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Influence of Weather Parameters (Epidemiology) on Powdery Mildew Disease Development caused by *Leveillula taurica*

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ABSTRACT: Chilli (*Capsicum annum* L.) is a well known commercial crop in the centre of the world. It is an important spice in developed and developing nations because of its pungency and taste it makes even in household. The current research was conducted at College of Agriculture, Shivamogga, during Rabi 2020-2021 to create a prediction model for chilli powdery mildew disease on susceptible cultivar Byadagi Kaddi with suggested package of practises except for powdery mildew disease management. Prediction of powdery mildew was made one week well in advance. The simple regression equation for 2020-21 was $\hat{y}$ = 8.32 + 0.95x with R = 0.95741 and R2 = 0.9166. However, it is important to note that the disease was influenced by various weather factors. The studies on effect of weather factors on development of disease revealed that, 5th standard week was highly favourable for initiation and further development of disease and the biggest challenge is to predict the favourable weather conditions and time of appearance of disease and this was employed successfully here.

Keywords: Powdery mildew, *Leveillula taurica*, Area under disease progress curve.

INTRODUCTION

Chilli (*Capsicum annum* L. and *Capsicum fruitscens*) is a popular commercial horticulture crop cultivated for domestic and international markets. It belongs to the family *Solanaceae.* Chilli is composed of an alkaloid called Capsicin and found rich in vitamins which are Vitamin C, Vitamin A, Thiamine, and Riboflavin. The nutrients which includes 1.9 g of protein, 5.3 g of sugar, 8.8 g of carbohydrate, and 534 µg of beta carotene per 100 g of edible chilli and is used for medicinal and health purposes (Panda *et al*., 2010; Saleh *et al*., 2018). China, India, Mexico, Morocco, Pakistan, Thailand, and Turkey are well famed to be the world's top chilli producers and exporters (Lakshmi *et al.,* 2014).

Chilli crop is susceptible to various diseases caused by fungus, bacteria, viruses, and nematodes which lower yields. Damping-off is the most common disease in nursery caused by, *Pythium aphanidermatum*. In field crop *Leveillula taurica* causes powdery mildew (Lev.), Anthracnose (*Colletotrichum capsici* (Syd.)), Cercospora leaf spot (*Cercospora capsici*), *Rhizoctonia solani* causes dry root rot, *Xanthomonas campestris pv vesicatoria* Kuhn causes bacterial leaf spot, Chilli Leaf Curl (*Tobacco Leaf Curl Virus*), and Chilli Mosaic (*Chilli Mosaic Virus*) and Root knot nematode by *Meloidogyne incognita.*

Leveillula taurica (Lev.) Arn. causing powdery mildew of chilli is one of the most dangerous chilli diseases, causing 14 to 30 *per cent* production losses due to severe defoliation and reduction in photosynthesis, size, and quantity of fruits per plant (Gohokar and Peshney 1981). Powdery mildew of chilli is an endemic disease that has become a severe limitation to chilli output in India (Singh and Lodha 1985).

Yellowing on the upper surface of the leaf is accompanied by a whitish powdery mass on the bottom surface, which is characteristic symptom of the powdery mildew. The powdery mildew fungus is ectophytic in nature. A white mass forms on both surfaces in extreme instances, resulting in premature defoliation (Jharia *et al*., 1978). Powdery mildew infection usually shows up first on older plants and lower leaves. Greenhouse pepper producers must implement a comprehensive disease prevention strategy to ensure that powdery mildew does not become a problem (Bettiol *et al.,* 2008).

Powdery mildew is difficult to manage after it has affected chilli leaves, and if left untreated, it might completely ruin the crop (Abdel Kader *et al.,* 2012). The chilli pathogen *Leveillula taurica*'s powdery

mildew is an obligatory parasite that requires live host tissue to develop and propagate. Endoparasitic fungi live in plant leaves, entering through stomata and forming haustoria through which they feed on (Clerk and Ayesu-Offei, 1967). *L. taurica* conidial germination occurs at temperatures ranging from 10 to 37°C (optimal 20°C).

During adverse environmental circumstances, the pathogen might persist in many forms. In order to properly control the disease, the pathogen's survival and dissemination mechanisms must be found out to delink the infection chain at the right moment. The most practical, realistic, and cost-effective technique of plant disease control is host plant resistance.

This research on powdery mildew with respect to variation among isolates in connection to environmental conditions will aid us in quantifying the correlation and variability between the many independent variables like variety, temperature, humidity, location, rainfall, wind speed etc.

