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Host-plant phenology and weather based forecasting models for population prediction of mango leaf roller *Dudua aprobola* Meyrick

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Abstract
The present investigation was carried out to predict the *Dudua aprobola* Meyrick population before its infestation on mango ecosystem will contribute to the success of IPM programs in India. The experiment was conducted at mango orchard of Indian Institute of Horticultural Research during 2014 - 2015. The study explored the scope of using host-plant phenology variables in addition to abiotic variables for fine tuning the current system of *D. aprobola* population prediction. Variables representing host-plant (Mango, *Mangifera indica*) phenology and weather were used and compared as components in step-wise regression to develop a comprehensive forecasting model for the pest. The combined equation models of phenology and phenology-weather variables gave the best fit to predict the highest variability in *D.aprobola* population both in vegetative ($R^2 = 0.75$) and reproductive ($R^2 = 0.46$) stage respectively. By using these variables the emerging pest, *D. aprobola* on mango can be predicted well before its severe attack.

Keywords: Abiotic factors, mango leaf roller, phenology, prediction models

1. Introduction

In perennial plants like mango, the chlorophyll content of the leaves, total sugar content, specific leaf weight are associated with photosynthetic ability of plants [1, 2]. Photosynthesis is a tool for natural development and increase of yield in mango plants. In turn, the growth of new tender mango leaves and their photosynthetic efficiency mainly depend on fluctuating weather. The mango is a fleshy stone fruit belonging to the genus 'Mangifera' consisting of numerous tropical fruiting trees. Among the mango producing states, Karnataka contributes to 9.7 t ha^{-1} productivity which is more than the total productivity (7.3 t ha^{-1}) of mango in India. The state is potential to increase the mango productivity, however the invasive lepidopterans are one among the several obstructers for its growth since few decades. Studies of various lepidopterans on mango ecosystem were done by various workers such as about inflorescence caterpillars [3, 4], *Orthaga exvinacea* [5-9], *Dudua aprobola* [10] *Citripestis eutraphera* [11, 12], *Chlumetia transversa* [13], *Acrocercops syngramma* [14, 15], *Lymantria marginata* [16]. One such example is leaf roller, *Dudua aprobola.* It is economically important pest causing infestation to Litchi crop [17]. *Dudua aprobola*, an emerging pest on mango, mainly infests both leaf and flower of mango by feeding inside rolled leaf and webbed flowers [12]. This pest is believed to be less significant on the crop but in recent years the diversity and abundance of lepidopterans are gaining importance due to rapid change in agro-ecosystem and climate.

The poikilothermic insects cause damage on new vegetative flush and reproductive parts (crop phenology) as well. These are often temperature mediated, a fundamental key concept of population prediction [18, 11]. The environmental factors that favour fecundity or speed of development, and are adverse to the pest-survival, promote its increase, and those having a reverse influence, cause a decline in its number. The same factor may be favorable in case of one population, but may become unfavorable in case of another. It is, thus necessary to consider the influence of various factors, with respect to a particular pest-population. Hence climate change is a typical to affect both phenology of the crop and their insect dynamics. A combined and concentrated effort about the relationship of mango leaf roller with host-plant phenology and weather based forecasting models is scanty. So there is a need to anticipate infestation with sound models for need-based IPM intervention for *D. aprobola*.

This study was conducted to develop forecast models that would help to predict expected infestation along with host plant phenology.

2. Materials and Methods

The study was conducted in a 25-year-old mango (var, Alphonso) orchard of Indian Institute of Horticultural Research, Bangalore during 2014-2015. The area of the experimental plot was 3.5 acres with a total plant population of 75 mango plants, at spacing of 10 x 10 m^2. The trees were maintained regular agronomic practices but no insecticides were sprayed during the study period. Thirty trees were selected at random for the study. Each tree was divided into four quadrants *viz.*, east, west, north and south directions. Ten shoots or inflorescence at random were sampled from each direction. Thus 40 shoots or inflorescence per tree and total of 1200 units per week were sampled for the study.

Parallel field observations were also done on host-plant phenology both vegetative phase *viz*., x_1 - mature leaf; x_2 - leaf bud (unopened leaf buds); x_3 - tender green leaf and x_4 - pink leaf stage and reproductive phase *viz.*, x_5 - inflorescence bud (unopened flower buds), x_6 -inflorescence bloom (half opened flowers) and x_7 - full bloom (full opened flowers) stage of mango inflorescence. For determining the scores of host-plant phenology, each tree canopy was thoroughly inspected and assigned the proportional availability of the different phenological stages and all these variables were scored visually on percent basis (0 -100) on 20 randomly selected mango plants. In addition to mango leaf roller and host-plant phenology availability data, the weather parameters including x_8 - maximum temperature (ºC), x_9 - minimum temperature (º C), x_{10} - morning relative humidity (%), x_{11} - evening relative humidity (%), and x_{12} - rainfall (mm) were collected from meteorological section of the Institute located in close proximity of the study orchard at weekly interval. The mean weekly meteorological data was then subjected to correlation and regression analyses with mean *D. aprobola* population as the dependent factor along with host-plant phenology variables. Significant correlation coefficient (r) values were taken as criteria to select suitable factor(s) to develop linear models with population of *D. aprobola* on the Y-axis.

