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Influence of Weather Parameters on Incidence of Brown Plant Hopper (*Nilaparvata lugens*)

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Abstract

The incidence of Brown Plant Hopper (BPH) in rice in relation to the weather variables at Regional Agricultural Research Station (RARS), Pattambi, Kerala for a period of 27 years (1997 to 2023) was studied using regression analysis approach. Weather variables like minimum temperature (TMIN), morning relative humidity (RH I), evening relative humidity (RH II), rainfall (RF) and sunshine hours (SSH) had significant association with the count of BPH. Regression models like multiple linear regression, composite regression and multinomial logistic regression analysis were fitted using significantly correlated weather variables. Composite regression analysis with BPH count and weather variables revealed significance of weighted interaction of temperature and relative humidity. Individual and joint effect of the weather variables influencing the BPH count were determined using the multiple linear regression analysis and composite regression analysis respectively, with composite regression model providing higher model accuracy in comparison to multiple linear regression model. On the other hand, multinomial logistic regression analysis helped to determine the epidemic status of BPH at different peak periods of incidence. This epidemic status can be used as a warning alert for the farmers on the level of incidence of these pests.

***Key words*:** SMW, Correlation analysis, Multinomial logistic regression, Composite regression, Weather variables, R^2 value, Log odds

Rice (*Oryza sativa* L) is the staple food crop of majority of the global population and is found to be yielding significant economic benefits to the farmers. Rice is having significant area under cultivation in Asian subcontinent and demand for rice is considerably higher in the market. Even though there is such huge demand in the market, the supply of rice is found to be inadequate to meet the demand [1]. This happens because of various factors that is hindering the production of rice. It constitutes both biotic as well as abiotic factors. The biotic factors primarily include the insect pests which is a key reason for yield reduction in the paddy crop. Many insect pests are found to be infesting the paddy crop and among them pests like yellow stem borer (*Scirpophaga incertulus* Walker), Brown Plant Hopper (*Nilaparvata lugens* Stal), Rice Gall Midge (*Orselio oryzae* Wood-Mason) etc. are found to be significantly affecting the paddy crop [2-3].

Brown Plant Hopper is found to be a major insect pest of rice which is causing considerably high amount of yield loss in rice. Nymphal and adult stages of Brown Plant Hopper (BPH) infest all stages of rice growth. It feeds at base of the tillers that can lead to drying and wilting of the rice crop and thus cause the hopper burn symptoms. It is considered to be a sap feeder and is marked as a serious pest in Asia [4-5]. BPH attack results in decreased amount of chlorophyll, proteins and even reduces the rate of photosynthesis in rice. During 1970's, the outbreak of BPH was reported in various regions of India and high infestation of BPH in Kuttanad region of Kerala was also reported during this period [6].

The change in environmental factors over a region determine the severity of pest attack [7]. Thus, use of weather variables to determine the future infestation of pest is a significant step in monitoring the pest attack and thereby helping farmers to mitigate the incidence of pest. Literature provides several studies based on the relationship of BPH and weather parameters, which explains the population dynamics of BPH. Sharma *et al*. [8] studied the relation of weather factors with BPH using correlation analysis wherein they found a positive correlation with relative humidity as well as temperature factors. Nair *et al*. [9] also determined a significant influence of temperature, relative humidity and rainfall with BPH population. A change of 7 to 8 °C in temperature was found to have a boosting effect on BPH incidence, an observation from the study conducted by Varadharajan [10]. They even recorded that the peak BPH population was in the month of September. Jeyarani [11] identified that January, September and October were peak periods of incidence of BPH population. Mukherjee *et al*. [12] studied the impact of various weather factors on incidence of BPH population and found a high correlation of BPH count with the mean temperature. Misra and Israel [13] observed in their study conducted at Cuttack that an increase in BPH population during August and September months, resulted in peak incidence during October.

