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Effect of weather parameters and varieties on occurrence of insect pests and natural enemies of rice

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Abstract
The study on effect of weather parameter and rice varieties on occurrence and population fluctuation of insect pests and natural enemies conducted at Assam Agricultural University during 2016-17 revealed that amongst four different popular rice varieties, traditional variety *Black rice* was the least preferred by the insect pests attacking rice, while traditional scented rice variety *Kola Joha* (scented rice) was found to be highly susceptible to insect infestation. The peak appearance of case worm and whorl maggot was found to be restricted to 33rd-34th Standard Meteorological Week (SMW), while leaf folder in 37th-38th SMW, gundhi bug in 43rd-45th SMW and green leaf hopper in 38th-39th SMW. The population build up of case worm, whorl maggot and leaf folder was found positively correlated with max. temperature (Tmax), min. temperature (Tmin) and rainfall (RF); while rice hispa and stem borer were positively correlated to Tmax and Tmin but negatively correlated with morning relative humidity (RHm), and gundhi bug was found negatively correlated with Tmax and Tmin and positively correlated with RHm.

Keywords: Rice, insect pests, variety, weather parameters, correlation, regression

Introduction
Rice, the oldest (Fernando, 1977) [13] and second most intensively cultivated cereals reported to be first cultivated in Asia (Grist, 1965) [18]. Out of the major rice growing countries in the world, China and India collectively shares 50% of world's total rice production. About 90 per cent of the world's rice production i.e. 653.83 MT is produced on 143 million hectares in Asia (FAO, 2011) [14]; while, India contributes about 157.90 MT annually sharing 22% of world's production (Kakde and Patel, 2014) [26] with a productivity of 2372 kg/ha (Tetarwal *et al.*, 2014) [41], which is comparatively less than some other countries. Rice has been cultivated in Assam since time immemorial and is the most dominant crop occupying about 80% of the total agricultural land of the region (Islam *et al.*, 2004) [23], covering approximately 25.03 lakh hectares under autumn, winter and summer crops during 2013-14 (Anon. 2016) [6] with a productivity averaging 1,500-2,101 kg/ha, which is less than the national average. In Assam, the rice growing seasons can be broadly divided into *sali / kharif* or *winter* (June/July to November/December); *ahu* or *autumn* (March/April to June/July); and *boro* or *summer* (November/December to May/June) based on geoclimatic variations. Among the predominant crop sequences, the rice-rice cropping pattern is generally practiced in traditional rice growing areas with high rainfall during *kharif* and assured irrigation during *summer* season. As such, rice is present in the field year round, which provides a suitable environment to continue in the same field year after year.

Out of several constraints contributing towards low productivity, insect pests, diseases and other biotic stresses are the major ones causing a yield loss of about 30.0%. Moreover, cultivation of high yielding rice cultivars with excessive use of nitrogenous fertilizers has already aggravated the situation. Approximately 100 insect pests have been reported to attack the rice crop at different stages of crop growth under various seasons, out of which 20 are considered to be major pests with varied degree of yield loss depending upon the agroclimatic situations (Cramer, 1967; Pathak and Dhaliwal, 1981; Kumar *et al.*, 2015) [11, 36, 30]. The Natural Resources Institute (NRI), London has developed a methodology for ranking different pests and diseases affecting agricultural crops of South Asia (Geddes and Lles 1991) [16] and ranked rice yellow stem borer, *Scirpophaga incertulas* Walker (Pyralidae : Lepidoptera) as the principal yield reducing insect factor holding second place after rice blast (Pathak and Khan, 1994). According to another report, the yield loss estimates due to yellow stem borer, brown plant hopper, gall midge, leaf folder and other pests are 25-30, 10-70, 15-60%, 10% and 25%, respectively (Krishnaiah and Varma, 2013) [29]. Moreover, intensification of rice cultivation resulted in change in pest scenario, making it difficult to manage them. In addition, abiotic factors also play an important role for determining the seasonal abundance of major insect pests in rice (Singh *et al*., 2012) [39]. Therefore, it is necessary to document them scientifically, and to analyze critically to understand why this is happening. Considering the above facts, the study on influence of different abiotic factors along with plant characteristics on incidence of insect pests in rice was undertaken and the data were summarized below.

Materials and Methods

Geographical location and season of investigation

The present investigation was conducted in Instruction Cum Research (ICR) Farm, Assam Agricultural University (AAU) of Jorhat districts of Assam (26.71°N, 94.19°E and 97.3 meter above MSL) during 2016-17.

Sampling and experimentation procedures

During the course of study, three most popular local rice varieties *viz*., black rice (special rice), kola joha (scented rice) and mahsuri (most preferred rice) along with a high yielding rice variety *viz*., *Ranjit* were grown in an area of 1333.0 m^2 following standard package of practices during 2016-17. Out of the total cultivated area, an area of 1000 m^2 at the middle of the plot was considered for subsequent data collection and analysis. The data on population dynamics of insect pest and natural enemy complex were recorded early in the morning at weekly interval starting from 15 days after transplanting till harvesting of the crop. The data on abundance and diversity were collected by following standard visual count and identification or capture, identification and release methods (Anon., 2002) [4]. The case worm (CW), *Nymphula depunctalis* (Pyralidae : Lepidoptera), whorl maggot (WM), *Hydrellia philippina* Ferino (Ephydridae : Diptera) and leaf folder (LF), *Cnaphalocrocis medinalis* Guenee (Pyralidae : Lepidoptera) were counted by percent leaf damage per hill and population of green leaf hopper (GLH), *Nephotettix nigropictus* Stal. and *N. virescens* Stal. (Cicadellidae : (Hemiptera), white backed plant hopper (WBPH), *Sogatella furcifera* (Delphacidae : Hemiptera) and grass hopper (GH), *Hieroglyphus banian* (Acridiidae : Orthoptera), rice hispa (RH), *Dicladispa armigera* (Olivier) (Chrysomelidae : Coleoptera), gundhi bug (GB), *Leptocorisa acuta* (Thunberg) (Alydidae : Hemiptera), stem borer (SB), *Scirpophaga innotata* Walker and *S. incertulas* Walker (Pyralidae : Lepidoptera) and whorl maggot (WM), *Hydrellia philippina* Ferino (Ephydridae : Diptera) were recorded as numbers of insect per hill. Population estimation of dominant natural enemies like dragon and damsel fly (DDF) (numbers per square meter), spiders (SP) (numbers per square meter) and coccinelid beetles (CB) (numbers per hill) were also recorded early in the morning at weekly interval and all the data were subjected to statistical analysis. Damage caused by each pest was counted by the following equations (Chakraborty and Deb, 2011a; Mondal and Chakraborty, 2016) [8].

$$\text{LF/CW/WM (infestation \%)} = \frac{\text{Numbers of damaged leaves}}{\text{Total numbers of leaves}} \times 100$$

