

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 combination 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 chillies and famous for its colour and pungency.

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

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

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

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

72 rationalize the use of chemicals. In this view, experiment was set up to determine the impact of
73 several meteorological parameters on the initiation and progression of PM in chilli.

74 **MATERIALS AND METHODS**

76 **Experimental Layout**

77 Field research was conducted at College of Agriculture, Burdwan, under the aegis of Bidhan
78 Chandra Krishi Viswavidyalaya West Bengal during kharif season of 2020-21 and 2021-22.
79 Popular chilli variety '*Bullet*' seeds were sown in nursery bed in the month of August and one
80 month old seedlings were transplanted in the main field. Each plot measured was 5×5 m² with
81 spacing 50 cm X 50 cm (number of plants per plot was 100). All the agronomic practices were
82 followed to have a good crop stand and natural epiphytotic condition was permitted. The
83 experiment was laid out in Randomized Block Design with three replications.

84 **Bio-efficacy Evaluation**

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

90 **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	--	--

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

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

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

96 **Phytotoxicity Evaluation**

97 To assess the phytotoxicity higher dose of KK-21 was sprayed as mentioned in Table 2 and
98 its effect on the plants were scrutinized by using the following phytotoxicity rating scale 0-10
99 given by (Mazarura, 2001) (Table 3). Observation taken on parameters like chlorosis, necrosis,
100 wilting, scorching, hyponasty and epinasty etc. Five plants were selected randomly from each
101

102 treatment and the number of leaves showing phytotoxicity was counted after 1, 3, 5, 7 and 10
 103 days after the spraying. Phytotoxicity was assessed before spray, 3, 7, 10 and 15 days after first
 104 spray as per **Central Insecticide Board and Registration Committee** (CIB and RC) guidelines.

105 **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)	--	--

106 ai= Active ingredient, SC= Suspensible Concentrate.

107 **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		

108 **Computation of Disease**

109 Data on disease severity was recorded once before spray and 5 days after each spray. Initial
 110 spraying was given just after the initiation of the disease and two more successive spraying was
 111 given at 15 days interval. Disease severity of PM was recorded on 10 plants and 10 leaves on
 112 lower, middle and upper leaves by using 0-9 disease rating scale (Mayee and Datar, 1986) viz.
 113 0= no symptoms; 1= few tiny necrotic patches covering 1% or less of the leaf area; 3= tiny
 114 necrotic patches covering 1-5% of the leaf surface; 5= coalescing spots expanding 6-20% of
 115 leaf area; 7= spots grow in size and coalesce to reach 21-50% of the compound leaf area; 9=
 116 spots expanding and merging to encompass at least 51% of the leaf area.

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

$$119 \text{ Disease severity} = \frac{\sum[\text{No of leaves/scale} \times \text{scale value}]}{\text{Total number of observation} \times \text{highest scale}} \times 100$$

120 Vertical disease spread was calculated as Area Under Disease Progress Curve (AUDPC) to
 121 quantify the disease over the period of time as per the formula given by Campbell and Madden
 122 (1990).

$$123 \text{ AUDPC} = \sum_{i=1}^{n-1} \left(\frac{Y_i + Y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

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

128 Apparent infection rate (r) was calculated on PDI using the formula given by Vander Plank
129 (1963):

$$130 \quad r = \frac{2.3}{t_2 - t_1} \left\{ \log \frac{x^2}{1 - x_2} - \log \frac{x^1}{1 - X_2} \right\}$$

131 Where, r= Apparent infection rate, t₁= First date for recording disease intensity, t₂= Second
132 date for recording disease intensity, X₁= Disease severity at time t₁, X₂= Disease severity at
133 time t₂, 2.3= Constant value.