A series of step-wise regression models were developed considering weather variables and host-plant phenology parameters singly as well as in various combinations to achieve maximum coefficient of determination (R^2) for estimating the population of *D. aprobola* [19]. Further, as a measure of goodness-of-fit, the extent of variability in the population of *D. aprobola* due to developed models were determined based on the coefficient of determination (R^2) [20]. The variance inflation factor (VIF) also calculated to quantify the severity of multi-collinearity among the variables. It was used to measure the correlated increase in the variance of the estimated regression coefficient. The better VIF should be near to value one but not one [21].

3. Results and Discussion

There was no *D. aprobola* incidence on mature leaf stage of mango. In the leaf bud stage (Fig. 1A), *D. aprobola* population was 608 and 412 during 2014 and 2015 respectively (Table 1), 397 and 229 in tender green stage (Fig. 1B) during 2014 and 2015 respectively, 520 and 392 in pink leaf stage during 2014 and 2015 respectively.

In reproductive stage of mango *D. aprobola* infestation was seen in all stages. The number of *D. aprobola* infested during inflorescence bud stage (Fig. 2) was 317 and 120 during 2014 and 2015 respectively. It was 225 and 107 numbers in inflorescence bloom stage during 2014 and 2015 respectively and 136 and 78 in full bloom stage during 2014 and 2015 (Table 2).

3.1 Vegetative phase

The maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and rainfall showed non-significant correlation with infestation of *D. aprobola.* Hence linear model could not explain the variability in *D. aprobola* infestation.

Among the host-plant phenology variables considered, *D. aprobola* showed significant negative relationship with matured leaf (r =-0.77, P< 0.05). However, *D. aprobola* incidence showed a significant positive relationship with leaf bud stage (r = 0.67, P<0.05), tender green leaf stage (r = 0.64, P < 0.05) and pink leaf stage (r=0.66, P< 0.05) (Table 3).

The variability in the *D. aprobola* population was explained by combination of host plant variables *viz*., leaf bud stage and tender green stage, which could explained to the tune of 75% (y= 1,45+1.96x_2 +2.01x_3, R^2 = 0.75, VIF= 2.4). The model was significant at all levels P<0.01. The VIF value is also below ten which is acceptable. From the earlier work it is confirmed that predicting the insect using phenological traits shows greatest consistency from year to year compared to abiotic factors which exhibit remarkable variations [22, 23]. However co-efficient of determination due to other combinations of host plant variables *viz*., leaf bud and pink leaf stage (y= 2.97+1.98x_2 + 1.76x_4, R^2 = 0,72, VIF=4.07), tender green and pink leaf stage (y= 1.45+ 2.41x_3 + 1.76x_4, R^2= 0.69, VIF=4.92) was about 72% and 69% respectively, were lower than the co-efficient of determination of leaf bud and tender green leaf stage. The models of both combinations were significant at all levels of P<0.01. Though VIF value of both combinations was acceptable but the value was more compared to leaf bud and tender green leaf stage combination (Table 3).

Combining all phenological variables showed variability in *D. aprobola* population of about 75%, but VIF value was not acceptable (8.39). In the model, y = 1.42+0.21x_2 +1.90x_3+ 1.83x_4 pink leaf stage was not significant with other two factors. Hence this model was not best to predict *D. aprobola* population. There is no earlier work to predict *D. aprobola* population. This study clearly shows phenological variables *viz.*, leaf bud and tender green stage can explains the variability of *D. aprobola* more accurately than any other variables studied.

Plotting the graph along with observed and estimated *D. aprobola* population using the combined equations of leaf bud and tender green leaf stage (x_2+x_3) showed a random dispersal of points across x-axis explained good-fit of linear models (Fig 3). As VIF value (2.54) computed for this model was less than 10. VIF value less than 10 indicating lack of multi-collinearity [24]. The observed *D. aprobola* population compared to predicted value clearly shows that the model could predict the *D. aprobola* population efficiently well before.

