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Impact of Weather Parameters on Chilli Powdery Mildew and its Management through New Fungicide Combination

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ABSTRACT

Powdery mildew (PM) of chilli caused by *Leveillula taurica* is one of the major diseases affecting yield and quality of chilli. The pathogen perpetuates in the infected crop debris and also produce airborne conidia responsible for rapid secondary spread. Prophylactic application of fungicides is admissible to keep the disease under threshold. Therefore, an experiment was designed to determine bio-efficacy and phytotoxicity of different doses of a new combi-fungicide KK-21 (Sulphur 84% + Azoxystrobin 6% SC) along with optimization of its number of sprayings. This fungicide was also compared with the most popularly used fungicides in PM of chilli. Additionally, influence of weather variables on the initiation and progression of the disease were studied and prediction model developed by stepwise regression equation for timely forecasting and managing the disease. Study revealed, depending upon the prevailing weather the disease first appears between 44 to 64 days after transplanting then progress gradually at a rate varied from 0.0012 to 0.0139. Among the fungicides applied, three spraying of KK-21 @ 2500 ml/ha at an interval of 15 days just after initiation of the disease was most effective with lowest disease severity index (5.12) and highest yield 144.98 q/ha and no phytotoxic effect was recorded even at higher dose. Result also showed, maximum temperature and relative humidity had significantly positive and negative correlation respectively with the disease severity and the prediction equation demonstrated that, these two factors could explain 78.2 - 87.6% of the variation in disease severity.

Key words: Chilli, Disease severity, Fungicides, Powdery mildew, Prediction equation.

INTRODUCTION

Chilli (*Capsicum annuum* L.), also known as wonder spice is one of the major cultivated commercial spice crops all around the world. India is the largest producer and exporter of chilli with 13.76 million tons of production which share around 36% of global chilli production (FAO, 2021). India is the only source for hot chilies and famous for its colour and pungency.

It is also rich in vitamins A and C, iron, potassium, magnesium, and anti-oxidant that stimulate the immune system while dropping cholesterol levels (Grubben and Mohamed, 2004).

Chilli is severely affected by various abiotic and biotic stresses from nursery to harvest. Among the biotic stresses, powdery mildew (PM) caused by *Leveillula taurica* (Lev.) Arn. is one of the major impediments to the production of chillies in India, resulting in huge yield losses ranging from 14 to 30% (Daunde *et al.*, 2018; Abdul Kareem *et al.*, 2020). Economic losses associated with the disease is due to severe defoliation and decrease in photosynthetic activity, that gradually leads to a decline in yield, premature fruits drop, deterioration in quality and commercial acceptability (Saxena *et al.*, 2014).

Majority of Indian farmers still rely upon chemicals for managing the diseases and consider it as the most effective measures, other than the use of resistant varieties. Till date, numerous fungicides e.g. Carbendazim, Penconazole, Propiconazole, wettable sulphur, Hexaconazole, Difenconazole, Azoxystrobin, myclobutanil etc. have been tested and proven effective against PM (Sabeena and Ashtaputre, 2020; Mondal and Sarkar, 2023). But reiterate use of the same chemical may leads to the development resistance to the pathogen (Brent, 2007; Mosquera *et al.*, 2019). Furthermore, in case of PM the risk of resistance development is high due to typical spray programs that include multiple applications of same chemical. This situation has decreased the bio-efficacy of the major classes of fungicide that are majorly employed against PM of chilli. Therefore, experiment was conducted to find out the bio-efficacy of the fungicides e.g. Sulphur, Azoxystrobin, and Azoxystrobin 11% + Tebuconazole 18.3% SC at their recommended dose along with a new combination of fungicide KK21 (Sulphur 84% + Azoxystrobin 6%SC) was also tested at different doses. The phytotoxicity of the new combi-fungicide were evaluated and the number of spray and dose required for managing PM were also standardized.

Weather plays a critical role on the disease development as it helps in the growth and development of the pathogen, disease initiation, and its dissemination as well as expression of the symptoms. Meteorological factors such as temperature, relative humidity and rainfall are the main contributory for the onset of PM epiphytotic in chilli (Akhileshwari *et al.*, 2012). Conidial germination takes place at a temperature 10 to 37°C (optimum 20°C) with relative humidity 75 to 85% and optimal temperature for leaf colonization is 15 to 25°C (Saini and Bunker, 2019). In order to formulate reliable and effective disease management strategies; it is of paramount important to find the relationship between weather factors and disease progression. Therefore, urge felt to develop area specific weather-based prognostic model to provide an early warning to the farmers that would help them to take timely actions and rationalize the use of chemicals. In this view, experiment was set up to determine the impact of several meteorological parameters on the initiation and progression of PM in chilli.

MATERIALS AND METHODS

Experimental Layout

Field research was conducted at College of Agriculture, Burdwan, under the aegis of Bidhan Chandra Krishi Viswavidyalaya West Bengal during kharif season of 2020-21 and 2021-22. Popular chilli variety '*Bullet*' seeds were sown in nursery bed in the month of August and one month old seedlings were transplanted in the main field. Each plot measured was 5×5 m^2 with spacing 50 cm X 50 cm (number of plants per plot was 100). All the agronomic practices were followed to have a good crop stand and natural epiphytotic condition was permitted. The experiment was laid out in Randomized Block Design with three replications.

Bio-efficacy Evaluation

For bio-efficacy evaluation of the fungicides, all the foliar-sprays (treatments) were given as per their doses mentioned in (Table 1). The first spray of fungicides was applied just after the first appearance of disease. The same concentration was followed for second and third sprays at 15 days interval. Only water sprayed plots served as control.