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Statistical models are used to study the influence of weather parameters with pest population, which helps in suitable forewarning of the pest. In this context, the present study was undertaken to establish the relationship between weather parameters and BPH population and thereby developing suitable statistical models using regression analysis approach to determine the incidence of BPH at Regional Agricultural Research Station (RARS), Pattambi in Kerala.

MATERIALS AND METHODS

The data on count on BPH, from light trap catches at the Regional Agricultural Research Station (RARS), Pattambi, Kerala under All India Co-ordinated Rice Improvement Programme (AICRIP) was used for the study. Daily population count of BPH for 27 years (1997 to 2023) was converted to weekly averages based upon SMW's and weather variables like maximum temperature (T*max*), minimum temperature (T*min*), morning (RH I) and evening relative humidity (RH II), rainfall (RF), sunshine hours (SSH) for the corresponding time period was also obtained from the research station. The distribution pattern of BPH is studied with the help of graphical representation of pest incidence during the study period and thus the peak period of incidence of BPH is also determined. The relationship between BPH population and weather variables is determined with the help of correlation analysis and significantly correlated weather variables is being utilized for the development of various regression models like multiple linear regression, composite regression and multinomial logistic regression. The statistical analysis was carried with the help of R software.

Multiple linear regression

Multiple linear is an extended form of simple linear regression in which a dependent variable is being determined based up on the effect of different independent variables. In this study, BPH population count is the dependent variable, and the weather variables are the considered to be the independent variables. The model is given as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon$$

Where in Y is taken as the dependent variable which denote the population value of the pest , $Xi's$ indicate the independent variable and it is weather variables in the study, β_0 is the intercept term in the model and the terms $\beta_1, \beta_2, \ldots \beta_n$ are the partial regression coefficients corresponding to the independent variables in the model and ε represent the error or residual term in the model. The adequacy of the developed model is determined with the help of coefficient of determination value (R^2).

Composite regression

The joint effect of weather variables on the incidence of BPH population is carried out with the composite regression models. It uses combination of two weather variables at a time and find the influence on BPH incidence.

Let X_{iw} be the i^{th} weather variable value at w^{th} week and r_{iw} be the correlation coefficient between pest population count and the weather variable at w^{th} week for the 27-year period. Then, the generated variables are:

$$Z_{i0} = \sum X_{iw}$$
$$Z_{i1} = \sum r_{iw} X_{iw}$$

To study the joint effect, the generated variables are:

$$Q_{ii',0} = \sum X_{iw} X_{i'w}$$
$$Q_{ii',1} = \sum r_{ii'w} X_{iw} X_{i'w}$$

Where in r_{iiw}' is the correlation coefficient between pest count and product of weather variables X_{iw} and $X_{i'w}$.

The weather variables were denoted using numerals from 1 to 6, thus maximum temperature is denoted as 1, minimum temperature as 2, morning and evening relative humidity as 3 and 4 respectively, rainfall as 5 and sunshine hours as 6. Thus, from the generated variable equations, the individual effect of maximum temperature without weights can be denoted as Z_{10}. Similarly, the individual and the interaction effect of all the weather variables are represented for the study. The appropriateness of the model developed was checked by using the coefficient of determination (R^2).

Multinomial logistic regression

The type of regression model wherein the dependent variable is found to be qualitative in nature which is affected by more than one independent variable is referred as logistic regression. The case in which dependent variable is having more than two outcomes is an extended form of the logistic regression which is termed as multinomial logistic regression. This is applied by using one of the categories as a baseline category using which other categories are being compared.

The model can be represented as:

$$Log\ (P(Y = k)/P(Y = K)) = \beta_{0k} + \beta_{1k} X_1 + \beta_{2k} X_2 + \ldots + \beta_{nk} X_n + \varepsilon$$

Where P(Y=k) represent probability of the concerned category and K is baseline.

