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Development and validation of predictive regression model for Brown planthopper population in rice

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Abstract

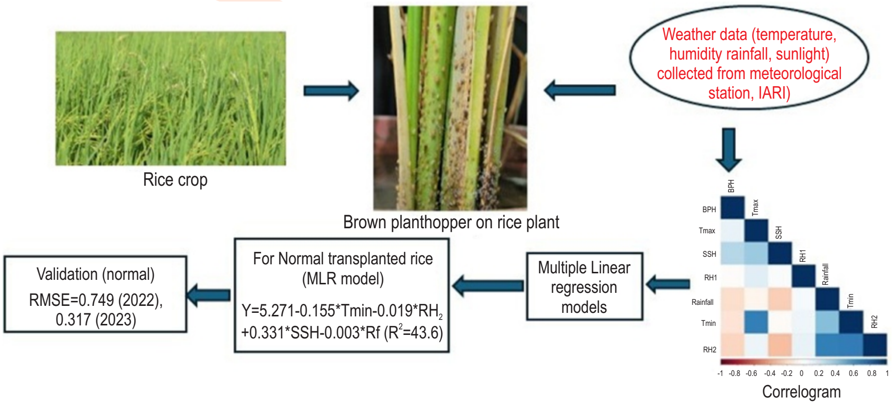
Aim: To develop and validate a multi-linear regression model correlating brown planthopper (*Nilaparvata lugens*) population with weather parameters specific to New Delhi conditions.

Methodology: A weather-based forecasting model was developed for predicting brown planthopper (BPH) infestation for early, normal and late transplanted rice. The field data during 2017 to 2021 were utilized for the model development and was validated during 2022 and 2023.

Results: In early transplanted rice, a significant negative correlation with BPH infestation and minimum temperature (r=-0.462) and evening relative humidity (-0.387) as well as a significant positive correlation with total sunshine hours (r=0.447) were observed. For normal transplanted rice, BPH population was significantly and negatively correlated with minimum temperature (r=-0.526), evening relative humidity (r=-0.559) and rainfall (r=-0.411) while it was significantly positively correlated with sunshine hours (r=0.390). In case of late transplanted rice, the abiotic factor, sunshine hours (r = 0.355) alone showed a positive correlation with BPH population. Multiple linear regression (MLR) models were developed using data from 2017 to 2021 and validated with 2022 and 2023 data. The models were evaluated based on mean bias error (MBE), mean absolute error (MAE), and root mean square error (RMSE). Correlation analyses indicated significant negative correlations between BPH populations and T_{min} and RH_2 in early and normal transplanting, while positive correlations with SSH were observed. Validation showed satisfactory accuracy for early and normal transplanting (RMSE: 0.237-0.749), but lower accuracy for late transplanting (RMSE: 2.033-3.259).

Interpretation: These findings show the importance of weather parameters in predicting BPH infestations, with temperature, humidity, and sunshine hours playing significant roles. The study highlights the necessity for integration of pest management strategies time of planting and weather conditions to effectively mitigate BPH impacts on rice yields.

Key words: Multiple regression model, *Nilaparvata lugens,* Rice, Weather parameters



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Introduction

Rice is the most important food crop consumed globally, and it sustains about 800 million people in India. Rice production in the country has experienced tremendous advancements over the years. However, it has faced unprecedented hurdles posed by environmental degradation and climate change in recent years (Gupta and Mishra, 2019; Guntukula, 2020). Both biotic and abiotic stress factors significantly impact rice crop yields. Recent studies have highlighted yield loss of up to 46% due to these stresses, with insect pests alone accounting for approximately 27% of the losses (Teshome *et al.,* 2020). There are over 100 insect species that damage rice crop from nursery to maturity. While most of these insects cause minor damage to the crop, about 20 insect species pose significant importance due to their regular occurrence. Of these pests, brown planthopper (BPH), scientifically known as *Nilaparvata lugens* (Stal.), holds utmost importance as a sucking pest. It is an oligophagous pest having very little host range other than rice.