Temperature, relative humidity and rainfall are important weather variables that can influence mango fruit fly population [25, 13, 21]. However even the plant phenological variables can also predict fruit fly population on mango ecosystem [21, 26]. Hence in the present study, the role of both biotic (plant phenology) and abiotic variables were studied to increase the predictive accuracy of *D. aprobola* population.

3.2 Flowering phase

Among the weather variables studied, only the maximum temperature showed significant positive correlation with the infestation of *D. aprobola* during panicle initiation stage in mango. Whereas, other variables *viz*., minimum temperature, morning and evening relative humidity and rainfall were not significant.

Among the host-plant phenology variables considered, *D. aprobola* incidence showed a significant positive correlation with inflorescence bud stage. However, other parameters had non-significant correlation.

During reproductive stage the variability in the *D. aprobola* was explained by combined factor variable *viz*., inflorescence bud and maximum temperature with acceptable VIF value. Both explained individually, the *D. aprobola* population to the tune of 30% and 46% respectively. But maximum temperature was not significant ($y= 325.86-10.25x_8$, VIF=1) at $P<0.01$, whereas inflorescence bud was significant ($y=21.25+0.94x_5$; VIF=1) at $P<0.01$ but co-efficient of determination was less as compared to combined equation ($y=249.42-7.76x_8+0.46x_5$; VIF=1.52) of maximum temperature and inflorescence bud stage (Table 4).

Variability of *D. aprobola* explained by combined equation was up to 46% which was significant at $P<0.01$. The acceptable VIF value is also less than 10. Hence during flowering period the variability of *D. aprobola* can be predicted with both meteorological (maximum temperature) and phenological parameter (inflorescence bud).

Climate change and insect lifecycles are typical in the context of economically important insects on crops [27]. It is well established from the literature that abiotic factors such as temperature and rainfall is closely related with insect distribution [28] as well as their population dynamics [29]. A fundamental concept for insect population prediction was that, insect development depends mainly on the temperature to which they are exposed to environment (30).

The developed optimized model was to predict the *D. aprobola* population using minimum number of variables with reasonable R^2 value. The linear model $y= 1,45+1.96x_2 +2.01 x_3$ can be considered as optimized model to predict *D. aprobola* population during mango vegetative phase. Further, validation of optimized model (the observed *D. aprobola* population compared to predicted value) clearly indicated that the model could predict the *D. aprobola* population effectively (Fig. 3). During reproductive phase the model ($y=249.42-7.76x_8+0.46x_5$) could predict the *D. aprobola* population more accurately (Fig. 4).

In mango, the phenology especially cycles of flowering, vegetative flushing and also fruiting are triggered by changes in weather parameter [31]. Thus changes in abiotic factors also influences the incidences of insects. Lepidopterans are known to be highly sensitive to weather changes especially temperature [32].

Table 1: Population of *D. aprobola* on different stages of vegetative phase on mango during 2014 and 2015

Vegetative phase	Year	
Mature leaf	2014	2015
Leaf bud	0	0
Tender green	608	412
Pink leaf	397	229
Total	520	392
	1525	1033

Table 2: Population of *D. aprobola* on different stages of flowering phase on mango during 2014 and 2015

Reproductive phase	Year	
Inflorescence bud	2014	2015
Bloom	317	120
Full bloom	225	107
Total	136	78
	678	305

Table 3: Linear models to estimate *D. aprobola* population based on host-plant phenology during vegetative phase of mango

Variables	Correlation (r) with mean *D. aprobola*	Model	R^2	VIF
x_1	-0.77	-	-	-
x_2	0.67	$y = 5.42^{**}+3.09^{**} x_2$	0.67	1
x_3	0.64	$y =2.09^{NS}+3.911^{**} x_3$	0.64	1
x_4	0.66	$y=2.89^{NS}+3.99^{**} x_4$	0.66	1
x_2+x_3	-	$y=1.45^{NS}+1.96x_2^{**}+2.01x_3^{**}$	0.75	2.4
x_2+x_4	-	$y=2.97^{NS}+1.98x_2^{**}+1.76x_4^{**}$	0.72	4.07
x_3+x_4	-	$y=1.45^{NS}+2.41x_3^{**}+1.76x_4^{**}$	0.69	4.92
$x_2+x_3+x_4$	-	$y=1.42^{NS}+0.21x_2^{NS}+1.90x_3^{**}+1.83x_4^{**}$	0.75	8.39

NS=Non significant: * = significant at P=0.05; **= significant at P=0.01

Table 4: Linear models to estimate *D. aprobola* population based on host-plant phenology and meteorological parameter during flowering phase of mango

