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Research Paper

Weather based forecasting model for emergence of *Aprostocetus purpureus* (Cameron) – a parasitoid of lac insect, *Kerria lacca* (Kerr)

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ABSTRACT

Indian lac insect, *Kerria lacca* is a scale group beneficial insect which suffers by several natural enemies. The establishment of the relationship between the incidences of natural enemies on lac insects with weather variables is essential for formulating management strategies well in advance. The relationship between weather factors and the emergence of *A. purpureus* was studied from 2011–12 to 2020–21 on the *rangeeni* summer (*baisakhi*) lac crop. Correlation and regression analyses were done after pooling ten years data (2011-12 to 2020-21) during the critical lac growth period i.e. SMW 8 to SMW 20. The relative abundance of lac-associated fauna showed that three parasitoids ((*Aprostocetus purpureus*, *Tachardiaephagus tachardiae,* and *Tyndarichus*(=*Parechthrodryinus*) *clavicornis*)) and one predator (*Eublemma amabilis*) were abundant. Among them, *A. purpureus* recorded maximum percent infestation, which was 84% and 75% on *ber* and *palas*, respectively. Maximum number of *A. purpureus* was emerged during the sexual maturity period (8 to 20 SMW) of the summer lac crop. The incidence exhibited a significant negative correlation with maximum (Tmax) and minimum temperature (Tmin) and a significant positive correlation with evening relative humidity (RH-II). Stepwise regression analysis showed Tmax and RH-II were the most important factors contributing to 68% variation in the incidence of *A. purpureus* on *palas.* The present study results indicated that environmental factors played a significant role in the incidence of parasitoids on lac insect.

Key words: Lac insect, *Aprostocetus purpureus, rangeeni, baisakhi,* correlation, regression and prediction

India is the largest producer of lac in the world and is a source of livelihood for millions of economically backward people, especially tribal people in Jharkhand, Madhya Pradesh, Chhattisgarh, Maharashtra, and West Bengal. It is the only natural resin of insect origin, derived mostly from a few species of *Kerria* (Coccoidea: Tachardiidae), belonging to a specialised group of scale insects that are phytosuccivorous and thrive well only on specific plants called lac-hosts. In India, lac is mainly derived from the Indian lac insect, *Kerria lacca* Kerr, 1782, characterised by two strains, *Rangeeni* and *Kusmi.* Both strains complete two cycles in a year, producing two crops. But these two forms differ in their life cycle patterns due to their genetic differences in their developmental response to temperature. Thus, these two forms exhibit differences in their vulnerability to deviations from normal weather conditions. The Indian lac insect, *K. lacca,* is encountered with large number of natural enemies mainly of predatory and parasitic insects. Ninety-seven species of such natural enemies which have been reported, are either pests of the lac insect or their predators, besides several fungal pathogens, and represent the rich biodiversity of this ecosystem. Out of the 97 species, 22 species were reported as lac predators, 30 species as primary parasitoids, and 45 species as secondary parasitoids (Sharma *et al*., 2006). But only a few of them are economically important, which causes a significant reduction in yield loss for lac crops. These reported species of natural enemies of different species of *Kerria* can be expected to be highly responsive to climate change in view of their relatively shorter life cycles.

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In recent years, large deviations in the relative contribution of *kusmi* and *rangeeni* yields have been reported at National level as compared to long-term average. The relative contribution of the *kusmi* crop has increased to over half of the country's lac production, compared to about 20% earlier. This change had been due to the intervention of ICAR-National Institute of Secondary Agriculture (NISA) (erstwhile ICAR-Indian Institute of Natural Resins and Gums), Ranchi, in promoting *kusmi* lac production, especially on *ber* during the winter crop season, coupled with a drastic decline in the production of the summer *rangeeni* lac crop, which was earlier used to be the major crop (Mohanasundaram *et al*., 2014). This declining trend is largely attributed to the unusual pre-summer mortality of *Rangeeni* lac insects.

