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Research Paper

Effect of weather variabilities on dispersion pattern of *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae) in paddy field

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ABSTRACT

Field experiments were conducted to find out the impact of weather factors and crop phenological stages on the dispersion pattern of brown planthopper (BPH), *Nilaparvata lugens* (Stål) in paddy during *kharif* 2019 and 2020 at three paddy crop phenological stages like the active tillering stage (IV week of July to III week of August), panicle bearing and grain filling stage (IV week of August to III week of October) and grain maturity stage (IV week of October to IV week of November). Weather factors in relation with mean BPH population were subjected to multiple regression and correlation analysis. The dispersion patterns were studied by regression models using Index of dispersion, Elliott's law, Taylor's Power Law and Iwao's patchiness regression model. Maximum population of BPH was observed during panicle bearing and grain filling stage at 108 days after transplanting. The BPH counts were fitted to negative binomial which indicated aggregated distribution in the field and most of the weather parameters like temperature, evening relative humidity and wind speed is negatively correlated during this stage. During active tillering and grain maturity stage, Poisson distribution pattern of BPH population in the field was observed which showed random distribution.

Keywords: Brown planthopper, Elliott's law, Iwao's model, Taylor's Power Law, temperature, relative humidity, dispersion

Rice is a tropical crop and is estimated that alone in South and Southeast Asia, it is cultivated on 108 million hectares (FAO, 2019). In India, most rice production is irrigated therefore temperature is the most important climatic factor to investigate in climate change context. There are several insect herbivores feeding on rice and there is direct correlation with changes in their life cycle and global climate peculiarities (Ali, 2021). Among all these insects, brown planthopper (BPH), *Nilaparvata lugens* (Stål) is one of the major and most destructive pests of rice (Sarao, 2015). BPH nymphs and adults are phloem sap feeders. This leads to yellowing of leaves, less tillering and unfilled grains. In case of severe attack during vegetative to reproductive stage of rice, it leads to condition called as "hopper burn". It also acts as the vector for viral diseases such as rice grassy stunt and ragged stunt. More than 60% reduction in yield is observed in case of large *N. lugens* populations (Kumar *et al*., 2012b).

There are various abiotic and biotic factors that influence the development and growth of BPH. The degree of effect of various environmental factors determined the magnitude of pest population increase or decrease (Prasad *et al.,* 2008). Insects are poikilothermic organisms which leads to internal body temperature same as that of the environment. Therefore, temperature is the only most efficient environmental factor affecting the behaviour, distribution, development, survival and reproduction of insects. Due to the economic importance of BPH, various studies have been conducted to assess the temperature tolerances and temperature profiles of these planthopper (Piyaphongkul *et al.,* 2014; Ali *et al.,* 2021). For a specific agro-ecosystem, knowledge on abundance and distribution of pest in association with weather parameters is a fundamental requirement for the development of effective management strategies (Patel and Shekh, 2006). The information on crop phenological stages, BPH population distribution and weather factors is important because crop growth stages and weather factors affect the extent to which pest severity is associated to yield. Also, the monitoring of BPH population levels and timings of insecticide applications carried out at the crop phenological stages can be adjusted so that damage can be restricted. Keeping above factors in mind, the present studies were conducted over the years to bridge the knowledge gap between BPH population, weather factors and paddy phenological stages under field conditions.

MATERIAL AND METHODS

The present investigations were carried out at Rice

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Research Area, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana (30°54'N latitude; 75°48'E longitude and altitude of 247 m above mean sea level) during 2019 and 2020 *kharif* crop seasons. The crop was raised as per recommended package and practices except pesticide application (Anonymous, 2019). For the collection of data, entire plot of 1500 m^2 area was divided into 60 blocks each of 5×5 m in size and number of BPH adults and nymphs were counted at a rate of five hills per plot selected randomly from each plot. The hills were slightly tilted and tapped two or three times at the base. BPH seen floating on the water or that had fallen to the ground were counted. Observations were recorded at three days interval, starting 30 days after transplanting until the crop maturity. Meteorological data were collected from the meteorological observatory of Punjab Agricultural University, Ludhiana, India (30°54'N latitude and 75°48'E longitude, 247 m above mean sea level).

