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Weather-Based Fruit Fly population Dynamics Prediction Model for the Mid-Hills of Eastern Himalayan Region of India

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Abstract

Across the globe, it is widely observed that current change in climate or weather pattern has marked effect on insect population dynamics and behavior, though with varied aspects and intensity. Understanding the correlations of insect population dynamics with weather parameters is the fundamental first step in formulating an effective integrated pest management programme. In the major citrus growing mid-hill regions of Arunachal Pradesh, fruitfly, *Bactroceradorsalis*, is one of the chief reasons for heavy loss leadingto pre-harvest fruit drop in citrus. The current study aims to determine how changes in weather parameters influence the population dynamics of fruit flies and to develop an optimized weather-based population prediction model for fruit flies infesting citrus in the mid-hills of Arunachal Pradesh. The population was monitored throughstandard methyl eugenolpara-pheromone traps and a model was developed using stepwise multiple regression technique. The study revealed that the population was highest during the fruit development and ripening stageand it was found that the number of flies per trap and meteorological parameters (temperature and humidity) is positively correlated with appreciable statistical significance. The optimized regression model was developed with variables temperature and humidity, and was found to be 79 percent accurate in thestudy site. This model will serve as an important tool in pre-estimationof the fruit fly population in the citrus growing mid-hills of Arunachal Pradesh and for formulation of effective preventive management strategies.

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Introduction

The climate change is an inevitable natural phenomenon and climate has been changing since the earth was formed.[1] The climate always changes slowly, giving ample time to all natural phenomena and living beings to change accordingly to adopt with it. But the present human-induced climate change is unique in the history of the world because of its pace of change. It is changing so fast that it is not giving sufficient time to all related phenomenon and lives to change and adopt with it, and thus, become a threat to the well-being of the earth's environment and the survival of lives.

The obvious impact of climate change is visible in every sector related to agriculture, as the sector greatly depends on ecosystem services.[2,3,4] The projected impact of climate change on agriculture and related sectors was aptly envisaged in the Fourth Inter governmental Panel on Climate Change.[5] The change and variability in climate are posing enormous challenges that are influencing the performance of agriculture, especially the annual and perennial horticulture crops.[6] The uncertainties and risksthat are created by variability in the seasonal and annual weather pattern have further imposed constraints on horticultural production systems. One of the major risks has been the significant impact of climate variability on insect pests of horticultural crops.[7,8,9] For insect pests, studies have revealed that climate change has marked impact on geographical distribution, overwintering, growth rate of population, generation numbers, development season, simultaneous occurrence of crop & pests, inter-specific interactions and risk of invasion by migrant pests.[10] There are ample research findings and documents showing how insect population dynamics are impacted by climate change.[11,12,13,14]

Fig. 1: The red spot depicted the study site (Basar) in the district map of Arunachal Pradesh, India.

The study was done at Basar in the subtropical hills of Arunachal Pradesh (fig.1) located at 27o59.53' N and 94°41.27' Eat an altitude of 616 meters AMSL.

According to the agro-climatic classification of India, the region comes under the Eastern Himalayan Ecozone-II. Moreover,the study site is located in the Sub-tropical Hill Zone under Thermic Per-humid Mid-hills and Valleys. Fruit production is among the fastest growing sectors in the state of Arunachal Pradesh, located in the eastern Himalayan part of India, providing wide opportunities for income and employment. Mandarin (loose jacketed orange) is economically significant fruit crop of Arunachal Pradesh, with about 33 thousand hectare areas under it and production of 79 thousand metric tons.[15]

