

Research Article

Are pheromone traps applicable to forecast an insect pest phenology? A case study on codling moth

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Abstract: Applying a precise forecasting method is necessary to achieve acceptable results in IPM programs. Performances of the wing and delta pheromone traps for forecasting the codling moth phenology were compared with physiological time data based on Degree-Hours. Six pheromone traps (three wing and three delta style) were applied for the monitoring of the codling moth population. Traps were placed in an apple orchard in Tehran Province, Damavand region by the start of bloom. All traps were checked every week and the number of moths caught was recorded. Physiological time was estimated by using hourly recorded temperature, considering temperature thresholds for codling moth development. The results showed that the delta style traps statistically caught more male moth than wing traps. It was also shown that the results of the pheromone traps data were affected severely by weather conditions. Moreover, false fluctuations in recorded data from pheromone traps made some false population peaks, the interpretation of which was very hard. On the other hand, forecasting model based on the physiological time data, was not affected by the mentioned conditions and its results was easy to use for determination of the pest phenology without further interpretations.

Keywords: *Cydia pomonella*, forecasting model, pheromone, tarp, population

Introduction

Temperature is a critical abiotic factor influencing the dynamics of mite and insect pests and their natural enemies (Huffaker *et al.*, 1999). The rate of development of codling moth is governed by environmental temperature (Rock and Shaffer, 1983; Ranjbar Aghdam *et al.*, 2009). The concept of using heat unit accumulation or degree days to explain codling moth activity originated in Illinois during the 1920's. Many modifications of the phenology

models have been made over time, with the initial models being developed in the early 1920s (Glenn, 1922). A practical program has been published in 1978 by Michigan State University and has been modified and used successfully in Washington state orchards since 1982. In British Columbia, tests of the Washington model during 1983-1985 have demonstrated its accuracy in predicting codling moth activity and spray dates under Okanagan weather conditions (Procter *et al.*, 1986).

Heat unit accumulation between the lower and upper thermal thresholds, for an organism to develop from one point to another in its life cycle is called physiological time and is calculated as degree-days (DD) or more precisely based on degree-hours (DH) unit

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(Roltsch *et al.*, 1999; Howell and Neven, 2000; Stevenson *et al.*, 2008). Many mathematical methods are developed to estimate more precisely growing degree days (GDD) or growing degree hours (GDH) (Roltsch *et al.*, 1999). The simplest method to use is average temperature method (Arnold, 1960). This method is easy to use but has the highest error among degree-days estimation methods (Roltsch *et al.*, 1999; Ranjbar Aghdam, 2009). Single sine wave (Baskerville and Emin, 1969; Allen, 1976), double sine wave (Allen, 1976), single triangle (Lindsey and Newman, 1956), double triangle (Sevacherian *et al.*, 1977), and corrected sine wave and triangle all are the other mathematical methods to estimate physiological time (Roltsch *et al.*, 1999). All of these methods are based on daily minimum and maximum temperatures. Using hourly-recorded real weather data offers the greatest accuracy for degree-day values rather than daily minimum and maximum temperatures (Roltsch *et al.*, 1999; Cesaraccio *et al.*, 2001; Ranjbar Aghdam, 2009).

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is the key pest of apple, pear and walnut trees in much of the world (Alston, 2006; Jones *et al.*, 2013), and particularly in Iran (Radjabi, 1986). Codling moth management in commercial orchards is essential for economic fruit production. Current management tactics for codling moth typically consist of mating disruption in combination with insecticide sprays or insecticide sprays alone (Radjabi, 1986; Brunner *et al.*, 2001; Jones *et al.*, 2010). Depending on the insecticide used, sprays are targeted either at the egg stage or when first instar larvae are emerging and are timed by the information obtained from pheromone traps or in advanced systems by using heat-driven phenology models and calculating empirically derived number of growing degree-days (GDD) or growing degree-hours (GDH) (Ranjbar Aghdam, 2008; Jones *et al.*, 2013).