Table 1. Treatment details for evaluating bioefficacy of fungicides.

Tr. No.	Product	Dose ha^{-1}	
		ai (g)	Formulation (ml or g)
T1	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	1260 + 90	1500
T2	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	1680 + 120	2000
T3	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2100 + 150	2500
T4	Azoxystrobin 23% SC	125	500
T5	Sulphur 80% WP	2500	3130
T6	Azoxystrobin 11% + Tebuconazole 18.3% SC	72 + 120	600
T7	Untreated Control	--	--

ai= Active ingredient, SC= Suspensible Concentrate, WP= Wettable Powder, T= Treatment.

For spraying the fungicides Knapsack sprayer fitted with hollow cone nozzle was used directed over the top and to the sides of the plants to give full coverage of the canopy.

Observations were recorded before spray, 10 days after each spray.

Phytotoxicity Evaluation

To assess the phytotoxicity higher dose of KK-21 was sprayed as mentioned in Table 2 and its effect on the plants were scrutinized by using the following phytotoxicity rating scale 0-10 given by (Mazarura, 2001) (Table 3). Observation taken on parameters like chlorosis, necrosis, wilting, scorching, hyponasty and epinasty etc. Five plants were selected randomly from each treatment and the number of leaves showing phytotoxicity was counted after 1, 3, 5, 7 and 10 days after the spraying. Phytotoxicity was assessed before spray, 3, 7, 10 and 15 days after first spray as per Central Insecticide Board and Registration Committee (CIB and RC) guidelines.

Table 2. Evaluation of phytotoxicity of the test fungicide.

Product	Dose ha^{-1}	
	a.i. (g)	Formulation (ml or g)
KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	3360 + 240	4000
Untreated Control (water spray only)	--	--

ai= Active ingredient, SC= Suspensible Concentrate.

Table 3. Scoring scale for phytotoxicity.

Rating	Phytotoxicity (%)	Rating	Phytotoxicity (%)
0	0	6	51-60
1	0-10	7	61-70
2	11-20	8	71-80
3	21-30	9	81-90
4	31-40	10	91-100
5	41-50		

Computation of Disease

Data on disease severity was recorded once before spray and 5 days after each spray. Initial spraying was given just after the initiation of the disease and two more successive spraying was given at 15 days interval. Disease severity of PM was recorded on 10 plants and 10 leaves on lower, middle and upper leaves by using 0-9 disease rating scale (Mayee and Datar, 1986) viz. 0= no symptoms; 1= few tiny necrotic patches covering 1% or less of the leaf area; 3= tiny necrotic patches covering 1-5% of the leaf surface; 5= coalescing spots expanding 6-20% of leaf area; 7= spots grow in size and coalesce to reach 21-50% of the compound leaf area; 9= spots expanding and merging to encompass at least 51% of the leaf area.

Disease severity or percent disease index (PDI) was calculated using the following formula (McKinney 1923).

$$\text{Disease severity} = \frac{\sum[\text{No of leaves/scale} \times \text{scale value}]}{\text{Total number of observation} \times \text{highest scale}} \times 100$$

Vertical disease spread was calculated as Area Under Disease Progress Curve (AUDPC) to quantify the disease over the period of time as per the formula given by Campbell and Madden (1990).

$$\text{AUDPC} = \sum_{\text{i}=1}^{n-1} \left(\frac{\text{Yi} + \text{Yi+l}}{2}\right)(t_{i+1} - t_i)$$

In this formula, n is the number of evaluation times, i is the evaluation time, y_i and t_i are respectively the average severity of the disease and time in the previous evaluation, y_{i+1} and t_{i+1} are respectively the average severity of the disease and time in the current evaluation.

Apparent infection rate (r) was calculated on PDI using the formula given by Vander Plank (1963):

$$r = \frac{2.3}{t_2 - t_1}\left\{log\frac{x^2}{1 - x_2} - log\frac{x^1}{1 - X_2}\right\}$$

Where, r= Apparent infection rate, t_1= First date for recording disease intensity, t_2= Second date for recording disease intensity, X_1= Disease severity at time t_1, X_2= Disease severity at time t_2, 2.3= Constant value.

Yield

The fruits were harvested from individual plots and yield was recorded in kg. Cumulative yield of five pickings were recorded and converted into quintal per ha.

Collection of Weather Data

Meteorological data like maximum temperature (X_1), minimum temperature (X_2), total rainfall (X_3), average relative humidity (X_4), wind speed (X_5) and dew point temperature (X_6) were collected from nearest Meteorological Station, District Seed Farm, Purba Barddhaman. Disease severity was recorded at 7 days interval from control plots. Time of disease onset and rate of progression of the disease were collected and correlated with meteorological variables to establish quantitative relationship between disease severity of chilli powder mildew and weather parameters expressed through correlation coefficient (r). The data were further subjected to the stepwise multiple regressions analysis following the equation $Y= a + b_1 X_1 + b_2 X_2 +\ldots b_n X_n$ where, Y= predicted disease severity, a= intercept, b_1 to b_n = regression coefficient, X_1 to X_n = independent weather variables. The linearity of relationship between the independent (weather) and dependent (PDI) variables was used to develop the model for disease prediction, and goodness of fit was assessed by co-efficient determination (R^2) and standard error of estimate (Coakley *et al.*, 1988).

