 / t_2 - t_1 \log10 \, x_2/x_1$$

Where r = infection rate

$t_2 - t_1$ = time interval

x_2 = disease at time t_2

x_1 = disease at time t_1

Area under disease progress curve (AUDPC). The amount of progress of disease tissue is given by a curve that shows the progress of disease over time in a cropped area and is called area under disease progress curve (AUDPC). The AUDPC was calculated (Shaner and Finny 1977):

$$AUDPC = \sum_{i=1}^{n-1} (y_i + y_{i+1}) \times \frac{(t_{i+1} - t_i)}{2}$$

Where *yi* is an assessment of a disease (percentage, proportion, ordinal score, etc.) at the i^{th} observation, *ti* is time (in days, hours, etc.) at the i^{th} observation, and *n* is the total number of observations.

Correlation and multiple linear regression (Cornell and Berger 1987)

Correlation of disease with weather parameters. The per cent disease severity was correlated with the metrological data obtained from the division of Agro-Meteorology, SKUAST-J, Chatha. The effect of weather parameter on bacterial leaf blight of rice was correlated by using R software. The regression and R^2 values were also analyzed to find out the effect of different weather parameters *viz*., maximum and minimum temperature (ºC), relative humidity (%), rainy days (nos.) and rainfall (mm) on the development of bacterial blight of rice.

Multiple linear regression. To predict the disease severity of bacterial leaf blight of rice on cv. Basmati 370, different models were generated with the disease severity and abiotic factors by using multiple linear regression.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6$$

Where, Y is the predicted disease severity of disease 'a' is the intercept, 'b_1' to 'b_6' are the partial regression coefficients, X_1 is the maximum temperature, X_2 is the minimum temperature, X_3 is the relative humidity in the morning (%), X_4 is the minimum relative humidity (%), X_5 is the total rainfall (mm) and X_6 is the sunshine (hrs).

Global test of model assumptions (gvlma). Global test of predicted models of bacterial leaf blight of rice of variety Basmati 370 were conducted by using the *gvlma* package (R version 4.0.2) to find out that assumptions of linearity, reliability of measurement, homoscedasticity and normality are acceptable or not. The *gvlma* package provides a numerical measure of violation through significance testing for global stat, skewness, kurtosis, link function, and heteroscedasticity. The *gvlma* calculates a directional test statistic for each assumption using the standardized residuals from the fitted linear model.

1 Global Stat: It showed the relation between dependent and independent variables. Rejection of null ($p<0.05$) indicates a non linear relationship between one or more dependent and independent variables.

2 Skewness: Implies that weather data is skewed positively or negatively. Rejection of null ($p<0.05$) indicate that data is not acceptable.

3 Kurtosis: Shows whether the distribution of data weather is highly peaked or shallowly peaked.

4 Link Function: Shows whether the data set of dependent variable truly is continuous or not.

5 Heteroscedasticity: Rejection of the null ($p < .05$) indicates that your residuals are heteroscedastic.

Statistical analysis. The data sets were subjected for correlation and regression analysis by using R version 4.0.2 (R Core Team, 2013).

RESULTS AND DISCUSSION

Effect of weather parameters on severity of bacterial leaf blight of riceon cv. Basmati-370

In the year 2019, per cent disease severity and average weekly weather parameters data i.e. maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours were assessed. A perusal of data in Table 1 revealed that bacterial blight was appeared from Ist August, 2019 (31stmeteorological standard week) with 1.03 per cent severity, when the crop was at tillering stage when maximum and minimum temperature of 32.66 and 26.20°C, relative humidity morning and evening was 86.00 and 67.71 percent, sunshine hours was 5.71 hrs and total rain of 50.20mm, respectively. Subsequently disease severity increased from 3.43 to 23.35 per cent, during 32th to 38th standard meteorological week with respective maximum temperature ranged from 34.09 to 32.17°C, minimum temperature from 27.20 to 22.99°C, relative humidity morning from 87.29 to 89.43, relative humidity evening from 70.00 to 61.14 percent, sunshine hours ranged from 5.70 to 6.67 hrs and total rain ranged from 23.00 to 62.80mm. Terminal severity of bacterial blight was recorded 44.13 per cent when the crop was at harvest stage during 46th standard meteorological week with maximum and minimum temperature of 24.00 to 13.41°C, relative humidity morning and evening of 89.86 to 61.71 per cent, sunshine hours of 3.54 and total rain of 2.80mm.