Traps baited with codlemone, the main sex pheromone component of codling moth have

been used for many years to monitor populations in fruit orchards (Roelofs *et al.*, 1971; Butt *et al.*, 1974; Maitlen *et al.*, 1976; Knight *et al.*, 1999). Codling moth catch in codlemone-baited traps has been used to establish action thresholds and as an indicator of codling moth phenology (Madsen and Vakenti, 1972; Riedl and Croft 1974; Madsen *et al.*, 1974; Riedl *et al.*, 1976; Oloumi-Sadeghi and Esmaili, 1980; Beers and Brunner, 1992; Knight *et al.*, 1999; Radjabi *et al.*, 2007). From many years ago, sex pheromone trapping has been the commonly used method to determine time of spraying against the above mentioned pest in Iran (Oloumi-Sadeghi and Esmaili, 1980; Radjabi *et al.*, 2007). However, application of sex pheromones is commonly used technique to forecast insect pest phenology in Iran, especially for codling moth.

The objective of this study was to compare the ability of two different techniques, pheromone traps and calculation of growing degree hours based on hourly recorded real temperature to forecast the most important phenological event (moth population peaks) of the codling moth. This study may help us to implement an appropriate and accurate technique to forecast pest phenological events in future.

Materials and Methods

Research location

Study was conducted in a 125ha economically important apple orchard in Sarbandan (35°38' 6.65"N, 52°14'26.14"E, and 2149.12 m elevation), Damavand region, Tehran Province, in 2013. Apple varieties were different, but Golden Delicious and Red Delicious were dominant as compared with others.

Pheromone traps and pheromone

Pheromone traps were wing (PHERO TECH INC., 1-800-665-0076, USA) and delta (PPB, 307397, I. R. Iran) styles. Pheromone dispenser capsules (AgriSense, UK) were placed in the center of the traps sticky surface. Pheromone traps were placed within the upper third of the outer surface of tree the canopy. Six pheromone

traps (three wing style and three delta style) were applied for population monitoring. Traps were installed at 3 different locations within orchard, first was in the orchard entrance about 200 meter distance from the border, second was in the middle part of the orchard and third was in the other side of the orchard about 100 meter far from the border. In each locality, two pheromone traps (Wing and Delta styles) were placed about 100 meters from each other. Traps were placed in the orchard when blooming started (late-April). In order to determine accurate date of biofix, all the traps were observed daily after installation. When the first consistent moth flight occurred, (at least two moths were trapped in two consecutive nights), biofix was confirmed. Biofix is a biological marking point from which the rest of an insects development is measured (Alston, 2006). After biofix, traps were observed every week and the number of moths recorded. Pheromone capsules were changed every three to four weeks. Sticky layer of traps was changed after it was covered by dust and debris.

Recording temperature

Temperature was recorded using a temperature and %RH data logger (Germany, Testo, 175-H2) installed in the center of the apple orchard since the determined biofix date. Data logger was set to record hourly ambient temperature, at the height of 1.5 m from the ground level. In order to keep the data logger away from direct sunlight, precipitation, and wind, the instrument was kept under a green cardboard shelter, which was perforated on both sides to provide easy air circulation.

Calculation of GDH (Physiological time)

Growing (or cumulative) Degree-Hours Celsius (GDH) was calculated by using hourly-recorded real temperature data between the lower and upper thermal thresholds for the most important phenological events of the codling moth from the date of biofix to harvest. Thermal thresholds for the population of the codling moth were estimated previously by Ghasemi *et al.* (2013) using non-linear models. Based on the recorded data, population fluctuation

of the codling moth in relation to GDH was determined. Moreover, the forecasting model of Ranjbar Aghdam (2009) for the codling moth phenological events was used to determine its phenology.

Analysis of Data and Drawing Chart

Statistical analysis of data was carried out using Minitab Release 14 and drawing chart was done using Microsoft Excel ver. 2007.