Statistical Analysis

Prior to data analysis, arcsine transformation of the PDI value was done, and statistical calculations were performed in MS Excel and R programme, Version 4.1.3.

RESULTS AND DISCUSSION

Bio-efficacy of Different Fungicides against Powdery Mildew of Chilli

Powdery mildew (PM) appeared in the month of November and continued upto February (till maturity) depending upon the prevailing weather condition. Observation on disease severity

(PDI) was recorded at regular interval for the two consecutive years are presented in the Table 4 and 5 respectively. Pooled analysis was also performed and presented in Table 6.

The result showed that all the treatments significantly check the PM disease severity as compared to control. During first season 2020-21, spraying of KK-21: Sulphur 84% + Azoxystrobin 6% SC @ 2500 ml/ha just after the initiation of the disease followed by second spray and third spraying at 15 DI was found most effective with lowest PDI: 5.00. This was followed by KK-21 @ 2000 ml/ha with PDI: 5.46 and their differences were statistically non-significant. Application of KK-21 @ 1500 ml/ha recorded PDI 14.34 followed by Sulphur 80% WP @ 3130 g/ha (PDI: 14.20) and Azoxystrobin 23% SC @ 500 ml/ha (PDI: 14.00) at final observation and their differences were statistically at par but differ significantly from Azoxystrobin 11% + Tebuconazole 18.3% SC @ 600 ml/ha (PDI: 12.46) and from the untreated control that score highest PDI: 36.36. The control efficacy percentage was calculated over control based on terminal disease severity revealed that KK-21 @ 2500 ml/ha controlled the disease significantly with maximum reduction 86.25% (Table 4).

AUDPC value calculated separately for each treatment (Table 4) to know the ultimate disease stand that may affect the yield of the crop.

Analysis of variance (ANOVA) done for 15 days after third spray and presented in (Table 4a) also confirmed that the treatment and replication schedule used in the study to manage PM of chilli was significant at ($p< 0.01$).

Table 4. Evaluation of bio-efficacy of different fungicides against powdery mildew of chilli in the year 2020-21

Tr. No.	Product	Formulation dose (ml or g/ha)	Disease severity of chilli powdery mildew (PDI)										AUDPC	Control efficacy %
				First spray			Second spray			Third spray				
			Before first spray	After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days		
T1	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	1500	5.89^{f} (14.05)*	7.56^{b} (15.96)	10.56^{c} (18.96)	11.89^{cd} (20.17)	13.25^{c} (21.35)	14.56^{c} (22.43)	15.86^{c} (23.47)	15.68^{b} (23.33)	14.8^{b} (22.63)	14.34^{b} (22.25)	406.3	60.56
T2	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2000	5.75^{g} (13.87)	6.20^{d} (14.42)	8.58^{d} (17.03)	9.26^{e} (17.72)	9.45^{e} (17.90)	8.65^{e} (17.10)	10.54^{d} (18.94)	8.00^{c} (16.43)	7.58^{c} (15.98)	5.46^{d} (13.51)	258.31	84.98
T3	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2500	6.45^{a} (14.71)	6.00^{d} (14.18)	7.95^{e} (16.38)	8.56^{e} (17.01)	9.26^{e} (17.72)	8.56^{e} (17.01)	10.35^{d} (18.77)	7.68^{c} (16.09)	6.80^{c} (15.12)	5.00^{d} (12.92)	247.01	86.25
T4	Azoxystrobin 23% SC	500	6.35^{b} (14.60)	7.34^{bc} (15.72)	11.69^{b} (19.99)	13.26^{b} (21.35)	14.86^{b} (22.67)	15.75^{b} (23.38)	16.45^{bc} (23.93)	14.58^{b} (22.45)	14.24^{b} (22.17)	14.00^{b} (21.97)	419.95	61.50
T5	Sulphur 80% WP	3130	6.05^{e} (14.24)	7.68^{b} (16.09)	11.42^{b} (19.75)	12.56^{bc} (20.76)	14.98^{b} (22.77)	15.87^{b} (23.48)	17.25^{b} (24.54)	15.88^{b} (23.48)	15.00^{b} (22.79)	14.2^{b} (22.14)	428.79	60.95
T6	Azoxystrobin 11% + Tebuconazole 18.3% SC	600	6.25^{c} (14.48)	7.00^{c} (15.34)	10.56^{c} (18.96)	11.25^{d} (19.6)	12.23^{d} (20.47)	13.06^{d} (21.19)	15.85^{c} (23.46)	14.36^{b} (22.27)	14.54^{b} (22.42)	12.46^{c} (20.67)	383.37	65.73
T7	Untreated Control	-	6.15^{d} (14.36)	15.69^{a} (23.33)	20.20^{a} (26.71)	25.45^{a} (30.3)	30.33^{a} (33.42)	35.65^{a} (36.66)	40.23^{a} (39.37)	45.36^{a} (42.34)	40.24^{a} (39.37)	36.36^{a} (37.08)	983.07	0.00
	SEm (±)		0.010	0.136	0.164	0.229	0.290	0.371	0.411	0.518	0.452	0.422	-	-
	CD = 0.05		0.031	0.419	0.505	0.706	0.894	1.144	1.266	1.597	1.393	1.300	-	-

Same English letter followed by mean are not significantly differ from each other, * Figure in the parenthesis represent angular transformed value, SC= Suspensible Concentrate, WP = Wettable powder, CD= Critical difference, AUDPC = Area under disease progress curve, T= Treatment.

Table 4a. ANOVA for 15 days after third spraying in the year 2020-21.