Variables	Correlation (r) with mean *D. aprobola*	Model	R^2	VIF
x_5	0.55	$y=21.25^{**}+0.94x_5^{**}$	0.30	1
x_8	0.64	$y=325.86^{NS}-10.25x_8^{NS}$	0.46	1
x_5+x_8	-	$y=249.42^{**}-7.76x_8^{**}+0.46x_5^{**}$	0.46	1.52

NS=Non significant: * = significant at P=0.05; **= significant at P=0.01

Fig 1: Infestation of *D. aprobola* on vegetative phase of mango. A: Leaf bud stage B: Tender green leaf stage

Fig 2: Infestation of *D.aprobola* on flowering phase of mango (inflorescence bud stage)

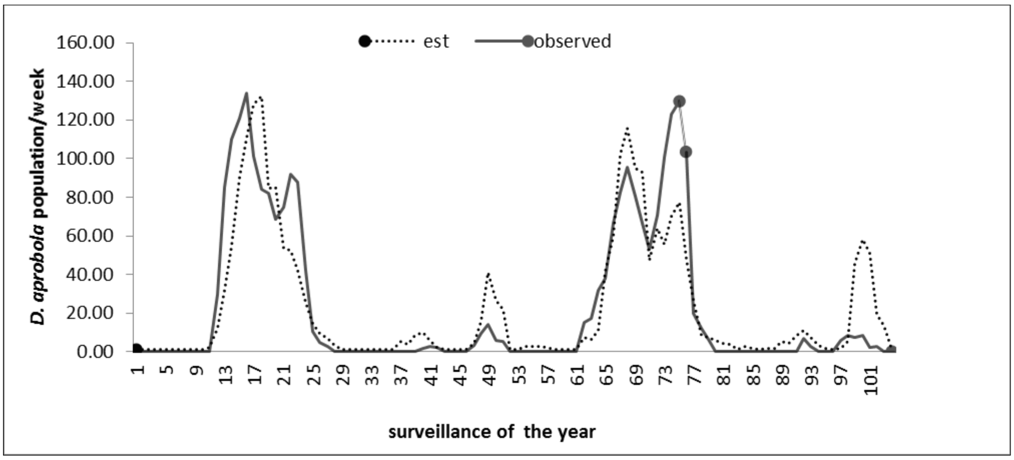

Fig 3: Estimated and observed *D. aprobola* using the obtimized model (y= 1, 45+1.91x$_1$ +2.016 x$_{2,}$ R^2 = 0.75) during vegetative phase of mango

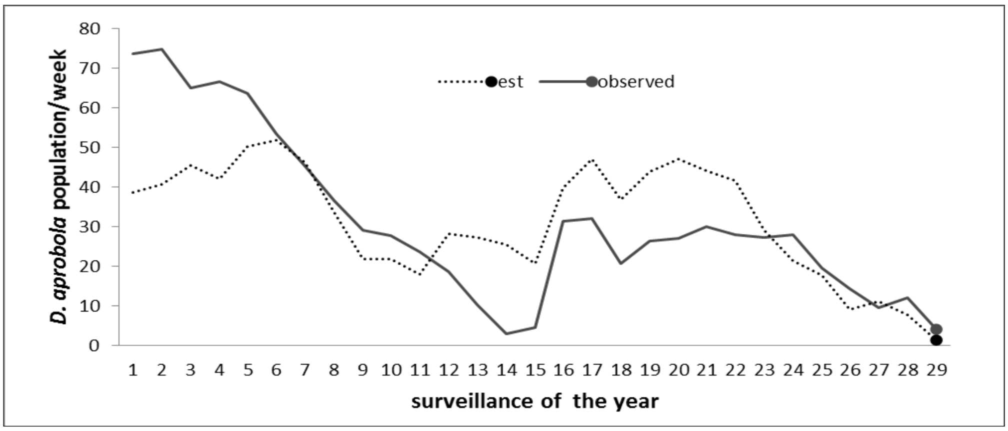

Fig 4: Estimated and observed *D. aprobola* using the obtimized model (y=249.42-7.76x$_8$+0.46x$_5$ R^2 =0.46) during flowering phase of mango

4. Conclusion

Effect of abiotic factors on biodiversity and dynamics of *D. aprobola* has great ecological significance. As mango is an economically important crop, this will reflect on the overall flower set, fruit set and yield of commercial varieties. Models based on plant phenological parameters are alternative to weather variables and can be user friendly and more practical. Hence there should be application of insecticide before opening of leaf and flower buds of mango. Thus studying the host plant phenological character as indicator for *D. aprobola* activity in relation to temperature will help not only to have better understanding of impact of climate change on the insect but also to quantify its future impacts. In this context, the effect of abiotic and crop phenology are considered major factor for implementing successful integrated pest management.

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