Influence of abiotic factors on insect pest population

Meteorological parameters, *viz*., maximum and minimum temperatures, relative humidity (morning at 8.30 AM and evening at 15.30 PM), rainfall and bright sunshine hours (BSSH) for the entire period of study were obtained from the Meteorological Observatory of the Department of Agrometeorology, Assam Agricultural University, Jorhat during 2016-17. Influence of abiotic factors on insect pests and natural enemies on different rice varieties were assessed through correlation and regression analyses. A simple correlation analysis was done between the mean population of rice insect pests along with their dominant natural enemies in different rice varieties and meteorological parameters to know the influence of weather factors. The average meteorological data for standard meteorological weeks were calculated and correlated for their influence on population build up. To calculate correlation coefficient (r), the following standard statistical formula was adopted.

$$r = \frac{\sum xy - \frac{\sum x . \sum y}{N}}{\sqrt{\left(\sum x^2 - \frac{(\sum x)^2}{N}\right)\left(\sum y^2 - \frac{(\sum y)^2}{N}\right)}}$$

Where,
r = Co-efficient of correlation
N = Number of observation or pairs of scores
x = Mean population
y = Independent variable
Then the correlation co-efficient (r) was tested for significance or non-significance by Fisher 't' test, which can be defined as follows

$$t = \frac{r}{\sqrt{(1-r^2)}} \times \sqrt{(n-2)} \text{ with (n-2) degrees of freedom}$$

Simple regression line was fitted to know the impact of meteorological parameters on the population of insect pest and natural enemies of rice appearing on the most popular rice variety *Ranjit* during 2016-17. The regression line was obtained with the formula given below –

$$y = a + bx$$

Where,
y = Dependent variable
x = Independent variable
a = Intercept

Results and Discussion

Pest and natural enemy complex analysis in rice

Variety - Ranjit

The data on seasonal incidence of insect pests and natural enemies (NE) of rice during 2016-17 are presented in Figure 1a against the Standard Meteorological Week (SMW). The population of nine persistent insect pests, *viz.* CW, WM, LF, RH, GLH, WBPH, GH, GB and SB, and three NEs, *viz*., SP, DDF and CB were found fluctuated in all the four rice varieties *viz*., *Black rice*, *Kola joha*, *Mahsuri* and *Ranjit*; a few days after transplanting during the course of experimentation. The incidence of CW was found peaked during 3rd week of August, 2016 (34th SMW); and subsequently declined to minimum during 41st SMW. Likewise, WM caused 4.06% damaged leaves / hill at 1st week of August, 2016 (31st SMW) initially, which get peaked (8.49% damaged leaves / hill) during the 34th SMW, but declined to the minimum after the 42nd SMW. The incidence of LF was found maximum of 10.00% damaged leaves / hill during the 34th SMW, however, unlike that of CW and WM, it incidence continued till reproductive growth stage. This might be because of the fact that LF can complete three generations in a cropping season as reported by Sharma *et al.* (2013). The adults of RH was also seen sooner as 15 days after transplanting with two peaks at 33rd MSW (0.55 Nos./hill) and 43rd SMW (0.20 Nos./hill) but their population was found insignificant. A season round occurrence of GLH, WBPH and GH was recorded on rice variety *Ranjit* during 2016-17, ranging between 0.40 –1.05, 0.40 – 1.05 and 0.35 – 0.95 numbers/hill with a peak during 39th, 37th and 42nd SMW, respectively (Figure 1a). The GB started to appear from 3rd week of October (42nd SMW) onwards, but peaked (1.15 numbers/hill) during the 2nd week of November (45th SMW). The adults of SB are persistent throughout the cropping season with two peaks, one during 32nd SMW (0.60 Nos./hill) and another in the 39th SMW (0.65 Nos./hill). Present data are also in close conformity with the results of Kumar *et al*. (1995), who also reported peak appearance of dead heart during the 37th SMW with two peaks in 34th and 37th SMW.

Two groups of general predator occur in rice field during different growth stages is related to avoid competition, may be related to temporal resource partitioning, which helps them to coexist in the same nutritional niche. In any agro-ecosystem, spiders though play significant role in natural insect pest suppression, and it is estimated that a ratio of 1:2 is optimum for management of a particular insect pest (Hazarika *et al*., 2009) [22]. In our case, spider population fluctuation between 0.30 – 1.40 Nos./meter^2 occurred throughout the rice growing season, which, however peaked during 42nd SMW. The population of DDF was in between 0.25 – 0.85 Nos./meter^2 during 2016-17. The population of CB was found to be less during early stages of the crop, but it increased during later growth stages fluctuating in between 0.20 – 0.95 Nos./hill. Similarly some coexisting spiders or odonates have demonstrated coarse-grain differences in time and space with respect to food resources and habitat use; and the combined outcomes of interactions between bottom up factors and competitors determines the foraging discussions, which needs to be explained scientifically and is a virgin field of ecology, yet to be researched.

Variety- Black rice

Black rice is a high nutrient containing glutinous rice with a long history of cultivation in Southeast Asian countries such as China, India and Thailand (Kong *et al.* 2008) [28]. Variety *Black rice* is now a days getting popularity amongst the consumers because of the high nutrient content and medicinal properties. The data on seasonal incidence of insect pest and natural enemies during 2016-17 are presented in Figure 1b. The results revealed that the variety was least preferred as compared to popular rice varieties such as *Ranjit, Kola Joha* and *Mahsuri* by CW with a damage ranging between 0.74 – 4.39% damaged leaves/hill. Interestingly, no WM incidence was recorded along with a minimal population of RH peaking at 33rd SMW recording only 0.40 adults/ ill. The incidence of LF was found to appear during the 2nd week of August, 2016 (33rd SMW) and gradually increased to cause 6.37% leaf damage/hill (38th SMW), which was 3.67% less than that of incidence recorded in case of Var. *Ranjit*. GLH, WBPH and GH population build up was in a steady state in the tested varieties, with a peak during 40th, 41st and 36th SMW, respectively (Figure 1b). Similarly, Nath and Bhagawati (2002) [33] also reported that leaf hopper populated in seed bed during June – July which, however, peaked during October – November, which corroborate our results. The population GB was also found to be least, and started to appear from 42nd SMW with a peak of 0.85 Nos./hill during 2nd week of November (46th SMW). Unlike *Ranjit*, the population of SB in *Black rice* variety was fluctuating between 0.05 – 0.45 Nos. of adults / hill with only one peak during 32nd SMW (0.45 Nos./hill) and the population declined after 41st SMW (2nd week of October), which might because of the non-preference of the variety. Moreover, presence of anthocyanin, which is an antioxidant that gives the characteristic black colour, is constituted by cyaniding-3-O-glucoside and peonidin-3-O-glucoside sharing about 90% of the total anthocyanin content (Chang *et al*., 2010) [10] could play a role in their non-preference. This variety was also found containing high level of flavanoids along with other macro and micro-nutrients, might cause reduced appearance of insect pests on this variety. Hazarika and Dutta (1991) [21] also reported that presence of amylopectin elicits non-preference against RH. The appearance of spiders can also be seen throughout the rice growing season and fluctuates to a lower level in between 0.30 – 8.00 Nos./ meter^2, which peaked during 40th SMW. Likewise the population of DDF and CB was also lower and fluctuated in between 0.25 to 0.55 Nos./meter^2 and 0.45 Nos./hill, respectively during 2016-17.