In the year 2020 (Table 2) bacterial blight was appeared from 4th August, 2020 (31st meteorological standard week) with disease severity 1.47 per cent, when the crop was at tillering stage and maximum and minimum temperature of 34.6 and 25.7°C, relative humidity morning and evening was 87.0 and 64.6 percent, sunshine hours was 6.4 and total rain of 54.6mm respectively, was recorded during this period. Subsequently disease severity increased from 2.25 to 21.76 per cent, during 32th to 38th standard meteorological with respective maximum temperature ranged from 34.8 to 36.0°C, minimum temperature ranged from 27.0 to 25.3°C, relative humidity morning ranged from 86.6 to 82.4, relative humidity evening ranged from 67.7 to 49.4 percent, sunshine hours from 4.1 to 8.7 hrs and total rain from 25.6to 0.0mm. Terminal disease severity was recorded as 45.45 per cent when the crop was at harvest stage during 46th standard meteorological week with maximum and minimum temperature of 23.2 to 9.8°C, relative humidity morning and evening of 92.7 to 58.0 per cent, sunshine hours of 4.3 and total rain of 27.8mm .

On the basis of pooled data of two years (2019 and 2020), average per cent disease severity and average weekly weather parameters data are presented in Table 3. A perusal of data revealed that bacterial blight was appeared from August with disease severity1.25 per cent with maximum and minimum temperature of 34.60 and 25.97°C, relative humidity morning and evening was 86.50 and 66.14 percent, sunshine hours was 6.05 and total rain of 52.40 mm respectively. Subsequently disease severity increased from 2.84 to 22.56 per cent, during 32th to 38th standard meteorological week with respective maximum temperature ranged from 34.80 to 36.03, minimum temperature from 27.09 to 24.12°C, relative humidity morning from 86.93 to 85.93 per cent, relative humidity evening from 68.86 to 55.29 percent, sunshine hours ranged from 4.91 to 7.66 and total rain from 24.30 to 31.40 mm. Terminal disease severity was recorded as 44.79 per cent when the crop was at harvest stage during 46th standard meteorological week with maximum and minimum temperature of 23.21 to 11.63°C, relative humidity morning and evening of 91.29 to 59.86, sunshine hours of 3.90 and total rain of 15.30 mm.

Table 1: Effect of weather parameters on disease severity of bacterial leaf blight of rice on cv. Basmati-370 during 2019.

SMW	Disease severity (%)	Weather parameters					
		T_{Max}	T_{Min}	$RH_{Morning}$	$RH_{Evening}$	SS (hrs)	Total Rain (mm)
31th	1.03	32.66	26.20	86.00	67.71	5.71	50.20
32nd	3.43	34.09	27.20	87.29	70.00	5.70	23.00
33rd	5.45	32.66	26.20	86.00	67.71	5.71	131.10
34th	8.76	34.57	25.79	84.43	58.29	8.86	9.40
35th	11.98	35.23	26.67	87.71	61.00	7.81	2.00
36th	15.37	34.63	25.63	85.43	61.86	6.29	9.00
37th	18.46	35.03	25.90	87.00	63.43	4.87	3.00
38th	23.35	32.17	22.99	89.43	61.14	6.67	62.80
39th	27.36	29.71	23.13	93.14	75.86	2.71	93.40
40th	29.56	28.76	18.84	88.57	64.57	5.36	21.40
41st	31.16	30.54	18.60	86.43	52.14	8.10	0.00
42nd	33.15	29.16	17.33	87.29	51.57	5.93	9.20
43rd	35.00	29.30	14.47	84.57	43.57	8.87	0.00
44th	36.25	28.01	15.76	89.86	52.29	5.20	0.00
45th	39.64	25.41	13.04	83.14	52.00	5.63	51.80
46th	44.13	24.00	13.41	89.86	61.71	3.54	2.80

SMW = Standard meteorological week, T_{Max} = Maximum temperature, T_{Min} = Minimum temperature, $RH_{morning}$ = Morning relative humidity, $RH_{evening}$ = Evening relative humidity, SS = sunshine (hours)

Table 2: Effect of weather parameters on disease severity of bacterial leaf blight of rice on cv. Basmati-370 during 2020.

