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Research Article

Forecasting Models of Male Flight and Egg Laying Activities of the European Grapevine Moth *Lobesia botrana* (Den and Shiff.) (Lepidoptera: Tortricidae) in Vineyards at Northern Coast of Egypt

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Abstract

The European grapevine moth, is considered to be a key pest of vineyards in the Mediterranean countries. The present study was carried out at Nubaria region in Northern coast of Egypt for three successive years, 2017, 2018 and 2019. The farm cultivated with different varieties of grape. Flame seedless variety was selected for the current study and divided into two groups. In the first, trees were covered with transparent plastic sheets (indoor vineyards) for production early grape. In the second one, grape trees left without sheets (outdoor vineyards).

Statistical analysis showed that male flight activity and egg deposition of *L. botrana* were positively correlated with Growing Degree Days (GDD) through the three successive years in both indoor and outdoor vineyards.

Regression analysis showed a good fit between male moth activity and laid eggs versus GDD in indoor and outdoor vineyards during the three consecutive years. In indoor vineyards, obtained determination coefficient (R^2) of male flight activity was 0.32, 0.88 and 0.82 for the three seasons 2017, 2018 and 2019, respectively. While in outdoor vineyards they were 0.57, 0.66 and 0.83 for the three seasons, respectively. In indoor vineyards, R2 of egg laying were 0.34, 0.96 and 0.83 for the three seasons 2017, 2018 and 2019, respectively. While in outdoor vineyards they were 0.89 0.78 and 0.96 for the three seasons, respectively. These models forecast male flight activity or egg laying (Y) by determine GDD (X) during the activity period of *L. botrana* moths in both covered grape (indoor) and exposed grape (outdoors). In the present study, Applications of temperature predicting models to the study male flight activity and egg laying may help entomologists in assembling effective forecasting systems for planning IPM programs in vineyard ecosystem.

Keywords: Flame Seedless; Growing Degree Days; Models; IPM; Indoor Vineyard; Outdoor Vineyard

Introduction

The European grapevine moth, *Lobesia botrana* (Den. and Shiff.) (Lepidoptera: Tortricidae), is considered to be a key pest of vineyards [11]. This pest is native to Southern Italy [6], it can be found in Southern Europe [3], North Africa [22]. Recently it has been introduced into Chile and Argentina [11] and the optimum conditions of activity are an annual average temperature around 20 Cº and a relative humidity around 70%, respectively.

In Egypt, *L. botrana* has three generations per year [1,2]. The first generation appears during the flowering growth stage of grape trees. The following generations attack the fruiting growth stage causing direct damage to grape berries and indirect damage, such as the fungal rottenness caused by *Botrytis cinerea* which is favored by the larval activity inside the berry during maturation. Egyptian vineyards owners apply several pesticides treatments per year with traditional insecticides and/or I.G.R products such as Runer 24% (methoxyfenozide) or insect pathogenic bacteria *Bacillus thuringiensis*, to keep this notorious pest under the economic injury level. Other integrated pest management approaches, such as release egg parasitoid, *Trichogramma* spp. have been applied [22]. but mating disruption with pheromone dispensers are not currently implemented.

Degree-Days models are used to predict developmental and biological events of insects [14].

In central Europe, predictive strategies have been developed to predict the first appearance of *L. botrana* under field conditions and to monitor their flight activity, where the moth has one to two generations per year [10].

The operational availability of information about *L. botrana* and crop phenology of grapevine (*Vitis vinifera* L.) should enhance the effectiveness of grape IPM programs, [17]. In the context of global warming, there is also a need to understand how pest species dynamics will evolve in the future. Phenological models are interesting tools to monitor population dynamics and to predict their evolution e.g., under environmental changing and climatic conditions [7,24]. Such models are capable of forecasting insect generations and allow improving treatment information [19].

Recently, phenological, and predictive models are applying in IPM strategies. Combining the simplicity of temperature-driven models and some ecological tools such as sex-pheromone traps and weather stations contribute to and supported IPM plans. The relationship between *L. botrana* pheromone trap catches and degree-day accumulations using phenological models has been developed to determine the best time for insecticide treatments [8,11,13,18].

The aim of the current study is to predict male flight activity and egg laying of *L. botrana* using GDD in vineyards at Nubaria region in Northern coast of Egypt for three successive three years.

Materials and Methods

The present study was carried out at El-Rouda grapevine farm which located in Nubaria province, Egypt (30º44’20”N 29º54’14”E) for three successive years, 2017, 2018 and 2019. The farm cultivated with different varieties of grape at area of 800 feddans (feddan = 4200 m^2). Design of the farm is divided into vineyard sectors. The area of the sector ranged from 6-15 feddans. Common recommended agricultural practices were seasonally applied.