Variety *Kola Joha*

Variety *Kola Joha* is a popular aromatic rice variety grown throughout Assam, and the data on seasonal incidence of insect pest and natural enemies of rice during 2016-17 (Figure 1c) revealed the highest incidence of insect pests. The incidence of CW was found to be as high as 14.01% damaged leaves/hill (32nd SMW). The WM damage was found to ranging between 0.24 – 10.14% damaged leaves / hill during early stages of crop growth (32nd SMW). The LF incidence started to appear from 33rd SMW (6.09% damaged leaves/hill) with a peak at 10.49 % damaged leaves/hill during 38th SMW, which however, continued to occur up to 2nd week of November, 2016. Alvi *et al.* (2003) [3] and Vinitha *et al.* (2015) [42] also reported that *C. medinalis* attack starts from 2nd week of August with a peak in the 2nd fortnight of September (39th SMW), which corroborates our results. Being an early season pest, the population of RH was maximum during 33rd and 34th SMW (0.40 Nos. of adults / hill), while the population of GLH was as high as 1.50 Nos. /hill during 3rd week of October, 2016 (43rd SMW), whereas the population of WBPH and GH were at 1.05 and 1.45 nos. of insect / hill on 38th and 43rd SMW, respectively (Figure 1c). The GB, appearing from the 41st SMW population was also as high as 1.35 Nos. /hill during 45th SMW (1st week of November, 2016). The population of SB had also showed two peaks during 33rd SMW and 38th SMW ranging in between 0.10 – 0.75 Nos. of adults /meter^2. In support of our present investigation, Xue-zhu *et al*. (2013) had also reported higher fitness of striped stem borer (SSB), *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae), *C. medinalis* and *N. lugens* in high quality aromatic rice varieties in China. Das *et al.* (2010) [12] had also reported incidence of insects pests particularly stem borers is more in aromatic rice varieties of Assam. Likewise, Jena *et al.* (2009) [25] also reported higher pest population in scented rice varieties in Orissa during 2001-2006. Ahmed *et al.* (1998) [1] have reported a higher crude protein (10.42%), soluble protein (5.72%), albumin (13.48%), globulin (15.86%), prolamine (5.77%), glutelin (64.65%), TSS (0.64%), reducing sugar (0.14%) non-reducing sugar (0.51%), starch (72.67%), amylose (21.39%), amylopectin (78.61%), P (0.28%), Ca (0.21%) and Fe (3.25mg/100g) in the rice variety *Kola Joha*; which might entice insect pests with increased growth parameters. Moreover, *Kola Joha*, contains a very strong aroma due to the presence of an aromatic compound, 2 acetyl-1 pyrroline (Ahmed, 2003) [2], which might act as a cue for insects to select this over others. The population of SP was as high as 1.10 Nos. /meter^2 at 38th SMW that coincided with the higher population of LF, GLH and WBPH. Likewise, the population of DDF and CB fluctuated in between 0.25 – 0.70 Nos. /meter^2 and 0.10 – 0.65 Nos. /hill, respectively during 2016-17.

Variety- *Mahsuri*

The data on seasonal incidence of insect pests and natural enemies during 2016-17 (Table 4 and Figure 1d) revealed that CW and WM, being the pest of vegetative stage recorded as high as 9.87% and 8.25% damaged leaves/hill during 34th SMW and got minimized from 40th SMW onwards. The incidence LF was

started to appear from 36th SMW (2.42 % damaged leaves/hill) with a peak of 7.77 % damaged leaves/hill during 38th SMW. Nirala *et al.* (2015b) [34] reported the maximum incidence of LF during 37th and 38th SMW in month of September, which is in close conformity with our results. The population of RH was ranging between 0.10 – 0.50 adults/hill in the early vegetative stage. GLH, WBPH and GH were found to appear throughout the crop stages and ranged in between 0.25 – 1.05, 0.20 – 0.65 and 0.30 – 0.95 insects/hill, respectively, which peaked at 38th and 38th SMW (Table 4). Begum *et al*. (2014) [7] reported the present of GLH species in higher numbers year round in all the three rice growing seasons, which supports our present investigation. The highest population of GB was recorded to be 1.15 Nos. /hill during 43rd SMW, which coincided the reproductive stage of the crop. The population of SB was found fluctuating in between 0.10 – 0.60 Nos./meter^2 which got peaked during 35th SMW. The population of SP, DDF and CB was ranging in between 0.35 – 0.95 Nos./meter^2, 0.25 – 0.60 Nos. /meter^2 and 0.25 – 0.65 Nos. / hill, respectively.

Correlation studies of major insect pests and natural enemies of rice

Different weather parameters such as maximum temperature (Tmax), minimum temperature (Tmin), morning relative humidity (RHm), evening relative humidity (RHe), total rainfall (RF) and bright sunshine hours (BSSH) affected population dynamics of insect pests and natural enemies. Hence, simple correlation studies were carried out and results are discussed below

Variety: Ranjit

Correlation studies of major insect pests and natural enemies with weather parameters during 2016-17 (Table 1) revealed that incidence of CW had a significant positive correlation with Tmax (r=0.706), Tmin (r=0.656) and RF (r=0.434), while significant negative correlation with RHm (r= -0.806). Gogoi and Bora (2013) [17] had also conformed positive correlation on CW incidence and total rainfall. Likewise, WM incidence also showed significant positive correlation Tmax (r=0.696), Tmin (r=0.745) and RF (r=0.550), while significant negative correlation with RHm (r= -0.631). During the course of investigation it was also found that heavy rain at vegetative growth stage favours the occurrence of CW population but a drought like situation favours appearance of WM. While attack of CW was always less in *rabi* season as the rainfall is very scanty during early crop growth period; while this favours appearance of WM at a higher rate. LF incidence revealed significant positive correlation with Tmax (r=0.447), Tmin (r=0.617) and RHe (r=0.516), while significant negative correlation with BSSH (r= -0.479). Nirala *et al.* (2015b) [34] also reported significant correlation between LF incidence and average temperature. Chakraborty and Deb (2011b) [9] had also reported a significant positive relationship of relative humidity with LF population, while negative relationship to BSSH. RH population also showed significant positive correlation with Tmax (r=0.644) and Tmin (r=0.525) but significant negative correlation with RHm (r= -0.843). GLH and WBPH have not shown any significant correlation with weather parameters, but the GH showed significant positive correlation with RHm (r=0.524), as their population was more during later part of the crop growth stages. Occurrence of GB revealed significant negative correlation with Tmax (r= -0.782), Tmin (r= -0.827) and RF (r= -0.549), while significant positive correlation with RHm (r=0.552). Likewise SB population showed significant positive correlation with Tmax (r=0.839 and, Tmin (r=0.869) and significant negative correlation with RHm (r= -0.534). Pandya *et al*. (1989) had also reported positive influence of minimum temperature and vapour pressure on the population abundance of paddy stem borer during *kharif* in Gujarat.