As located in the Northeastern region of India, Arunachal Pradesh is one of the major centers of diversity of citrus in the world.[16] The major citrus belts of Arunachal Pradesh are West Siang, East Siang, Upper Siang and parts of Lower Subansiri districts.[17] Though this crop has great economic potential in this region, but it is constrained by several environmental factors. Damage due to insect infestation ranked high among the constraints. The Biodiversity Strategy and Action Plan for the Northeastern Eco-region recorded 3624 species of insects from this region,[18] and a great many of them are serious agricultural and horticultural pests. Hill agriculture is comparatively more vulnerable to insect pest infestation due to the occurrence of varied climatic condition. Insects pose a serious threat with resultant low productivity in almost all the crops. Out of the various insect pests of citrus in Arunachal Pradesh, fruit fly (*Bactrocera dorsalis*) is of considerable economic significance in terms of damages caused. Fruit fly is one of the chief reasons for heavy loss due to pre-harvest fruit drop in citrus in this region. It is the female ovi position that is the cause of damaging activity of fruit fly, as the females lays eggs in clutches penetrating the flavedo of the fruit using their ovipositor.[19] The eggs laid inside the fruit hatched into larvae or maggots that feed on the decaying flesh. During the process the spoilage microbes that develop inside the fruit cause breakdown and rotting of the fruit. Inside the fruit when the larvae grow fully, it came out of the fruit and burrows itself into the soil or organic matter and it become pupae.[20] The whole life cycle repeats itself in about a period of 20 days when the adult fruit fly came out from the puparium.[21] Considering the damage caused by the insect, conventional chemical control measures need to be followed that have high economic as well as environmental costs. But when the probable time of occurrence of the insect as per the environmental conditions is known before hand, the infestation and spread of the fruit fly can be controlled or managed to a great extent through appropriate environment-friendly and cost-effective cultural practices. Keeping in view the significance of timely application of remedial measures to reduce the yield-loss caused by the infestation of the pest, the prior knowledge of the time and severity of the outbreak of the pest is absolutely essential.[22] A robust pest management strategy can only be effectively devised with appropriate knowledge about the part of the year when they are abundant, and time of their maximum damage and extent of damage, also the idea of variation of pest numbers.[23] Also, pest monitoring is a first fundamental step in designing and formulating a proper integrated pest management programme. Weather is one of the primary factors that govern the development, multiplication and extension of insect pests. So a weather-based location-specific statistical fore warning model can assist in estimation of probable time of insect occurrence and severity so that suitable timely preventive measures can be taken up to avoid crop damages. In this regard, evaluation of relationships between population dynamics of the pest with the meteorological parameters is of paramount significance, especially during current climate related uncertainties. Thus, primary objective of the research was to evaluate the relationship between the fruitfly population dynamics and weather parameters undermid-hill thermic prehumid conditions of Basar, Arunachal Pradesh and to develop a weather-based fruit fly population dynamics prediction model for Basar and identical locations.

Several researchers has done identical works in different agro-climatic conditions for various crops across the country,[24,25,26,27] but little focus has been given on citrus grown in the Eastern Himalayan region of the country.

Though climate change is a global phenomenon, its magnitude of impact is location specific. So, understanding the behavior of insects in different agro-climatic conditions is very much essential. The study will help understand the seasonal changes of population of fruitflies in the region. It will aid in formulating appropriate management strategies, especially in the current climate change scenario.

Materials and Methods

The study was done at the orange orchard of Indian Council of Agricultural Research regional centre at Basar, Arunachal Pradesh on 12-15 year old orange (Khasi Mandarin- *Citrus reticulata* Blanco) trees (planted at 5 x 5 m distance) during the year 2015-18. Methyl eugenolpara-pheromone traps were used to monitor the fruit fly (B. *dorsalis*) population based on all males trapped within the period of standard meteorological week (SMW) starting from 44th week (29th Oct - 04th Nov) to 43rd week (22nd- 28th Oct). One trap was placed per 15 plants and likewise all total 10 traps were placed across the orchard and were placed at the height of 2 meters above the ground. During the study period, no insecticides were applied to the orchard. Stereomicroscope (SZ61 Magnification 2.0x-270x) was used for identification of the fruit flies and species description was done as per standard methodology.[28] Number of flies trapped in each traps within the day was calculated using the formulae = {Total numbers of flies trapped (by species)} / {Number of trapping days x Number of traps}.[29]

The daily relevant weather data viz. rainfall, temperature, relative humidity (RH) and wind speed were collected from the meteorological observatory of the institution. The quality checking of meteorological data were done by removing obvious irregularities due to typing/ writing mistakes, anomaly or failure of instruments, changes in measurement techniques etc.

The model was developed using a regression model of the form Y= f(X) + e, where Y is the pest population of current week and f(X) is function of X, X being weather variables with an appropriate lags22. Karl Pearson's method of correlation[30] was used to evaluate the relationship between weather variables and population dynamics of the insect. The correlation between the population dynamics of a fruitfly was done with mean daily temperature (observations taken four times a day), mean relative humidity (observations taken four times a day), total daily rainfall and average wind speed.