Flame seedless variety was selected for the current study. Sectors were divided into two groups: in the first, trees were covered with transparent plastic sheets (indoor vineyards) for production early grape. In the second, grape trees were lift without sheets (outdoor vineyards). Number of indoor vineyard sectors were 16 while, number of outdoor vineyard sectors were 8.

Estimation of male grape moth numbers

Pest monitoring of *L. botrana* is done by using pheromone water-traps. They baited with a synthetic pheromone of *L. botrana* (E, Z)-7,9-dodecadienyl acetate as the major component of the synthetic pheromone. Traps were fixed 1.5 m above the ground on the trees. They were distributed at rate of 1 trap per 5 feddans. Pheromone dispensers were renewed at least once a month. Caught moths per week were recorded. Weekly average catches of *L. botrana* males and degree-day accumulation were independently calculated for each of the three agricultural seasons, 2017- 2018 and 2019. Male. Male moth numbers were transformed to accumulated percentages to plot regression lines between GDD and percentages of collected male moths per trap.

Estimation of deposited eggs/berry

Egg counting is a reliable sampling method, but it needs a trained eye to find eggs because *L. botrana* lays them singly, and it is rather difficult on inflorescences [4].

From each flame variety sector (indoor and outdoor vineyards) ten grape berry samples from each sector were weekly randomly collected and transferred to the laboratory in ventilated bags (160 berry from indoor sectors and 80 berry from outdoor sector). In the laboratory, berries were examined using stereomicroscope. Deposited eggs/berry was counted and recorded. Egg is minute spherical in shape and transparent white in colour (Figure 1). Egg numbers were transformed to accumulated percentages to plot regression lines between GDD and percentages of eggs per berry.

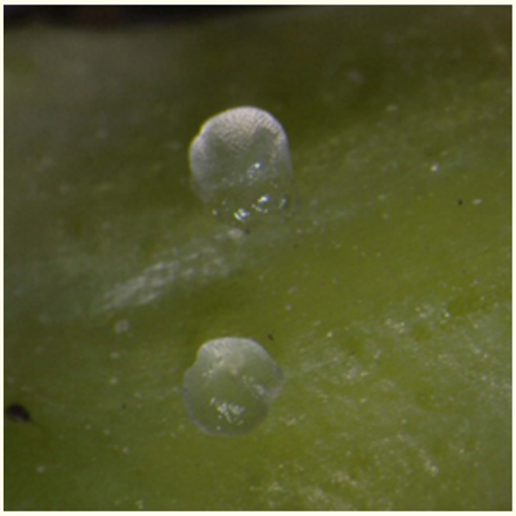

Figure 1: Eggs of grape moth, Lobesia botrana (40 x).

Recording daily temperature

In indoor and outdoor vineyards, to calculate Growing Degree Days (GDD), mean daily maximum and minimum temperature were recorded by meteorological units inside El-Rouda farm from first January until the end of grape maturation.

Calculation of growing degree days

In indoor and outdoor vineyards, to calculate Growing Degree Days (GDD

Calculating GDD was applied according to [9] as follows

DD = [(Max Temperature + Minimum Temperature)/2]-Base Temperature

Where base temperature (temperature threshold) is 10 C° for *L. botrana*. DD was added daily to create cumulative number of GDD.

Inferring prediction models of male flight activity and egg laying

Prediction of *L. botrana* male flight activity and egg laying were carried out by determining the relationship between the thermal heat units expressed as GDD and weekly catches moths in pheromone water-traps during the period from first January to the end of grape maturation. Also, prediction of deposited eggs per berry was estimated by the same method.

Statistical analysis

Regression analysis by [21] was used for this purpose, the correlation between GDD and both percentages of male moth/trap and percentages of eggs per berry were calculated using least squares regression**.** Prediction models were constructed from the collected data through the seasons of 2017, 2018 and 2019 years.

Results

Male flight activity of *Lobesia Botrana* according to growing degree days

Estimation of percentage of caught male grape moths

Flight activity of *L. botrana* was presented as percentages of male moths caught per trap (Figure 2). The first caught of moths in indoor vineyards occurred at 465, 444 and 667 GDD for the three years of study, respectively. While, the first caught of moths in outdoor vineyards occurred at 366.8, 463 and 207.4 GDD (Figure 2). Flight male activity of *L. botrana* started early in February and March in indoor vineyards. While it started late in April in outdoor vineyards.

Estimation of percentages of deposited grape moth eggs

Egg deposition activity of *L. botrana* presented as percentages of deposited eggs per berry. The first appearance of deposited egg in indoor vineyards occurred at 465.2, 444.1 and 667.4 GDD for the three years of study, respectively (Figure 2). While, the first appearance of deposited egg in outdoor vineyards occurred at 366.8, 463 and 207.4 GDD for the three years of study, respectively (Figure 2). Egg laying activity of *L. botrana* started early in February and March in indoor vineyards. While it started late in April in outdoor vineyards.