Statistical analysis

The role of abiotic factors on the abundance of *N. lugens* were statistically analyzed using stepwise linear regression and correlation using SPSS 16.0 software and PCA and correlogram (visualization of a correlation matrix) were plotted by R software (IBM SPSS, 2017; R core Team, 2017). A set of observations of potentially correlated variables are transformed via an orthogonal transformation in the statistical process known as principal component analysis (PCA) into a (potentially smaller) set of values of linearly uncorrelated variables known as principle components (Pandit *et al.,* 2022). The number BPH per plant is a response variable whereas maximum temperature, minimum temperature, morning and evening relative humidity, total rainfall, sunshine and wind speed are the predictor variables. To explain the dispersion pattern of arthropods many methods have been summarized. In this study, the dispersion pattern of BPH was studied using statistical measurements as shown in table and described here under:

Parameter	Formula	Spatial distribution pattern	Reference
Index of dispersion	$I_D=(n-1)S^2/m$	Random when $S^2/m=1$, regular when $S^2/m=<1$ and aggregated when $S^2/m=>1$	Cox and Lewis, 1966
Taylor's power law	$S^2=am^b$	Random when $b=1$, regular when $b<1$ and aggregated when $b>1$	Taylor, 1961
Iwao's patchiness regression	$m^*=\alpha+\beta m$	Random when $\beta=1$, regular when $\beta<1$ and aggregated when $\beta>1$	Iwao, 1968

RESULTS AND DISCUSSIONS

Weather variabilities v/s BPH dispersion patterns

Abiotic factors play a major role in understanding the geographical distribution and periodic abundance of major insect pests in rice (Singh *et al.,* 2012). The data for both the *kharif* crop seasons (2019 and 2020) were combined for all the three crop phenological stages. To check the association between one or more independent variables and a dependent or target variable regression models were applied on the data. In order to authenticate our results two regression models i.e. Taylor's power law and Iwao's patchiness regression were used. Both these regression models have been commonly used to assess developing sampling protocols for many insects, to evaluate dispersal and for normalizing of data for statistical analysis (Deligeorgidis *et al.,* 2002). The data of mean BPH population and standard normal deviate (d) indicating discrete frequency distribution on paddy along with weather parameters from August to November are shown in Table 1.

Active tillering stage

The results revealed that the population of BPH varied significantly due to the weather factors ($P\leq0.05$). The population of hoppers started in the first week of August, increased gradually upto 57 DAT (Table 1). Significant positive correlation was observed with morning (r=0.74) and evening (r=0.78) relative humidity, sunshine (r=0.71) and wind speed (r=0.61) (Table 2). Regression coefficient explains variation in BPH population with respect to maximum temperature, minimum temperature, morning and evening relative humidity, sunshine and wind speed (Table 3). Principle component analysis (PCA) was used to perform multivariate analysis so as to reduce the dimensions of data. The variables were transformed into principal components (PC) because principal components are the newly generated variables constructed as linear combinations of the initial variables. Khokhar and Rolania (2021) also used PCA to study population dynamics of aphid and its coexisting predators in tomato agroecosystem. PCA (Fig 1a) and correlogram (Fig 1b) during active tillering stage, PC1 and PC2 capture shows 60.1 and 21.9% variability in data, respectively. It explains that negatively correlated variable (minimum temperature) is positioned on the opposite side of the quadrat, whereas, positively correlated variables (maximum temperature, morning and evening relative humidity, wind and sunshine) are positioned on the same side of the axis. The distance between each vector component explains the significance of each variable i.e. lesser the distance more significant is the relation (Fig 1a). The length of the vector explains the variance due to that vector i.e. longer the vector length, the more is the variation caused by the vector (Fig. 1a). The mean BPH population over the years (2019 and 2020) varied from 0.09 to 0.86 (30 to 57 DAT) and the value of standard normal deviate (d) remains negative during this stage, which indicates the random distribution of the BPH in the field (Table 1). Values of Taylor's law (b=1) and regression equation as Y = 1.00 log x+ 0.03 (R^2=0.96) also revealed the random distribution pattern of BPH in the field. According to Iwao's patchiness regression, the density contagiousness coefficient (β) values indicated random distribution of BPH in the field because the β values were almost equals to ١. The regression equation for mean crowding index and density relationship of BPH according to Iwao's law was Y = 0.99 x - 0.03 (R^2=0.96) for active tillering. The data showed that during this stage BPH population was low at the beginning due to high temperature but as temperature started to decrease in the last week of August (about 53 DAT) population begin to rise. Comparable results were given by Chaudhary *et al.,* (2014) who explained that at the beginning, the incidence of BPH was low and with the growth of vegetative stage of crop, the