Results

Calendar based Phenology and Pheromone trap

In this study, codling moth flights activity were recorded between the start of May and early October (Table 1). Based on the recorded captures in pheromone traps, first of May were considered as the biofix date for the codling moth development in the study area. The results showed that, there were two active generations of the codling moth per year in Damavand region, the first (overwintering) and second (summer) generations. Population density as measured by male moth captured in pheromone traps, during the first and second generations is presented in Table 1. The activity of the first generation started from early May. In continuation, the rate of captures in pheromone traps was increased and reached a peak in 12-May (Table 1). Then, three to four days of rainy weather caused a rapid decrease in codling moth flight activity and reduced number of moths captured per traps during the coming weeks, as recorded on the 20th and 27th of May (Table 1). This caused a distinct peak for mean number of moths captured per trap in the 12-May observation, regarding the overwintering or first generation. During the next weeks, there was no evidence for population increase as was recorded earlier on 12-May. However, another peak was shown for summer generation in recordings of 23 -29 July. Moreover, cumulative percent of capture from the date of biofix to each studied time intervals were calculated for wing, delta, and both wing and delta style pheromone traps (Table 1). Based on the results, fluctuation of the codling moth flight activity during the growing season can be determined.

Table 1 Capture/trap, percentage of cumulative capture of the moths in pheromone traps, and evaluated phenological events of the codling moth in relation to calendar time and estimated physiological time for codling moth development in Damavand region.

Calendar time (Date)	Physiological time (GDH) ¹	Wing style		Delta style		Wing and delta styles		Calendar based phenological events
		Capture/trap	Cumulative %capture	Capture/trap	Cumulative %capture	Capture/trap	Cumulative %capture	
30-Apr-2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
1-May-2013	99.80	4.00	0.93	27.00	2.13	11.67	1.55	Biofix
2-May-2013	215.60	4.00	1.86	14.00	3.24	7.33	2.52	-
6-May-2013	587.00	14.50	5.22	79.00	9.47	36.00	7.31	-
12-May-2013	1396.90	56.50	18.33	213.00	26.28	108.67	21.74	Overwintering generation flight peak
20-May-2013	2224.20	3.67	19.18	1.50	26.40	2.80	22.11	-
27-May-2013	3167.20	4.67	20.26	2.50	26.60	3.80	22.62	-
3-Jun-2013	4480.70	31.67	25.75	44.00	26.84	36.60	24.96	-
11-Jun-2013	6451.20	39.33	36.74	64.00	35.12	49.20	34.02	-
18-Jun-2013	8450.10	29.67	43.62	85.50	41.87	52.00	40.92	-
25-Jun-2013	10492.10	41.00	53.13	70.00	47.40	55.50	48.30	-
2-Jul-2013	12151.90	25.67	59.09	30.50	49.80	27.60	51.96	-
9-Jul-2013	14303.10	28.67	65.74	64.00	54.85	42.80	57.65	-
16-Jul-2013	16464.90	37.00	74.32	65.00	59.98	48.20	64.05	-
23-Jul-2013	19069.70	46.33	85.07	102.00	68.03	68.60	73.17	Summer generation flight peak
29-Jul-2013	21580.90	17.00	89.02	117.00	77.27	57.00	80.74	-
6-Aug-2013	24365.20	14.67	92.42	77.50	83.39	39.80	86.02	-
13-Aug-2013	26284.50	6.67	93.97	66.00	88.60	30.40	90.06	-
20-Aug-2013	28108.20	6.67	95.51	26.50	90.69	14.60	92.00	-
26-Aug-2013	29827.70	3.00	96.21	17.50	92.07	8.80	93.17	-
2-Sep-2013	31804.40	4.00	97.14	18.00	93.49	11.00	94.63	-
10-Sep-2013	34147.20	6.33	98.61	7.00	94.04	6.60	95.51	-
24-Sep-2013	37440.00	4.00	99.54	66.00	99.25	28.80	99.34	-
8-Oct-2013	39870.40	2.00	100.00	9.50	100.00	5.00	100.00	-
Total seasonal captures / trap		431.00	-	1267.00	-	752.77	-	-

¹GDH: Growing Degree Hours.