Inferring prediction models of male flight activity and deposited eggs

Since percentages of moths/trap and eggs/berry are positively correlated with GDD, they were used as predictable variable to build up regression models for predicting independent variables (% moths/trap and % eggs/berry).

Linear regression equation for accumulated caught moths and laid eggs versus accumulated degree days for the three studied years of indoor and outdoor vineyards are presented in tables 1 and 2.

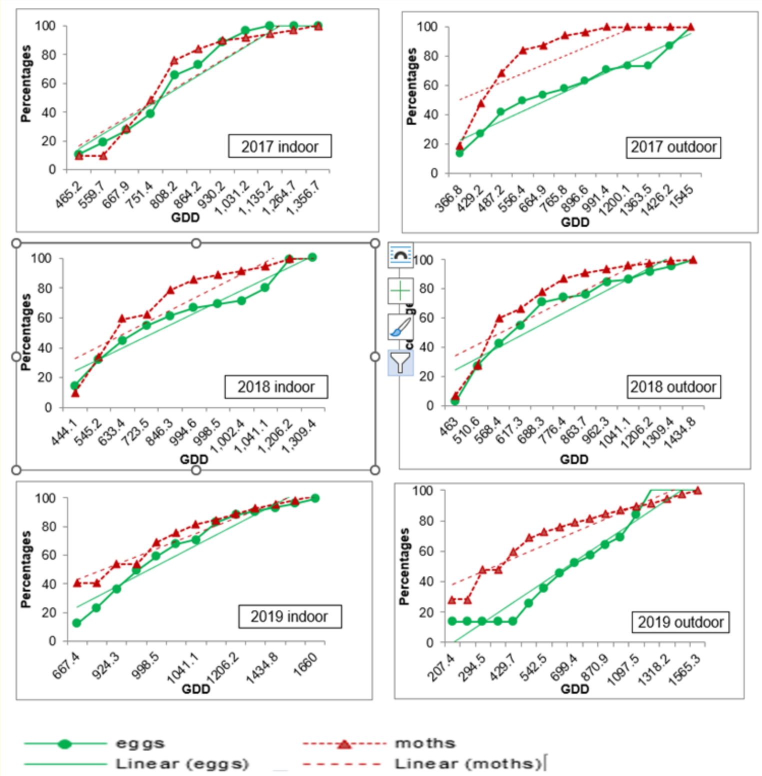

Figure 2: Regression lines between Growing Degree Days (GDD) and percentages of caught moths and deposited eggs of *Lobesia botrana* at El-Rouda vineyards in Nubaria province during three successive years.

Regression analysis showed a good fit between both male flight activity and laid eggs versus GDD in indoor and outdoor vineyards during the three consecutive years (2017, 2018 and 2019). In indoor vineyards, obtained determination coefficient (R^2) of flight activity were 0.32, 0.88 and 0.82 for the three seasons 2017, 2018 and 2019, respectively (Table 1). While in outdoor vineyards they were 0.57, 0.66 and 0.83 for the three seasons, respectively (Table 2). These models forecast male flight activity and egg laying (Y) by determine GDD (X) during the activity period of *L. botrana* moths.in both covered grape (indoor) and exposed grape (outdoors).

In indoor vineyards, obtained determination coefficient (R^2) of egg laying were 0.34, 0.96 and 0.83 for the three seasons 2017, 2018 and 2019, respectively (Table 1). While in outdoor vineyards they were 0.89, 0.78 and 0.96 for the three seasons, respectively (Table 2).

Parameter	Year	Model	r	R^2
Flight activity	2017	Y= 25.39 + (0.052) x	0.570	0.32
Egg laying		Y= 25.07 + (0.052) x	0.585	0.34
Flight activity	2018	Y= 15.83 + (0.10) x	0.938	0.88
Egg laying		Y= - 19.96 + (0.094) x	0.981	0.96
Flight activity	2019	Y= 0.36 + (0.066) x	0.908	0.82
Egg laying		Y= -36.39 + (0.091) x	0.913	0.83

Table 1: Statistical parameters of linear models of male flight activity and egg laying of European grape moth, *Lobesia botrana* in indoor vineyards during three consecutive years.

Parameter	Year	Model	r	R^2
Flight activity	2017	Y= 41.17 + (0.047) x	0.753	0.57
Egg laying		Y= 9.48 + (0.056) x	0.942	0.89
Flight activity	2018	Y= 9.25 + (0.076) x	0.811	0.66
Egg laying		Y= - 3.43 + (0.081) x	0.828	0.78
Flight activity	2019	Y= 39.22 + (0.045) x	0	0.83
Egg laying		Y= - 12.62 + (0.083) x	.909	0.96

Table 2: Statistical parameters of linear models of male flight activity and egg laying of European grape moth, *Lobesia botrana* in outdoor vineyards during three consecutive years.