134

135 **Yield**

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

138

139 **Collection of Weather Data**

140 Meteorological data like maximum temperature (X₁), minimum temperature (X₂), total
141 rainfall (X₃), average relative humidity (X₄), wind speed (X₅) and dew point temperature (X₆)
142 were collected from nearest Meteorological Station, District Seed Farm, Purba Bardhaman.
143 Disease severity was recorded at 7 days interval from control plots. Time of disease onset and
144 rate of progression of the disease were collected and correlated with meteorological variables
145 to establish quantitative relationship between disease severity of chilli powder mildew and
146 weather parameters expressed through correlation coefficient (r). The data were further
147 subjected to the stepwise multiple regressions analysis following the equation Y= a + b₁ X₁ +
148 b₂ X₂ +... b_nX_n where, Y= predicted disease severity, a= intercept, b₁ to b_n = regression
149 coefficient, X₁ to X_n = independent weather variables. The linearity of relationship between the
150 independent (weather) and dependent (PDI) variables was used to develop the model for disease
151 prediction, and goodness of fit was assessed by co-efficient determination (R²) and standard
152 error of estimate (Coakley *et al.*, 1988).

153

154 **Statistical Analysis**

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

157

158 **RESULTS AND DISCUSSION**

159 **Bio-efficacy of Different Fungicides against Powdery Mildew of Chilli**

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

162 (PDI) was recorded at regular interval for the two consecutive years are presented in the Table
163 4 and 5 respectively. Pooled analysis was also performed and presented in Table 6.

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

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

178 Analysis of variance (ANOVA) done for 15 days after third spray and presented in (Table 4a)
179 also confirmed that the treatment and replication schedule used in the study to manage PM of
180 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	-	-

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

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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).

186

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

198 The result of the pooled analysis was presented in Table 6. It was very clear that all the
199 treatments reduced the disease significantly compared to the unsprayed control plot. Minimum
200 PDI: 5.12 was noticed in KK-21 @ 2500 ml/ha treated plot which is significantly superior over
201 all the treatments except KK-21 @ 2000 ml/ha with PDI: 5.53. Plots treated with Azoxystrobin
202 11% + Tebuconazole 18.3% SC recorded PDI: 10.97 followed Azoxystrobin 23% SC (PDI:
203 12.28) and Sulphur 80% WP (PDI: 12.50) and their differences were statistically significant
204 except the later two. Maximum disease severity (PDI: 33.48) was recorded in untreated control.

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

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

212 Chemicals are the most common and practically accessible method for the management of
213 PM. Azoxystrobin belongs to strobilurins group of systemic fungicide with translaminar
214 activity. It is broad spectrum, takes entry inside the tissues and gets widely distributed from the
215 point of application by diffusion (Vincelli, 2002). It prevents mitochondrial respiration of fungi
216 as it binds Qo site of Complex III within the mitochondrion. On the other hand, sulphur is
217 contact in nature and interfere with the electron transport system of the pathogen therefore,
218 impair the ATP formation. Tebuconazole is also systemic fungicide that cause irreparable
219 damage to the fungal cell wall by inhibiting the sterol biosynthesis process of cell wall
220 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	After 5 days	First spray		Second spray			Third spray				
					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 ^c (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	-	-

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

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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 %
			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	-	-

228 Same English letter followed by mean are not significantly differ from each other,*Figure in the parenthesis represent angular transformed value, SC = Suspensible concentrate,
229 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).

232 As per the fungicide resistance action committee (FRAC, 2004) to reduce the risk of
 233 development of fungicide resistance pathogen alternate use of contact and systemic fungicide
 234 has been recommended. Therefore, new combi-fungicide KK 21 (Sulphur 84% + Azoxystrobin
 235 6% SC) has been tested and found to be effective in reducing PM. Several workers tried
 236 different combination of chemicals including Azoxystrobin against chilli powdery mildew.
 237 Ajithkumar *et al.*, (2014) conducted similar study in Chill-PM pathosystem with combi-
 238 fungicide (Azoxystrobin 8.3%+Mancozeb 66.7%); Ahila Devi and Prakasam, 2014 reported
 239 effective management of powdery mildew of chilli by using azoxystrobin 25% SC.
 240 Management of PM in chilli through different fungicides was also conducted by Daunde *et al.*,
 241 (2018).