Evaluation of pheromone trap styles

Statistical analysis using t-test, confirmed significant difference between mean number of moths per trap by wing style and delta style pheromone traps (T-value = -3.34, P-value = 0.002, df = 46). Total mean capture of male moths per trap by delta style pheromone traps was about 3-fold more than wing style pheromone traps (Table 1). Though, codling moth population fluctuation seems sharper in delta style traps in comparison with wing style traps. This may facilitate determination of population peaks to make a suitable decision for management.

Physiological time based phenology

On the other hand, occurrence of important phenological events of the codling moth was determined by estimation of physiological time based on GDH, between lower and upper developmental temperature thresholds, based on codling moth GDH forecasting model. Then, population fluctuations of *C. pomonella* male moths from the date of biofix to harvest in relation to the estimated values for physiological time (GDH) were determined (Fig. 1).

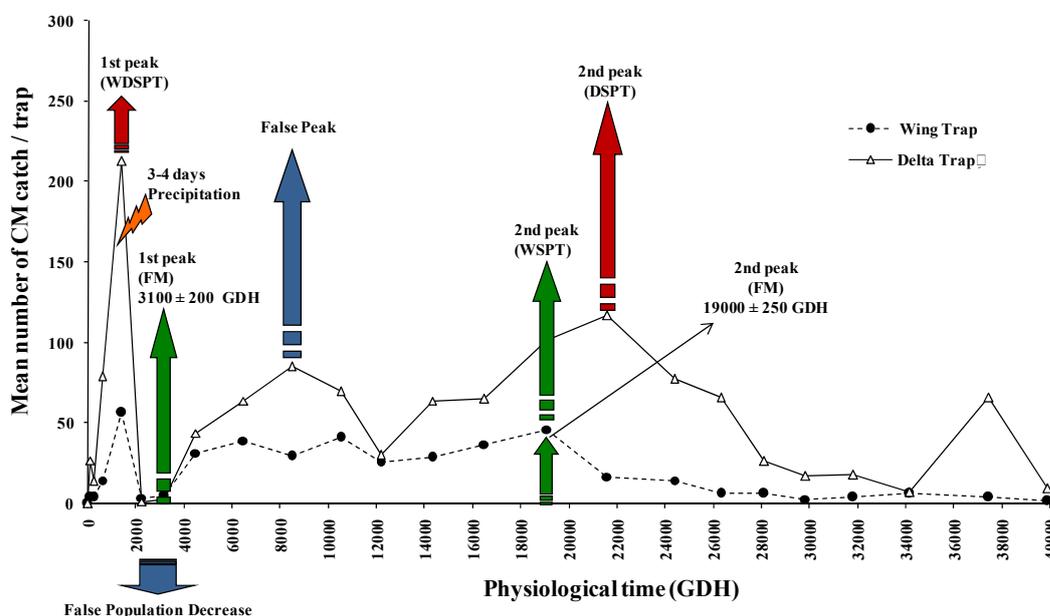


Figure 1 Population fluctuation of the codling moth (CM) from the date of biofix to harvest by using wing and delta styles pheromone traps in relation to the codling moth physiological time based on Growing Degree-Hours in Damavand region. Abbreviations: WSPT: Wing Style Pheromone Trap, DSPT: Delta Style Pheromone Trap, WDSPT: Wing and Delta Style Pheromone Traps, FM: Forecasting Model.