The adult insect measures about 2.0-3.5 mm in length, brownish in colour and belongs to the family Delphacidae (Order: Hemiptera). Both the nymphs and adults of the brown planthopper feed on the phloem sap of rice plants, causing significant damage known as "hopper burn." This condition is characterized by circular dry patches on the plant, leading to severe yield losses ranging from 20-80% (Jeevanandham *et al.,* 2022; Shah *et al.,* 2022). *N. lugens* also act as a vector for transmitting viral diseases like grassy and ragged stunt disease in rice. Seasonal weather variations and ongoing climatic changes have a direct effect on the distribution and development of insect species. Elevated temperatures notably impact pest dynamics, altering their survival, reproduction, dispersal, and interactions with both their environment and natural predators (Tian *et al.,* 2020). The frequency and severity of insect pest occurrences are influenced by heavy and unseasonal rainfall, increased humidity, soil moisture, and wind conditions, which affect their development, reproduction, distribution, and survival rates (Karthik *et al.,* 2022).

Comprehending the seasonal patterns and population dynamics of pests is essential for devising effective control measures (Kamiyama *et al.,* 2024). Extreme weather events can alter pest habitats, often resulting in increased infestations as pests migrate in search of new environments. Recent research continues to emphasize the considerable impact of weather factors, including temperature, rainfall and relative humidity on the population dynamics of insect pests, which in turn significantly affects the rice crop yields (Singh *et al.,* 2024). The relationship between pests and weather has been evaluated through empirical models, which exhibit location-specific behaviour (Prasannakumar and Chander, 2014). It has been previously noted that the empirical pest weather models are helpful in assessing the population dynamics of pests (Neta *et al.,* 2023).

A prediction model was developed using T_{max}, RF, and RH_2 as key predictors, using brown planthopper light trap catches at Mandya, Karnataka, from 1990 to 2006, and validated with independent datasets spanning from 2002-2006, achieving an R^2 of 0.845 and an RMSE of 7.64% (Prasannakumar and Chander, 2014). Using stepwise regression, a model was developed for *Helicoverpa armigera* in chickpea over two *rabi* seasons (2021-22 and 2022-23), identified with high R^2 values of 61 and 63.4 %, respectively (Choudhary *et al.,* 2024).

Efforts have been undertaken to enhance assessments of the warming impact on climate by integrating information from extended datasets concerning weather conditions, as well as distribution of pests. Different computer modelling developed to assess the population of insect pests will also be helpful in forewarning (Nurhayati *et al.,* 2017; Susanti *et al.,* 2018). Several bioclimatic models, including Bioclimatic Modeling (BIOCLIM), Boosted Regression Trees (BRT), Generalized Linear Models (GLM), and Maximum Entropy (MaxEnt) are used to estimate the potential distribution of pests and diseases in advanced countries (Byeon *et al.,* 2018; Kumar *et al.,* 2014; Tang *et al.,* 2021). The current study aimed to assess the population fluctuation of BPH in respect to changing the time of transplanting of rice crop and establish its correlation with weather factors. Multiple regression models were constructed using data on pest occurrences and weather for five years from 2017 to 2021, across three transplanting dates. The validated model can be further utilized for forecasting the brown planthopper population in Delhi region.

Materials and Methods

The field experiment on population dynamics of brown planthoppers on rice was conducted at the experimental farm of the Division of Entomology, ICAR- Indian Agricultural Research Institute, New Delhi (28.080N, 77.120 E, 22.61 m) from kharif 2017 to 2023 in large plot techniques design with segmented small subplots. Each plot was 3x4 m in size and there were 10 such plots for each transplanting. The rice variety 'Pusa-1121' was transplanted on three different dates, with a 15-day gap between each transplant. These were categorized as early, normal, and late transplanting and the date of transplanting for each year with Standard meteorological week (SMW) is mentioned in Table 1. The dates of sowing and transplanting for all the years are listed in Table 1. The experimental field was maintained weed-free through fortnightly manual cleaning, and no insecticides or management strategies were employed throughout the study. Brown planthopper (BPH) populations were monitored from 30 days after transplanting, with counts taken every 10 days from five randomly selected plants per subplot via visual inspection. The BPH population data collected over five years (2017-2021) were subjected to square root transformation for normalization. The weather data, including maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_1), evening relative humidity (RH_2), total sunshine hours (SSH), and rainfall (RF), were sourced from the ICAR-IARI website. The relationship between BPH populations and these weather parameters across different standard meteorological

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Table 1: Details about sowing and transplanting of rice crop