Table 1: Discrete frequency distribution values for *N. lugens* population in relation to weather parameters during various rice crop growth stage over the years (2019 and 2020)

Crop phenological stage	Max. Temp.	Min Temp.	Relative humidity		Sunshine	Wind km/h	Mean (X)	Standard normal deviate (d)	Discrete frequency distribution	Chi square (χ^2)
			M	E						
Active tillering	33.22	27.23	79.95	62.72	7.27	3.21	0.51	-0.96	Poisson	6.45 NS*
Panicle bearing and grain filling	33.02	22.97	85.06	53.12	6.85	2.60	2.15	5.42	Negative binomial	21.76 NS*
Grain maturity	25.92	12.57	87.8	43.3	4.67	2.794	1.17	-4.62	Poisson	6.32 NS*

*NS = Non significant at 5% level

Table 2: Correlation between population of *N. lugens* and weather parameters in paddy crop

Crop stage	Max temp.	Min temp.	Morning RH	Evening RH	Wind	Sunshine
Active tillering	0.57^{NS}	-0.64^{NS}	0.74^{*}	0.780^{*}	0.61^{NS}	0.71^{*}
Panicle bearing and grain filling	-0.63^{**}	-0.85^{**}	0.06^{NS}	-0.82^{**}	-0.20^{NS}	0.01^{NS}
Grain maturity	0.93^{**}	0.77^{*}	0.07^{NS}	-0.55^{NS}	0.08^{NS}	-0.47^{NS}

*Significant at p=0.05 (2-tailed); ** Significant at p=0.01 (2-tailed)