Discussion

Pheromone traps are manufactured in several designs, capitalizing on certain behaviors of some insects, such as a tendency to fly upward or search for protected sites (Clark *et al.*, 2008). According to Madsen and Procter, 1986; Knight *et al.*, 1999; Alston, 2006; Jones *et al.*, 2013 wing style pheromone traps have been applied for monitoring, and mating disruption of the codling moth. The "delta" style trap is another design, which can be used when changing the bottom is not necessary (Clark *et al.*, 2008). Based on current study, there was a distinct difference between the captures of two styles of pheromone traps. Vincent *et al.* (1990) have considered three criteria to evaluate different types of traps for monitoring of the codling moth, (1) total seasonal captures, (2) maximum seasonal captures of the first generation, and (3) first date of captures. The obtained results in this

study showed that total seasonal captures in the delta style traps were significantly higher than in wing style pheromone traps. Maximum seasonal mean number of moths / trap of the first generation was 213.00 for delta style traps and 56.50 for the wing style traps. Calculated value for the maximum seasonal mean number of moths / trap also showed more captures by delta style traps. Regarding 3rd criteria, one of the wing style traps had no capture in the first date of captures, while, all of the delta style traps captured codling moth in the first day (1-May). Moreover, distinct sharp fluctuations were seen during recording the seasonal flight of the codling moth by using delta style traps. Capture of high density of male moths in delta traps showed that it is applicable for mating disruption or mass trapping of the codling moth. While, the wing style pheromone traps caught lower density of the codling moth. However, recorded population fluctuation by wing style pheromone

traps showed two population peaks regarding two codling moth generations. In most of the apple orchards, with high codling moth population, typically two peaks for moth flights regarding to overwintering and summer generations of the codling moth can be seen (Alston, 2006; Radjabi *et al.*, 2007; Ranjbar Aghdam, 2009; Breth, 2013).

Phenological models, using physiological time data, have been developed previously for the codling moth to predict emergence of adults from the overwintering generation, eggs eclosion, larval and pupal development, and generation time (Falcon and Pickel, 1976; Geier and Briese, 1978; Brunner *et al.*, 1982; Rock and Shaffer, 1983; Dastqeib and Seyedoleslami, 1988; Setyobudi, 1989; Pitcairn *et al.*, 1992; Howell and Neven, 2000). These models, which are all based on the mathematical relationship between temperature and codling moth developmental rate, have been used with varying degrees of success to determine the best time for pesticide application (Rock and Shaffer, 1983; Dastqeib and Seyedoleslami, 1988; Howell and Neven, 2000). All of these studies were based on a maximum and a minimum temperature during each 24-hours time intervals. Ranjbar Aghdam (2009) developed more precise forecasting model based on GDH for a codling moth population in Iran. This model was based on hourly recorded real temperatures in apple orchards. Its validation and its performance were confirmed in economically important apple orchards (Ranjbar Aghdam, 2009). During the current study, this phenological forecasting model was applied to predict codling moth phenological events. Based on the codling moth forecasting model (Ranjbar Aghdam, 2009), physiological times for population peak of the overwintering and summer generations were 3100 ± 200 , and 19000 ± 250 GDH, respectively.

The objective of current study was to determine performance of the pheromone trap data to forecast codling moth phenology in a growing season. Much accurate physiological time estimation based on hourly recorded temperatures has been mentioned in the literature (e.g. Roltsch *et al.*, 1999; Cesaraccio *et al.*, 2001; Ranjbar Aghdam, 2009).