242

243 **Phytotoxicity of Fungicide**

244 The observations on phytotoxicity symptoms on the basis of chlorosis, necrosis, wilting,
 245 scorching, hyponasty and epinasty were recorded for the two years presented in Table 7. The
 246 results noted no phytotoxic effect at 0, 1, 3, 5,7 and 10 days after spraying at higher dose of KK
 247 - 21@ 4000 ml/ha over chilli. Hence the product KK-21 proved non-phytotoxic (Table 7). For
 248 residue analysis, both soil and ripe chillies were used as sample that resulted the trace of
 249 chemical below determination level i.e. <0.01 mg/kg of KK 21. The result was supported by
 250 effective management of PM of chilli by using azoxystrobin 25% SC without any residual effect
 251 by Ahila Devi and Prakasam, 2014 and Mondal and Sarkar, 2023.

252

253 **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

254 *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%,
 255 8=71-80%, 9= 81-90%, 10= 91-100%.

256

257 **Yield**

258 Yield data was recorded treatment wise and converted into quintal per hectare and presented
 259 in Table 8, revealed that all the treatments were effective to increase the yield significantly over
 260 control. Maximum yield was recorded 139.71 q/ha and 150.24 q/ha respectively for the two
 261 consecutive years of experiment upon spraying of KK-21 @ 2500 ml/ha thrice as foliar spray
 262 followed by KK-21 @ 2000 ml/ha with yield 124.43 q/ha and 142.93 q/ha consecutively (Table
 263 8). Least yield was recorded in unsprayed control with 64.47 and 75.21 q/ha for the year 2020-
 264 21and 2021-2022 respectively. Two years pooled mean also recorded maximum yields of

265 144.98 q/ ha in the plot sprayed with KK-21 @ 2500 ml/ha followed by KK-21 @ 2000 ml/ha
 266 (133.43 q/ha) and KK-21 @ 1500 ml/ha (129.70 q/ha) their differences were statistically
 267 significant. Yield obtained from Azoxystrobin 11% + Tebuconazole 18.3% SC (118.31 q/ha)
 268 were statistically at par with the yield realized from Azoxystrobin 23% SC (116.7 q/ha).
 269 Minimum significant yield was recorded from the untreated control plot for both the year and
 270 also in pooled mean 69.84 q/ha (Table 8). ANOVA also performed and presented in Table 8a.
 271 Our research results were in accordance with Raju *et al.*, (2017) and Sabeena and Ashtaputre
 272 (2019) who worked on PM of chilli and estimated yield loss due to this disease. Marthand
 273 (2016) and reported three sprays of Azoxystrobin were optimum in reducing the disease
 274 severity and obtaining maximum yield.

275 **Table 8.** Yield data recorded during two consecutive years of experiment on fungicides
 276 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

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

279
 280

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			

281

**= significant (p< 0.01).

282 **Progression of PM of Chilli in Relation with Different Weather Parameters**

283 Under natural conditions, in the year 2020-21 initial infection of PM on chilli variety 'Bullet'
284 was recorded at 49 SMW (Standard meteorological weeks) when the age of the crop was 44
285 days after transplanting (DAT) with PDI 8.15 and reaching its peak at 4 SMW (93 DAT) with
286 PDI 44.36. After that gradually proceed to reach the plateau at 5 SMW (Table 9). On the
287 contrary, during the second year 2021-22, disease initiation started quite late in the season i.e.
288 around 64 DAT at 1 SMW with PDI 9.65 then, the disease gradually increased from PDI 14.56
289 to 41.86 during 2 – 6 SMW. The rate of progress (increase/decrease) was also measured at
290 weekly interval and presented in Fig. 1. The apparent infection rate (r) was highest in mid-
291 December to mid- January ranging from 0.0139 to 0.0092 respectively for PM in chilli (Table
292 9).

293 The weather data recorded during the experimental period of 2020-21 and 2021-22 are
294 displayed in Fig. 1 and the range of variation in PDI of PM along with the changes in different
295 weather parameters are exhibited in Table 10. With the maximum temperature range 21.71 to
296 31.26⁰C the disease severity varied from 8.15 to 44.36 along with RH 58.62 to 82.25.