Results and Discussion

Population Dynamics of Fruit Fly

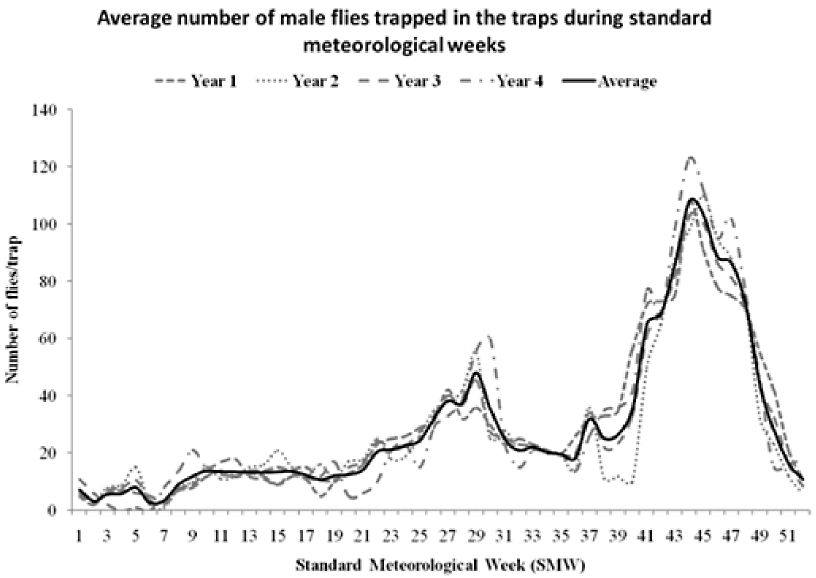

Fig. 2: Average number of male fruitflies trapped during standard meteorological weeks. The highest flies/trap was observed during the 44th SMW.

During the study period, it was found that the mean number of males trapped varied from 0.23 to 107.80 per trap (fig 2). The maximum population was found during 44th SMW (107.80 males trapped per trap) and at that period it was observed that maximum temperature, minimum temperature, morning RH, evening RH, rainfall and wind speed were 29.3°C, 18.3°C, 92.1%, 68.4%, 88.7 mm and 4.9 kmh^{-1} respectively. It was followed by the 45th SMW (90.30 males/trap) and 46th SMW (78.10 males/ trap). These weeks in the months of October and November coincide with the ripening stage of Khasi Mandarin in this region. The insect remained active till 48th SMW (26th Nov to 2nd Dec) with an average of 55.20 males per trap. Thereafter, the population started declining gradually (mid December to late

March) and the lowest population was observed during 1st SMW (1st to 7th Jan). The findings of the experiment are in agreement with the study done by Musasa *et al.* (2019) on population dynamics of B. *dorsalis* on citrus[20] and similar work done on mango,[31,27] where the highest population were found in the near ripening and ripening stage of the fruits.

Relationships Between the Weather Variables and Population Dynamics of Fruit Fly

During the study, it was noticed that there were differences in the total flies trapped daily during the months of fruit development and ripening stage of orange. This difference may be attributed to variation in weather conditions during these months. The correlation analysis between the evaluated population of flies and weather variables showed a statistically significant positive correlation between population and mean temperature (‘r’= 0.751), mean relative humidity (‘r’= 0.712) and rainfall (‘r’= 0.410) (Table 1). Thus, we can, to a great extent, conclude that the increase in mean temperature, relative humidity and rainfall favors the growth and activities of fruit flies in this location. These findings also support the observation of the highest number of flies per trap during the month of October and early November, which could be justified by the prevailing weather condition of relatively high mean temperature (23.5°C), humidity (75.2 %) and rainfall (65 mm) in this location. It also explains the comparatively low activity of flies during 51st SMW to 6th SMW in which the mean temperature, relative humidity and rainfall range from 11.2-15.5°C, 55-60%, and 6-12 mm respectively, although these period coincide with the fruit ripening stage of citrus in some parts of this region. These findings are very much in agreement with a study conducted on fruitflies infesting sweet oranges in Zimbabwe,[20] where also statistically significant correlationswerefound between the fruit fly population and meteorological parameters of relative humidity and mean temperature. The observation is also in agreement with the findings in mango,[27,20] where the population of fruit flies was directly correlated with temperature, humidity and rainfall. But the wind speed, in the current study, is not show a statistically significant correlation with flies per trap (Table 1), which may be due to undulated topography where wind speed is generally not appreciable and does not show much seasonal or monthly variation. It is very important to note while making inference that even if the null hypothesis is accepted based on the evidences, it does not imply that the null hypothesis is true, but it only indicates that the “data are not inconsistent with the null hypothesis” and there is the possibility that the outcome is merely happened by chance.

