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Host-plant phenology and weather based forecasting models for population prediction of the oriental fruit fly, *Bactrocera dorsalis* Hendel

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ABSTRACT

Predicting oriental fruit fly, *Bactrocera dorsalis* Hendel, populations well in advance with maximum accuracy will contribute to the success of IPM programs in India. The present study explored the scope of using host-plant phenology variables in addition to abiotic variables for fine tuning the current system of fruit fly population prediction. Variables representing host-plant (Guava, *Psidium guajava* L.) phenology and weather were used and compared as components in step-wise regression to develop a comprehensive forecasting model for the pest. Significant associations ($P < 0.05$) were observed between host-plant phenology and synoptic weather variables. Among all the combinations of step-wise linear regression models, the model that used the availability of small immature *P. guajava* fruits as a single independent variable gave the best-fit as it explained the highest variability ($R^2 = 0.78$) in the trap catch with R^2 being 78% and 80% for linear and 6th order polynomial regression, respectively. Thus, the simple linear regression model derived for small immature *P. guajava* fruits had the strongest relationship with fruit fly trap catch and can be derived easily from visual scoring data. The best single predictor, small immature *P. guajava* fruits, is proposed as an accurate indicator suitable for forecasting the changes in *B. dorsalis* population well in advance. The predictive performance of linear regression models involving both host-plant phenology and weather variables and their prescriptive use is discussed.

1. Introduction

Oriental fruit fly, *Bactrocera dorsalis* Hendel (Diptera: Tephritidae), is a serious pest of a wide range of fruit crops in the Indian subcontinent. On mango (*Mangifera indica* L.), it causes enormous losses up to 80% (Verghese and Jayanthi, 2001). During the off-season (mango is usually available in India from March to mid-August), *B. dorsalis* survives on its alternative host guava (*Psidium guajava* L.), thereby completing several generations within a year. Given the economic importance of this species, progress has been made in managing the pest using methyl-eugenol traps (Ishtiaq et al., 1999), proteinaceous food baits (Cornelius et al., 1999, 2000; Pinero et al., 2009), classical biological control (Vargas et al., 2007), insecticidal applications (Anjum et al., 2000) and integrated methods (Verghese et al., 2004). Current integrated pest management programs in mango use sanitation and a male annihilation technique with methyl-eugenol traps to kill males along with need-based insecticidal cover sprays during fruit maturity, the stage most vulnerable to attack by ovipositing gravid females. The number of cover sprays usually ranges from 1 to 3 depending upon the *B. dorsalis* population levels (Verghese and Jayanthi, 2001). Thus, the efficiency of management strategies mainly depends on the fruit fly population, so prediction of *B. dorsalis* population levels well in advance would help greatly to plan/implement the management strategies as it will aid precise determination of the timings of treatments in order to maximize their effectiveness and minimize the number of sprays required. Therefore, constant monitoring of fruit fly populations and accurate forecasting of incidence forms part of an effective management strategy.

Several attempts have been made to monitor the population dynamics of *B. dorsalis* and to analyze the factors influencing field population fluctuations (Shukla and Prasad, 1985; Tan and Serit, 1994; Ye and Liu, 2005a,b,c; Chen et al., 2006). Nevertheless, limited studies were directed toward predicting *B. dorsalis* populations using abiotic variables. Regression models have been developed in Pakistan to predict the population density of melon fly, *Bactrocera cucurbitae* (Coq.), using daily mean temperature (Inayatulla et al., 1991). In India, weather parameters were mostly studied to develop weather based forecasting models to predict the fruit fly population level in a region (Verghese and Sudha Devi,

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1998; Verghese et al., 2006a). Previously, Peng et al. (2006) analyzed the effect of climatic factors and host plants on *B. dorsalis* population fluctuation in Yunnan Province, China and found that the monthly mean temperature, monthly days of rain and host plants were the major factors influencing *B. dorsalis* populations. However, they did not attempt to predict the population of the fruit fly based on these variables.

The objective of the present study was to make a simple user-friendly model using the minimum number of variables to predict the *B. dorsalis* populations without compromising prediction accuracy. Therefore, this study was planned to investigate whether host-plant phenology alone or in combination with weather parameters would improve the precision of fruit fly population estimation in the field and to compare different host-plant phenology/weather components in order to propose accurate indicators that influence fruit fly population changes.

2. Materials and methods

The study was conducted in a 15-year-old guava, *P. guajava* cv. *Allahabad Safeda* orchard of Indian Institute of Horticultural Research, Bangalore (12°58′N; 77°35′E). The area of the experimental plot was two hectares with a total plant population of 800 guava plants, at 5 × 5 m spacing.