Discussion

Ecologically, development of insects and their natural enemies occur between low and high temperature thresholds. [7]. Researchers have been studied biological development over time of insects in correlation to GDD, discovering information on key physiological and biological activities, such as egg laying and hatch, adult flight, etc. This predictive information is known as an insect model. Prediction models are efficient tools for development of sustainable pest management as they describe the population dynamics and abundance in the environment. Insect models help in timing insecticide application because the entire life cycle and some biological events of the insect development are known. Forecasting models have been developed for several insect pests [20].

Since temperature may vary widely from year to year, pest management strategies may not be effective if control instructions are based on calendar dates rather than on insect development. A widely used method for predicting insect growth is the GDD models. These models calculate the number of DD or heat units that are accumulated between the minimum (base) temperature threshold and the upper threshold. Pest managers can use the GDD to predict adult emergence, egg laying, and other important events based on the amount of heat accumulated in the vineyards, fields or orchards [16] and [15]. DD models are practical to develop and easier to use by growers, after doing validation locally because emergence of *L. botrana* adults varies with location, climate, and year [11].

In the current study, Thermal requirements for *L. botrana* started from biofix on first January using base temperature of 10 Cº. Starting male flight activity occurred at 465.2, 444.1 and 667.4 GDD in 2017, 2018 and 2019, respectively in indoor vineyards. While in outdoor vineyards, they occurred at 366.8, 463.0 and 207.4 DD in the three studied years, respectively (Figure 2). Similar findings were recorded in different geographical regions. In Italy, [6] estimated the occurrence of the first generation flight peak at 236 DD. While In Spain, [3] predicted maximum flight of the first generations of *L. botrana*, in Ribera del Duero region (Spain), at 144 DD above a minimum threshold of 10ºC, from January 1st. Using the same biofix and base temperature.

Other authors have chosen 1 March as the date from which to start computing the degree-days (biofix). In two regions of Greece (Thessaloniki and Naoussa), [18] estimated degree days required for the first generation of *L. botrana* from 276 DD to 334 DD. [16] reported that if applying a conventional insecticide for the first generation of European grapevine moth, the application was done between 250 and 350º DC (450 - 594º DF). This is a period that spans from peak flight (=peak egg laying) to 10% egg hatch.

In Argantina, [11] estimated degree-day accumulations corresponding to 50% of captures for the second generation to be 902 DD, above a minimum threshold of 7 ºC. [13] predicted 50% of male adult emergence for the first flight of *L. botrana* occurs at 443.9 DD which synchronized with the month of September. We noticed that accumulation around 441 DD was occurred between February and March (synchronized with the activity of first generation) in Northern coast of Egypt. This indicate that justification of applying control methods depend on accumulation of DD not on calendar dates. The high variations in the patterns of adult emergence of *L. botrana* were recorded under field conditions, is not only limited to differences between study regions, but also occurs between different generations of the same year or between different agricultural seasons [5,8,18].

With attention to constructed regression models in indoor and outdoor (Figure 2), it can be noticed that regression lines in indoor are more homogenous than lines in outdoor, Where statistical indicators such as R^2 are similar in indoor (0.88 and 0.82 for flight activity in 2018 and 2019) and 0.96 and 0.83 for egg laying for the two years (Table 1). While in outdoor R^2 are (0.66 and 0.83 for flight activity in 2018 and 2019) and 0.78 and 0.96 for egg laying for the two years (Table 2). This may refer to the effect of controlled conditions of temperature on moth activities in indoor sectors under plastic sheets. Our gained results indicate to that the constructed models are suitable in predicting flight male activity and egg laying of *L. botrana* in both indoor and outdoor vineyards at the Northern coast of Egypt. However, validation of the models in predicting should be done in the following seasons by collecting new observations under different field conditions. From a practical point of view, the applications of temperature predicting models to the study of grape moth egg laying and male flight activity could help entomologists in assembling effective forecasting systems for planning IPM programs in vineyard ecosystem.

Conclusion

Flight male activity of *Lobesia botrana* and female laying eggs started early in February and March in indoor vineyards and late in March and April in outdoor vineyards. This difference in activity time is due to GDD required for moth development.

Regression analysis showed a good fit between male moth activity or laid eggs of *Lobesia botrana* versus GDD in indoor and outdoor vineyards during the three consecutive years. These models forecast male flight activity or egg laying (Y) by determine GDD (X) during the activity period of *L. botrana* moths.in both covered grape (indoor) and exposed grape (outdoors). Applications of the constructed predicting models may help entomologists in assembling effective forecasting systems for planning IPM programs in vineyard ecosystem.

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Conflict of Interest

The authors declare no conflict of interest.

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