MATERIALS AND METHODS

Prediction model for powdery mildew. The current research was conducted at College of Agriculture, Shivamogga, during Rabi 2020-2021 to create a prediction model for chilli powdery mildew disease on susceptible cultivar Byadagi Kaddi with suggested package of practises except for powdery mildew disease management.

A simple regression equation was used to study the development of powdery mildew disease in relation to the severity for the initial occurrence of the disease. Starting from the earliest appearance of disease through the end of the crop, the powdery mildew disease was recorded on 10 randomly selected plants using a 0-5 scale at seven-day intervals. The per cent disease index (PDI) was determined according to Wheeler (1969).

Later, disease was predicted using a simple regression equation that was developed based on the onset and progression of the disease.

The relationship between disease development and week of beginning of disease was shown to be in the order of in a simple regression equation.

$$\hat{Y} = a + bx$$

Where, $\hat{Y}$ = Predicted PDI

X = Previous week PDI

b = Co-efficient (slope)

a = Constant

$$b = \frac{1/n \Sigma xy - xy}{1/n \Sigma x 2 - y 2}$$

$$a = \hat{Y} - bx$$

R value can be calculated by

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

R = Co-efficient of correlation

Weather parameter correlation and regression with per cent disease index (PDI). During 2020-2021, epidemiological research was conducted at College of Agriculture, Shivamogga. The powdery mildew susceptible cultivar Byadagi Kaddi was selected for this research. Ten plants with age of about 45 days were chosen at random and labelled to monitor the development of powdery mildew disease on leaves.

At weekly intervals of standard MW, observations were made by following 0-5 scale. During the crop season, meteorological factors such as rainfall, maximum and minimum temperatures, and morning and evening relative humidity were all recorded on a weekly basis. The weekly average of weather parameters was computed. A correlation matrix was devised. Multiple regressions with the aforesaid factors in relation to PDI were also performed.

Apparent rate of infection (r) and Area Under Disease Progress Curve (AUDPC) for powdery mildew. For the study, 10 plants were randomly selected at flowering stage and tagged from the powdery mildew susceptible cultivar Byadagi Kaddi. On these plants, the disease severity was measured on a scale of 0 to 5. The Wheeler formula was used to compute the PDI (1969). Van der Plank (1963a) formula was used to determine the rate of disease development 'r' at different intervals, and Wilcoxson *et al*. formula was used to get the Area Under the Disease Progress Curve (1975).

Rate of disease spread (r)

$$r = \frac{2.3}{t2 - t1}\left(\log 10 \frac{X2}{1 - X2} - \log 10 \frac{X1}{1 - X1}\right)$$

Where, r = Apparent rate of infection

X1 = PDI at time t1

X2 = PDI at time t2

t2 – t1 = Time interval in days between the two consecutive observation

Area Under Disease Progress Curve (AUDPC)

$$AUDPC = \sum_{i=1}^{K} \tfrac{1}{2} (Si + Si - 1)(t2 - t1)$$

Where,

Si = Amount of disease at i^{th} time

Si-1 = Amount of disease at $(i - 1)^{th}$ time

t2 – t1 = Number of days between two observations

K = Number of successive evaluation of disease

Observations recorded

Per cent disease index (PDI). The severity of the disease was determined by rating each of the 10 plants on a scale of 0 to 5 (Gawande and Patil 2003). The PDI was also computed using the aforementioned scales and the Wheeler formula (1969).

$$\text{Per cent Disease Index (PDI)} = \frac{\text{Total sum of numerical rating}}{\text{No. of leaves observed} \times \text{Max. grade value}} \times 100$$

RESULTS

Role of environmental factors on the development of powdery mildew. During 2020-2021, the impact of weather factors on the degree of powdery mildew growth in the sensitive cultivar Byadagi kaddi was studied at College of Agriculture, Shivamogga. As indicated in "Material and Methods," the severity of disease was recorded at weekly intervals, and the data were analysed using simple correlation and shown in Table 2 and Fig. 1.

No powdery symptoms were reported till the 28th of January, according to the data (4th MSW). Powdery mildew initially appeared on the 29th of January through the 4th of February, with a PDI of 2.86 per cent. The Per cent disease index (PDI) rose from 2.86 to 60.1 per cent, with a peak in the 11th MSW (12th March to 18th March 2021) before gradually declining.