SMW	Disease severity (%)	Weather parameters					
		T_{Max}	T_{Min}	$RH_{Morning}$	$RH_{Evening}$	SS (hrs)	Total Rain (mm)
31th	1.47	34.6	25.7	87.0	64.6	6.4	54.6
32nd	2.25	34.8	27.0	86.6	67.7	4.1	25.6
33rd	6.78	33.3	25.8	93.4	72.4	4.8	185.6
34th	11.67	31.2	25.2	91.1	73.4	4.0	170.8
35th	14.56	31.7	24.9	91.1	71.4	6.9	160.6
36th	16.76	32.7	25.2	88.9	64.4	5.7	17.6
37th	18.43	35.2	26.0	85.3	56.3	8.2	0.0
38th	21.76	36.0	25.3	82.4	49.4	8.7	0.0
39th	24.33	34.1	21.4	79.1	49.3	7.2	0.0
40th	27.79	33.9	18.2	76.3	39.6	8.7	0.0
41st	29.33	33.5	18.0	81.4	40.0	8.0	0.0
42nd	34.53	32.4	14.4	90.3	31.9	8.7	0.0
43rd	36.21	30.3	12.4	89.9	34.4	8.4	0.0
44th	38.45	28.7	10.8	85.7	32.4	7.6	0.0
45th	41.77	27.9	9.6	88.4	39.6	5.8	0.0
46th	45.45	23.2	9.8	92.7	58.0	4.3	27.8

SMW = Standard meteorological week, T_{Max} = Maximum temperature, T_{Min} = Minimum temperature, $RH_{morning}$ = Morning relative humidity, $RH_{evening}$ = Evening relative humidity, SS = sunshine (hours)

Table 3: Effect of weather parameters on disease severity of bacterial leaf blight of rice on cv. Basmati-370 (Pooled).

SMW	Disease severity (%)	Weather parameters					
		T_{Max}	T_{Min}	$RH_{Morning}$	$RH_{Evening}$	SS (hrs)	Total Rain (mm)
31th	1.25	34.60	25.97	86.50	66.14	6.05	52.40
32nd	2.84	34.80	27.09	86.93	68.86	4.91	24.30
33rd	6.12	33.34	25.99	89.71	70.07	5.28	158.35
34th	10.22	31.21	25.51	87.79	65.86	6.41	90.10
35th	13.27	31.67	25.79	89.43	66.21	7.36	81.30
36th	16.07	32.74	25.41	87.14	63.14	6.01	13.30
37th	18.45	35.21	25.96	86.14	59.86	6.56	1.50
38th	22.56	36.03	24.12	85.93	55.29	7.66	31.40
39th	25.85	34.13	22.25	86.14	62.57	4.94	46.70
40th	28.68	33.86	18.51	82.43	52.07	7.02	10.70
41st	30.25	33.50	18.29	83.93	46.07	8.05	0.00
42nd	33.84	32.37	15.85	88.79	41.71	7.32	4.60
43rd	35.61	30.26	13.42	87.21	39.00	8.61	0.00
44th	37.35	28.66	13.30	87.79	42.36	6.38	0.00
45th	40.71	27.90	11.33	85.79	45.79	5.71	25.90
46th	44.79	23.21	11.63	91.29	59.86	3.90	15.30

SMW = Standard meteorological week, T_{Max} = Maximum temperature, T_{Min} = Minimum temperature, $RH_{morning}$ = Morning relative humidity, $RH_{evening}$ = Evening relative humidity, SS = sunshine (hours)

Rate of infection(r) and area under disease progress curve (AUDPC) of bacterial leaf blight of rice on cv. Basmati-370. The rate of infection (r) and area under disease progress curve (AUDPC) of bacterial leaf blight of rice on cv. Basmati-370 during 2019, 2020 and pooled were calculated. Data showed that the infection rate (r) of bacterial leaf blight of rice on cv. Basmati-370 during 2019, 2020 and pooled progressed at a proportion of 0.175, 0.062 and 0.119 on 32nd SMW and ended with 0.026, 0.021 and 0.024 up to 46th SMW, respectively (Table 10). In 2019, maximum infection rate (r) was observed during 32nd standard week and it was 0.175 in basmati-370 and minimum infection rate (r) was observed during 44th standard week and it was 0.008 in basmati-370

In 2020, maximum infection rate (r) was observed during 33rd standard week and it was 0.164 in basmati-370and minimum infection rate (r) was observed during 43rd standard meterological week and it was 0.010 in basmati 370. On the basis of pooled data, maximum infection rate was observed during 32nd standard week and it was 0.119 in basmati-370 and minimum infection rate (r) was observed during 41st 43rd and 44th standard meterological weeks and it was 0.011 in all these three weeks. Data presented in Table 4.

Further, data presented in Table 4 indicated that area under disease progress curve (AUDPC), of bacterial leaf blight of rice on cv. Basmati 370 during 2019, 2020 and pooled. In the year 2019, it was minimum at 32nd meterological week (15.61) when disease severity was 3.43 % and it was maximum at 46th standard meterological week (293.19) when disease severity was 44.13%. Similarly in the year, 2020 it was minimum at 32ndmeterological week (13.02) when disease severity was 2.25 % and it was maximum at 46th standard meterological week (305.27) when disease severity was 45.74%. On the basis of pooled data, it was minimum at 32nd meterological week (14.32) when disease severity was 2.84 % and it was maximum at 46th standard meterological week (299.23) when disease severity was 44.79% presented in Table 4.