The performance of the *rangeeni* strain of *K. lacca* in India, especially in Jharkhand, was analysed in relation to long- and short-term changes in climatic parameters. The concomitant changes in certain weather parameters during the critical period of lac insects' were attributed to a decline in summer crop production (Ramani, 2010). Sharma *et al.,* (2010) observed 57.6% parasitization of the lac insects with the endoparasitoid, i.e., *A. purpureus,* Observations of parasitoid population fluctuations over the years suggest that changes in weather conditions may have played a major role in parasitization dynamics. Moreover, pest population density may be influenced by weather parameters of the preceding weeks or months, so it becomes necessary to explore forward and reverse relationships between pest population and weather parameters (Prasannakumar *et al*., 2015; Gundappa *et al*., 2016; Sagar *et al*., 2017). It was found out that the incidence of insect pests was correlated with the current time period as well as 1 to 4 lead times (Balikai *et al.,* 2019). Correlation analysis indicates that the weather parameters such as minimum temperature at the current week, maximum RH at one week lag, minimum temperature, and minimum and maximum RH at two-week lag are significantly correlated with the incidence of jute yellow mite (*Polyphagotarsonemus latus* Banks), while in the case of jute semilooper (*Anomis sabulifera* Guen), maximum temperature, minimum, and maximum RH at two-week lag are significantly correlated (Sarkar *et al.,* 2023). Based on these studies, we have hypothesised that lac insect parasitoid may not be associated with current weather parameters and may be associated with backward weeks of weather parameters based upon the life cycle pattern of lac insect parasitoid. Based on such a perspective, the present study was formulated to develop and validate the weather-based prediction model for *A. purpureus* in *Palas* and *Ber*.

MATERIAL AND METHODS

Experimental field and data observations

The experiment was conducted at the Institute Research Farm of ICAR-National Institute of Secondary Agriculture (NISA) (erstwhile ICAR-IINRG), Namkum, Ranchi, Jharkhand. *Rangeeni* broodlac was inoculated and cultivated in summer season *Baisakhi* crop on *Palas* and *Ber* for consecutive ten years (2011–12 to 2020–21) without application of any chemical pesticides. Broodlac was inoculated at 15 g/meter shoot length on forty trees each in *Palas* and *Ber* during October–November. After one month of inoculation, well-settled lac insect on one-metre-long encrustations were randomly collected from each direction of plant and three plants were selected for observations of lac-associated fauna. Sample collections were done at fifteen-day intervals up to crop maturity. The collected encrustations were caged in a specially designed parasitoid emergence cage fitted with glass tubes to collect parasitoids while exploiting their phototropic behaviour. The number of parasitoids emerging from each sample was counted daily up to last emergence. The counts were expressed as the number of parasitoids and predators that emerged per metre lac encrustations starting from the 1^{st} standard meteorological week (SMW) to the 35^{th} SMW.

Weather data, *viz*., maximum temperature (Tmax), minimum temperature (Tmin), relative humidity morning (RH-I), relative humidity evening (RH-II), and rainfall (RF), were recorded from the Meteorological Observatory, ICAR-NISA, Namkum, Ranchi, Jharkhand, during study period.

Model parametrization and data analysis

Relative abundance and emergence profiles of lac-associated pests were analysed and identified as key natural enemies of the summer lac crop. The relationship between weather parameters and the emergence of a key pest (based on intensity and severity), A. *purpureus,* was established. Data normality and homogeneity were done using trend analysis of pest populations. Regression was done after pooling the ten years data (2011–12 to 2020–21) during the critical period SMW 8–SMW 20. *A. purpureus* is an endoparasitoid and completes 10–12 generations in a year (Mohanasundaram *et al*., 2016). Based on the life cycle pattern of *A. purpureus,* it was correlated with 4-lag and 5-lag weather parameters.

