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Effect of Meteorological variables on Larval Population of Legume Pod Borer *Maruca vitrata* (Fabricius) (Crambidae: Lepidoptera) in Vegetable Cowpea

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ABSTRACT: The present study was designed to develop an infestation predictive model based upon meteorological variables, that is, maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_m), evening relative humidity (RH_e), rainfall (RF), number of rainy days (NRD), bright sunshine hours (BSH), wind velocity (WV), and evapotranspiration (EVP), to predict *Maruca vitrata* larval density per plant. Correlation and regression analyses were performed to determine the relationship of meteorological variables with larval density per plant. A significant correlation was found between larval density per plant WV (r =.793) as well as with EVP (r =.804) and during summer 2021, whereas there was a negative significant correlation between T_{min} (r = -.713) and a significant positive correlation between RH_m (r = .804) and larval density per plant during *kharif*, 2021. Environmental variables and larval density per plant data from two consecutive seasons (summer and *kharif*, 2021) were used to develop a *Maruca vitrata* infestation predictive model using a stepwise multiple regression analysis. During summer 2021 T_{min}, RH_e, NRD, EVP; and during *kharif* 2021, RH_m, RH_e, RF, NRD, WV, and EVP significantly ($p<0.05$) contributed to larval density per plant and explained 99% (R^2) of the total variance in larval density per plant during both seasons. The forecasting model developed would be useful to predict infestation severity by the legume pod borer before epidemic occurrence and the time of pesticide application. Hence, the model is helpful to reduce the use of pesticides, lessen environmental pollution, and help limit the cost of production for cowpea growers.

Keywords: Meteorological variables, correlation, stepwise multiple regression analysis, *Maruca vitrata*, larval density per plant and predictive model.

INTRODUCTION

The complex interaction of climatic factors and agricultural ecosystems is critical to understanding and managing insect populations. Among the numerous issues confronting agricultural communities, the legume pod borer, *Maruca vitrata* (Fabricius) (Crambiade: Lepidoptera) stands out as a serious menace, in legume crops notably in cultivation of vegetable cowpea, (*Vigna unguiculata* (L.) Walp) (Srinivasan *et al*., 2021). This study investigates the complex link between climatic conditions and the larval population of *Maruca vitrata* in vegetable cowpea, providing useful insights that may be used to develop long-term pest control techniques.

To gain a comprehensive understanding, this study cautiously analyses a wide range of meteorological parameters, including maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_m), evening relative humidity (RH_e), rainfall (RF), number of rainy days (NRD), bright sunshine hours (BSH), wind velocity (WV), and evapotranspiration (EVP). Researchers want to understand the complex interactions that drive the spread of *Maruca vitrata* larvae, a renowned pest recognized for its influence on cowpea yields, by conducting a comprehensive investigation of these parameters.

This study extends basic correlation analysis by make use of stepwise regression to identify the climatic factors with the greatest impact on larval density per plant. We want to establish equations that accurately forecast larval density throughout the summer and *kharif* seasons of 2021. This research will not only enhance our theoretical understanding of the incidence of legume pod borer infestation, but also provide practical ways for forecasting and managing it.

As worldwide weather patterns shift, the impact of meteorological factors on insect populations becomes more complicated. In such a context, our study aims to close the knowledge gap by providing a comprehensive viewpoint that combines meteorology, the agricultural sector, and entomology. The findings of this study are likely to have profound consequences for environmentally friendly farming methods and the implementation of tailored pest management measures in vegetable cowpea production.

Bhuva and Patel (2022) while studying population dynamics of *M. vitrata* in green gram found that BSH had recorded positive significant correlation whereas WS recorded negative significant correlation with larval population of *M. vitrata*.

Singh *et al*. (2022) conducted an experiment to study the effect of weather parameters on the incidence of insect pests in mungbean during the summer and found that T_{max} (r = 0.088), T_{min} (r = 0.464), RH (r = 0.258), RF (r = 0.066), and WS (r = 0.650) had a positive correlation with the mean number of spotted pod borer larvae per plant, but BSH (r = -0.041) recorded a negative correlation.

Ajithkumar *et al*. (2021) found that RH_e, rainfall, and NRD recorded a negative correlation with cowpea pod borer incidence, but T_{max} recorded a positive correlation with cowpea pod borer incidence.