The adequacy of the multinomial logistic regression is usually represented by the confusion matrix and accuracy values generated by the model. In this study, the BPH population count was categorized into three classes of epidemic incidence i.e. 'high', 'medium' and 'low' classes. This classification was carried out based upon the mean ($\bar{x}$) and standard deviation (σ) of BPH count data, i.e. count values below 'mean-standard deviation' ($\bar{x} - \sigma$) were classified as 'low incidence', those values that lie between 'mean-standard deviation to mean + standard deviation' range is classified as 'medium incidence' i.e. values between ($\bar{x} - \sigma$) to ($\bar{x} + \sigma$) and those values above 'mean + standard deviation' i.e. values above ($\bar{x} + \sigma$) as 'high incidence' of BPH population. The low level of incidence is considered as baseline category in this study.

RESULTS AND DISCUSSION

The distribution of BPH population count during the period of 1997 to 2023 over 52 SMW's is shown in (Fig 1). As observed in the plot, there is a distinct spike of BPH during 39th – 44th SMW and this period was considered as the peak period of incidence of the BPH population. Moreover 42nd SMW was selected as the peak week of incidence of BPH which showed the maximum BPH population over the study period. Samui *et al.* [14] analyzed the insect pest incidence in rice based on the peak period criteria. These findings were similar to those obtained by Firake *et al.* [15] wherein they observed August and September as the peak months of incidence. Further, Varadharajan (1979) in their study also identified September month as the peak incidence period of BPH. In the study conducted by Jeyarani [11] as well, September and October were found to be the peak period of incidence of BPH.