Source	DF	SS	MSS	F cal	F tab
Replication	2	14.514	7.257	13.580**	3.88529
Treatment	6	1963.031	327.172	612.245**	2.99612
Error	12	6.412	0.534		

**= Significant ($p < 0.01$).

Similarly, during 2021-22, three times spray of KK-21@ 2500 ml/ha against PM was also found superior with lowest PDI 5.25 and it was followed by KK-21 @ 2000 ml/ha with PDI: 5.60 and their differences were statistically insignificant. Likewise, data recorded for all the other treatments at final observation were statistically at par except Azoxystrobin 11% + Tebuconazole 18.3% SC @ 600 ml/ha (PDI: 9.48). Significantly highest disease severity was recorded in the untreated plot with PDI 30.60. The control efficacy percentage was calculated over control revealed that KK-21 @ 2500 ml/ha controlled the disease significantly with maximum reduction 82.84% followed by KK-21 @ 2000 ml/ha 81.70% (Table 5). Here also AUDPC calculated and ANOVA performed (Table 5a) on last disease situation after third spray revealed that the treatment and replication combination had significant ($p<0.01$) effect on managing the disease effectively.

The result of the pooled analysis was presented in Table 6. It was very clear that all the treatments reduced the disease significantly compared to the unsprayed control plot. Minimum PDI: 5.12 was noticed in KK-21@ 2500 ml/ha treated plot which is significantly superior over all the treatments except KK-21@ 2000 ml/ha with PDI: 5.53. Plots treated with Azoxystrobin 11% + Tebuconazole 18.3% SC recorded PDI: 10.97 followed Azoxystrobin 23% SC (PDI: 12.28) and Sulphur 80% WP (PDI: 12.50) and their differences were statistically significant except the later two. Maximum disease severity (PDI: 33.48) was recorded in untreated control.

Moreover, spray of KK-21@ 2500 ml/ha provided 89.69 percent reduction of disease over control immediately followed by KK-21@ 2000 ml/ha with 83.48 percent reduction in disease. Spray of Azoxystrobin 11% + Tebuconazole 18.3% SC, only Azoxystrobin 23% SC and Sulphur 80% WP were also found effective with 67.27, 63.32 and 62.66 percent disease control respectively.

AUDPC calculated and presented in Table 6. ANOVA (Table 6a) showed that years, replications and treatments exerted significant ($p<0.01$) effect in managing PM disease in chilli.

Chemicals are the most common and practically accessible method for the management of PM. Azoxystrobin belongs to strobilurins group of systemic fungicide with translaminar activity. It is broad spectrum, takes entry inside the tissues and gets widely distributed from the point of application by diffusion (Vincelli, 2002). It prevents mitochondrial respiration of fungi as it binds Qo site of Complex III within the mitochondrion. On the other hand, sulphur is contact in nature and interfere with the electron transport system of the pathogen therefore, impair the ATP formation. Tebuconazole is also systemic fungicide that cause irreparable damage to the fungal cell wall by inhibiting the sterol biosynthesis process of cell wall formation. It also affects conidia and haustoria production (Nene and Thapliyal, 1993).

Table 5. Evaluation of bio-efficacy of different fungicides against powdery mildew of chilli in the year 2021-22

Tr. No.	Product	Formulation dose (ml or g /ha)	Disease severity of chilli powdery mildew (PDI)										AUDPC	Control efficacy %
			Before first spray	First spray			Second spray			Third spray				
				After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days		
T1	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	1500	5.12^{g} (13.08)	7.67^{d} (16.08)	9.68^{c} (18.13)	11.42^{c} (19.75)	12.24^{c} (20.48)	13.39^{c} (21.46)	14.6^{b} (22.46)	13.33^{b} (21.41)	10.23^{b} (18.65)	11.34^{b} (19.68)	357.43	62.94
T2	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2000	6.75^{d} (15.06)	6.60^{e} (14.89)	7.00^{d} (15.34)	7.44^{e} (15.83)	7.22^{d} (15.59)	7.45^{d} (15.84)	7.67^{c} (16.08)	7.50^{e} (15.89)	6.56^{c} (14.84)	5.60^{d} (13.69)	221.79	81.70
T3	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2500	5.34^{f} (13.36)	6.00^{f} (14.18)	6.88^{d} (15.21)	7.00^{e} (15.34)	7.00^{d} (15.34)	7.30^{d} (15.68)	7.50^{c} (15.89)	7.40^{e} (15.79)	6.30^{c} (14.54)	5.25^{d} (13.25)	212.29	82.84
T4	Azoxystrobin 23% SC	500	6.45^{e} (14.71)	8.88^{b} (17.34)	9.89^{bc} (18.33)	11.34^{cd} (19.68)	12.59^{c} (20.78)	13.45^{c} (21.51)	14.33^{b} (22.24)	11.68^{c} (19.98)	11^{b} (19.37)	10.56^{b} (18.96)	358.91	65.49
T5	Sulphur 80% WP	3130	6.98^{c} (15.32)	8.45^{c} (16.9)	10.56^{b} (18.96)	12.67^{b} (20.85)	14.67^{b} (22.52)	15.23^{b} (22.97)	15.00^{b} (22.79)	12.82^{bc} (20.98)	11.15^{b} (19.51)	10.8^{b} (19.19)	385.91	64.71
T6	Azoxystrobin 11% + Tebuconazole 18.3% SC	600	7.34^{a} (15.72)	7.89^{d} (16.31)	9.26^{c} (17.72)	10.45^{d} (18.86)	11.79^{c} (20.08)	12.04^{c} (20.3)	13.8^{b} (21.81)	10.33^{d} (18.75)	10.00^{b} (18.43)	9.48^{c} (17.93)	330.50	69.02
T7	Untreated Control	-	7.15^{b} (15.51)	14.56^{a} (22.43)	22.65^{a} (28.42)	28.15^{a} (32.04)	35.68^{a} (36.68)	41.86^{a} (40.32)	38.6^{a} (38.41)	35.25^{a} (36.42)	32.00^{a} (34.45)	30.60^{a} (33.58)	954.27	0
	SEm (±)		0.036	0.114	0.218	0.289	0.395	0.480	0.425	0.390	0.357	0.347	-	-
	CD = 0.05		0.110	0.351	0.672	0.891	1.218	1.479	1.309	1.201	1.101	1.070	-	-