Biswas and Banerjee (2019) observed a significant negative correlation between T_{max} (r = -0.82 and r = -0.84) and the population of spotted pod borer per plant in black gram during both the summer and *kharif* seasons, whereas T_{min} (r = -0.72) recorded a negative correlation only during the summer season. However, during summer RH_e (0.85), RF (r = 0.68), and during *kharif* BSH (r = 0.63), reinforced a positive correlation with the population of spotted pod borer per plant in black gram.

In a study conducted by Kapoor and Shankar (2019) in blackgram, RH_m (r = -0.551) and RH_e (r= -0.593) recorded a negative and significant correlation but T_{max} (0.633), T_{min} (0.586) recorded a positive significant correlation with larval population of *Maruca vitrata*.

Berani *et al*. (2017) found that *Maruca vitrata* larvae per plant have a significant negative association with T_{min} (r = -0.559) but a positive association with evapotranspiration in their study on the population dynamics of insect pests in black gram. Whereas RH_e (r =0.278), EVP (r = 0.126), and BSH (r = 0.469) exhibited positive correlation, while T_{max} (r = -0.104), RH_e (r = -0.063), and RF (r = -0.011) recorded negative correlation with larval population.

Jat *et al*. (2017) reported that in their research, during different dates of sowing (D_1, D_2, D_3, and D_4) significant associations were recorded between weather factors and the *M. vitrata* population. RH_e (r = -0.671, r = -0.586, r = 0.906 during D_1, D_2, D_3, and D_4 respectively); wind speed (r = -0.533, r = -0.829 during D_1 and D_2 respectively); and T_{min} (r = -0.653 during D_2) had a recorded significant correlation with the incidence of *Maruca vitrata* in pigeonpea during the *kharif* season.

Reddy *et al*. (2017) observed that T_{max} (r = -0.351 during *kharif* 2015-16 and r = -0.553 during *kharif* 2016-17), T_{min} (r = -0.575 during *kharif* 2016-17), and EVP (r = -0.581 during *kharif* 2016-17) recorded negative correlations, but RH_e (r = 0.129 during *kharif* 2015-16) recorded positive correlations with *M. vitrata* larval population in dolichos bean during *kharif*.

Sreekanth *et al*. (2015), in their investigation on the population dynamics of spotted pod borer, reported that WS (r = -0.838), T_{min} (r = -0.759), and RH_e (r = -0.609) were negatively correlated with the *M. vitrata* larvae per plant, whereas BSH (r = 0.656) were positively correlated with the *M. vitrata* larvae per plant.

There was a negative and significant correlation recorded between T_{min} (r = -0.554) and mean larval population of *M. testulalis* per plant investigated by Sonune *et al*. (2010) in blackgram during the *kharif* season.

A stepwise regression study performed by Ajithkumar *et al*. (2021) revealed that the prior week's T_{max} and RH_e, as well as RF and the NRD in the prior two weeks, constitute significant meteorological variables for forecasting pod borer infestation in cowpea with R^2 = 0.07 and 0.08 respectively.

The predictive model established by Dharavath *et al*. (2021) found that for every one unit rise in maximum temperature, the population of *M. vitrata* larvae rose by 1.856 units, accounting for 63.7% of the variation in population size (R^2 = 0.637).

Jayabal and Kennedy (2022) investigated the effect of weather conditions on the seasonal incidence of spotted pod borer on dolichos bean and reported that T_{max}, T_{min}, RH_m, and RF contribute to the larval abundance of *Maruca vitrata*, with R^2 = 0.039 and R^2 = 0.443 in flowers and pods, respectively.

In the rabi season of 2015–16, Naresh *et al*. (2017) investigated the seasonal abundance of spotted pod borer in groundnut, evaluating two groundnut varieties (Kadiri–6 and Dharani) and two distinct sowing dates (D_1 and D_2). In K-6 and Dharani, the combined effects of weather parameters (T_{max}, T_{min}, RH_m, RH_e, WS and BSH) on this legume pod borer damage were 74% (R^2 = 0.74) and 77% (R^2 = 0.77), respectively, for D_1-sown crops. These meteorological factors affected damage to D_2-sown crops by 76% (R^2 = 0.76) and 77% (R^2 = 0.77) in K-6 and Dharani, respectively.

A regression study conducted by Reddy *et al*. (2017) found that the combined effect of all meteorological conditions accounted for 83.83% (R^2 = 0.838) of the variation in the number of *M. vitrata* larvae, a pest that affects field beans.