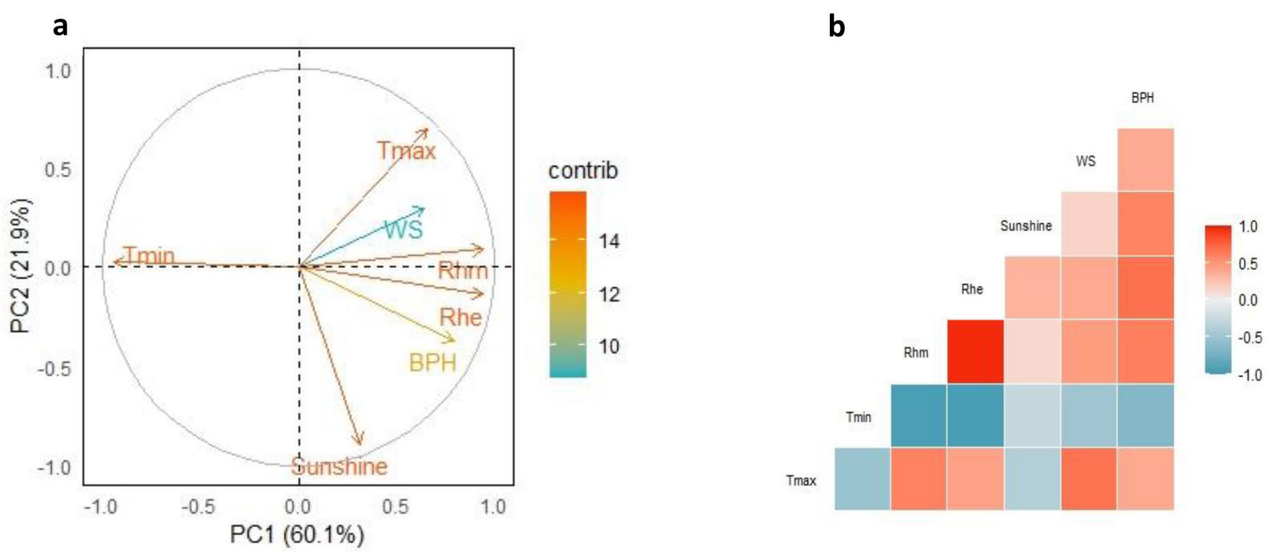

Fig. 1: PCA (a) and Correlogram (b) explaining the relation between *N. lugens* population during active tillering stage of paddy.

population also increases.

Panicle bearing and grain filling

During panicle bearing and grain filling stage, mean BPH population was found to be negatively correlated with maximum (r=-0.63) and minimum (r=-0.85) temperature, evening relative humidity (r=-0.82) and wind speed (r=-0.20), whereas sunshine (r=0.01) and morning relative humidity (r=0.06) were non significantly positively correlated (Table 2). Variations in population due to various weather factors as explained by regression coefficient are depicted in Table 3. In this stage, the mean BPH population varied from 0.94 to 3.90 (61 to 119 DAT). The value of d has varied from -0.06 to 9.03. These values were more than 1.96 except at 64, 72 and 115 DAT, which indicates aggregated distribution behaviour of BPH individuals. Also, peak population of BPH was observed during this stage at 108 DAT. Taylor's law and regression equation Y = 1.19 log x+ 0.11 (R^2=0.89) further also indicated aggregated distribution pattern of BPH during this stage. Likewise, β values of Iwao's patchiness regression were significantly >1 (1.11) indicated aggregated distribution pattern of BPH in the field. The regression equation for mean crowding index and density relationship of BPH according to Iwao's law was Y= 1.66 x – 0.25 (R^2=0.86). PCA analysis (Fig 2a) and correlogram (Fig 2b) showed that PC1 and PC2 captured 18.8 and 49.9 per cent of the variability in data, respectively. It indicates all the weather factors such as maximum temperature (r=-0.63), minimum temperature (r=-0.85), evening relative humidity (r=-0.82) and wind speed (r=-0.20) are on the opposite side of quadrat except morning relative humidity (r=0.06) and sunshine (r=0.01). Present observations are also in line with Jeyarani (2004) who reported the occurrence of the BPH peak population during September and October months. During this stage, although temperature and RH decrease (after 91 DAT) but insect population increased significantly and becomes aggregated.

Table 3: Regression between population of *N. lugens* and weather parameters in paddy crop

Crop stage	Max temp.	Min temp.	Morning RH	Evening RH	Wind	Sunshine
Active tillering	0.15	0.42	0.38	0.48	0.00	0.45
RMSE	0.23	0.19	0.20	0.49	0.29	0.21
Accuracy	0.46	0.38	0.40	0.97	0.57	0.42
Panicle bearing & grain filling	0.49	0.85	0.03	0.80	0.04	0.00
RMSE	0.67	0.35	1.01	0.42	0.89	0.90
Accuracy	1.32	0.70	2.06	0.82	1.75	1.76
Grain maturity	0.86	0.56	0.00	0.43	0.00	0.18
RMSE	0.39	0.71	1.07	0.80	1.00	0.90
Accuracy	0.77	1.39	2.10	1.58	1.96	1.77

RMSE= Root mean square error stage of paddy.