Year	Transplanting time	Date of sowing	Date of transplanting	Standard Meteorological Week (SMW) of translating
2017	early	05-06-17	03-07-17	27
	normal	19-06-17	18-07-17	29
	late	04-07-17	04-08-17	31
2018	early	05-06-18	07-07-18	27
	normal	20-06-18	19-07-18	29
	late	06-07-18	5-08-18	31
2019	early	07-06-19	05-07-19	27
	normal	28-06-19	24-07-19	30
	late	07-07-19	12-08-19	32
2020	early	09-06-20	07-07-20	27
	normal	29-06-20	23-07-20	30
	late	18-07-20	10-08-20	32
2021	early	09-06-21	06-07-21	27
	normal	29-06-21	22-07-21	29
	late	20-07-21	09-08-21	32
2022	early	08-06-22	05-07-22	27
	normal	17-06-22	20-07-22	29
	late	02-07-22	05-08-22	31
2023	early	05-06-23	04-07-23	27
	normal	20-06-23	20-07-23	29
	late	05-07-23	04-08-23	31

weeks (SMW) was analyzed using correlation and multiple linear regression (MLR) models. Additionally, principal component analysis (PCA) was conducted using R software (version 4.3.3) to explore the underlying patterns and relationships between variables. The MLR models were validated with the data for the next two years (2022 and 2023). The accuracy of the model was evaluated by comparing the mean bias error (MBE), mean absolute error (MAE) and root-mean-square error (RMSE) of the predicted and observed data sets of BPH population using the following formula (Gomez and Gomez, 1984):

$$\text{Mean bias error (MBE)} = \frac{1}{n}\sum_{1}^{n} (M — O)$$

$$\text{Mean absolute error (MAE)}\ \frac{1}{n}\sum_{1}^{n} [M — O]$$

$$\text{Root mean square error (RMSE)} = \sqrt{\frac{\sum_{1}^{n} (M - O)^2}{n}}$$

Where, M=Predicted data, O=Observed data, n=number of observations

Results and Discussion

Data presented in Table 2 shows the correlation between mean brown planthopper (BPH) population and weather parameters viz., maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_1), evening relative humidity (RH_2), sunshine hours (SSH) and rainfall (RF) for five-years under different time of transplanting of the rice. The correlation studies in early transplanting revealed that the mean BPH population had a significantly negative correlation with minimum temperature (r=-0.462) and evening relative humidity (r= -0.387). It also showed a significant positive correlation with

Table 2: Correlation and regression analysis of brown plant hopper with weather parameters

	Tmax	Tmin	RH1	RH2	SSH	rainfall	MLR	R^2 value
Early TP	-.092	-.462**	.015	-.387*	.447**	-.251	Y=4.228-0.141*Tmin-0.003*RH2+0.203*SSH	0.286
Normal TP	.016	-.526**	-.098	-.559**	.390*	-.411**	Y=5.271-0.155*Tmin-0.019*RH2+0.331*SSH-0.003*Rf	0.436
Late TP	.307	.041	-.083	-.188	.355*	-.107	Y=0.217+0.550*SSH	0.126

TP- Transplanting, *significant at p=0.05 level, **significant at p=0.01 level

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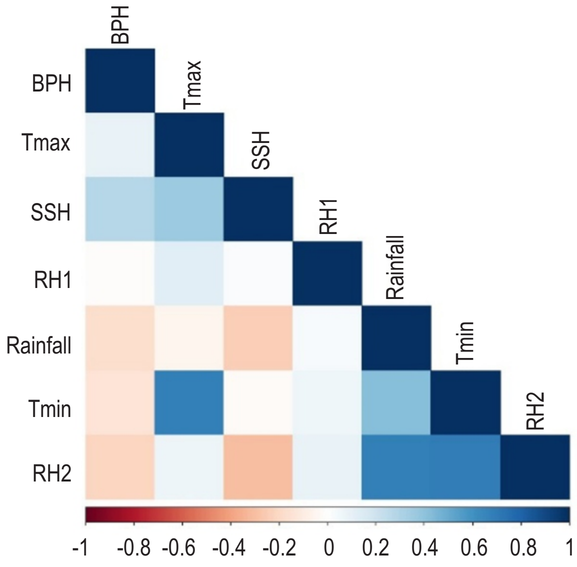

Fig.1: Correlogram.