The weather parameters of 4-lag and 5-lag weeks and the incidence of A. *purpureus* were computed using Pearson's simple correlation. Subsequently, stepwise multiple linear regression analysis was performed by regressing dependent parameters, i.e., weekly number of *A. purpureus* per metre lac encrustation, against independent weather parameters based on the highest correlation among 4-lag and 5-lag week periods. Stepwise regression was carried out to assess distinct weather variables on the basis of level of significance and coefficient of determination (R^2). The best-fitting model was validated keeping important variables during the year 2019–20. Data analysis was performed using statistical software, SPSS v. 20.

RESULTS AND DISCUSSION

Relative abundance of lac associated fauna on rangeeni (Baisakhi) lac crop

Relative abundance and emergence profiles of parasitoids and predators associated with lac insects were recorded at the Institute Research Farm during *Baisakhi* (2011–12 to 2020–21). Three parasitoids ((*Aprostocetus purpureus*, *Tachardiaephagus tachardiae,* and *Tyndarichus*(=*Parechthrodryinus*) *clavicornis*)) and one predator (*Eublemma amabilis*) were observed in the *Baisakhi* crop. The incidence of natural enemies on *rangeeni* lac crop in the present study was in accordance with the previous findings (Mohanasundaram *et al*., 2016; Mohanasundaram *et al*., 2018). Among lac-associated fauna, *A. purpureus* (71 and 94/metre

Table 1: Correlation coefficients - *A. purpureus incidence* vs. weather factors (2011-2021)

Lag period	Tmax	Tmin	RH-I	RH-II	RF
Palas					
Current	-0.385 ^{ns}	-0.514 ^{ns}	0.035 ^{ns}	-0.012 ^{ns}	-0.184^{ns}
4 week lag	-0.559*	-0.567*	0.615*	0.709**	0.316^{ns}
5 week lag	-0.619*	-0.594*	0.673*	0.742**	0.045^{ns}
Ber					
Current	-0.420 ^{ns}	-0.476 ^{ns}	0.189 ^{ns}	0.133 ^{ns}	0.072^{ns}
4 week lag	-0.543 ^{ns}	-0.522 ^{ns}	0.564*	0.621*	0.409^{ns}
5 week lag	-0.562*	-0.544 ^{ns}	0.620*	0.659*	0.003^{ns}

* Significant at p = 0.05; ** at p=0.01; ns= Non Significant Tmax = Maximum temperature, Tmin = Minimum temperature, RH-I= Morning relative humidity, RH-II= Evening relative humidity and RF= Rainfall

Table 2: Regression equation for the *A. purpureus* population density with weather variables

Regression equation	R^2	Fcal	*P* Value
Palas:Y=-159.16*+3.01Tmax-1.549Tmin+0.298RH-I +1.213RH-II+1.56** at 4-lag	0.78	7.086	0.010
Ber:Y=103.581*+1.062Tmax+0.440RH-I+0.773RH-II+3.12** at 5-lag	0.50	2.945	0.091

*values denotes constant estimated from the data; ** random error term

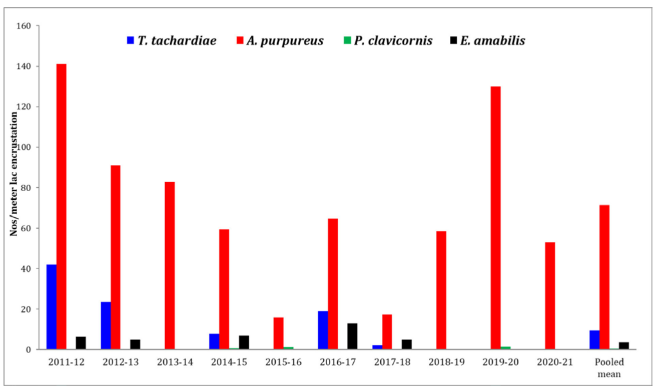

Fig. 1: Relative abundance of lac associated fauna on *ber* during *Baisakhi* 2011-12 to 2020-21