Through correlation and multiple linear regression, the relationship between weather parameters such as maximum and minimum temperature, maximum and minimum relative humidity, and rainfall with the per cent disease index of disease in susceptible cultivar Byadagi Kaddi was found.

During 2020-2021, the relationship between powdery mildew (PDI) and weather factors (Table 1) were revealed a positive correlation between all weather parameters, with the minimum temperature showing a negative correlation coefficient -0.014).

The multiple linear regression between PDI of powdery mildew and weather parameters during 2020-21 (Table 1) indicated that, the regression coefficients for maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, rainfall and were found to be 0.86, 0.83, 0.57, -0.014, 0.13 and 0.52 respectively.

The multiple linear regression equation was fitted to the data and equation is Y = -96.73 + 1.38X1 + 5.71X2 + 0.19X3 -1.05X4 + 0.35X5 -0.08X6. Where, X1 = Max. Temperature (°C), X2 = Min. Temperature (°C), X3 = Max. RH (%), X4 = Min. RH (%), X5 = Rainfall (mm) and X6 = Wind speed.

This revealed that when there was increase in one unit of maximum and minimum temperature, maximum relative humidity, rainfall and wind speed the per cent disease index were increased by 0.86, 0.83, 0.57, 0.13 and 0.52 units. Similarly, when there was increase in one unit of minimum relative humidity the per cent disease index was decreased by 0.014 units respectively. The weather factors influence the powdery mildew incidence in Byadagi Kaddi to the extent of 60 per cent.

Prediction model by 'Simple regression' method on powdery mildew disease development was done. The powdery mildew incidence was recorded at seven days interval during 2020-21, by using 0-5 scale and converted to per cent disease index (PDI). Further, disease development was predicted using the simple regression equation methods as explained in "Material and Methods" observed and predicted values of PDI, obtained are presented in Table 4 and Fig. 2.

The predicted values were ranged from 8.32 PDI to 64.80 PDI. The difference between observed and predicted PDI was maximum at 7th MW (8.11), the predicted PDI values were almost on par with observed PDI values during 6 and 10 MW.

Disease progression and apparent rate of infection on Chilli powdery mildew. During 2020-2021 at College of Agriculture, Shivamogga, the sensitive Byadagi Kaddi cultivar was used to assess disease progression and apparent rate of infection (r). From the beginning of the disease to the conclusion of the crop, disease incidence was reported at weekly intervals. In addition to the PDI, apparent rate of infection (r), and AUDPC were computed over two weeks and are shown in Table 5 and Fig. 3. The disease began with a 2.86 PDI in the fifth meteorological standard week (MSW), steadily grew, and peaked at 60.10 per cent in the eleventh MSW of March 2021. On April 22nd, the PDI dropped to 35.75 per cent at 16th MSW.

After three weeks of first infection at 7th MSW, the maximum apparent rate of infection (r) (0.154) was recorded. The disease progressed steadily from the time of infection, with the highest AUDPC value (400.54) which was recorded on the 18th of March 2021 (11th MSW) and the lowest (10.01) recorded was on the 4th of February 2021 (5th MSW). The total or cumulative AUDPC obtained, on the other hand, was 1201.41 (Fig. 4 and Table 5).

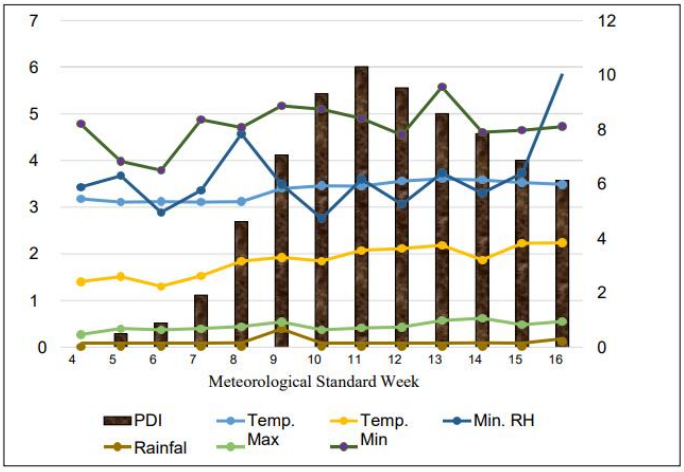

Fig. 1. Influence of Weather Parameters on Chilli Powdery Mildew during 2020-21.

Table 1: Effect of weather parameters on severity of chilli powdery mildew caused by *Leveillula taurica* (Lev.) Arn. during 2020-2021.