While assessing the effect of weather parameters on population build-up of natural enemies, more particularly SP, DDF and CB and found that RHm plays a significant positive correlation with RHm (r=0.525, r=0.538 and r=0.538, respectively) and significant negative correlation with Tmax (r= -0.509) in case of CB. Jena *et al.* (2009) [25] reported a positive influence of weather parameters like temperature, rainfall, bright sunshine hours, etc. on population build-up rice insect pests. Predator aggregation with high density of plant hoppers is a behavioural attribute of spiders in natural regulation of the pest (Hassell, 1978) [20], our correlation studied also revealed significant positive correlation of SP, DDF and CB with GLH (r=0.622, r=0.554 and r=0.551). Bambaradeniya and Edirisinghe (2008) [6] had reported a positive correlation of parasitoid and predators with the arthropod fauna, species richness and diversity of terrestrial arthropods that gradually peaked with crop age, which is very much prominent in our present investigation. Kenmore (1980) [27] suggested a strong positive correlation between population peak of *N. lugens* and the spider species, *Lycosa* sp. to reduce outbreak in a particular season, which still persist today. Gangurde (2007) [15] had reported a strong correlation with the appearance of natural predators like spiders and lady bird beetles to plant hopper population, suggesting their significant role natural population regulation. Kumar *et al*. (2017) [31] have reported a significant positive correlation between spider and mirid bug appearance with WBPH, supporting our present investigation.

Variety: *Black rice*

The correlation matrix of major insect pests and natural enemies with weather parameters (Table 2) revealed that CW had a significant positive correlation with Tmax (r=0.580) and Tmin (r=0.530), while significant negative correlation with RHm (r= -0.694). Likewise, LF incidence showed significant positive correlation with Tmax (r=0.586), Tmin (r=0.802) and RHe (r=0.537), while significant negative correlation with BSSH (r= -0.495). Chakraborty and Deb (2011b) [9] had also reported a negative impact of BSSH on leaf folder incidence. RH population also showed positive correlation with Tmax (r=0.496) and Tmin (r=0.426), whereas GLH and WBPH have shown significant positive correlation with RHm (r=0.619 and r=0.708). GH showed significant positive correlation with RHm (r=0.441) and negative correlation with Tmin (r= -0.590). GB occurrence also showed significant negative correlation with Tmax (r= -0.796), Tmin (r= -0.926) and RF (r= -0.462), while significant positive correlation with RHm (r=0.420). Likewise SB population showed significant positive correlation with Tmax (r=0.609), Tmin (r=0.658) and RF (r=0.489) but significant negative correlation with RHm (r= -0.538). Kumar *et al*. (2015) [30] also added that population SB is positively correlated with Tmax, Tmin and RF, which confront out present investigation.

While assessing the effect of weather parameters on population build-up of natural enemies, more particularly SP, DDF and CB revealed that SP population had a significant positive correlation with RHm (r=0.687). Moreover, a significant positive correlation of SP with population peaks of GLH and WBPH (r=0.697 and r=0.805) was also recorded. Jayakumar and Sankari (2010) [24] had also revealed that spider species *viz., L. pseudoannulata, Callitrichia formosana, T. javanas* and *A. catenulate* prevalent in rice ecosystem showed positive correlation with the occurrence of plant hoppers, which supports our present investigation.

Var. *Kola Joha*

The correlation studies of major insect pests and natural enemies with weather parameters (Table 3) revealed significant positive correlation of CW with Tmax (r=0.679) and Tmin (r=0.634), while significant negative correlation with RHm (r= -0.764). While, appearance of WM could positively correlated with Tmax (r=0.717) and Tmin (r=0.709), but negatively correlation with RHm (r= -0.671). Likewise, LF incidence showed significant positive correlation with Tmin (r=0.558) and RHe (r=0.593), while significant negative correlation with BSSH (r = -0.527). Although RH appeared at a lower rate but it showed significant positive correlation with Tmax (r=0.627), Tmin (r=0.592) and RF (r=0.514); while negative correlation with RHe (r= -0.758). WBPH recorded significant positive correlation with Tmin (r=0.609) and RHe (r=0.578) with significant negative correlation with BSSH (r=-0.582). Hafizal and Idris (2014) reported significant influence of temperature fluctuation on population abundance of Delphacidae; which was also prominent in our correlation studies. GH showed significant positive correlation with RHm (r=0.552) and negative correlation with Tmax (r= -0.421), While GB occurrence also showed significant negative correlation with Tmax (r= -0.747), Tmin (r= -0.779) and RF (r= -0.504), along with significant positive correlation with RHm (r=0.449). Likewise SB population showed significant positive correlation with Tmax (r=0.699), Tmin (r=0.850), RHe (r=0.625) and RF (r=0.565).

While assessing the effect of weather parameters on population build-up of natural enemies, it was revealed that RHm plays a significant positive impact on DDF and CB with correlation coefficient of 0.472 and 0.436, respectively. Moreover it was seen that population of SP, DDF and CB has significant positive correlation with the population build-up of GLH (r=0.810, r=0.717 and r=0.847, respectively) and WBPH (r=0.837, r=0.745 and r=0.846, respectively).