MATERIAL AND METHODS

The study was conducted on vegetable cowpea crop during summer 2021 and *kharif* 2021 in Entomology Department Research Farm of College of Agriculture, OUAT, Bhubaneswar, Odisha. Geographically the location is situated at 20°15'N latitude and 85° 52' E longitude at an altitude of 45 metres above mean sea level. The study was laid down in randomised block design consisting of 60 vegetable cowpea genotypes with two replications. The crop was sown during 4th week of February month during summer, 2021 and 4th week of July month during *kharif*, 2021. The research plots were maintained following the recommended agronomic practices in the same manner for all the treatments. All the plots were kept free from any insecticidal spray throughout the crop period. The number of larvae per flower and pod were calculated as larval density per plant from the five pre-labelled randomly selected plants from each replication counted at weekly interval from the day of *Maruca vitrata* appearance in the field and then was averaged from the two replications.

The daily meteorological parameters *viz*., maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_m), evening relative humidity (RH_e), rainfall (RF), number of rainy days (NRD), wind velocity (WV), bright sunshine hours (BSH), evapotranspiration (EVP) were recorded at the meteorological station located in OUAT, Bhubaneswar and then converted into weekly basis against standard meteorological week (SMW) with correspondence to weekly population of legume pod borer.

The larval density per plant (weekly data) and weekly weather parameters were taken for the correlation and regression analysis. The weekly larval density per plant was taken as dependent variable and correlated with corresponding weekly weather parameters as independent variables. On the bases of significant Pearson correlation coefficients observed between larval density per plant and weather parameters, step wise regression study was performed to develop statistical forewarning model. The larval density per plant was influenced not only by a single weather parameter, but by the interaction effect of more than one variable. Hence, multiple regression model was developed based on significant correlation coefficient between larval density per plant and weather variables by using stepwise regression method for predicting larval density per plant. The Pearson correlation coefficients and their p- values were calculated using "*Hmisc*" package and the stepwise regression was computed using "*olsrr*" package in R.

The multiple linear regression model used as follows.

$$Y= \beta_0 + \beta_1 x_1+ \beta_2 x_2+ \beta_3 x_3+ \beta_4 x_4+ \beta_5 x_5+ \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 +\varepsilon$$

Where, y= dependent variable or response variable *i.e.* larval density per plant

β_0 = Constant

$\beta_{(1\text{-}6)}$ = Un-standardized coefficients for each predictor variable

x_1= Average T_{max} in ºC during the respective SMW

x_2= Average T_{min} in ºC during the respective SMW

x_3= Average RH_m in % during the respective SMW

x_4= Average RH_e in % during the respective SMW

x_5= Average RF in mm during the respective SMW

x_6= Average NRD in days during the respective SMW

x_7= Average BSH in hrday^{-1} during the respective SMW

x_8= Average WV in kmhr^{-1} during the respective SMW

x_9= Average EVP in mm during the respective SMW

ε= the error term

Here, the larval density per pant (LDPP) is a response variable whereas maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_m), evening relative humidity (RH_e), rainfall (RF), number of rainy days (NRD), wind velocity (WV), bright sunshine hours (BSH), evapotranspiration (EVP) are predictor variables.

RESULTS AND DISCUSSION

A. Correlation analysis

Correlation among the weather parameters and larval density per plant during summer, 2021 season were calculated and Pearson's correlation coefficients along with p-values were presented in table 1. Two weather parameters *viz*., wind velocity [r(6)= .793, p= 0.019] and evapotranspiration [r(6)= .804, p= 0.016] had recorded a significant positive correlation with larval density per plant at 5% level of significance. Whereas the other weather parameters have not recorded any significant positive or negative association with larval density. From the Table 2, it is evident that during *kharif*, 2021 there was a significant positive correlation between RH_m [r(6)= .804, p= 0.016] and larval density per plant but a significant negative correlation with T_{min} [r(6)= -.713, p= 0.047] and larval density per plant. Whereas the other weather parameters have not recorded any significant positive or negative association with larval density. The results in the present investigation are in corroboration with the findings of Patel *et al*. (2022) in cowpea, Singh *et al*. (2022) in mungbean, Sreekanth *et al*. (2022) in pigeonpea, Ajithkumar *et al*. (2021) in cowpea, Biswas and Banerjee (2019) in green gram, Kapoor and Shankar (2019) in black gam, Berani *et al*. (2017) in black gram, Jat *et al*. (2017) in pigeonpea, Reddy *et al*. (2017) in dolichos bean, Sreekanth *et al*. (2015) in pigeonpea and Sonune *et al*. (2010) black gram with reference to the *M. vitrata* infestation.