Same English letter followed by mean are not significantly differ from each other,*Figure in the parenthesis represent angular transformed value, SC = Suspensible concentrate, WP = Wettable powder, CD= Critical difference, AUDPC = Area under disease progress curve, T= Treatment.

Table 5a. ANOVA for 15 days after third spraying in the year 2021-22.

Source	DF	SS	MSS	F cal	F tab
Replication	2	9.791	4.896	13.539**	3.88529
Treatment	6	1328.288	221.381	612.244**	2.99612
Error	12	4.339	0.361		

**=significant (p<0.01).

Table 6. Evaluation of bio-efficacy of different fungicides against powdery mildew of chilli (Pooled).

Tr. No.	Product	Formulation dose (ml or g /ha)	Disease severity of chilli powdery mildew (PDI)										AUDPC	Control efficacy %
				First spray			Second spray			Third spray				
			Before first spray	After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days	After 5 days	After 10 days	After 15 Days		
T1	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	1500	5.51^{g} (13.57)	7.62^{c} (16.02)	10.12^{c} (18.55)	11.66^{c} (19.96)	12.75^{cd} (20.92)	13.975^{c} (21.95)	15.23^{b} (22.97)	14.51^{b} (22.39)	12.52^{b} (20.72)	12.84^{b} (21.00)	381.86	61.65
T2	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2000	6.25^{e} (14.48)	6.40^{d} (14.65)	7.79^{d} (16.21)	8.35^{e} (16.8)	8.335^{e} (16.78)	8.05^{e} (16.48)	9.105^{c} (17.56)	7.75^{d} (16.16)	7.07^{c} (15.42)	5.53^{d} (13.60)	240.05	83.48
T3	KK-21 (Sulphur 84% + Azoxystrobin 6% SC)	2500	5.90^{f} (14.05)	6.00^{e} (14.18)	7.42^{d} (15.80)	7.78^{e} (16.20)	8.13^{e} (16.57)	7.93^{e} (16.36)	8.925^{c} (17.38)	7.54^{d} (15.94)	6.55^{c} (14.83)	5.125^{d} (13.08)	229.65	84.69
T4	Azoxystrobin 23% SC	500	6.40^{d} (14.65)	8.11^{b} (16.55)	10.79^{b} (19.18)	12.3^{bc} (20.53)	13.73^{c} (21.74)	14.6^{bc} (22.46)	15.39^{b} (23.1)	13.13^{bc} (21.24)	12.62^{b} (20.81)	12.28^{b} (20.51)	389.42	63.32
T5	Sulphur 80% WP	3130	6.52^{c} (14.79)	8.07^{b} (16.5)	10.99^{b} (19.36)	12.62^{b} (20.80)	14.83^{b} (22.65)	15.55^{b} (23.22)	16.13^{b} (23.68)	14.35^{b} (22.26)	13.08^{b} (21.20)	12.50^{b} (20.70)	407.34	62.66
T6	Azoxystrobin 11% + Tebuconazole 18.3% SC	600	6.80^{a} (15.11)	7.445^{c} (15.83)	9.91^{c} (18.35)	10.85^{d} (19.23)	12.01^{d} (20.28)	12.55^{d} (20.75)	14.82^{b} (22.65)	12.35^{c} (20.57)	12.27^{b} (20.50)	10.97^{c} (19.34)	356.93	67.23
T7	Untreated Control	-	6.65^{b} (14.94)	15.13^{a} (22.89)	21.43^{a} (27.57)	26.8^{a} (31.18)	33.01^{a} (35.06)	38.76^{a} (38.5)	39.42^{a} (38.89)	40.31^{a} (39.41)	36.12^{a} (36.94)	33.48^{a} (35.35)	968.67	0
	SEm (±)		0.018	0.089	0.136	0.185	0.245	0.303	0.296	0.324	0.288	0.273	-	-
	CD= 0.05		0.054	0.259	0.398	0.539	0.716	0.886	0.863	0.946	0.841	0.798	-	-

Same English letter followed by mean are not significantly differ from each other,*Figure in the parenthesis represent angular transformed value, SC = Suspensible concentrate, WP = Wettable Powder, CD= critical difference, AUDPC = Area Under disease progress curve, T= Treatment.

Table 6a. ANOVA of pooled analysis.