Months	Meteorological Standard Week (MSW)	PDI	Temp. (°C)		RH (%)		Rainfall (mm)	Wind Speed (km/hr)
			Max.	Min.	Max.	Min.		
Jan 22nd - 28th	4	0	31.8	14.06	82	34.3	0	2.7
Jan 29th - Feb 4th	5	2.86	31.1	15.11	68.3	36.7	0	4
Feb 5th - 11th	6	5.15	31.2	13.03	65	28.9	0	3.7
Feb 12th - 18th	7	11.15	31.1	15.29	83.6	33.6	0	4
Feb 19th - 25th	8	26.9	31.2	18.43	80.7	45.7	0.1	4.4
Feb 26th - Mar 4th	9	41.18	34	19.26	88.7	34.9	3.9	5.4
Mar 5th - 11th	10	54.34	34.6	18.46	87.4	27.6	0	3.7
Mar 12th - 18th	11	60.1	34.5	20.77	84	36	0	4.1

Table 2: Correlation matrix of epidemiological factors and chilli powdery mildew disease severity during 2020-21.

Characters	PDI (%)	TEMP (°C) max	TEMP (°C) min	RH (%) max	RH (%) min	Rainfall (mm)	Wind speed (km/hr)
PDI (%)	1						
TEMP (°C). max	0.855119671	1					
TEMP(°C). min..	0.834479936*	0.832127832	1				
RH (%). max	0.567003923	0.517945253	0.53888412	1			
RH (%). Min.	-0.01393158	0.045754544	0.42740813	0.0925649	1		
Rainfall (mm)	0.126429131	0.106795925	0.17797411	0.2833663	0.1966909	1	
Windspeed (km/hr)	0.515703855	0.628026808	0.64472878	0.3318972	0.3702411	0.377671713	1

Note: * indicates significance at 5 per cent level

Table 3: Multiple linear regression analysis for influence of weather parameters on chilli powdery mildew disease.

Constant	X1	X2	X3	X4	X5	X6
-96.726	1.387	5.711	0.198	-1.055	0.357	-0.075
Regression equation					R^2	Multiple R
Y = -96.726 + 1.387 X1 + 5.711 X2 + 0.198 X3 – 1.055 X4 + 0.357 X5 -0.075X6					0.872	0.934

Where,
X1- Max. Temperature X2- Min. Temperature X3- Max. RH
X4- Min. RH
X5- Rainfall
X6- Wind speed.

Table 4: Observed and predicted PDI values by using simple regression equation for chilli powdery mildew progression during 2020-21.

Dates	Meteorological Standard Week (MSW)	Previous week PDI (X)	Observed PDI (Y)	Predicted PDI ($\hat{y}$)	Difference (y-$\hat{y}$)
Jan 22nd -28th (2021)	4	0	2.86	8.32	-5.45
Jan 29th - Feb 4th	5	2.86	5.15	10.9984	-5.85
Feb 5th - 11th	6	5.15	11.15	13.151	-2.00
Feb 12th - 18th	7	11.15	26.9	18.791	8.11
Feb 19th - 25th	8	26.9	41.18	33.596	7.58
Feb 26th - Mar 4th	9	41.18	54.34	47.0192	7.32
Mar 5th - 11th	10	54.34	60.1	59.3896	0.71
Mar 12th - 18th	11	60.1	55.58	64.804	-9.22

PDI = Per cent Disease Index
Simple regression equation $\hat{y} = 8.32 + 0.95x$ Co-efficient of correlation R = 0.95741
$R^2 = 0.9166$

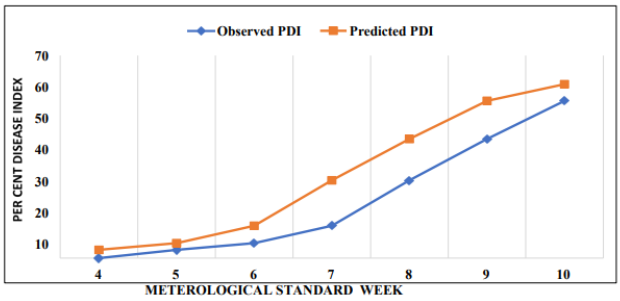

Fig. 2. Observed and predicted PDI values as per the simple regression equation for chilli powdery mildew progression during 2020-2021.

Table 5: Apparent rate of infection (r) and Area Under Disease Progress Curve (AUDPC) for chilli powdery mildew during 2020-2021.