B. Regression analysis

An extension of basic linear regression is multiple regression. We use it to forecast the value of one variable depending on the values of two or more other variables. There was multicollinearity among the predictor variables and consequently, multiple linear regressions have not resulted in fitting an appropriate prediction model. Hence, a stepwise regression procedure was performed to obtain the ideal regression model.

To fit a regression model that explain significant amount of variance in the larval density per plant (dependent variable) by the weather parameters (independent variables) namely T_{max}, T_{min}, RH_m, RH_e, RF, NRD, BSH, WV, EVP; the stepwise regression was computed. The variables namely T_{min}, RH_e, NRD, EVP (Table 4) explains 99% (R^2) of the total variance in the dependent variable, LDPP with $F(4,3) = 174.4$ with $p<0.001$ during summer, 2021. The p-value for the full model is small enough at both 5% and 1% level of significance to suggest that at least one of the predictor variables may be useful for the prediction. The model has an adjusted R^2 value of 0.99 and standard error is 0.1223 (Table 3).

The fitted regression equation is as follows:

LDPP = 19.34 -1.62 x T_{min} (°C) + 0.12 x RH_e (%) -0.66 x NRD (days)+ 2.46 x EVP (mm)

The Observed versus predicted (*Maruca vitrata*) larval density per plant as affected by meteorological parameters in Bhubaneswar, Odisha, India during summer, 2021 were calculated and presented in table 6.

During the *kharif* season, the variables namely RH_m, RH_e, RF, NRD, WV, EVP (Table 5) explains 99% (R^2) of the total variation in the dependent variable, LDPP with $F(6,1) = 1230$ with p-value of 0.02182. The p-value for the full model is small enough at 5% level of significance to suggest that at least one of the predictor variables may be useful for the prediction. The model has an adjusted R^2 value of 0.99 and standard error is 0.0363 (Table 3).

The fitted regression equation is as follows:

LDPP = 5.10 -5.414 x RH_m (%) + 0.8746 x RH_e (%) + 0.0055 x RF (mm) -3.301 x NRD (days) -8.433 x WV (kmhr^{-1}) -17.07 x EVP (mm)

The Observed versus predicted (*Maruca vitrata*) larval density per plant as affected by meteorological parameters in Bhubaneswar, Odisha, India during *kharif*, 2021 were calculated and presented in table 7.

The findings in the current investigation are comparable to the observations obtained by Jayabal and Kennedy (2022) in dolichos bean, Ajithkumar *et al*. (2021) in cowpea, Dharavath *et al*. (2021) in pigeonpea, and Naresh *et al*. (2017) in ground nut with reference to the *M. vitrata* infestation.

To assess the correctness of the fitted regression models, the agreement between projected values and observed values of larval density per plant was assessed through the fitting of a 1:1 line and the determination of RMSE. There was acceptable agreement between observed and anticipated values of *Maruca vitrata* larval density per plant (R^2 =0.99 ; RMSE = 0.075) during summer 2021 (Fig. 1), and conversely comparable interpretation was obtained during *kharif* 2021 (R^2 =0.99 ; RMSE =0.0360) (Fig. 2).

Table 1: Correlation among the weather parameters and larval density per plant during summer, 2021 season.

	T_{max}	T_{min}	RH_m	RH_e	RF	NRD	BSH	WV	EVP
T_{min}	0.229								
	(0.585)								
RH_m	0.483	-0.364							
	(0.225)	(0.376)							
RH_e	-0.729*	0.321	-0.778*						
	(0.04)	(0.438)	(0.023)						
RF	0.183	-0.137	-0.043	0.196					
	(0.665)	(0.747)	(0.92)	(0.643)					
NRD	-0.561	0.024	-0.721*	0.827*	0.564				
	(0.148)	(0.956)	(0.044)	(0.011)	(0.145)				
BSH	0.027	0.795*	-0.548	0.500	0.14	0.414			
	(0.949)	(0.018)	(0.16)	(0.207)	(0.741)	(0.308)			
WV	-0.111	0.82*	-0.433	0.504	-0.13	0.159	0.822*		
	(0.794)	(0.013)	(0.284)	(0.203)	(0.759)	(0.707)	(0.012)		
EVP	0.189	0.953***	-0.445	0.328	-0.168	0.002	0.746*	0.874**	
	(0.654)	(0.000)	(0.269)	(0.428)	(0.69)	(0.997)	(0.034)	(0.005)	
LDPP	-0.217	0.642	-0.477	0.476	-0.316	0.007	0.405	0.793*	0.804*
	(0.605)	(0.086)	(0.232)	(0.233)	(0.445)	(0.986)	(0.319)	(0.019)	(0.016)

Values in parenthesis denote p-values.