Source	DF	SS	MSS	F cal	F tab
Years	1	70.9020	70.9020		
Replication within years	4	24.3058	6.07645		
Treatment(T)	6	3250.42	541.7367	1209.274**	2.508189
Years(Y) x Treatment(T)	6	40.8985	6.8164	15.21573**	2.508189
Pooled Error	24	10.7516	0.4479		
Total	41	3397.278			

**= Significant ($p < 0.01$).

As per the fungicide resistance action committee (FRAC, 2004) to reduce the risk of development of fungicide resistance pathogen alternate use of contact and systemic fungicide has been recommended. Therefore, new combi-fungicide KK 21 (Sulphur 84% + Azoxystrobin 6% SC) has been tested and found to be effective in reducing PM. Several workers tried different combination of chemicals including Azoxystrobin against chilli powdery mildew. Ajithkumar *et al.*, (2014) conducted similar study in Chill-PM pathosystem with combi-fungicide (Azoxystrobin 8.3%+Mancozeb 66.7%); Ahila Devi and Prakasam, 2014 reported effective management of powdery mildew of chilli by using azoxystrobin 25% SC. Management of PM in chilli through different fungicides was also conducted by Daunde *et al.*, (2018).

Phytotoxicity of Fungicide

The observations on phytotoxicity symptoms on the basis of chlorosis, necrosis, wilting, scorching, hyponasty and epinasty were recorded for the two years presented in Table 7. The results noted no phytotoxic effect at 0, 1, 3, 5,7 and 10 days after spraying at higher dose of KK - 21@ 4000 ml/ha over chilli. Hence the product KK-21 proved non-phytotoxic (Table 7). For residue analysis, both soil and ripe chillies were used as sample that resulted the trace of chemical below determination level i.e. <0.01 mg/kg of KK 21. The result was supported by effective management of PM of chilli by using azoxystrobin 25% SC without any residual effect by Ahila Devi and Prakasam, 2014 and Mondal and Sarkar, 2023.

Table 7. Phytotoxicity of KK 21(Sulphur 84% + Azoxystrobin 6% SC) to chilli.

Treatment details	Dose Formulation (g/ha)	Phytotoxicity rating at 1,3,5,7 and 10 days after application of					
		Chlorosis	Necrosis	Wilting	Scorching	Hyponasty	Epinasty
KK -21	4000	0	0	0	0	0	0
Untreated control	Water spray	0	0	0	0	0	0

*Based on Scale (1-10): 1= 0-10%, 2= 11-20%, 3= 21-30%, 4=31-40%, 5=41-50%, 6=51-60%, 7=61-70%, 8=71-80%, 9= 81-90%, 10= 91-100%.

Yield

Yield data was recorded treatment wise and converted into quintal per hectare and presented in Table 8, revealed that all the treatments were effective to increase the yield significantly over control. Maximum yield was recorded 139.71 q/ha and 150.24 q/ha respectively for the two consecutive years of experiment upon spraying of KK-21 @ 2500 ml/ha thrice as foliar spray followed by KK-21 @ 2000 ml/ha with yield 124.43 q/ha and 142.93 q/ha consecutively (Table 8). Least yield was recorded in unsprayed control with 64.47 and 75.21 q/ha for the year 2020-21and 2021-2022 respectively. Two years pooled mean also recorded maximum yields of

144.98 q/ ha in the plot sprayed with KK-21 @ 2500 ml/ha followed by KK-21 @ 2000 ml/ha (133.43 q/ha) and KK-21 @ 1500 ml/ha (129.70 q/ha) their differences were statistically significant. Yield obtained from Azoxystrobin 11% + Tebuconazole 18.3% SC (118.31 q/ha) were statistically at par with the yield realized from Azoxystrobin 23% SC (116.7 q/ha). Minimum significant yield was recorded from the untreated control plot for both the year and also in pooled mean 69.84 q/ha (Table 8). ANOVA also performed and presented in Table 8a. Our research results were in accordance with Raju *et al*., (2017) and Sabeena and Ashtaputre (2019) who worked on PM of chilli and estimated yield loss due to this disease. Marthand (2016) and reported three sprays of Azoxystrobin were optimum in reducing the disease severity and obtaining maximum yield.

Table 8. Yield data recorded during two consecutive years of experiment on fungicides application against powdery mildew of chilli.

Trt.	Product	Formulation dose (g /ha)	Yield (q /ha) 2020-21	2021-22	Pooled
T1	KK-21: Sulphur 84% + Azoxystrobin 6% SC	1500	123.45^{b}	135.96^{c}	129.705^{c}
T2	KK-21: Sulphur 84% + Azoxystrobin 6% SC	2000	124.43^{b}	142.43^{b}	133.43^{b}
T3	KK-21: Sulphur 84% + Azoxystrobin 6% SC	2500	139.71^{a}	150.24^{a}	144.975^{a}
T4	Azoxystrobin 23% SC	500	114.86^{c}	118.61^{e}	116.735^{d}
T5	Sulphur 80% WP	3130	100.26^{d}	125.25^{d}	112.755^{e}
T6	Azoxystrobin 11%+ Tebuconazole 18.3% SC	600	116.06^{c}	120.56^{e}	118.31^{d}
T7	Untreated Check	-	64.47^{e}	75.21^{f}	69.84^{f}
		SEm (±)	0.973	0.989	0.694
		CD=0.05	2.996	3.047	2.024

Same English letter followed by mean are not significantly differ from each other, SC= Suspensible Concentrate, WP = Wettable powder, CD= Critical difference, T= treatment.

Table 8a. ANOVA of pooled analysis (Yield).