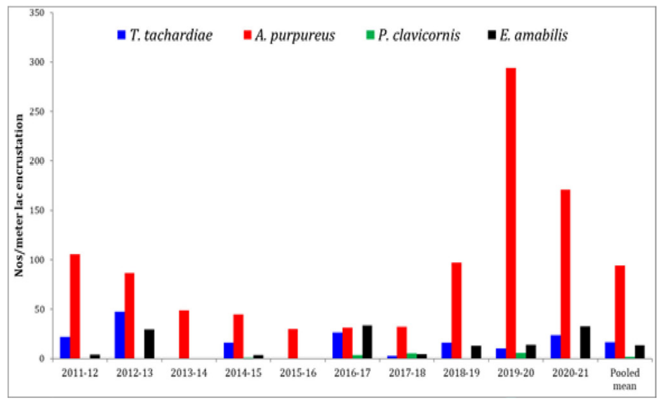

Fig. 2: Relative abundance of lac associated fauna on *palas* during *Baisakhi* 2011-12 to 2020-21

of encrustation) was recorded in higher pooled mean numbers, followed by *T. tachardiae* (10 and 16/metre of encrustation), *E. amabilis* (4 and 13/metre of encrustation), and *T. clavicornis* (0.4 and 2 /metre of encrustation) on *ber* and *palas,* respectively, during the *Baisakhi crop*, during 2011–2021 (Fig. 1 and 2). Based on total encrustation infested, it was observed that *A. purpureus* recorded maximum percent damage, 84% and 75% on *ber* and *palas*, respectively. The resurgence of *A. purpureus* in the recent past on lac insect is one of the major concerns which is causing huge economic losses. *A. purpureus* was considered a minor pest of the lac insect in earlier days (Mohanasundaram *et al*., 2016)

Temporal emergence of lac associated fauna during rangeeni summer lac crop

The emergence of *A. purpureus* was maximum during the sexual maturity period (8 to 20 SMW) of the summer (*Baisakhi*) crop during ten years except 2019-20 and 2020-21 on *palas* and 2011-12 and 2014-15 on *ber.* The weekly emergence rate of the lac-associated parasitoid, *A. purpureus,* showed that maximum emergence was 30 and 44/metre of encrustation on *palas* and *ber*, respectively, during 8 to 20 Standard Meteorological Weeks (SMW). These samples were collected in the 14th and 11th SMW during the critical growth period (sexual maturity period) when caged on *palas* and *ber* during *Baisakhi* 2018–19 and 2011–2012, respectively (Fig. 3 and 4). The vulnerability level of lac insects is high during and prior to the sexual maturity stage in the summer crop; thus, the post-winter season is the critical period for lac insect survival, and any undesired variability in weather parameters in this stage can impact adversely on lac productivity (Mohanasundaram *et al*., 2014).

Srivastava *et al.* (1984) observed that the maximum peak of the *A. purpureus* population coincided with the time of sexual maturity of the lac insect. Parasitization at an early development stage of the lac insect by *A. purpureus* leads to the complete failure of the lac crop, so it has assumed the status of a key pest in the lac ecosystem in the changing scenario of climate change. *A. purpureus* alone constituted 100 percent of the population during the critical/ sexual maturity period, causing complete lac insect mortality on *ber* and *palas* during *Baisakhi* (Mohanasundaram *et al*., 2016). Mohanasundaram *et al*. (2018) also reported that during the *Baisakhi* crop, *Rangeeni* strains of *A. purpureus* were significantly higher in the month of March.