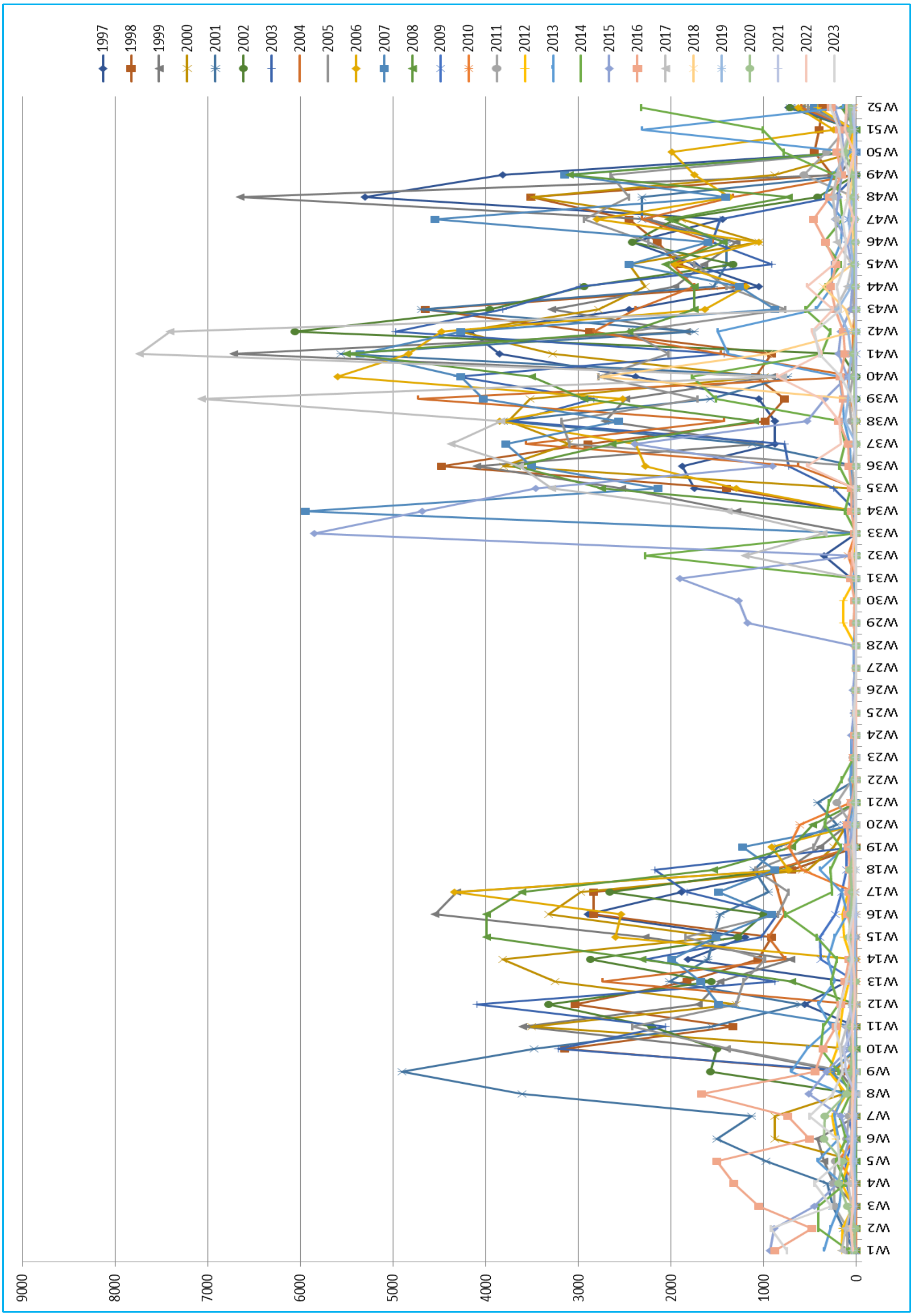

Fig 1 BPH incidence corresponding to 52 SMW's from 1997-2023

Correlation analysis

Correlation analysis based on Karl Pearson correlation coefficients revealed that there is a negative association between BPH population and maximum temperature of 38th – 43rd SMW. A significant negative association with minimum temperature of 39th- 44th SMW was also observed. Negative association with minimum temperature at one lag week as well as at two lag week was also identified. Morning relative humidity corresponding to 38th – 43rd SMW has shown maximum negative association with the BPH population. There was a significant negative association of evening relative humidity corresponding to 39th – 44th SMW with the BPH population. Rainfall during 35th – 40th SMW and sunshine hours corresponding to 39th – 44th SMW also had a significant positive association with the BPH incidence in the peak period. The results of correlation analysis performed between BPH population during 42nd SMW and weather variables of prior weeks showed a high negative correlation with the minimum temperature variable of 42nd SMW, whereas morning relative humidity of 39th SMW showed a negative association with the BPH population. It is found that the evening relative humidity corresponding to 41st SMW was having a negative association with the BPH emergence. Weather variables like sunshine hours of 42nd SMW and rainfall of 38th SMW showed a positive correlation with the incidence of BPH population (Table 1). Similar finding was reported by Krishnaiah [16], where a significant association of temperature and relative humidity with the occurrence of BPH was found. Negative correlation between BPH emergence and the weather variables were also explained by Kaur *et al*. [17]. From the study it is identified that a minimum temperature of 20 to 22 °C was present during the peak period of 39th to 44th SMW of incidence of BPH. Similarly, during the peak period, the morning relative humidity was in the range of 85 to 90% and evening relative humidity at 65 to 70%. Thus, indicating that these weather conditions were critical for the incidence of BPH.

Table 1 Correlation between Brown Plant Hopper (BPH) population and weather variables for peak period (39th – 44th SMW) and peak week (42nd SMW)

Peak week / Peak period	Significant variables	Week number of correlated variables	Correlation coefficient
SMW 39-44	T_{min}	39-44	-0.445**
	T_{max}	38-43	-0.261**
	RH I	38-43	-0.359**
	RH II	39-44	-0.350**
	RF	35-40	0.311**
	SSH	39-44	0.328**
SMW 42	T_{min}	42	-0.546**
	RF	38	0.39*
	RH I	39	-0.527**
	RH II	41	-0.548**
	SSH	42	0.410*

**significant at 1% level, *significant at 5% level

Multiple linear regression analysis

Multiple linear regression analysis was carried out based on the significantly correlated weather variables. Logarithmic transformation of the BPH count data is carried out since the data deviates from the normality assumption. The obtained multiple linear regression models for the selected peak period are given in (Table 2).