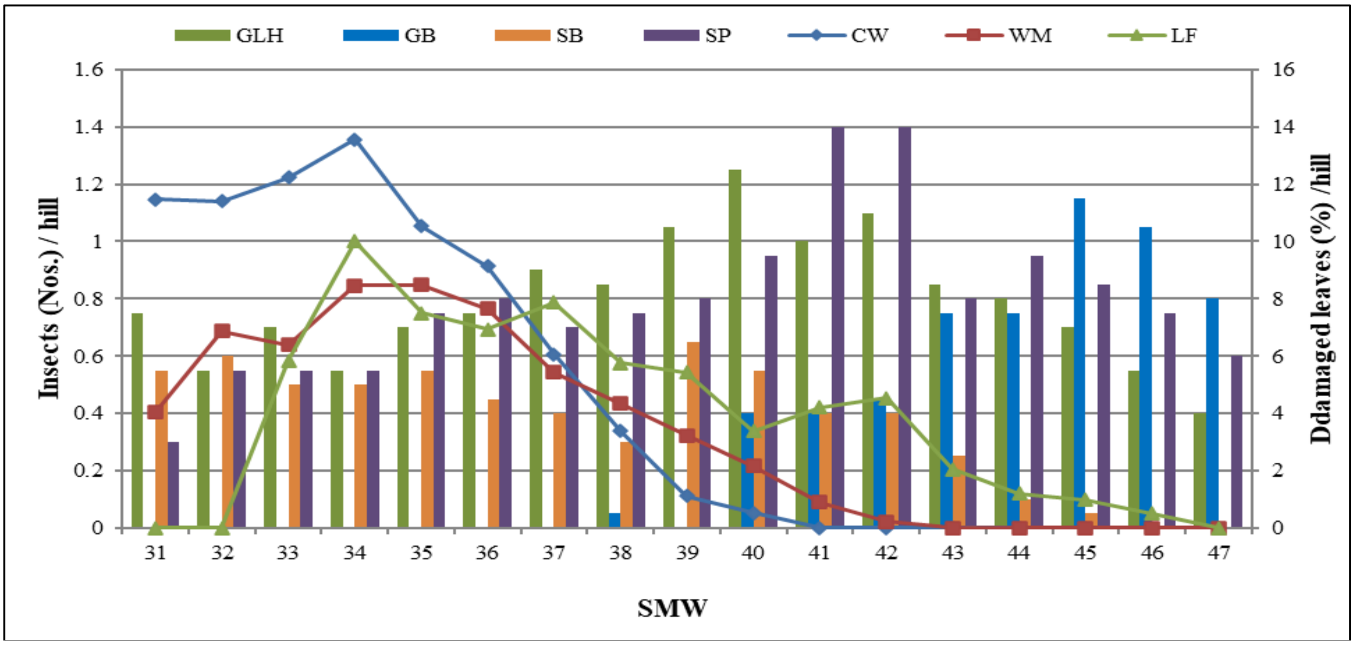
Variety- *Mahsuri*

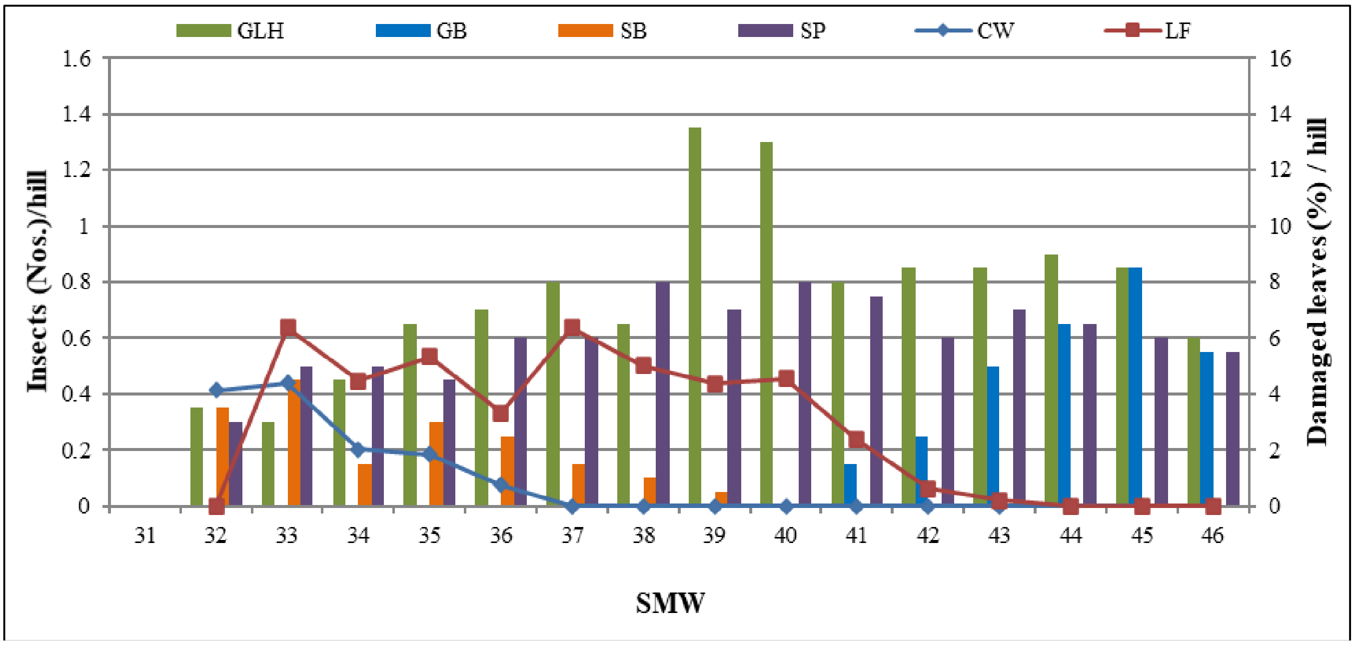
The correlation of rice insect pests and natural enemies with weather parameters are presented in Table 4 and the data revealed a significant positive correlation of CW with Tmax (r=0.619), Tmin (r=0.595) and RF (r=0.435), while significant negative correlation with RHm (r= -0.700). The incidence of WM is also significantly correlated with Tmax (r=0.631) and Tmin (r=0.639), but significant negative correlation with RHm (r= -0.727). Likewise, LF recorded significant positive correlation with Tmin (r=0.405) and RHe (r=0.570). RH population showed significant positive correlation with Tmax (r=0.610) and Tmin (r=0.531) but a negative correlation with RHe (r= -0.777). GLH had also showed significant positive correlation with Tmax (r =0.568), Tmin (r=0.733), RHe (r=0.601) and RF (r =0.483), but negative correlation with BSSH (r = -0.560). Our results were in close conformity with the work of Begum *et al*. (2014) [7] revealing influence of temperature and rainfall on the GLH population build-up. Likewise, WBPH had showed positive correlation with Tmax (r =0.673) and Tmin (r=0.739) but a negative correlation with BSSH (r = -0.447). Whereas GH showed significant positive correlation with RHm (r =0.507). GB occurrence also showed significant negative correlation with Tmax (r = -0.471), Tmin (r = -0.533) and RHe (r= -0.489). Likewise SB population showed significant positive correlation with Tmax (r=0.718), Tmin (r=0.774), RHe (r=0.539) and RF (r=0.565), but negative correlation with RHm (r= -0.606) and BSSH (r= -0.464).