* Indicates significant correlation at 5% level of significance

** Indicates significant correlation at 1% level of significance

Table 2: Correlation among the weather parameters and larval density per plant during *kharif*, 2021 season.

	T_{max}	T_{min}	RH_m	RH_e	RF	NRD	BSH	WV	EVP
T_{min}	0.32								
	(0.44)								
RH_m	-0.758*	-0.566							
	(0.029)	(0.144)							
RH_e	-0.865**	0.108	0.611						
	(0.006)	(0.8)	(0.108)						
RF	-0.486	-0.263	0.619	0.613					
	(0.222)	(0.529)	(0.102)	(0.106)					
NRD	-0.185	0.296	-0.118	0.444	0.411				
	(0.661)	(0.476)	(0.781)	(0.27)	(0.312)				
BSH	0.694	-0.145	-0.592	-0.814*	-0.367	-0.016			
	(0.056)	(0.731)	(0.122)	(0.014)	(0.371)	(0.97)			
WV	0.189	0.602	-0.468	0.113	0.03	0.139	-0.249		
	(0.654)	(0.114)	(0.242)	(0.79)	(0.944)	(0.743)	(0.553)		
EVP	0.687	0.46	-0.835**	-0.684	-0.848**	-0.372	0.476	0.27	
	(0.06)	(0.251)	(0.01)	(0.061)	(0.008)	(0.364)	(0.233)	(0.518)	
LDPP	-0.625	-0.713*	0.804*	0.323	0.357	-0.272	-0.2	-0.542	-0.621
	(0.098)	(0.047)	(0.016)	(0.435)	(0.385)	(0.514)	(0.635)	(0.166)	(0.1)

Values in parenthesis denote p-values.
* Indicates significant correlation at 5% level of significance
** Indicates significant correlation at 1% level of significance

Table 3: Summary of Stepwise regression.

Regression statistics	Summer	Kharif
Multiple R	0.9978	0.9999
R square	0.9957	0.9999
Adjusted R square	0.99	0.9991
Standard Error	0.1223	0.676
Observations	8	8

Table 4: Parameters of larval density per plant as affected by meteorological parameters in stepwise regression analysis during summer 2021.

Parameter	Coefficients	Std. Error	t value	Pr(>|t|)
Intercept	19.33798	2.76835	6.985	0.006022**
T_{min}	-1.62378	0.16186	-10.032	0.002109**
RH_e	0.12008	0.01067	11.251	0.001505**
NRD	-0.66496	0.07079	-9.393	0.002556**
EVP	2.46238	0.18829	13.078	0.000966***

Significant codes '***' 0.001 '**' 0.01 '*' 0.05

Table 5: Parameters of larval density per plant as affected by meteorological parameters in stepwise regression analysis during kharif, 2021.

Parameter	Coefficients	Std. Error	t value	Pr(>|t|)
Intercept	51.00	12.100	42.17	0.0151 *
RH_m	-5.414	0.1300	-41.55	0.0153 *
RHAft	0.8746	0.0206	42.4	0.0150 *
RF	0.0055	0.000395	13.98	0.0454 *
NRD	-3.301	0.0719	-45.89	0.0139 *
WV	-8.433	0.1900	-44.38	0.0143 *
EVP	-17.07	0.3680	-46.39	0.0137 *

Significant codes '***' 0.001 '**' 0.01 '*' 0.05

Table 6: Residual output for the forecasting model for *M. vitrata* larval density per plant during summer, 2021.

SMW	*Maruca vitrata* larval density per plant		Prediction interval		Residuals
	Observed value	Predicted value (mean)	lower 95%	upper 95%	
12 SMW	0.00	0.05	-0.29	0.38	-0.05
13 SMW	1.01	0.91	0.65	1.17	0.10
14 SMW	1.5	1.5	1.17	1.84	0.00
15 SMW	3.71	3.61	3.27	3.95	0.10
16 SMW	3.26	3.34	3.10	3.58	-0.08
17 SMW	2.79	2.75	2.43	3.07	0.04
18 SMW	2.39	2.51	2.26	2.76	-0.12
19 SMW	1.94	1.93	1.58	2.28	0.01

Table 7: Residual output for the forecasting model for *M. vitrata* larval density per plant during *kharif*, 2021.