During the analysis for peak period corresponding to 39th - 44th SMW, the model obtained had independent variables like minimum temperature of 39th - 44th SMW, morning relative humidity of 38th – 44th SMW and evening relative humidity of 39th – 44th SMW as these were the significant variables identified for the regression analysis. The model yielded an adjusted R^2 value of 0.39. During the peak week corresponding to 42nd SMW, it is noticed that minimum temperature of 42nd SMW, morning relative humidity of 41st SMW and evening relative humidity of 39th SMW were the significant independent variables. The fitted model had an adjusted R^2 value of 0.45. The multiple linear regression analysis showed the significance of weather variables like minimum temperature, morning and evening relative humidity in model development. This is similar to the findings of Prasannakumar and Chander [18] wherein the relative humidity factor was found to be key variable in multiple linear regression analysis of BPH.

Table 2 Multiple linear equation models for forecasting Brown Plant Hopper (BPH) during different peak weeks/periods

Peak SMW / peak period of BPH	Model	Adjusted R^2
39th - 44th	log BPH = 18.54** - 0.47** T_{min} - 0.01** RH I - 0.02** RH II T_{min} - 39-44th week RH I -38-43rd week RH II -39-44th week	0.39
42nd	log BPH = 28.81** - 0.54** T_{min} - 0.07* RH I - 0.06** RHII T_{min} – 42nd week RH I- 41st week RH II – 39th week	0.45

**significant at 1% level, *significant at 5% level

Composite regression models

The correlation of BPH population count with the product of weather variables in different combination during peak period is being calculated and significant combinations of weather variables are given in (Table 3). In case of composite regression, the generated variables are of two types, unweighted variables and weighted variables for individual and interaction effect where the weights correspond to the correlation coefficients between the individual and joint effects of weather variables with BPH count [19].

The joint effect of maximum temperature and evening relative humidity during 39th-44th SMW showed the maximum association with the BPH incidence. Along with this, joint effect of maximum temperature and morning relative humidity, maximum temperature and rainfall, maximum temperature and sunshine hours, minimum temperature and morning relative humidity, minimum temperature and evening relative humidity was also having significant correlations with the emergence of Brown Plant Hopper (BPH) population [20]. In this case, the weighted interaction effect of minimum temperature and evening relative humidity (Q_{241}) as wells as unweighted individual effect of evening relative humidity (Z_{40}) were found significant in model development. The generated composite regression had an adjusted R^2 value of 0.47. The unweighted individual effect of evening relative humidity (Z_{40}) and weighted interaction effect of the maximum temperature and evening relative humidity (Q_{141}) were also found to be significant for developing composite regression model. The model had an adjusted R^2 value of 0.50 (Table 4).

Table 3 Correlation between BPH population and joint weather variables for peak period (39th – 44th SMW)

Peak week/ peak period	Significant combination of variables	Correlation coefficient
SMW 39-44	T_{max} * RH I	-0.417**
	T_{max} *RH II	-0.473**
	T_{min} *RH I	-0.409**
	T_{min} *RH II	-0.461**
	T_{max} *RF	0.314**
	T_{max} *SSH	0.247**

**significant at 1% level, *significant at 5% level

The composite regression model thus revealed the significant impact of combination of temperature and relative humidity on the emergence of BPH population. Similar kind of results were obtained by Agrawal *et al.* [21] where they found the joint effect of temperature and relative humidity on the incidence of pod fly in pigeon pea. The joint effect of weather variables in the composite regression models were able to provide improved results in terms of an increased adjusted R^2 values and also indicated that combination of weather variables were better determinants to predict the incidence of BPH in comparison to individual effect of each variable as considered in the multiple linear regression.