As the trap catches are good indicators of the extent of occurrence of *B. dorsalis* in an area, three methyl-eugenol traps were deployed and spaced approximately 100 m apart. The traps were made from used mineral water bottles and consisted of plywood blocks of 2 cm^3 impregnated with methyl-eugenol and dichlorvos (as a killing agent). Traps were prepared by opening square holes (vents) of 2 cm^2 on four sides just below the shoulder of the bottle (i.e., 1/3rd from top). The holes were made by slitting along three sides of a square (i.e., two on the sides and one along the bottom) using a hot penknife. The cuts given in this manner enabled the slit to be lifted as a hood to form a 'rain guard'. In addition, four random holes of 3–4 mm diameter were punched at the bottom with warm needles to allow drainage of rain water that may have accumulated in the bottle. The impregnated plywood blocks were suspended inside the bottle in such a way that they were hanging vertically along the vents, by making a hole on the cap and passing a thread through it. Recharging of the blocks was done every 20 days with methyl-eugenol (1 ml) and dichlorvos (1 ml) using an ink-filler (Verghese et al., 2006b). The traps were held firmly to a *P. guajava* branch with twine at a height of 100 cm from the ground level (Madhura and Viraktamath, 2001). Monitoring *B. dorsalis* was done fortnightly (from June 2000 to June 2002) and the flies attracted to each trap were brought to the laboratory and identified based on the characters described by Drew and Hancock (1994) to separate *B. dorsalis* from other *Bactrocera* spp. Simultaneously field observations were recorded on the host-plant phenology variables viz., tender leaves (young flush with pinkish brown tender leaves), half mature leaves (new immature leaves with bright green color), full mature leaves (dark green leaves that fully matured), senescence (yellowish old leaves), flower buds (unopened flower buds), opened flowers (fully opened flowers with white petals), small immature fruits (marble to lime size immature fruits), medium size immature fruits (fruits that are intermediate in size and/or color between immature and mature) and large mature fruits (big mature fruits ready for harvest). 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 twenty randomly selected *P. guajava* plants.

In addition to lure trap catch and host-plant phenology data, the concurrent daily weather parameters were collected from the meteorological section of the Institute that was proximal to the study orchard and the means of the weather parameters [relative humidity (%), x_1; wind speed (km^{-h}), x_2; maximum temperature (°C), x_3; minimum temperature (°C), x_4; and rainfall (mm), x_5] were also calculated for every fortnight. The mean fortnightly data was then subjected to correlation and regression analyses with trap catches as the dependent factor along with host-plant phenology variables (tender leaves, x_6; half mature leaves, x_7; full mature leaves, x_8; leaf senescence, x_9; flower buds, x_{10}; flowers, x_{11}; small immature fruits, x_{12}; medium immature fruits, x_{13}; large mature fruits, x_{14}). Significant correlation coefficient (r) values were taken as criteria to select suitable factor(s) to develop linear models with catches of *B. dorsalis* 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 for estimating the trap catch (Little and Hills, 1978). Further, as a measure of goodness-of-fit, the extent of variability in the *B. dorsalis* catch due to developed models was determined based on the coefficient of determination (R^2) (Draper and Smith, 1981). The Variance Inflation Factor (VIF) that quantifies the severity of multicollinearity was calculated to measure the correlated increase in the variance of the estimated regression coefficient because of collinearity among the variables.

3. Results

Among the weather variables studied, the *B. dorsalis* trap catch showed a significant positive relationships with wind speed ($r = 0.48$, $P < 0.01$), maximum temperature ($r = 0.34$, $P < 0.05$), minimum temperature ($r = 0.68$, $P < 0.01$) and rainfall ($r = 0.40$, $P < 0.05$) (Table 1). Whereas, the relationship of trap catch with relative humidity was not significant.

Among the host-plant phenology variables considered, *B. dorsalis* trap catch showed significant positive relationships with half matured leaves ($r = 0.52$, $P < 0.01$), flowers ($r = 0.29$, $P < 0.05$), small immature fruits ($r = 0.81$, $P < 0.01$) and medium mature fruits ($r = 0.40$, $P < 0.01$) (Table 2). However, with leaf senescence it showed a significant negative relationship ($r = -0.37$, $P < 0.01$) and with fully matured leaves there was no significant relationship (Table 2).

3.1. Weather parameters

The linear models considering each weather variable independently explained the variability in the trap catch by up to 40%, 23%, 12% and 56%, with rainfall, wind speed, maximum temperature and minimum temperature respectively (Table 1). The VIF value computed for these models was in agreement with the acceptable limit (<10.0). The step-wise regression models involving weather variables did not improve the R^2 value beyond 0.55 (Table 1). The regression model considering all the weather variables [wind speed (x_2); maximum temperature (x_3); minimum temperature (x_4); rainfall (x_5)] that are significantly correlated to *B. dorsalis* trap catch explained 58% of the variability (Table 3).

3.2. Host-plant phenology parameters

The linear regression models developed using the host-plant phenology variables independently explained the variability in the *B. dorsalis* trap catch by up to 27% (half mature leaves); 14% (leaf senescence); 9% (fully opened flowers); 78% (small immature fruits) and 56% (medium immature fruits) (Table 2). The step-wise regression models involving all combinations of significant host-plant phenology variables could explain the variability in the