SMW	*Maruca vitrata* larval density per plant		Prediction interval		Residuals
	Observed value	Predicted value (mean)	lower 95%	upper 95%	
33 SMW	0.00	-0.01	-0.30	0.29	0.01
34 SMW	1.12	1.12	0.90	1.33	0.00
35 SMW	1.65	1.63	1.33	1.92	0.02
36 SMW	3.64	3.6	3.31	3.89	0.04
37 SMW	3.18	3.2	2.90	3.50	-0.02
38SMW	2.82	2.78	2.52	3.04	0.04
39 SMW	2.41	2.49	2.29	2.69	-0.08
40 SMW	2.04	2.05	1.76	2.35	-0.01

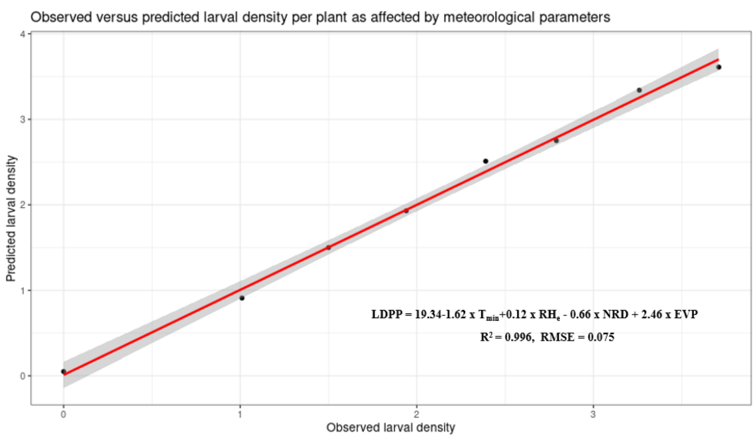

Fig. 1. Observed versus predicted larval density per plant as affected by meteorological parameters in Bhubaneswar, Odisha, India during summer, 2021.

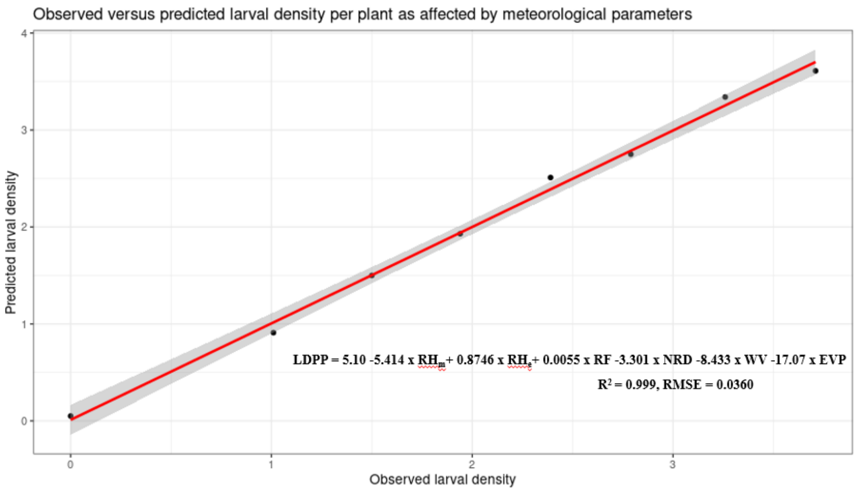

Fig. 2 Observed versus predicted larval density per plant as affected by meteorological parameters in Bhubaneswar, Odisha, India during *kharif*, 2021.

CONCLUSIONS

The study developed an infestation predictive model based on meteorological variables to predict *Maruca vitrata* larval density per plant. Correlation and regression analyses were performed to determine the relationship between meteorological variables and larval density. Results showed a significant correlation between wind velocity and larval density during summer 2021, while negative correlations were found during *kharif* 2021. This study aims to determine the ideal climatic conditions for the rapid spread of the cowpea pod borer. The regression model can help predict infestation severity and pesticide application time, reducing pesticide use, environmental pollution, and limiting production costs for cowpea growers. There was satisfactory agreement between actual and projected values of *M. vitrata* larvae density per plant, which implies the fitted regression model of *M. vitrata* infestation and weather association could rationally forecast the field incidence of legume pod borer in vegetable cowpea.

FUTURE SCOPE

Further investigation is required to enhance the precision of forecasts in highly fluctuating temperatures. It is often more advantageous to collect data from several geographic locations, even for a specific location.

Author contributions: All the authors including Mirala Sruthi conceived and designed the analysis; Mirala Sruthi collected the data, contributed data and analysis tools, performed the analysis, and wrote the paper.

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Conflict of Interest. None.

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