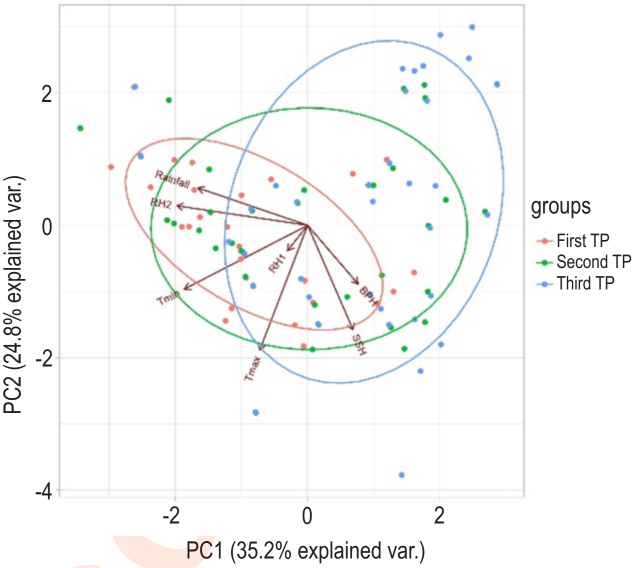

Fig.2: Biplot ellipse.

sunshine hours (r= 0.447). A non-significant negative correlation between maximum temperature (r=-0.092) and rainfall (r=-0.251) with the BPH population was also observed. In case of the normal transplanting, BPH population had a significantly negative correlation with minimum temperature (r=-0.526), evening relative humidity (r=-0.559) and rainfall (r=-0.411), while it was significant and positively correlated with sunshine hours (r=0.390). Data obtained from late transplanting depicted a significant positive correlation between BPH population and sunshine hours (r=0.355), and a non-significant negative correlation with morning relative humidity (r=-0.083) and evening relative humidity (r=-0.188). Moreover, it was non-significant and positively correlated with maximum temperature (r=0.307) and minimum temperature (r=0.041).

Fig. 1 represents the correlation between BPH population and the weather parameters from pooled data of early, normal and late transplanting. BPH population was positively correlated with T_{max}, SSH and RH_1 and negatively correlated with rainfall, T_{min}, and RH_2. Biplot (Fig. 2) graphically represents the observations and variables in reduced dimensionality space. The variables T_{max}, T_{min}, RH_2, and rainfall comparatively influenced the definition of the principal components. In the biplot, the direction of arrows of rainfall, RH_2, T_{min}, RH_1, and T_{max}, point towards the lower values of Principal component 1 (PC 1), indicating that the lower the value of PC1, the higher the values of these variables. It has been previously noted that empirical pest weather models are helpful in understanding the population dynamics of pests. These are totally affected by local weather conditions, and therefore, they exhibit location-specific behaviour. Prasannakumar and Chander (2014) observed that the minimum temperature showed a negative correlation, and the maximum temperature showed a positive correlation with BPH population. Morning and evening relative humidity, and rainfall had a positive correlation with BPH population. The present findings partially align with Adhikari *et al.* (2021), where a non-significant positive correlation with T_{max} was observed. T_{min} showed a significant positive correlation, relative humidity had a non-significant positive correlation, and rainfall with an insignificant positive correlation did not corroborate with the findings of this study, which could be due to the differences in the local environmental conditions. Deshmukh *et al.* (2021) found that the brown planthopper count had a strong positive relationship with maximum temperature, morning and evening humidity, and sunshine hours. However, the minimum temperature and rainfall showed a negative relationship with the brown planthopper population in both 2016 and 2017.

Table 2 shows that for the early transplanted rice crop, the combined effects of weather factors influenced the BPH population by 28.6%. The corresponding multiple regression equation was Y = 4.228 - 0.141 T_{min} - 0.003 RH_2 + 0.203*SSH, with an R^2 value of 0.286. For the normal transplanted rice, the combined weather factors had a greater impact, influencing the BPH population by 43.6%. The regression equation for this period was Y = 5.271 - 0.155 T_{min} - 0.019RH2 + 0.331SSH - 0.003 Rainfall, with an R^2 value of 0.436. However, during the late transplanted rice, the weather factors have much less influence, accounting for only 12.6% of the BPH population variation. The regression equation for this period was Y = 0.217 + 0.550*SSH, with a low R^2 value of 0.126. This low R^2 suggests that the model developed was not suitable for predicting BPH population for rice transplanted late. Moreover, low R^2 values in the experiment indicate that other factors, such as predation and parasitization, may also significantly affect BPH population. Although weather