Table 4: Infection rate and area under disease progress curve (AUDPC) of bacterial leaf blight of rice on cv. Basmati-370 during 2019, 2020 and pooled.

SMW	2019		2020		Pooled	
	infection rate	AUDPC	infection rate	AUDPC	infection rate	AUDPC
31th	-	-	-	-	-	-
32nd	0.175	15.61	0.062	13.02	0.119	14.32
33rd	0.069	31.08	0.164	31.605	0.114	31.36
34th	0.073	49.735	0.085	64.575	0.080	57.17
35th	0.050	72.59	0.036	91.805	0.042	82.20
36th	0.041	95.72	0.024	109.62	0.032	102.69
37th	0.031	118.40	0.016	123.165	0.024	120.80
38th	0.042	146.33	0.030	140.665	0.036	143.52
39th	0.030	177.48	0.021	161.315	0.026	169.42
40th	0.015	199.22	0.026	182.42	0.020	190.84
41st	0.011	212.52	0.011	199.92	0.011	206.24
42nd	0.013	225.08	0.034	223.51	0.024	224.30
43rd	0.012	238.52	0.010	247.59	0.011	243.08
44th	0.008	249.37	0.014	261.31	0.011	255.34
45th	0.021	265.61	0.020	280.77	0.020	273.21
46th	0.026	293.19	0.021	305.27	0.024	299.23

Where, SMW = Meterological standard week, AUDPC = Area under disease progress curve

Correlation and multiple linear regression

Correlation of disease with weather parameters on cv. Basmati 370. The correlation analysis between disease severity and independent variables *viz*., temperature (maximum and minimum), relative humidity (morning and evening), rainfall (mm) and bright sunshine (hrs) during the time course under investigation were calculated for both the cropping seasons 2019 and 2020. The relationship between disease severity and weather factors during 2019 indicated a significantly negative correlation with maximum temperature (-0.858), minimum temperature (-0.934) and relative humidity evening (-0.559) and non-significant negative correlation with rainfall (-0.298) and sunshine hours (-0.215) sunshine hours. The positive non-significant correlation was observed in relative humidity morning (0.225). Further, the relationship between disease severity and weather factors during 2020 indicated a significantly negative correlation with maximum temperature (-0.687), minimum temperature (-0.933), relative humidity evening (-0.776) and rainfall (-0.544), whereas non-significant negative correlation with relative humidity morning (-0.059). The positive non-significant correlation was observed in sunshine hours (0.343). On the basis of pooled data, the relationship between disease severity and weather parameters, indicated a significantly negative correlation with maximum temperature (-0.655), minimum temperature (-0.935), relative humidity evening (-0.796) and rainfall (-0.592) and non-significant negative correlation with relative humidity morning (-0.020). The positive non-significant correlation was observed in sunshine hours (0.117). Data presented in Table 5.

Table 5: Correlation of abiotic factors with the severity of bacterial leaf blight of rice on cv. Basmati-370 during 2019, 2020 and on the basis of pooled data.

Years	Max. temp	Mini temp	RH. Morning	RH. Evening	Rainfall (mm)	Sunshine (Hr)
2019	-0.858**	-0.934**	0.225	-0.559*	-0.298	-0.215
2020	-0.687**	-0.933**	-0.059	-0.776**	-0.544*	0.343
Pooled	-0.655**	-0.935**	-0.020	-0.796**	-0.592*	0.117