Table 1: Following table depict how the population dynamics of fruit fly is correlated with the weather variables during the study period.

Weather parameters	Correlation coefficient
Mean Temperature (X_1)	0.751**
Mean Relative Humidity (X_2)	0.712**
Rainfall (X_3)	0.410*
Wind Speed (X_4)	0.036

* Significant at 0.05 level, ** Significant at 0.01 level

Weather Based Fruit Fly Prediction Model

Correlation analysis revealed that the fruit fly population at a particular period is mostly governed by mean temperature (X_1) and mean relative humidity (X_2) of the location, so based on the observation a mathematical model was designed using the technique of step-wise multiple regression analysis having X_1 and X_2 parameters and the best fit optimized model was found to be

$Y = -322.14 + 3.76X_1 + 5.33X_2$ R^2 (adj) = 0.79 (R^2= 0.81).

Here from the value of R-squared (R^2) we can estimate how much variation of the dependent variable is explained by the independent variable(s) when we find the best fit in a regression model. From the value of correlation coefficient, we can only determine how strongly a dependent variable is dependent on the independent variable; from the value of R-squared we can have an idea of degree of variation of one variable cause variation of second variable. Here, we have taken the adjusted R-squared value, because the regression model contains several numbers of diverse independent variables. When we take only the R-squared value, addition of a new independent variable to the model increases the value of R-squared but never decreases it. Consequently, just because of the reason that it has more variables, a model with more independent variables seems to be better fit in the regression analysis. However, the value of the adjusted R-squared only increases if the addition of a new variable enhances the model above the predicted value and unlike R-squared value, the value of adjusted R-squared decreases when the addition of a new variable enhances the model below the predicted value. This model is accurate up to 79 per cent in explaining the population dynamics of fruit fly. Fig 3 depictsthe variation between the actual fruit fly population and that predicted by the above optimized model. This model will be highly useful in predicting the fruit fly population in citrus at least 1-2 weeks in advance so that necessary preventive and precautionary measures can be taken. A model for the fruit fly based on a similar concept was developed in mango[27] and in guava[32] and reported highly precise prediction.

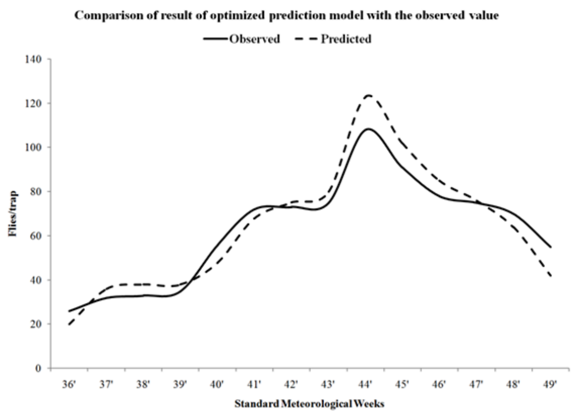

Fig. 3: The flies/trap as predicted by the optimized prediction model has been compared with the observed value. The prediction was found to be 79 percent accurate in most of the cases.

Conclusion

In conclusion, it was observed that the fruit fly (B. *dorsalis*) population was highest particularly during fruit development and ripening stage of fruit that causesan excessive damage to citrus in the mid-hills of Arunachal Pradesh. The study reveals that population is directly correlated with the weather parameters, particularly and significantly with temperature and humidity. The prediction model based on temperature and humidity is about 79 per cent accurate in explaining the population and behavior of the pest in such locations. The model can aid in estimation and prediction of possible variation in the population of the insect pest at least 1-2 weeks in advance in the mid-hill conations to an appreciable accuracy. Statistical significance has its own limitations, estimation of biological relevance of association between weather and insect needs to be explored to make the model more useful and reliable.

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Conflict of Interest

The author(s) declare no conflict of interest.

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