Source	DF	SS	MSS	Fcal	Ftab
Years	1	1548.943	1548.943		
Replication within years	4	1914.276	478.5691		
Treatment(T)	6	20707.95	3451.326	1195.657**	2.50818
Year(Y) x Treatment(T)	6	499.3689	83.22814	28.8331**	2.50818
Pooled Error	24	69.27725	2.886552		
Total	41	24739.82			

**= significant (p< 0.01).

Progression of PM of Chilli in Relation with Different Weather Parameters

Under natural conditions, in the year 2020-21 initial infection of PM on chilli variety 'Bullet' was recorded at 49 SMW (Standard meteorological weeks) when the age of the crop was 44 days after transplanting (DAT) with PDI 8.15 and reaching its peak at 4 SMW (93 DAT) with PDI 44.36. After that gradually proceed to reach the plateau at 5 SMW (Table 9). On the contrary, during the second year 2021-22, disease initiation started quite late in the season i.e. around 64 DAT at 1 SMW with PDI 9.65 then, the disease gradually increased from PDI 14.56 to 41.86 during 2 – 6 SMW. The rate of progress (increase/decrease) was also measured at weekly interval and presented in Fig. 1. The apparent infection rate (r) was highest in mid-December to mid- January ranging from 0.0139 to 0.0092 respectively for PM in chilli (Table 9).

The weather data recorded during the experimental period of 2020-21 and 2021-22 are displayed in Fig. 1 and the range of variation in PDI of PM along with the changes in different weather parameters are exhibited in Table 10. With the maximum temperature range 21.71 to 31.26^{0}C the disease severity varied from 8.15 to 44.36 along with RH 58.62 to 82.25.

Similar kind of experiment was done by Bhukal *et al.* (2015) in sheath blight of rice pathosystem. Peshaman *et al.* (2017) carried out survey on PM of chilli in Maharashtra also recorded PDI and detected variation in PDI is mainly attributed by the different climatic factors.

Correlation and Stepwise Regression

Initiation and progression of PM on chilli are greatly influenced by the different environmental factors and their interaction (Table 11). Therefore, to explore the role of weather variables in the epidemic development was investigated by employing two tools e.g. correlation and stepwise linear regression and data presented in Table 11 and 12 respectively.

Correlation analysis revealed that the maximum temperatures had positive significant effect on the disease severity of PM in chilli with correlation co-efficient value r = 0.91 and 0.88, individually for the two experimental years (Table 11). Whereas minimum temperature was found to have either negative or non-significant effect on the PDI. Contrary, statistically negative significant relationship was found with average RH with r = -0.89 and -0.88 consecutively. Among six variables only two viz.., maximum temperature and average RH were found to be significantly correlated with chilli PM disease severity, however, wind speed was found to be associated though positively but at low level of significance. Dew point and total rainfall exert no significant effect on progression of PM of chilli (Table 11).

Equations developed through stepwise regression analysis considering weather parameters as independent variables and PDI as dependent variables are presented in Table 12. R^2 value 0.876 and 0.782 respectively for the two years of experiment represented that both the equations are highly significant in predicting the severity of PM in chilli. Model generated for both years indicated that average RH played a major role in the development of PM in chilli for both the year however, during first year (2020-21) maximum temperature also played important role additionally (Table 12). Comparing both the equations, it was observed average RH and maximum temperature were most suitable in predicting PM explaining 78.2 - 87.6 per cent of the variation in disease severity when the other factors remain unchanged.

Our findings agreed with Gupta *et al.* (2020) who recorded 83 per cent variation in early blight of tomato due to weather factors. Saha and Bera (2021) also reported 92.7 – 94.1 percent variation in chilli anthracnose due to fluctuation in weather parameters.

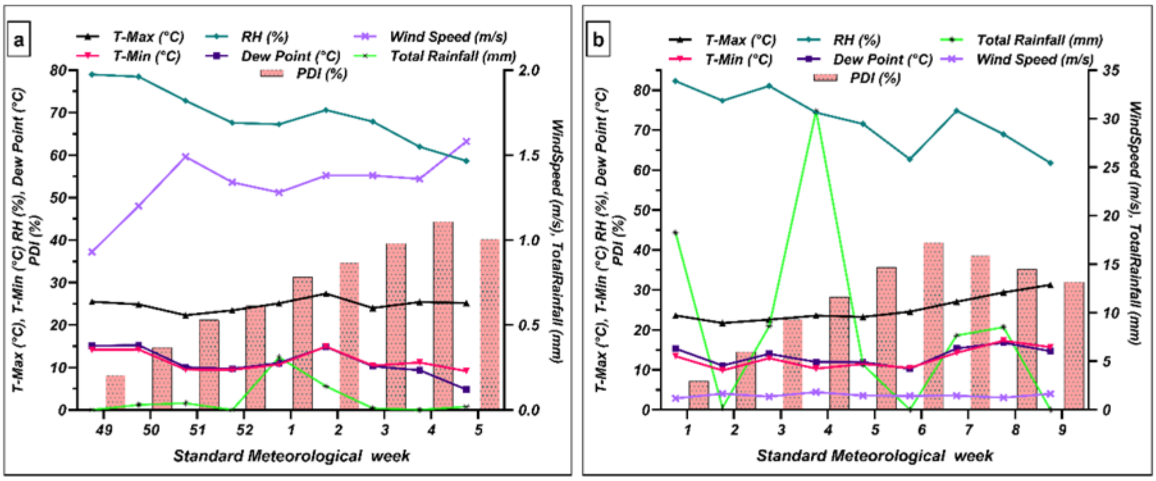

Fig. 1. Progression of Powdery mildew of chilli with weather variables during (a) 2020-21 and (b) 2021-22.

Table 9. Disease progression of powdery mildew on chilli over two experimental period.