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

300

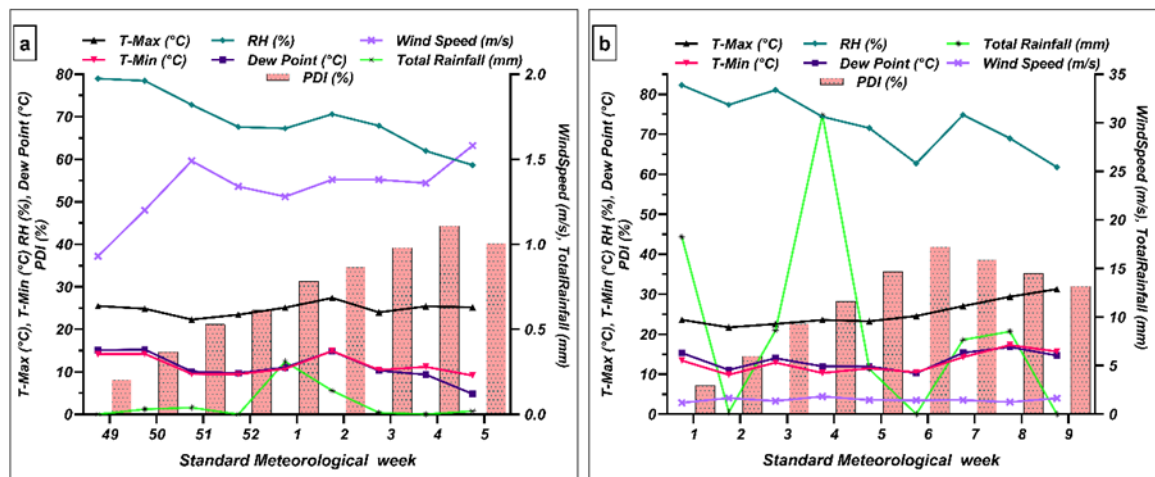
301 **Correlation and Stepwise Regression**

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

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

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

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



327 **Fig. 1.** Progression of Powdery mildew of chilli with weather variables during (a) 2020-21
 328 and (b) 2021-22.
 329

330

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	

331

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

332

333

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

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

334

335 **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

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

337
338 **Table 12.** Stepwise regression of different weather variables with the severity of Powdery
339 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 (**)

340 A Coefficient of determination, b Akaike information criterion, c Standard Error. Significance codes: '***'=
341 0.001, '**'= 0.01, '*'= 0.05 and 'ns'= >0.05. Tmax= Maximum Temperatures and RH= Relative Humidity.

342 CONCLUSIONS

344 From this study it is evident that progress of chilli powdery mildew is dependent on the
345 prevailing weather condition. Among the weather parameters maximum temperatures had
346 significantly positive and average RH significantly negative correlation with the development
347 and progression of the disease. The developed model exhibited that 78.2 to 87.6 % variation in
348 the disease severity could be explained by these two variables while the other factors effect was
349 found non-significant. The present studies revealed that a maximum temperature range between
350 22.32⁰C to 31.26⁰C, and RH 58.62 to 82.25% played major role in the progression of PM and
351 rate of weekly disease progression varied from 0.0012 to 0.0139. The information generated
352 through this study could be useful for developing area wise disease forecasting system for PM
353 in chilli. Thus, this model may be validated and utilized in the agro-advisories for developing
354 the spray schedule to management the disease. Powdery mildew of chilli being an obligate
355 parasite belongs at high risk to develop fungicide resistance mainly because of multiple
356 applications of same fungicide. This situation could be mitigated by the use of chemicals with
357 different mode of action. In this view, one combi-fungicide KK 21 (Sulphur 84% +
358 Azoxystrobin 6% SC) has been tested and found three times spraying of KK 21 @ 2500 ml/ha
359 at an interval of 15 days just after the initiation of the disease is highly effective in managing
360 the disease with least disease severity and highest yield. Additionally, no phytotoxic symptoms
361 were observed on the chilli plant when it was applied even at double dose. Therefore, it can be
362 concluded that it is friendly to the crop could be included in the IDM programme.

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367
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