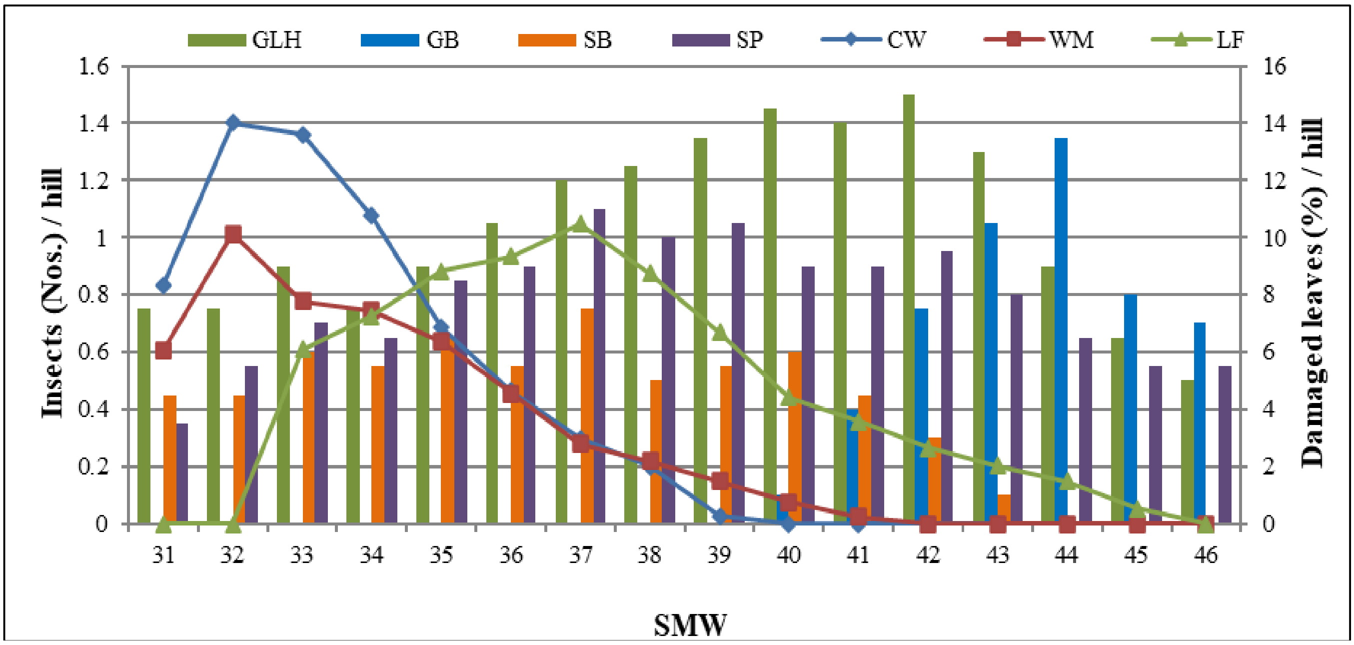
It was revealed that Tmin, RHe and RF had a positive correlation with appearance of SP with correlation coefficient of 0.445, 0.632 and 0.646, respectively, while SP showed negative correlation with BSSH (r= -0.549). Moreover, SP, DDF and CB population had showed significant positive correlation with the population of GLH (r=0.842, r=0.762 and r=0.729, respectively) and WBPH (r=0.753, r=0.642 and r=0.579, respectively) suggesting their strong relationship.

Regression analysis of insect pests and natural enemy populations with weather parameters

Correlation analysis revealed significant positive and negative correlation amongst the insect pests and natural enemy appearance with the prevailed weather condition. The significant relationship of the rice variety Ranjit was subjected to regression analysis and the regression equation along with the R^2 values were presented in Table 5. From Table 5 it was revealed that temperature and relative humidity are the major factors that cause population fluctuation in most of the rice insect pests, which ultimately affect the population fluctuation of the natural enemies too. During the experiment it was revealed that the variety and time of transplanting was critical for a variety to escape the incidence of major insect pests. Magunmder *et al.* (2013) [32] have also reported that rice variety and planting date had significant effects on rice pest incidence and early planted rice had lower pests and natural enemy population than that of late transplanted rice. Magunmder *et al.* (2013) [32] also found that both rice variety and planting date had significant effects on pest incidence, which corroborate our present investigation. Sarwar (2012) [38] had also reported the least incidence of *S. incertulas* on early sown crop as compared to medium and late sown crops. Sundararaju (1985) [40] had also stated that the early planted crop had significantly less damage of whorl maggot than the late planted rice crop. Therefore, selection of varieties and time of transplanting will be very much crucial in reducing insect pest attack in rice-rice cropping sequence.


GLH
GB
SB
SP
CW
WM
LF
Insects (Nos.) / hill
Ddamaged leaves (%) /hill
SMW


GLH
GB
SB
SP
CW
LF
Insects (Nos.)/hill
Damaged leaves (%) / hill
SMW


GLH
GB
SB
SP
CW
WM
LF
Insects (Nos.) / hill
Damaged leaves (%) / hill
SMW

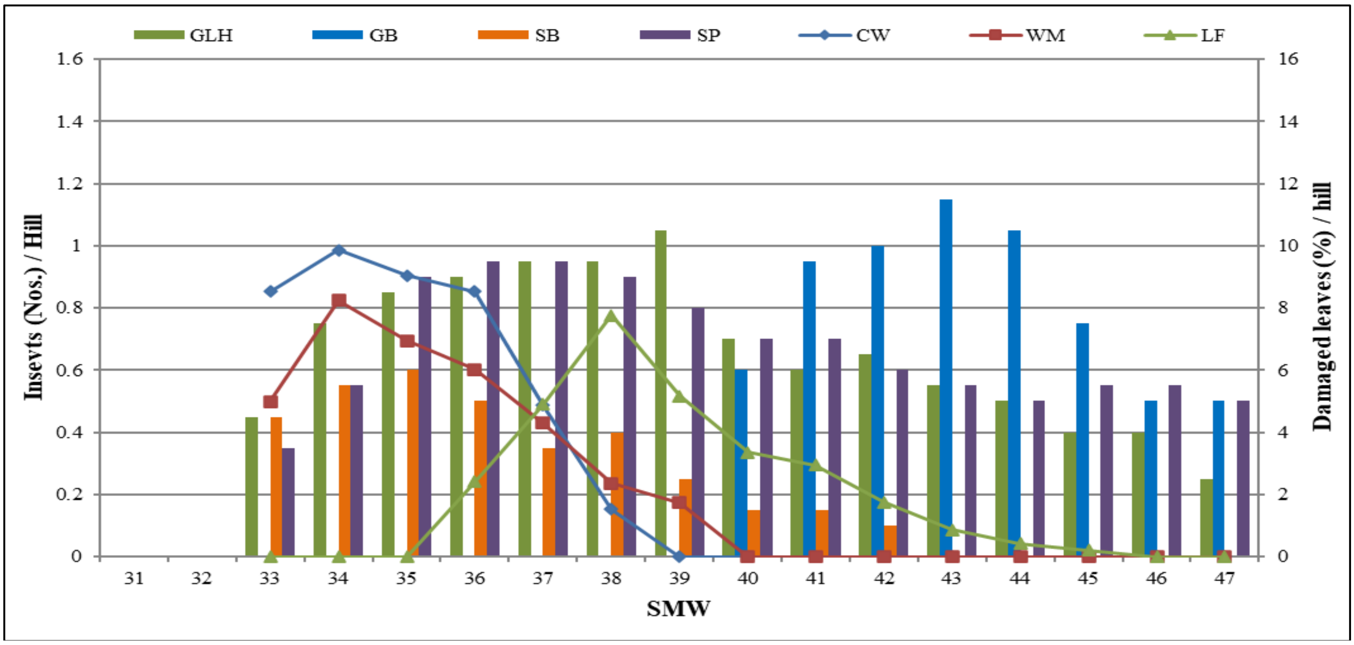


Fig 1: Population fluctuation of major insect pests and natural enemies during 2016-17. a.*Ranjit*, b. *Black rice*, c. *Kola Joha*, d. *Mahsuri*

- Data represented are the mean of 20 samples
- Data obtained were of visual counts
- CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