*Values are significant at p =0.05; **Values are significant at p =0.01

Multiple linear regression. The multiple linear regression analysis of disease severity with weather parameters *viz*., temperature (maximum and minimum), relative humidity (morning and evening), rainfall (mm) and bright sunshine (hrs) were analysed and the regression coefficients were obtained. The multiple linear regression equation was fitted to the data and the equation derived for the weather parameters are presented in Table 6 for the year 2019, 2020 and on the basis of pooled data, respectively. During the year 2019, best fit regression equation for bacterial leaf blight of rice for Basmati-370 was found to be $Y=121.412+4.637X_1-5.806X_2+1.126X_3+0.527X_4+0.016X_5-1.031X_6$. The model had coefficient of determination (R^2) of 0.95, which showed that 95 per cent of the variation in the disease severity of bacterial leaf blight of rice was influenced by maximum and minimum temperature, maximum and minimum relative humidity and rainfall, with adjusted R^2 (0.923) and P value (1.561). The model further explained that one unit increase in maximum temperature predicted severity increase of 4.63 per cent per week, if all the other predictors remained constant, whereas minimum temperature increased by one unit per week predicted disease severity decrease of 5.70 per cent, if all other predictors remained constant. When morning relative humidity increased one unit, then 1.12 per cent increased in predicted disease severity. Disease severity (predicted) increased 0.52 per cent per week if per unit increase in evening relative humidity. Further, disease severity (predicted) increased by 0.061 per cent if per unit increase in sunshine hours and disease severity (predicted) decreased 1.031 per cent per week if per unit decrease in rainfall. Similarly, during the year 2020 the best fit regression equation for bacterial leaf blight of rice in basmati-370 variety was $Y = 196.994 - 4.535X_1 + 1.082X_2 - 0.277X_3 - 0.685X_4 - 0.012X_5 + 1.614X_6$. This model had coefficient of determination (R^2) of 0.94 which showed 94% of the variation in the observed disease severity of bacterial leaf blight of rice was influenced by maximum and minimum temperature, morning and evening relative humidity, sunshine hours and rainfall with adjusted R^2 (0.907) and P value (3.731). The model further explained that one unit increase in maximum temperature predicted severity decreased of 4.53 per cent per week, if all the other predictors remained constant, whereas minimum temperature increase by one unit per week predicted disease severity increased of 1.08 per cent, if all other predictors remained constant. When morning relative humidity increased one unit, then 0.277 per cent decrease in predicted disease severity. Disease severity (predicted) decreased 0.68 per cent per week if per unit increase in evening relative humidity. Further, disease severity (predicted) decreased by 0.012 per cent if per unit increase in sunshine hours and disease severity (predicted) increased 1.614 per cent per week if per unit increase in rainfall. On the basis of Pooled data, best fit regression equation for bacterial leaf blight of rice for basmati-370 was found to be $Y = 17.622 + 0.439X_1 - 2.506X_2 + 0.284X_3 + 0.254X_4 - 0.057X_5 + 0.935X_6$ with coefficient of determination (R^2) of (0.89) which showed that 89 per cent of the variation in the observed disease severity of bacterial leaf blight of rice was influenced by maximum and minimum temperature, morning and evening relative humidity, sunshine hours and rainfall with adjusted R^2 (0.823) and P value (0.0006). The model further explained that one unit increase in maximum temperature predicted disease severity increase of 0.439 per cent per week, if all the other predictors remained constant, whereas minimum temperature increased by one unit per week predicted disease severity decreased of 2.506 per cent, if all other predictors remained constant. When morning relative humidity increased one unit, then 0.254 per cent increase in predicted disease severity. Disease severity (predicted) decreased 0.057 per cent per week if per unit increase in evening relative humidity. Further, disease severity (predicted) decreased by 0.057 per cent if per unit increase in sunshine hours and disease severity (predicted) increased 0.935 per cent per week if per unit increase in rainfall.

Table 6: Multiple linear regression equation of bacterial leaf blight of rice on cv. Basmati-370 during 2019, 2020 and pooled.

Regression equation	R^2	Adjusted R^2	P-value
$Y=121.412+4.637X_1-5.806X_2+1.126X_3+0.527X_4+0.016X_5-1.031X_6$	0.9541	0.923	1.561
$Y=196.994-4.535X_1+1.082X_2-0.277X_3-0.685X_4-0.012X_5+1.614X_6$	0.9442	0.907	3.371
$Y=17.622+0.439X_1-2.506X_2+0.284X_3+0.254X_4-0.057X_5+0.935X_6$	0.8940	0.823	0.0006

X_1= Maximum temperature, X_2= Minimum temperature, X_3= Morning relative humidity, X_4= Evening relative humidity, X_5= sunshine (hours), X_6= Total rain

Assumption of multiple linear regression of bacterial leaf blight of rice on cv. Basmati-370. For the better prediction of bacterial leaf blight in Basmati-370 by multiple linear regression, it is important to check the assumptions *viz*., linearity, reliability, homoscedasticity and normality. The global test of model assumption indicated that during 2019 except link function test which is not acceptable having P value of 0.015, all other assumptions were acceptable as the global stat, skewness, kurtosis and heteroscedasticity test having p value of 0.084, 0.270, 0.327 and 0.3276 in Basmati-370. The global test of model assumption indicated that during 2020 except skewness test and link function which were not acceptable having P value of 0.049 and 0.027**,** but other assumptions were acceptable as the global stat, kurtosis and heteroscedasticity test having p value of 0.052, 0.652 and 0.490 in Basmati-370. On the basis of pooled data, the global test of model assumption revealed that the assumptions were acceptable as the skewness and kurtosis test having p value 0.207 and 0.764 in Basmati-370 and other tests like global stat, link function and heteroscedasticity were not acceptable and having p value of 0.013, 0.015 and 0.025 in Basmati-370. Data presented in Table 7.