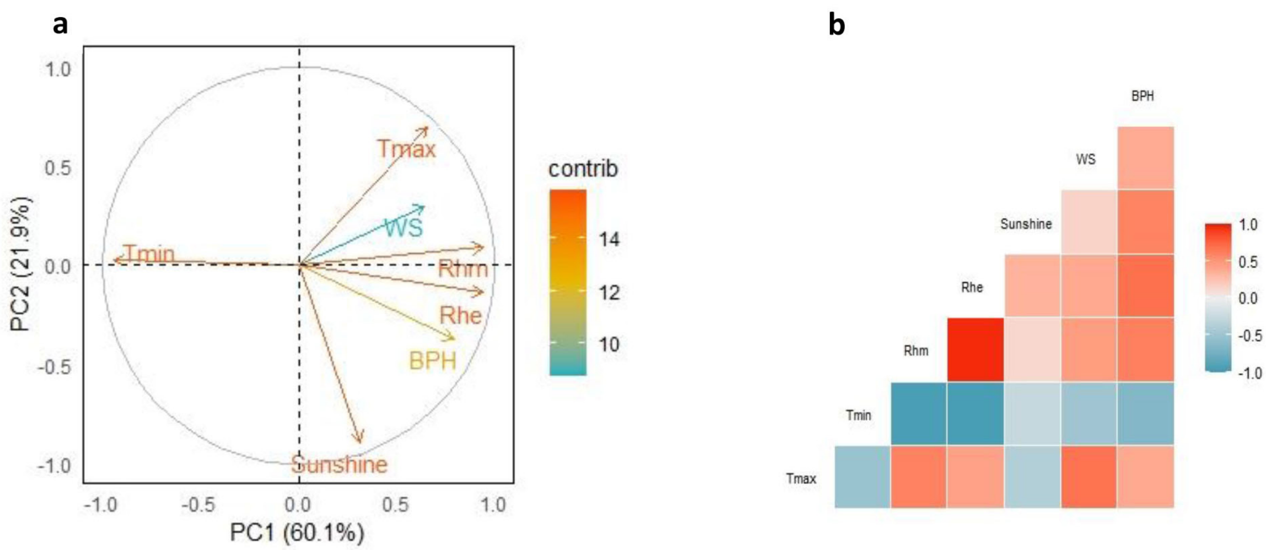

Fig. 1: PCA (a) and Correlogram (b) explaining the relation between *N. lugens* population during active tillering stage of paddy.

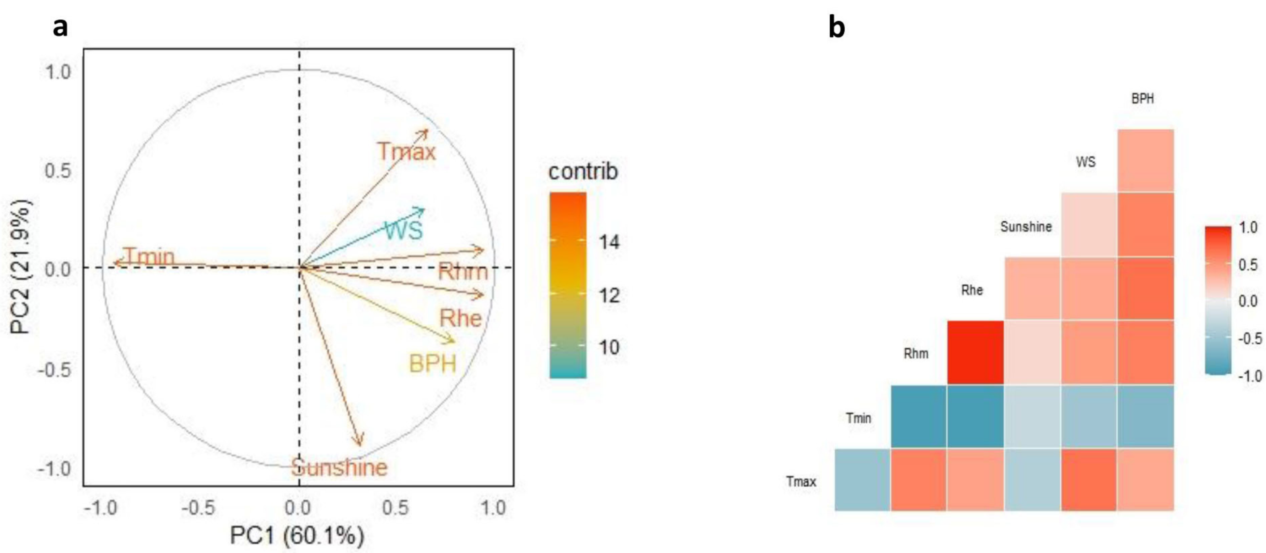

Fig. 1: PCA (a) and Correlogram (b) explaining the relation between *N. lugens* population during active tillering stage of paddy.