Units of measurements: CW, WM and LF (% damage leaves/hill); RH, GLH, WBPH, GH, GB and CB (Nos. of insect/hill); SB, SP and DDF (Nos. of adults/sq. mtr)

Table 1: Correlation matrix of insect pests and natural enemies with weather parameters during 2016-17 (Var. *Ranjit*)

	Tmax	Tmin	RHm	RHe	BSSH	RF	CW	WM	LF	RH	GLH	WBPH	GH	GB	SB	SP	DDF	CB
Tmax	-																	
Tmin	0.838**	-																
RHm	-0.701**	-0.534	-															
RHe	0.115	0.591	0.157	-														
BSSH	-0.169	-0.608	03	-0.856	-													
RF	0.237	0.473	-0.060	0.647**	-0.523	-												
CW	0.706**	0.656**	-0.806**	0.208	-0.187	0.434*	-											
WM	0.696**	0.745**	-0.631*	0.431*	-0.369	0.550**	0.908**	-										
LF	0.447*	0.617**	-0.223	0.516**	-0.479*	0.249	0.419*	0.656**	-									
RH	0.644**	0.525*	-0.843**	-0.012	-0.020	0.247	0.845	0.602**	0.137	-								
GLH	0.255	0.372	0.311	0.294	-0.268	-0.014	-0.393	-0.224	0.215	-0.311	-							
WBPH	0.164	0.371	0.277	0.361	-0.385	-08	-0.181	0.071	0.504**	-0.388	0.643**	-						
GH	-0.254	-0.142	0.524**	0.140	-0.188	-0.212	-0.534**	-0.296	0.323	-0.585**	0.492*	0.629**	-					
GB	-0.782**	-0.827**	0.552**	-0.450*	0.342	-0.549	-0.746**	-0.845**	-0.624**	-0.547**	-0.144	-0.179	0.282	-				
SB	0.839**	0.869**	-0.534**	0.401	-0.326	0.431	0.602**	0.683**	0.482*	0.553**	0.389	0.228	-0.104	-0.870**	-			
SP	-0.273	-0.137	0.525**	0.118	-0.088	-0.033	-0.640**	-0.485*	0.079	-0.487*	0.622**	0.361	0.628**	0.310	-0.127	-		
DDF	-0.290	-0.107	0.538**	0.214	-0.229	-0.066	-0.622**	-0.400*	0.175	-0.573**	0.554**	0.376	0.624**	0.345	-0.194	0.865**	-	
CB	-0.509**	-0.275	0.671**	0.159	-0.194	-0.183	-0.819**	-0.706**	-0.123	-0.633**	0.551**	0.308	0.579**	0.551**	-0.359	0.838**	0.839**	-

- *- significant at P=0.05; **- significant at P=0.01
- Tmax- Maximum temperature; Tmin- Minimum temperature; RHm- Relative humidity morning; RHe- Relative humidity evening; BSSH- Bright sun shine hours; RF- Rainfall; CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

Table 2: Correlation matrix of insect pests and natural enemies with weather parameters during 2016-17 (Var. *Black rice*)

	Tmax	Tmin	RHm	RHe	BSSH	RF	CW	LF	RH	GLH	WBPH	GH	GB	SB	SP	DDF	CB
Tmax	-																
Tmin	0.773**	-															
RHm	-0.616**	-0.451*	-														
RHe	-0.082	0.506**	0.280	-													
BSSH	0.248	-0.293	-0.226	-0.844**	-												
RF	0.104	0.442*	0.068	0.668**	-0.552**	-											
CW	0.580**	0.530**	-0.694**	0.030	0.066	0.225	-										
LF	0.586**	0.802**	-0.166	0.537**	-0.495**	0.236	0.217	-									
RH	0.496*	0.426*	-0.372	0.100	-0.106	0.037	0.710**	0.520**	-								
GLH	-0.186	-0.179	0.619**	-0.014	0.066	-0.237	-0.726**	-0.020	-0.510**	-							
WBPH	-0.374	-0.397	0.708**	-0.133	0.167	-0.406*	-0.810**	-0.195	-0.554**	0.882**	-						
GH	-0.333	-0.590**	0.441*	-0.294	0.205	-0.298	-0.605**	-0.327	-0.229	0.501**	0.509**	-					
GB	-0.796**	-0.926**	0.420*	-0.422	0.274	-0.462*	-0.411*	-0.761**	-0.298	0.127	0.345	0.545**	-				

SB	0.609**	0.658**	-0.538**	0.298	-0.192	0.489**	0.891**	0.469*	0.719**	-0.675**	-0.814**	-0.589**	-0.572**	-				
SP	-0.306	-0.156	0.687**	0.154	-0.168	-0.128	-0.769**	0.115	-0.395	0.697**	0.805**	0.338	0.104	-0.685**	-			
DDF	0.042	0.035	0.141	-04	-0.091	-0.351	-0.531**	0.388	-0.030	0.474*	0.472*	0.524**	-0.012	-0.428*	0.612**	-		
CB	-0.050	-0.065	0.320	0.103	-0.057	-0.137	-0.570**	0.237	-0.162	0.464*	0.463*	0.494*	03	-0.335	0.509**	0.765**	-	

- *- significant at P=0.05; **- significant at P=0.01
- Tmax- Maximum temperature; Tmin- Minimum temperature; RHm- Relative humidity morning; RHe- Relative humidity evening; BSSH- Bright sun shine hours; RF- Rainfall; CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

Table 3: Correlation matrix of insect pests and natural enemies with weather parameters during 2016-17 (Var. *Kola Joha*)

	Tmax	Tmin	RHm	RHe	BSSH	RF	CW	WM	LF	RH	GLH	WBPH	GH	GB	SB	SP	DDF	CB
Tmax	-																	
Tmin	0.841**	-																
RHm	-0.659**	-0.519**	-															
RHe	0.176	0.633**	0.104	-														
BSSH	-0.216	-0.637**	0.053	-0.854**	-													
RF	0.206	0.461*	-05	0.683**	-0.545**	-												
CW	0.679**	0.634**	-0.764**	0.254	-0.233	0.320	-											
WM	0.717**	0.709**	-0.671**	0.373	-0.318	0.444	0.976**	-										
LF	0.367	0.558**	0.038	0.593**	-0.527**	0.397	0.102	0.199	-									
RH	0.627**	0.592**	-0.758**	0.261	-0.210	0.514**	0.912**	0.907*	0.119	-								
GLH	0.102	0.225	0.210	0.107	-0.183	-0.093	-0.463**	-0.424*	0.347	-0.491**	-							
WBPH	0.337	0.609**	0.029	0.578**	-0.582**	0.229	-0.080	-07	0.743**	-0.134	0.792**	-						
GH	-0.421*	-0.305	0.552**	-0.102	0.020	-0.298	-0.771**	-0.766**	0.097	-0.775**	0.766**	0.397	-					
GB	-0.747**	-0.779**	0.449*	-0.476*	0.372	-0.504**	-0.579**	-0.674**	-0.582**	-0.565**	-0.029	-0.462*	0.500**	-				
SB	0.699**	0.850**	-0.348	0.625**	-0.518**	0.565**	0.455*	0.547**	0.750**	0.463*	0.334	0.738**	-0.190	-0.893**	-			
SP	0.099	0.248	0.386	0.302	-0.284	0.016	-0.405*	-0.322	0.728**	-0.468*	0.810**	0.837**	0.640**	-0.207	0.482**	-		
DDF	-0.021	0.195	0.472*	0.391	-0.388	0.132	-0.442*	-0.331	0.709**	-0.448*	0.717**	0.745**	0.658**	-0.160	0.413*	0.891**	-	
CB	-05	0.193	0.436*	0.308	-0.281	0.040	-0.494**	-0.410*	0.643**	-0.552**	0.847**	0.846**	0.651**	-0.193	0.442*	0.958**	0.876**	-