Multinomial logistic regression

A multinomial logistic regression model was fitted using significant weather parameters to identify the epidemic status of the BPH population during the peak period of incidence. Low level of incidence of Brown Plant Hopper (BPH) was selected as the reference category for the multinomial logistic regression model. In case of peak period corresponding to 39th – 44th SMW, minimum temperature and evening relative humidity were the independent variables selected in the model. The log odds values represented in (Table 5) indicated the significance of weather variables. The log odds of being in medium level when compared to low level decreased by 0.41 for an increase in minimum temperature Similarly, log odds of being in high level decreased by 0.61 for an increase in minimum temperature and log odds of being in high level versus low level decreases by 0.06 for an increase in evening relative humidity. The model accuracy was found to be 66 % for this peak period [22-23].

Table 4 Composite regression model for peak period of 39th -44th SMW

Peak period	Variables	Regression coefficient	Adjusted R^2
SMW 39-44	Intercept	16.90**	0.50
	Z_{40}	-0.11*	
	Q_{141}	0.004*	
SMW 39-44	Intercept	10.53*	0.47
	Z_{40}	-0.017*	
	Q_{241}	0.0027*	

**significant at 1% level, *significant at 5% level

In case of peak week corresponding to 42nd SMW, the variables utilized for the model were minimum temperature, morning and evening relative humidity. The log odds of being in medium level when compared to low level decreased by 0.87 for an increase in minimum temperature and in case of high level, the log odds of being in high level versus low level decreased by 0.53 for an increase in minimum temperature, decreased by 0.56 for an increase in morning relative humidity and decreased by 0.20 for an increase in evening relative humidity [24-25]. An accuracy measure of 64% was found for composite regression corresponding to 42nd SMW of Brown Plant Hopper (BPH) (Table 5).

Table 5 Coefficients of multinomial regression model for peak period (39th - 44th SMW) and peak week (42nd SMW)

Peak week/ Peak period	Variables	Medium level	High level	Accuracy
SMW 39-44	Intercept	10.70**	18.04**	66%
	T_{min}	-0.41*	-0.61**	
	RH II	-0.01	-0.06*	
SMW 42	Intercept	44.95**	76.27**	64%
	T_{min}	-0.87*	-0.53**	
	RH I	-0.24	-0.56**	
	RH II	-0.02	-0.20*	

**significant at 1% level, *significant at 5% level

The multinomial logistic regression analysis demonstrated that specific weather parameters significantly influence the epidemic status of Brown Plant Hopper (BPH) populations during peak incidence periods. Minimum temperature consistently emerged as a critical predictor, with increases in temperature associated with reduced likelihoods of both medium and high infestation levels relative to low incidence. Evening and morning relative humidity also played notable roles, particularly during the 42nd Standard Meteorological Week (SMW) peak week. The models achieved moderate prediction accuracies of 66% and 64% for the broader peak period (39th–44th Standard Meteorological Week) and the specific peak week (42nd SMW), respectively. These findings underscore the importance of incorporating climatic variables into predictive models for timely and effective pest management strategies [26-27].

CONCLUSION

The study investigated the suitability of various regression models that can be used to forewarn the incidence of brown plant hopper in rice. The regression models fitted in the present study acted in different manner on the selected peak periods of the Brown Plant Hopper (BPH) population and helped to understand the population dynamics of the Brown Plant Hopper (BPH) in relation with the weather variables. While the multiple linear regression model enables in identifying individual effect of various weather variables on the BPH incidence, composite regression models explained the joint effects of weather variables (temperature and relative humidity) on the Brown Plant Hopper (BPH) population and also had a higher predictive power in comparison to the multiple linear regression model. The multinomial logistic regression model fitted showcased a different approach in understanding the population dynamics; wherein the epidemic status of the Brown Plant Hopper (BPH) population was predicted. The study was able to determine that minimum temperature was the most significant weather parameter contributing to the prediction of epidemic levels of BPH population during the selected peak period of incidence.

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Competing interests

The authors declare no competing interests.

Author contributions

Concept creation and methodology constructed by Abishek K and Sajitha V M. Data provided and technical assistance given by Karthikeyan K, Sajitha V M, Dayana D and Chitra P. All the authors read and approved the manuscript.

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