Table 7: Assessment of the linear model of bacterial leaf blight of rice in basmati-370 by global test of model assumptions during 2019, 2020 and pooled.

Test	2019	2020	Pooled
Global Stat	0.084	0.052	0.013
Skewness	0.270	0.049	0.207
Kurtosis	0.327	0.652	0.764
Link Function	0.015	0.027	0.015
Heteroscedasticity	0.683	0.490	0.025

DISCUSSION

Environmental factors essentially affect severity and spread of plant diseases and thus, the knowledge concerning epidemiology can help in better management of the disease. In present study, experimental trials were conducted during 2019 and 2020 to assess the effect of different weather parameters (maximum temperature (°C), minimum temperature (°C), relative humidity morning (%), relative humidity evening (%), sunshine hours and rainfall (mm) on the development of bacterial leaf blight of rice on cv. Basmati-370. During 2019, the disease severity of 1.03 per cent was recorded in 31st standard meteorological week having maximum and minimum temperature of 32.66 and 26.20°C, relative humidity morning and evening of 86.00 and 67.71 percent, sunshine hours of 5.71 hrs and total rain of 50.20mm, respectively. Subsequently, a sharp progression in disease severity from 32th to 38th standard meteorological week and was 3.43 to 23.35 per cent with respective maximum temperature ranged from 34.09 to 32.17°C, minimum temperature from 27.20 to 22.99°C, relative humidity morning from 87.29 to 89.43, relative humidity evening from 70.00 to 61.14 percent, sunshine hours ranged from 5.70 to 6.67 hrs and total rain from 23.00 to 62.80mm. Terminal disease severity was observed at the time of crop maturity during 46th standard meteorological week and was 44.13 per cent having maximum and minimum temperature of 24.00 to 13.41°C, relative humidity morning and evening of 89.86 to 61.71 per cent, sunshine hours of 3.54 and total rain of 2.80mm. Similarly during 2020, the disease severity of 1.47 per cent was recorded in 31st standard meteorological week when the crop was at tillering stage having maximum and minimum temperature of 34.6 and 25.7°C, relative humidity morning and evening of 87.0 and 64.6 percent, sunshine hours of 6.4 and total rain of 54.6mm respectively. Subsequently, a sharp progression in disease severity from 32th to 38th standard meteorological week and was 2.25 to 21.76 per cent with maximum temperature ranged from 34.8 to 36.0°C, minimum temperature ranged from 27.0 to 25.3°C, relative humidity morning ranged from 86.6 to 82.4, relative humidity evening ranged from 67.7 to 49.4 percent, sunshine hours from 4.1 to 8.7 hrs and total rain from 25.6 to 0.0mm. Terminal disease severity was observed at the time of crop maturity during 46th standard meteorological week and was 45.45 per cent having maximum and minimum temperature of 23.2 to 9.8°C, relative humidity morning and evening of 92.7 to 58.0 per cent, sunshine hours of

4.3 and total rain of 27.8mm. On the basis of pooled data, the disease severity of 1.25 per cent was recorded in 31st standard meteorological week having maximum and minimum temperature of 34.60 and 25.97°C, relative humidity morning and evening was 86.50 and 66.14 percent, sunshine hours was 6.05 and total rain of 52.40 mm respectively. Subsequently, a sharp progression in disease severity was observed during 32th to 38th standard meteorological week and was 2.84 to 22.56 per cent with maximum temperature ranged from 34.80 to 36.03, minimum temperature from 27.09 to 24.12°C, relative humidity morning from 86.93 to 85.93 per cent, relative humidity evening from 68.86 to 55.29 percent, sunshine hours ranged from 4.91 to 7.66 and total rain from 24.30 to 31.40 mm. Terminal disease severity was observed at the time of crop maturity during 46th standard meteorological week and was 44.79 per cent having maximum and minimum temperature of 23.21 to 11.63°C, relative humidity morning and evening of 91.29 to 59.86, sunshine hours of 3.90 and total rain of 15.30 mm. Our results are in conformity with that all the environmental variables such that temperature, relative humidity, rainfall and sun shine hours have been considered effective for the development of different crop plants disease epidemics in different seasons as the wind speed and high rainfall favoured the dispersal of pathogens, high relative humidity supplied excess moisture at the host plant surface to favours the sporulation of most plant pathogens to infect the crop plants similarly sunshine provided favourable temperature for the successful development of disease (Ingold, 1971; Lacey, 1996; Francl and Panigrahi, 1997; Walters and Hardwick, 2000 and Naqvi *et al*. (2016). After a series of experiments, favourable environmental conditions for the development of bacterial blight were high temperature (32-35°C) during August till September and humid autumn were found to be best suited regarding the disease epidemic development (Goto *et al*., 1955).