Dates	Meteorological Standard Week (MSW)	PDI	AUDPC	Cumulative PDI	r value/week
Jan 22nd - 28th (2021)	4	0	-	-	-
Jan 29th - Feb 4th	5	2.86	10.01	10.01	0.087
Feb 5th - 11th	6	5.15	28.035	38.045	0.12
Feb 12th - 18th	7	11.15	57.05	95.095	0.154
Feb 19th - 25th	8	26.9	133.175	228.27	0.092
Feb 26th - Mar 4th	9	41.18	238.28	466.55	0.076
Mar 5th - 11th	10	54.34	334.32	800.87	0.034
Mar 12th - 18th	11	60.1	400.54	1201.41	-0.026

PDI = Per cent Disease Index
AUDPC = Area Under Disease Progressive Curve
r = Apparent Rate of Infection

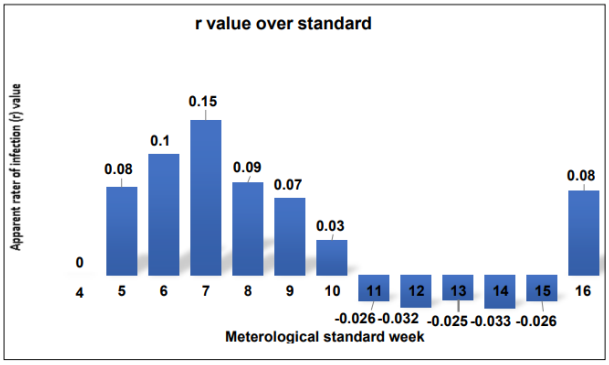

Fig. 3. Apparent rate of infection(r) of chilli powdery mildew during 2020-2021.

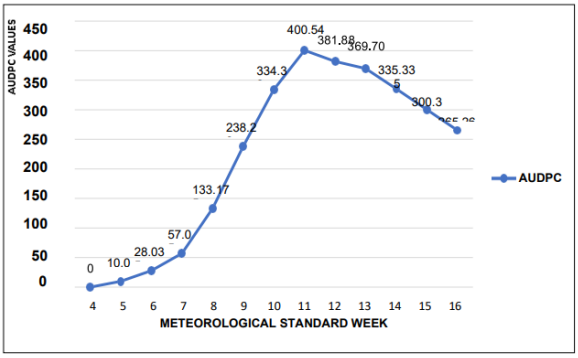

Fig. 4. Area Under Disease Progress Curve (AUDPC) for Chilli powdery mildew during 2020-2021.

DISCUSSION

Epidemiological studies

Prediction model for powdery mildew. A simple regression equation was used to predict the development of powdery mildew in chillies. The PDI was calculated using a simple regression technique in the current study. Below is a basic regression equation for 2020-21.

$\hat{y} = 8.32 + 0.95x$ R = 0.957 R2 = 0.916

Where,

Y = Observed PDI

X = Predicted PDI

With correlation coefficient of R = 0.957 the predicted powdery mildew varied from 8.32 to 90.32. The difference between observed and predicted was maximum at 1st MSW (11.91). The predicted values were almost on par with observed values during 50, 2 and 3 MSW. However, the results of chilli powdery mildew during 2015-16 are in accordance with Amaresh and Nargund (2002) in rust of sunflower and also Nargund (1989) in leaf rust of wheat.

During 2020-21, the powdery mildew symptoms were first observed on 5th standard week. The severity increased slowly and reached the upto 60.10 per cent during 11th MSW of 2021. During the previous week, maximum temperature of 34.6°C and minimum temperature was 18.46°C with maximum relative humidity of 87.4 per cent and minimum relative humidity of 27.6 per cent followed by 0 mm rainfall and a windspeed of 3.7 km/hr.

The favourable conditions such as no rainfall with minimum temperature of 20.77°C and maximum temperature of 34.5°C, maximum relative humidity of 84 per cent and minimum relative humidity of 36 per cent and windspeed of 4.1 km/hr prevailed during that week. Generally, the optimum temperature required for the growth of chilli powdery mildew was 15°C to 20°C, optimum relative humidity was 80 per cent to 85 per cent (Elad *et al*., 2007). As the minimum temperature during 8 to 11 Meteorological standard weeks was in the range of 18.43°C to 20.77 °C and relative humidity range was 80.70 per cent to 88.70 per cent. Thus, due to the favourable weather factors in experimental field, a high disease severity was observed which were in accordance with Nargund (1989).