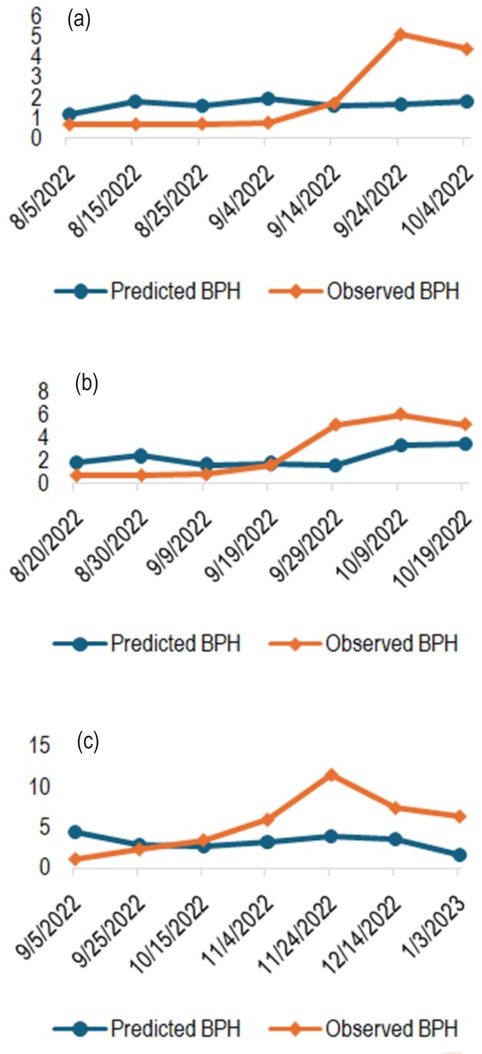

Fig. 3: Observed and Predicted values of BPH from MLR model-2022. (a) early (b) normal and (c) late transplanted rice.

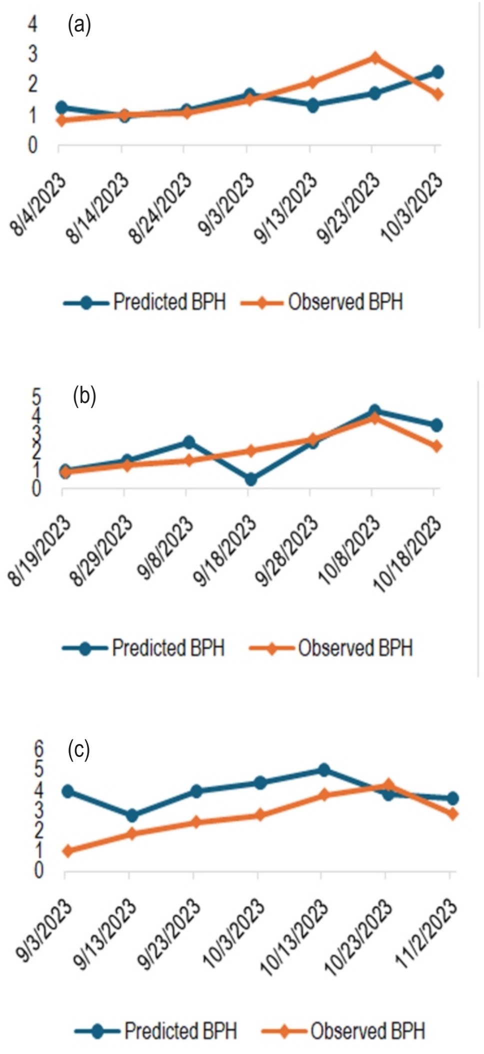

Fig. 4: Observed and Predicted values of BPH from MLR model-2023. (a) early (b) normal and (c) late transplanted rice.