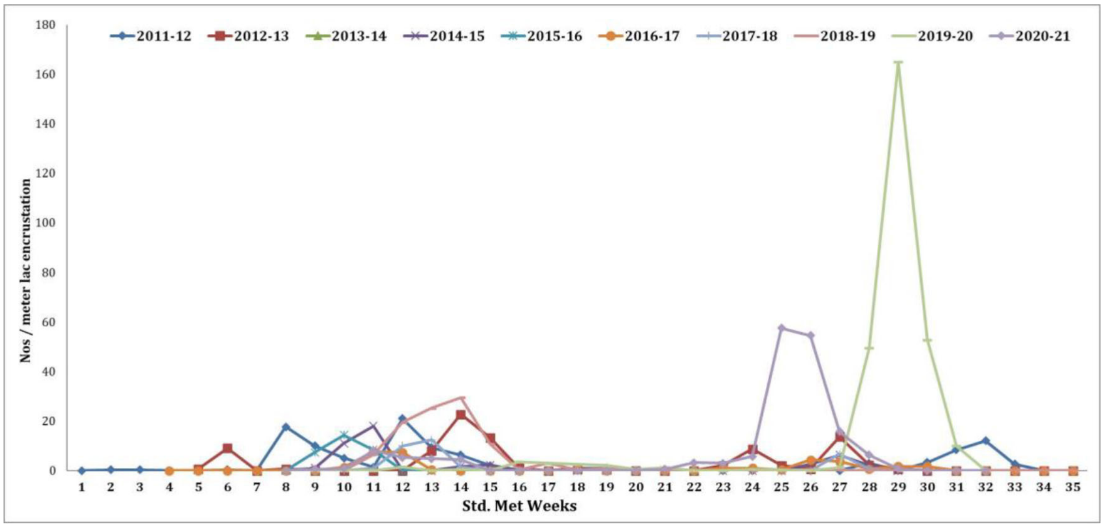

Fig. 3: Emergence profile of *Aprostocetus purpureus* on *palas* during *Baisakhi* 2011-12 to 2020-21

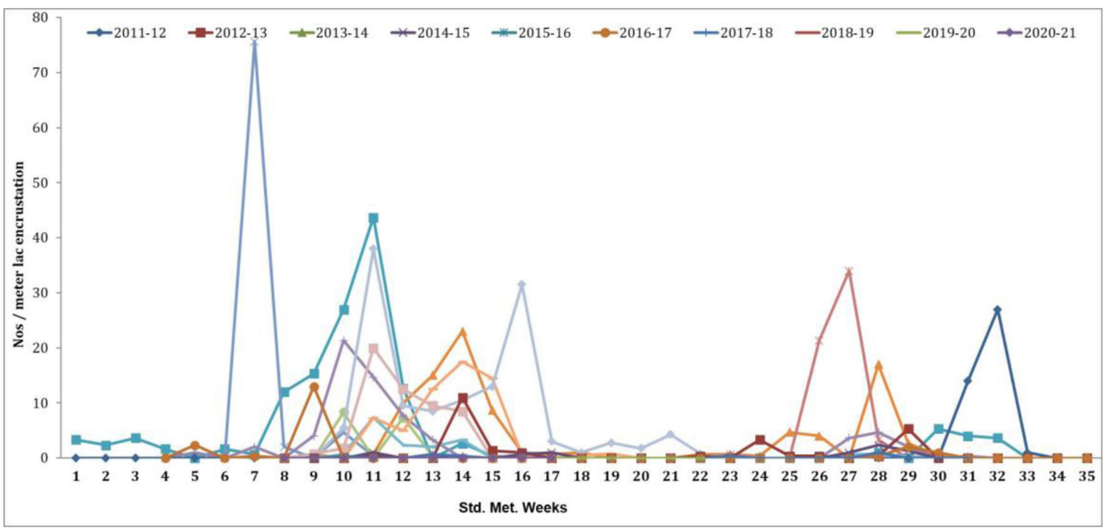

Fig. 4: Emergence profile of *Aprostocetus purpureus* on *ber* during *Baisakhi* 2011-12 to 2020-21

Emergence of major parasitoid, A. purpureus in relation to weather parameters

The correlation coefficients of *A. purpureus* incidence and weather factors in the day-to-day basis revealed a non-significant correlation. Moreover, the relationship between 4-lag week maximum (Tmax, r = -0.559*) and minimum temperature (Tmin, r = -0.567*) had shown a significant negative correlation on *palas*. The relative humidity of the morning and evening showed a significant positive correlation (RH-II, r = 0.709**) on *palas* and *ber.* The relationship between 5-lag maximum and minimum temperatures showed a significant negative correlation on *palas*, whereas only maximum temperatures showed a significant negative correlation on *ber*.