Later a gradual reduction in disease severity was also observed due to fluctuations in temperatures, relative humidity, rainfall and wind speed i.e., deviated from the optimum conditions for the growth of powdery mildew. In general, when comparatively high relative humidity is associated with warm weather then, the powdery mildew pathogens spread most rapidly. The ability of the powdery mildew to spread under humid climatic conditions may be largely due to the capacity of their conidia to germinate at higher humidity than most (Elad *et al*., 2007, Kumar and Chandal 2018).

Correlation and multiple linear regression analysis between severities of powdery mildew in relation to weather parameters. Through correlation and multiple linear regression analysis, the researchers were able to establish a link between meteorological variables and the per cent disease index of powdery mildew in the extremely sensitive chilli variety Byadagi Kaddi. With the exception of minimum relative humidity, the correlation between powdery mildew PDI and meteorological variables in 2020-21 revealed a positive relationship (Elad *et al*., 2007; Saini, 2019; Kumar and Chandel 2018) found similar results.

The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters during 2020-21 is Y = -96.73 + 1.38X1 + 5.71X2 + 0.19X3 -1.05X4 + 0.35X5 -0.08X6. Hence, the weather factors influence the disease severity for 2020-21 to the extent of 60 per cent.

Disease progress and apparent rate of infection on chilli powdery mildew. The apparent infection rate (r) is computed using Van der Plank's (1963b) formula, with the ‘r' value changing with time. They didn't stay consistent for certain cultivars, and this has been frequently utilised to identify cultivars with a delayed rate of disease development.

On the other hand, the Area Under Disease Progress Curve (AUDPC) value, which is a summation of values calculated at several intervals during the disease progression and was compared by Wilcoxson *et al*. (1975), who used the AUDPC value to compare the development of stem rust in different varieties, is probably a better epidemiological concept.

As a result, the apparent rate of infection (r) and Area Under Disease Progress Curve (AUDPC) were not utilised on powdery mildew growth on Byadagi Kaddi susceptible cultivar during 2020-21.

The apparent rate of infection (r) and the values of the Area Under the Disease Progress Curve (AUDPC) were crucial epidemic metrics. The greatest rate of infection (0.154) was found between the 7th and 8th meteorological weeks in 2020-21. The 5th MW had the lowest AUDPC value (10.01). AUDPC values grew steadily over the crop growth period, peaking at (400.54) on the 11th MW of 2021, then gradually decreasing to (262.265) on the 16th MW of 2021. The results were in accordance with Jharia *et al*. (1978).

There was a substantial difference in ‘r' values per unit per day for powdery mildew development. Changes in climatic circumstances, the quantity of powdery mildew lesions on the leaves, or plant growth might all affect the rate of disease development.

CONCLUSIONS

Prediction of powdery mildew was made one week well in advance. The simple regression equation for 2020-21 was $\hat{y}$ = 8.32 + 0.95x with R = 0.95741 and R2 = 0.9166. However, it is important to note that the disease was influenced by various weather factors. The studies on effect of weather factors on development of disease revealed that, 5th standard week was highly favourable for initiation and further development of disease.

There was a positive correlation between the disease incidence and all weather parameters except for minimum relative humidity. The multiple linear regression equation was fitted to the data and the equation arrived for all the weather parameters is Y = -96.73 + 1.38X1 + 5.71X2 + 0.19X3 -1.05X4 + 0.35X5 -0.08X6.

The apparent rate of infection (r) and Area Under Disease Progress Curve (AUDPC) values were important criteria of epidemics. During 2020-21, highest rate of infection (0.154) was observed between 7th meteorological week. Lowest AUDPC value (10.01) was obtained in the 5th MSW. During crop growth period, AUDPC values increased gradually and reached maximum (400.54) on 11th MSW of 2021 and further, gradually reduced and reached (262.265) on 16th MSW of 2021.

FUTURE SCOPE

Based on the present results obtained, it is necessary to focus on the following aspects to understand the powdery mildew in better way.

1. Seasonal prediction model evaluation is necessary.
2. Investigations on the pathogenic variability of isolates at the molecular level is needed.
3. Determination on the severity of the disease on different planting dates is required.
4. Study and identification of bio-chemical compounds that confer resistance to chilli powdery mildew disease

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Ethical approval. This article follows experimental guidelines and this research does not involve any human participants or animal performed.

Conflict of Interest. None.

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