The rate of infection (r) and area under disease progress curve (AUDPC) of bacterial leaf blight of rice on cv. Basmati 370 during 2019, 2020 and pooled was observed. The infection rate (r) of bacterial leaf blight of rice on cv. Basmati-370 progressed at a proportion of 0.175, 0.062 and 0.119 on 32nd SMW and ended with 0.026, 0.021 and 0.024 up to 46th SMW, during 2019, 2020 and pooled. During 2019, maximum infection rate (r) was 0.175, similarly during 2020, maximum infection rate (r) was 0.164 and on the basis of pooled data, maximum infection rate was 0.119 in basmati 370. During 2019, area under disease progress curve maximum at 46th standard meterological week (293.19) when disease severity was 44.13%. During 2020, area under disease progress curve was maximum at 46th standard meterological week (305.27) when disease severity was 45.74%. On the basis of pooled data, area under disease progress curve was was maximum at 46th standard meterological week (299.23) when disease severity was 44.79%. Maximum and minimum values of AUDPC indicate the response of resistance or susceptibility against the disease in the field. Similar results were also observed by Kiran and Singh (2015); Hasan *et al*., (2016).

During both the year 2019 and 2020, simple correlation was worked out to studied the influence of weather parameters on the development of the disease. All the weather parameters (maximum temperature, minimum temperature, relative humidity morning, relative humidity evening, sunshinehours and total rain) had a significant impacts on the per cent disease severity. The correlation analysis of bacterial leaf blight severity with weather parameters during 2019 depicted significantly negative correlation with maximum (-0.858), minimum temperature (-0.934) and relative humidity evening (-0.559) and non-significant negative correlation with rainfall (-0.298) and sunshine hours (-0.215) and depicted positive non-significant correlation in relative humidity morning (0.225). During 2020, maximum temperature (-0.687), minimum temperature (-0.933), relative humidity evening (-0.776) and rainfall (-0.544) showed a significant negative correlation and relative humidity morning (-0.059) but in case of sunshine hours non-significant positive correlation (0.343) was observed. On the basis of pooled data, the relationship between disease severity and weather parameters, depicted a significantly negative correlation with maximum temperature (-0.655), minimum temperature (-0.935), relative humidity evening (-0.796) and rainfall (-0.592) and relative humidity morning (-0.020) showed a non-significant negative correlation but in case of sunshine hours (0.117) positive non-significant correlation was observed. Similar results were observed by Fujikawa *et al*. (1957) who described that a significant correlation was found among the high temperature and relative humidity, for the development of bacterial leaf blight disease and particularly highlighted the role of heavy rainfall followed by the few hours of sun shine strongly favoured the development of disease in the rice growing areas. Muco *et al*. (1957) also described that climatic conditions greatly influenced the development of bacterial blight disease of rice. The promising factors for the development of epidemic were high relative humidity, rainfall, temperature and strong winds through paddy development season.

Multiple regression analysis revealed that all six weather parameters played an important role in the establishment of disease on rice. Among the weather parameters, the maximum temperature and number of rainy days had a significant contribution in increase per cent disease severity. The analysis indicated that in the development of disease, there were 94 and 89 per cent influences of all six weather factors on cv. Basmati 370 and the remaining 6 and 11 per cent variations were unexplained during both the years *i.e*. 2019 and 2020, respectively. It clearly shows that these parameters are highly linked with the disease progress and found as an important component in blight epidemic. Thus, the model can be used to forecast bacterial blight using six parameters of preceding week. The above result are in agreement with the results, that the rapid development of disease is associated with moderate temperature (30 to 35°C), high relative humidity (64 to 84), sunshine hours (6-7hours), wind velocity, high rain-fall (180mm) and more number of rainy days favours the development of bacterial leaf blight disease (Srinivasan and Singh 1983). Initiation of bacterial leaf blight symptoms were at the tillering stage, resulting in increased disease incidence and it peaked at the flowering stage. Plants less than 21 days old were the most susceptible and temperatures between 28 and 34°C favoured Kresek development (Gnanamanickam *et al*., 1999). Temperature of 22 to 26°C, rainy weathers and windy days were favourable for bacterial blight development. They further reported that high temperature 31 to 36°C, rainy weather and more number of rainy days were positively correlated with the disease severity (Rangaswami and Mahadevan 2005). Total rainfall (160mm), number of rainy days, days with temperature between 25-30°C were found more favourable for the development of bacterial leaf blight of rice (Sharma *et al*., 2007). Continuous rainfall over prolonged periods, humid weather and moderate temperature between 22 to 25°C favoured the development of bacterial blight of rice. Temperatures below 20°C, severe heat and drought were unfavourable for the disease development (Henry and Devasahayam 2011). Temperature more than 24°C, relative humidity from4-84 per cent, rainfall more than 200 mm, sunshine hours (5-6 hours) and strong winds were suitable for the disease development Ranjan *et al*. (2012). Maximum number of rainy and windy days, and temperature 22 to 25°C and close planting were favourable for bacterial blight development (Das, 2014). Maximum development of bacterial blight was favoured on matured crop plants having temperature of 30.1 to 33.1°C, and relative humidity of 79.1-91.2 per cent. They also observed that on matured crop the disease severity increases at 32^0C with relative humidity of 89 per cent. High temperature and high relative humidity were positively correlated with bacterial blight development (Swati *et al*., 2015).