First Season (2020-2021)					Second Season (2021-2022)				
Date of observation	Standard Meteorological Week (SMW)	Age of plant (DAT)	Powdery Mildew PDI (%)	Apparent Infection Rate (r)	Date of observation	Standard Meteorological Week (SMW)	Age of plant (DAT)	Powdery Mildew PDI (%)	Apparent Infection Rate (r)
09-12-2020	49	44	8.15(16.59)	-	07-01-2022	1	64	9.65 (18.10)	-
16-12-2020	50	51	14.69 (22.54)	0.0139	14-01-2022	2	71	14.56 (22.43)	0.0092
23-12-2020	51	58	21.20 (27.42)	0.0064	21-01-2022	3	78	22.65 (28.42)	0.0076
31-12-2020	52	65	24.45 (29.63)	0.0021	28-01-2022	4	85	28.15 (32.04)	0.0030
07-01-2021	1	72	31.33 (34.04)	0.0032	04-02-2022	5	92	35.68 (36.68)	0.0028
14-01-2021	2	79	34.65 (36.06)	0.0012	11-02-2022	6	99	41.86 (40.32)	0.0017
21-01-2021	3	86	39.23 (38.78)	0.0013	18-02-2022	7	106	38.60 (38.41)	-0.0008
28-01-2021	4	93	44.36 (41.76)	0.0012	25-02-2022	8	113	35.25 (36.42)	-0.0010
04-02-2021	5	100	40.24 (39.37)	-0.0010	04-03-2022	9	120	32.00 (34.45)	-0.0011

*Figure in the parenthesis represent angular transformed value; SMW = Standard Meteorological Week; DAT= Days after transplantation.

Table 10. Descriptive statistics of weather variables during both the experimental years.

Variables	2020-2021			2021-2022		
	Min.	Max.	Mean ± SD	Min.	Max.	Mean ± SD
PDI (%)	8.15	44.36	28.70 ± 12.37	9.65	41.86	28.71 ± 11.03
Maximum Temperature (°C)	22.32	27.38	24.80 ± 1.43	21.71	31.26	25.22 ± 3.28
Minimum Temperature (°C)	9.15	14.90	11.53 ± 2.28	9.86	17.29	12.85 ± 2.57
Relative Humidity (%)	58.62	78.98	69.35 ± 6.79	62.71	82.25	71.76 ± 7.24
Dew Point (°C)	4.82	15.27	11.17 ± 3.42	10.27	16.81	13.48 ± 2.26
Wind Speed (m/s)	0.93	1.58	1.33 ± 0.18	1.18	1.82	1.48 ± 0.20
Total Rainfall (mm)	0.00	0.31	0.06 ± 0.10	0.00	30.79	8.74 ± 10.12

Table 11. Correlation of weather variables with the severity of Powdery Mildew.

Weather Variables	Powdery Mildew PDI (%)	
	2020-2021	2021-2022
Maximum Temperature (°C)	0.91**	0.88**
Minimum Temperature (°C)	-0.42	0.20
Avg. Relative Humidity (%)	-0.89**	-0.88**
Dew Point (°C)	0.63*	-0.06
Wind Speed (m/s)	0.70*	0.71*
Total Rainfall (mm)	0.12	-0.29

Significance codes: '***'= 0.001, '**'= 0.01, '*'= 0.05 and 'ns'= >0.05.

Table 12. Stepwise regression of different weather variables with the severity of Powdery Mildew of chilli.

Year	Regression Equation	R^{2a}	R^2 Adjusted	Mallows CP	AIC[b]	SE[c]	P-value
First (2020-21)	Y=182.78 - 2.57 RH + 2.18 Tmax	0.876	0.835	0.49	58.96	5.03	P=< 0.01 (**)
Second (2021-22)	Y=125.39 -1.35 RH	0.782	0.751	33.52	59.99	5.50	P=< 0.01 (**)

A Coefficient of determination, b Akaike information criterion, c Standard Error. Significance codes: '***'= 0.001, '**'= 0.01, '*'= 0.05 and 'ns'= >0.05. Tmax= Maximum Temperatures and RH= Relative Humidity.

CONCLUSIONS

From this study it is evident that progress of chilli powdery mildew is dependent on the prevailing weather condition. Among the weather parameters maximum temperatures had significantly positive and average RH significantly negative correlation with the development and progression of the disease. The developed model exhibited that 78.2 to 87.6 % variation in the disease severity could be explained by these two variables while the other factors effect was found non-significant. The present studies revealed that a maximum temperature range between 22.32^0C to 31.26^0C, and RH 58.62 to 82.25% played major role in the progression of PM and rate of weekly disease progression varied from 0.0012 to 0.0139. The information generated through this study could be useful for developing area wise disease forecasting system for PM in chilli. Thus, this model may be validated and utilized in the agro-advisories for developing the spray schedule to management the disease. Powdery mildew of chilli being an obligate parasite belongs at high risk to develop fungicide resistance mainly because of multiple applications of same fungicide. This situation could be mitigated by the use of chemicals with different mode of action. In this view, one combi-fungicide KK 21 (Sulphur 84% + Azoxystrobin 6% SC) has been tested and found three times spraying of KK 21 @ 2500 ml/ha at an interval of 15 days just after the initiation of the disease is highly effective in managing the disease with least disease severity and highest yield. Additionally, no phytotoxic symptoms were observed on the chilli plant when it was applied even at double dose. Therefore, it can be concluded that it is friendly to the crop could be included in the IDM programme.

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