The relative humidity of the morning and evening showed a significant positive correlation "highly significant on *palas*" (RH-II, r = 0.742**) on *palas* and *ber* (Table 1). Mohanasundaram *et al.* (2014) revealed that maximum temperature had a significantly negative (-0.911* and -0.837*) and RH a significant positive (0.850* and 0.800*) correlation with lac production during the critical crop period (March and April) of development in the summer season (*baisakhi*) crop during 2006-07 to 2012-13. This study corroborates the present findings. Mohanasundaram *et al.,* (2016) studied the impact of weather factors on insect pests of lac insects and reported that a positive correlation with temperature and a significant negative correlation with relative humidity existed in *Baisakhi* (2011–12) during the critical periods. This finding was contradictory to the present finding; it may be due to previous results arrived at based on one-year data. Gundappa *et al.,* (2016) reported that maximum and minimum temperatures had adverse effects on thrips. Likewise, a significant positive correlation with morning relative humidity was reported by Jamuna *et al.,* (2019) on sucking pests. Morning relative humidity recorded a positive and significant correlation with all sucking pests and mites on pomegranate at two weeks lead time (Kotikal *et al*., 2011).

Model fitting of A. purpureus population in relation to lac insect

The regression equation was calculated by regressing the critical period of *A. purpureus* population (SMW 8 to SMW 20) recorded from *Palas* and *Ber* during *Baisakhi* 2011–12 to 2020–21

Table 3: Stepwise regression equations for *Palas* and *Ber*

Stepwise regression equation	(R^2)	Fcal	*P* Value
Palas: Y=-94.315*+0.92Tmax+1.164RH-II+1.69** at 4-lag	0.68	10.435	Tmax.: 0.043 RH-II: 0.007
Ber: Y=-27.752*+0.522RH-II+2.99** at 5-lag	0.43	8.450	RH-II: 0.014

*values denotes constant estimated from the data; ** random error term

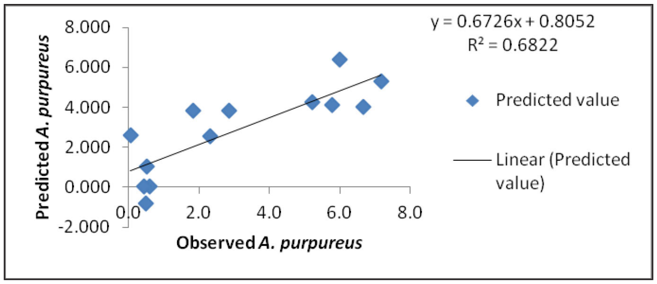

Fig. 5: Validation of *A. purpureus* weather based models on *Palas*

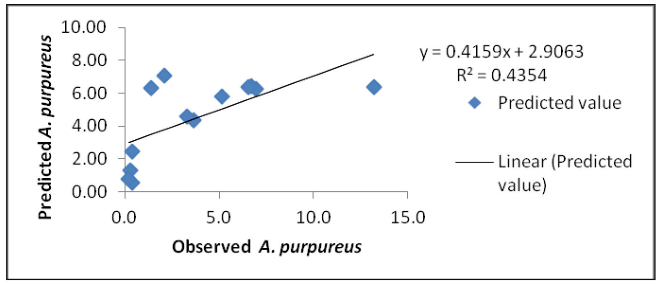

Fig. 6: Validation of *A. purpureus* weather based models on *ber*

as dependent variables against the pooled weather data of SMW (4-lag week, 5-lag week), which showed the highest coefficient correlation (x) as independent variables, i.e., Tmax, Tmin, RH-I, and RH-II (Table 2).