factors influence the BPH population during this period, the moderate R^2 value suggests that other factors, such as crop growth stages, pest management practices, or microclimatic variations, may also play a significant role. This aligns with the findings of Prasannakumar and Chander (2014), who highlighted the location-specific nature of pest population dynamics. A better R^2 value of 0.436 for normal transplanting suggests that weather factors are more predictive of BPH population dynamics during this period, likely due to more stable and favourable climatic conditions. This finding corroborate with the work of Deshmukh *et al.* (2021), who reported a strong correlation between weather parameters and BPH populations during optimal growth periods. The linear regression model prepared by Kaur *et al.* (2022) showed 70% variation in brown planthopper population due to weather parameters. The results highlight the importance of considering transplanting timing when predicting BPH population dynamics based on weather parameters. Early and normal transplanting periods showed stronger relationships with weather factors, suggesting that models incorporating these factors may be more effective during these periods. In contrast, the late transplanting period may require additional factors, such as biological control measures or detailed crop management practices, to accurately predict BPH populations.

The developed models were validated with field data for early, normal and late transplantings during *kharif* 2022 and 2023, separately (Table 3). The BPH population predicted from the regression model was compared with the observed population. During 2022, the pest-weather model was validated satisfactorily for early (MBE=0.355, MAE=1.414 and RMSE=0.678) and normal transplanting (MBE=0.539, MAE=1.702 and RMSE=0.749), while it did not have satisfactory validation during

Table 3: Validation of regression model for brown plant hopper populations during 2022 and 2023

	2022			2023		
Transplanting time	MBE	MAE	RMSE	MBE	MAE	RMSE
Early TP	0.355	1.414	0.678	0.093	0.481	0.237
Normal TP	0.539	1.702	0.749	-0.158	0.659	0.317
Late TP	2.262	3.356	3.259	-1.236	1.364	2.033

MBE- Mean Bias Error, MAE- Mean Absolute Error, RMSE-Root Mean Square Error

late transplanting with a comparatively higher RMSE value (MBE=2.626, MAE=3.356 and RMSE=3.259). For the data observed during the year 2023, the population of BPH was also validated satisfactorily during early transplanting, having MBE, MAE and RMSE values 0.093, 0.481 and 0.237, respectively, and late transplanting recorded MBE= -0.158, MAE= 0.659 and RMSE= 0.317, while it again revealed a lower degree of validation for late transplanting (MBE= -1.236, MAE= 1.364 and RMSE= 2.033). A weather-based prediction model was developed utilizing sweep net catch data collected from Delhi during the years 2017 and 2018 and validated using pest and weather data from the Kharif season of 2018, yielding a coefficient of determination (R^2) of 0.733, RMSE of 2.16, MBE of -0.64, and MAE of 1.72. Among the weather variables, relative humidity in the morning (RH_1), relative humidity in the evening (RH_2), and sunshine hours (SSH) were identified as significant factors influencing brown planthopper sweep net catches (Srinivasa *et al.,* 2020). Weather based prediction models were also validated for other major pest stem borer in rice with high RMSE values (Prasannakumar *et al.,* 2015; Shekhar *et al.,* 2018).

In the case of early and normal transplanted rice, a stronger correlation among weather parameters compared to late transplanted rice was reported. The model developed for late transplanting exhibited a notably low R^2 value, with only one significant variable (sunshine hours) showing correlation with population. The minimum temperature and evening relative humidity, which proved significant both for normal and early transplanted rice, did not pose any influence on late transplanted rice. This discrepancy could be attributed to the impact of low night temperatures leading to a reduction in the population (Pandi *et al.,* 2018). Among the regression model established, the model developed from normal transplanted rice was the best fit model which included four significant variables (T_{min}, RH_2, SSH and rainfall) out of a total six weather variables.

Brown planthopper outbreaks are frequently linked to climate variability and change, putting nearly all rice varieties at significant risk (Surmaini *et al.,* 2024). This shows the vital importance of weather-based prediction models for implementing proactive pest management strategies. The present study aims to develop regression models that utilize weather data to predict and mitigate the impact of brown planthopper infestations in rice crops. The models were developed using five year data, incorporating three different transplanting dates at fifteen-day intervals, and were validated over two additional years. These models can be effectively applied to make further predictions under Delhi weather conditions.

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Authors' contribution: S. Rajna: Conceptualized the study, designed methodology and revised the manuscript; **A. Vishwakarma:** Analyzed the data and drafted the initial manuscript; **V.K. Padala:** Collected and analyzed the data; **K.V. Raghavendra:** Contributed to the literature review and revised the manuscript; **S. Chander:** Provided critical feedback during manuscript preparation.

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