CONCLUSION

During 2019, the disease severity of 1.03 per cent was recorded in 31^{st} standard meteorological week (SMW) when the crop was at tillering stage and when maximum and minimum temperatures of 32.66 and 26.20°C, morning and evening relative humidity of 86.00 and 67.71 percent, sunshine of 5.71 hrs and total rainfall of 50.20 mm, was recorded. Terminal severity of BLB was 44.13 per cent when the crop was at harvest stage during 46^{th} SMW, with maximum and minimum temperatures of 24.00 to 13.41^{o}C, morning and evening relative humidity of 89.86 to 61.71 per cent, sunshine hours of 3.54 and total rainfall of 2.80mm. During 2020, the disease severity of 1.47 per cent was recorded in 31^{st} SMW, with maximum and minimum temperatures of 34.6 and 25.7^{o}C, morning and evening relative humidity of 87.0 and 64.6 percent, sunshine hours was 6.4 and total rainfall of 54.6mm. Terminal disease severity was 45.45 per cent when the crop was at harvest stage during 46^{th} SMW, with maximum and minimum temperatures of 3.2 to 9.8^{o}C, morning and evening relative humidity of 92.7 to 58.0 per cent, sunshine hours of 4.3 and total rainfall of 27.8 mm. On the basis of pooled data of the two years, the disease severity of 1.25 per cent was recorded in 31^{st} SMW with maximum and minimum temperatures of 34.60 and 25.97°C, morning and evening relative humidity of 86.50 and 66.14 percent, sunshine hours was 6.05 and total rainfall of 52.40 mm. Terminal disease severity was 44.79 per cent when the crop was at harvest stage during 46^{th} SMW with maximum and minimum temperatures of 23.21 and 11.63°C, morning and evening relative humidity of 91.29 and 59.86 per cent, sunshine hours of 3.90 and total rainfall of 15.30 mm.

In 2019, maximum infection rate (r) of 0.18 was observed during 32^{nd} SMW in basmati-370, while during 2020, maximum infection rate (r) of 0.16 was observed during 33^{rd} SMW. On the basis of pooled data, maximum infection rate (r) of 0.12 was observed during 32^{nd} SMW. During 2019 AUDPC was maximum at 46^{th} SMW (293.19) when the disease severity was 44.13 per cent. Similarly during 2020, it was maximum at 46^{th} SMW (305.27) when disease severity was 45.74 per cent. On the basis of pooled data, it was maximum at 46^{th} SMW (299.23) when disease severity was 44.79 per cent. Correlation studies revealed that the relationship between disease severity and weather factors during 2019 had significantly negative correlation with maximum temperature, minimum temperature and evening relative humidity, and non-significant negative correlation with rainfall and sunshine hours, though there was positive but non-significant correlation with morning relative humidity. During 2020, significantly negative correlation with maximum temperature, minimum temperature, evening relative humidity and rainfall, whereas non-significant negative correlation with morning relative humidity was observed, whereas, positive but non-significant correlation was observed with sunshine hours. On the basis of pooled data, significantly negative correlation with maximum temperature, minimum temperature, evening relative humidity and rainfall, and non-significant negative correlation with morning relative humidity was observed, however, there was positive but non-significant correlation with sunshine hours.

Multiple linear regression studies revealed that among the weather parameters, maximum temperature and number of rainy days had a significant contribution in the increase in per cent disease severity. For the development of disease, there were 94 and 89 per cent influences of all the six weather factors on cv. Basmati-370 and the remaining 6 and 11 per cent variations were unexplained, during both the years *i.e.* 2019 and 2020, respectively.

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