Multiple regression equations have shown that for every 1^0C increase in Tmax, the *A. purpureus* population per metre of lac encrustation increased by 3.01, while at a 1^0C reduction in Tmin, it was decreased 1.549 *A. purpureus* per metre of lac encrustation per week. Likewise, every 1% increase in RH-I and RH-II increased *A. purpureus* by 0.298 and 1.1213, respectively. The coefficient of determination showed that 78% of the variation in *A. purpureus* per metre of lac encrustation was due to distinct weather parameters.

Stepwise regression was performed to determine the relative importance of the weather factors (4-lag and 5-lag weeks) that influenced the critical period of *A. purpureus* incidence (SMW 8 to SMW 20) recorded from *Palas* and *Ber.* The pest-Tmax and RH-II models accounted for 68% of the variation in the occurrence of *A. purpureus,* showing their significant role. This model indicates that the maximum temperature and evening relative humidity of the 4-lag week were significant parameters on *Palas*. Whereas, the pest-RH-II model accounted for 43% of the variation in the occurrence of *A. purpureus,* showing its significant role (Table 3). This model indicates that the evening relative humidity of 5-lag week was a significant parameter on *ber*. Stepwise regression using 2-lag week weather parameter Minimum temperature was the most important factor contributing 82 percent variation in the incidence of *Thrips tabaci* in Maharashtra (Karuppaiah *et al*., 2021). Janu *et al.,* (2017) revealed that, in a stepwise linear regression model, morning relative humidity (RH-I) exerted (28.90 to 37.70 percent) the fluctuation of the whitefly population on cotton.

The model was validated by comparing observed *A. purpureus*/meter lac encrustation/week during the summer crop critical period, 2020–21, with the predicted value of incidence derived from 2019–20 models: $Y= -94.315+0.929Tmax_{(4\text{-lag})}+1.164RH\text{-}II_{(4\text{-lag})}+1.69$ from *Palas* (4 Week Lag) and $Y= -25.778+0.0.494RH\text{-}II_{(5\text{-lag})}+2.99$ from *Ber.* The parameters estimated in the validation showed that the model developed was moving in a positive direction and good fit (Fig. 5 and 6).

The pest-weather model was adequately validated (R^2=0.682 on *Palas* and 0.435 on *Ber*) with the 2020–21 datasets. When the performance of the *rangeeni* form of *K. lacca* in India, especially in Jharkhand, was analyzed in relation to long- and short-term changes in climatic parameters (Ramani, 2009 and 2010), it was reported that the concomitant changes in certain weather parameters during the critical period of lac insects were attributed to the decline in summer crop production. Likewise, Gundappa *et al*., (2016) and Sagar *et al*., (2017) revealed 62–75% and 75% variation in the population fluctuation of thrips on mango and *Helicoverpa armigera* in chickpea, respectively.

CONCLUSIONS

Among lac-associated fauna, *A. purpureus* was recorded with the highest and maximum percent damage, 84% and 75% on *ber* and *palas*, respectively. The emergence of *A. purpureus* was higher during the sexual maturity period of the summer (*Baisakhi*) crop. *A. purpureus* exhibited a significant negative association with maximum and minimum temperatures and a significant positive significant correlation with relative humidity. The present study revealed that Tmax and RH-II on *Palas* and only RH-II on *Ber* are the most important weather parameters determining the incidence of *A. purpureus*. The findings of the present study suggest that fluctuation in maximum temperature and relative humidity is to be monitored carefully to check the incidence of natural enemies on lac crop in advance.

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Conflict of Interests: The authors declare that there is no conflict of interests related to this article.

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***Data availability**:* Data can be shared as per request.

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