Moreover, this method was considered as a criterion to evaluate performance of the other forecasting methods (Roltsch *et al.*, 1999). Current study was trying to compare forecasting methods based on pheromone traps with hourly recorded temperature. Pheromone trap data showed a distinct peak on 12-May (Fig. 1). Then, there was relatively continuous raining from 12-May to 16-May. Therefore, captures of the pheromone traps were severely reduced and reached a minimum value during the next week (Based on the recorded data in 20-May). This created a false population peak for overwintering generation in 12-May, while based on the estimated value for the codling moth physiological time, a real peak was determined on 27-May. Delta style traps showed another false population peak in- 18-June, when there was no population peak according to the wing style traps data and physiological time estimation in the mentioned time (Fig. 1 and Table 1). Based on the physiological time data, as well as wing style pheromone traps data, population peak for the summer generation occurred on 23-July, while in that time population peak was not recorded by delta style pheromone traps. Blomefield and Knight (2000) indicated that the information provided by pheromone traps is not always easy to interpret. The number of male moths caught in a pheromone trap can be influenced by an array of factors such as, moth density, immigration, temperature, moonlight, wind speed, trap and lure placement and maintenance, and competition between traps and calling females (Blomefield and Knight, 2000). Each of these factors may affect the recorded data by pheromone traps and finally cause a conflict in interpretation of results. The same as results obtained from the pheromone traps in current study, especially in the first generation, failure to adequately manage codling moth has often been blamed on the poor quality of the data obtained from pheromone traps. In particular, "negative trap catch" which occurs when traps fail to catch moth despite the occurrence of fruit damage, have been problematic (Blomefield and Knight,

2000). Therefore, physiological time based forecasting models that link the moth biofix can be used to determine the best times for management tactics (Ranjbar Aghdam, 2009). Moreover, considering threshold temperature for mating and oviposition (Ranjbar Aghdam *et al.*, 2009) especially during the dusk period (Radjabi, 1986, Blomefield and Knight, 2000) can improve the best timing for implementation of management tactics.

Based on literatures and the results obtained here, using physiological time data (phenological models based on Degree-Days or Degree-Hours), is recommended to forecast pest phenological events instead of implementation of pheromone traps data. Phenological models can provide a wide range of information regarding all phenological stages of the pests (Ranjbar Aghdam, 2009), while pheromone traps give information only on adult stage, also problems for data interpretation may arise.

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آیا تله‌های فرمونی ابزار مناسبی برای پیش‌آگاهی فنولوژی آفات هستند؟ مطالعه‌ای در مورد کرم سیب

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چکیده: به‌کارگیری یک روش دقیق پیش‌آگاهی برای موفقیت در برنامه‌های مدیریت تلفیقی آفات ضروری است. کارایی دو نوع تله فرمونی بالی شکل و مثلثی شکل برای پیش‌آگاهی از فنولوژی کرم سیب در مقایسه با مدل پیش‌آگاهی بر مبنای محاسبه زمان فیزیولوژیک (ساعت-درجه) مورد ارزیابی قرار گرفت. ۶ تله‌ی فرمونی (۳ تله‌ی بالی شکل و ۳ تله‌ی مثلثی شکل) برای ردیابی نوسان‌های جمعیت کرم سیب استفاده شد. تله‌ها در زمان آغاز شکوفه‌دهی درختان سیب در باغ نصب شدند. تله‌ها به‌طور هفتگی بازدید شده و تعداد شب‌پرک‌های کرم سیب شکار شده در آن‌ها ثبت شد. زمان فیزیولوژیک نیز با توجه به آستانه‌های دمایی رشدونمو کرم سیب با استفاده از داده‌های دمایی ساعتی ثبت شده برآورد شد. نتایج به‌دست آمده نشان داد که تله‌های مثلثی شکل از نظر آماری شکار بیشتری نسبت به تله‌های بالی شکل داشتند. علاوه بر این مشخص شد که شکار تله‌های فرمونی به‌شدت متأثر از شرایط آب‌و-هوایی منطقه بودند و به‌دنبال آن ضمن بروز نوسان‌های دروغین در جمعیت، منجر به ایجاد اوج‌های دروغین می‌شدند و همین موضوع تفسیر نتایج به‌دست آمده از تله‌های فرمونی را مشکل می‌کرد. در مقابل مدل پیش‌آگاهی مبتنی بر تخمین زمان فیزیولوژیک متأثر از شرایط جوی نبود و نتایج آن بدون نیاز به تفسیر اضافی به‌راحتی برای تعیین فنولوژی آفت قابل استفاده بود.

واژگان کلیدی: *Cydia pomonella*، مدل پیش‌آگاهی، فرمون، تله، جمعیت