- *- significant at P=0.05; **- significant at P=0.01
- Tmax- Maximum temperature; Tmin- Minimum temperature; RHm- Relative humidity morning; RHe- Relative humidity evening; BSSH- Bright sun shine hours; RF- Rainfall; CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

Table 4: Correlation matrix of insect pests and natural enemies with weather parameters during 2016-17 (Var. *Mahsuri*)

	Tmax	Tmin	RHm	RHe	BSSH	RF	CW	WM	LF	RH	GLH	WBPH	GH	GB	SB	SP	DDF	CB
Tmax	-																	
Tmin	0.835**	-																
RHm	-0.652**	-0.501*	-															
RHe	0.185	0.648**	0.102	-														
BSSH	-0.240	-0.666**	0.105	-0.856**	-													
RF	0.167	0.439*	0.119	0.710**	-0.586**	-												
CW	0.619**	0.595**	-0.700**	0.302	-0.283	0.435*	-											
WM	0.631**	0.639**	-0.727**	0.354	-0.336	0.429*	0.972**	-										
LF	0.144	0.405*	0.269	0.570**	-0.446	0.316	-0.203	-0.058	-									
RH	0.610**	0.531**	-0.777**	0.183	-0.195	0.334	0.964**	0.947**	-0.336	-								
GLH	0.568**	0.733**	-0.223	0.601**	-0.560**	0.483*	0.334	0.492*	0.724**	0.266	-							
WBPH	0.673**	0.739**	-0.402	0.478*	-0.447*	0.368	0.467*	0.607**	0.541*	0.426	0.952**	-						
GH	-0.099	0.011	0.507**	0.147	-0.100	0.068	-0.601**	-0.523**	0.598**	-0.616**	0.348	0.226	-					
GB	-0.471*	-0.533**	0.360	-0.489*	0.387	-0.409	-0.705**	-0.784**	-0.308	-0.615**	-0.576**	-0.572**	0.409	-				
SB	0.718**	0.774**	-0.606**	0.539**	-0.464*	0.565**	0.896**	0.940**	0.198	0.846**	0.648**	0.715**	-0.334	-0.827**	-			
SP	0.226	0.445*	0.098	0.632**	-0.549**	0.646**	0.211	0.337	0.682**	0.123	0.842**	0.753**	0.502**	-0.473*	0.493**	-		
DDF	0.408	0.579**	0.058	0.473*	-0.441*	0.410	-0.074	0.039	0.758**	-0.111	0.762**	0.642**	0.739**	-0.055	0.273	0.685**	-	
CB	0.282	0.479*	0.278	0.486*	-0.401	0.393	-0.205	-0.101	0.834**	-0.291	0.729**	0.579**	0.757**	-0.044	0.143	0.668**	0.942**	-

- *- significant at P=0.05; **- significant at P=0.01
- Tmax- Maximum temperature; Tmin- Minimum temperature; RHm- Relative humidity morning; RHe- Relative humidity evening; BSSH- Bright sun shine hours; RF- Rainfall; CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

Table 5: Regression analysis of rice insect pests and natural enemies with weather parameters during 2016-17 (Var. *Ranjit*)

Insect name	Tmax (°C)	Tmin (°C)	RHm (%)	RHe (%)	Rainfall (mm)
CW	r=0.706**, R^2= 0.498 y= 1.750x –51.53	r =0.656**, R^2= 0.430 y= 0.913x –16.39	r = -0.806**, R^2= 0.650 y= -1.950x + 191.06	-	r =0.550**, R^2= 0.188 y= 0.067x – 2.576
WM	r =0.696**, R^2= 0.084 y= 1.044x –30	r =0.745**, R^2= 0.554 y= 0.627x – 11.04	r = -0.631 **, R^2= 0.398 y= -0.925x + 91.54	r =0.431*, R^2= 0.186 y= 0.257x – 13.86	r =0.550**, R^2= 0.302 y= 0.052x –1.815
LF	r =0.447*, R^2= 0.199 y= 0.651x – 16.94	r =0.617**, R^2= 0.380 y= 0.504x – 7.742	-	r =0.516**, R^2= 0.266 y= 0.276 – 16.17	r = -0.479*, R^2= 0.0.062 y= -0.022x + 3.186
RH	r =0.644**, R^2= 0.415 y= 0.060x – 1.722	r =0.525**, R^2= 0.275 y= 0.274x – 0.465	r = -0.843**, R^2= 0.711 y= - 0.077x + 7.591	-	-

GH	-	-	R=0.524**, R^2= 0.274 y= 0.042x – 3.303	-	-
GB	r = -0.782**, R^2= 0.611 y= -0.148x + 5.082	r = -0.827**, R^2= 0.684 y= -0.088x + 2.370	r = 0.552**, R^2= 0.305 y= 0.102x – 9.396	r = -0.450*, R^2= 0.202 y= -0.031x + 2.616	r = -0.549*, R^2= 0.300 y= -06x + 0.543
SB	r =0.839**, R^2= 0.704 y= 0.082x – 2.277	r =0.869**, R^2= 0.755 y= 0.048x – 0.740	r = -0.534**, R^2= 0.285 y= -0.051x + 5.267	-	-
SP	-	-	r =0.525**, R^2= 0.275 y= 0.068x – 5.487	-	-
DDF	-	-	r =0.538**, R^2= 0.289 y= 0.040x – 3.241	-	-
CB	r = -0.509**, R^2= 0.258 y= -0.054x + 2.276	-	r =0.671**, R^2= 0.450 y= 0.069 – 6.19	-	-

- *- significant at P=0.05; **- significant at P=0.01

Tmax- Maximum temperature; Tmin- Minimum temperature; RHm- Relative humidity morning; RHe- Relative humidity evening; BSSH- Bright sun shine hours; RF- Rainfall; CW- Case worm; WM- Whorl maggot; LF- Leaf folder; RH- Rice hispa; GLH- Green leaf hopper; WBPH- White backed plant hopper; GH- Grass hopper; GB- Gundhi bug; SB- Stem borer; SP- Spiders; DDF- Dragon and damsel fly; CB- Coccinellid beetle

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