During this crop growth stage, the phloem sap of rice plants also be rich in carbohydrates and proteins, which may lead to higher reproduction rate and more population buildup of BPH along with abiotic factors (Horgan *et al.,* 2021). Our studies are corroborated with the findings of Kumar *et al.,* (2012b) who also observed that the distribution pattern of BPH was negative binomial or clumped or aggregated, due to which hopper burn symptoms occur in clusters in the rice fields.

Grain maturity

In grain maturity crop growth stage, mean BPH population was found to be significantly positively correlated with maximum (r=0.93) and minimum temperature (r=0.77) (Table 2). PCA analysis (Fig 3a) and correlogram (Fig 3b) during grain maturity stage indicated that PC1 and PC2 captured 22.8 and 50.1 per cent of the variability in data, respectively and indicates that all the weather parameters except negatively correlated sunshine and evening relative humidity on same side of quadrat. During this stage, the mean population was observed as 0.1 to 3.56 hoppers. The value of d varied from 0.84 to 2.19 upto 131 DAT and there after varied from -3.94 to -6.27. During grain maturity crop growth stage, the value of Taylor's power law aggregation parameter (b=1) and regression equation Y = 1.58 log x - 0.55 (R^2=0.85) revealed the random distribution pattern of BPH. Whereas, the β value was 0.97 and the regression equation for mean crowding index and density relationship of BPH was Y = 1.11x - 0.25 (R^2=0.93). This indicated random distribution pattern of BPH. Thus, this data revealed that during this stage temperature and relative humidity were very low and population of BPH also tends to decrease as the crop reaches towards maturity.

Linear regression models to study dispersion pattern

Iwao's patchiness regression explained comparable results to Taylor's power law for the dispersion patterns of BPH population in the field. In both the regression models, the BPH population explained 85 to 96% variations in random or aggregated distribution patterns of BPH. This determines that Taylor's power law and Iwao's regression model gave a good fit to mean and variance ratio of BPH population. Also, it was earlier suggested that aggregated and random distribution patterns had been the most common feature of arthropod populations, whereas regular distributions occurred rarely, only in populations with strong intra-specific competition (Argov *et al.,* 1999).

Stepwise linear regression equation to study weather variabilities in asscociation with BPH population

To find the set of weather (independent) variables that significantly influence the BPH (dependent) population, stepwise linear regression equation was established. During whole paddy growth season, the most important variables contributing significantly towards the variance in the BPH population were maximum and minimum temperature, and evening relative humidity accounting for 70 per cent variability in the BPH population. Sarkar *et al.* (2018) performed population dynamics of BPH and its correlation with weather parameters and observed that maximum temperature, minimum temperature, morning relative humidity and evening relative humidity were favourable for peak population of BPH. The linear regression equation developed for prediction of BPH population is:

$$Y= -3.71+0.36\ Tmax-0.18\ Tmin+ RH\ Evening$$

CONCLUSION

The current study revealed that the distribution pattern of BPH followed random pattern at the beginning (active tillering stage) and end (grain maturity stage) of rice crop season. In panicle bearing & grain filling stage, the BPH population started to increase and become aggregated and follows negative binomial distribution as in this stage temperature drops down significantly as compared to active tillering stage. According to coefficient of correlation and regression during all the stages, sunshine and wind speed does not significantly affect the population. But stepwise linear regression equation at all the three crop growth stages explained that among all the weather factors, maximum temperature, minimum temperature and evening relative humidity contributes maximum in dispersion of *N. lugens* in field. During the stage of maximum BPH population, temperature had a negative and significant correlation indicating that decreasing temperature during month of September and October tends to increase the population and during final paddy stage (grain maturity stage), temperature is positively correlated with population indicating very low temperature and crop maturity leads to decrease in BPH population.

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Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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