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Original article (Orijinal araştırma)

Using degree-day and nonlinear regression models to predict seasonal flights of *Adoxophyes orana* (Fischer von Röslerstamm, 1834) (Lepidoptera: Tortricidae) in plum orchards

Erik bahçelerinde *Adoxophyes orana* (Fischer von Röslerstamm, 1834) (Lepidoptera: Tortricidae)'nın mevsimsel uçuşlarını tahmin etmek için gün-derece ve doğrusal olmayan regresyon modellerinin kullanılması

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Summary

Adoxophyes orana (Fischer von Röslerstamm, 1834) is a major pest of pome and stone fruits in Europe and Asia. This study reports the first record of *A. orana* in plum orchards in Turkey. Moth flight activity was monitored using pheromone traps in Bursa during 2011 to 2013. Also, cumulative degree-days (DD) were calculated to predict moth emergence time and flight peaks in plum orchards. *Adoxophyes orana* had three flight peaks. Depending on the year, the first, second and third flight of moths began between 2-25 May, 20 June-13 July, and 7 August-14 September, respectively. Emergence dates of each flight coincided with 325-391, 957-1065 and 1797-1943 DD in the same order. Richards' function and logistic regression models were applied to forecast seasonal flights of this pest. The 50% moth emergence of the first, second and third flight of *A. orana* was predicted at 606, 1407 and 2169 DD using the Richards' function, and 636, 1427 and 2341 DD using the logistic model as compared with observed values at 626, 1393 and 2110 DD, respectively. Previously developed forecasting models may help apply timely control and thus reducing the number of pesticide applications in plum orchards.

Keywords: *Adoxophyes orana*, logistic model, nonlinear regression, Richards' function, summer fruit tortrix moth

Özet

Adoxophyes orana (Fischer von Röslerstamm, 1834) Avrupa'da ve Asya'da yumuşak çekirdekli ve sert çekirdekli meyvelerde önemli bir zararlıdır. Bu çalışma, Türkiye'de erik bahçelerinde *A. orana*' nın ilk defa kaydedildiğini bildirmektedir. Bursa'da 2011-2013 yılları arasında feromon tuzakları kullanılarak güvenin uçuş zamanı izlenmiştir. Ayrıca, erik bahçelerinde güve çıkış zamanını ve uçuş piklerini tahmin etmek için gün-derece (GD) toplamları hesaplanmıştır. *Adoxophyes orana*' nın üç uçuş piki vardır. Yıla bağlı olarak, birinci, ikinci ve üçüncü güve uçuşu sırasıyla 2-25 Mayıs, 20 Haziran-13 Temmuz ve 7 Ağustos-14 Eylül tarihleri arasında gerçekleştirilmiştir. Her uçuşun başlangıç tarihi aynı sırayla 325-391, 957-1065 ve 1797-1943 GD toplamları ile çakışmıştır. Richards'ın fonksiyonu ve lojistik regresyon modeli bu zararlının mevsimsel uçuşlarını tahmin için uygulanmıştır. *Adoxophyes orana*' nın birinci, ikinci ve üçüncü uçuş dönemlerinde %50 güve çıkışı, gözlemlenen 626, 1393 ve 2110 GD değerleri ile karşılaştırıldığında Richards'ın fonksiyonu kullanılarak sırasıyla 606, 1407 ve 2169 GD ve lojistik model kullanılarak ise 636, 1427 ve 2341 GD değerleri tahmin edilmiştir. Daha önce geliştirilen tahmin modelleri zamanında mücadele yapılmasını sağlayarak erik bahçelerinde pestisit uygulamalarının sayısını azaltabilir.

Anahtar sözcükler: *Adoxophyes orana*, lojistik model, doğrusal olmayan regresyon analizi, Richards'ın fonksiyonu, yaprak yapıştıran

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Introduction

The summer fruit tortrix moth, *Adoxophyes orana* (Fischer von Röslerstamm, 1834) (Lepidoptera: Tortricidae), is a major pest of pome and stone fruits in Europe and Asia, particularly during the summer (Kocourek & Stara, 2005). *Adoxophyes orana* was first recorded in northwestern Turkey in 2010. Since then, it has become a key pest of pears and peaches in the Marmara Region. In addition, *A. orana* larvae have been observed to feed on leaves of sweet cherry and apple in Turkey (Pehlevan & Kovancı, 2014).

Larvae prefer to feed on young shoots and leaves of stone and pome fruits in spring. Leaf and shoot damage has no economic importance, unless leaf roller densities are high (Dickler, 1991). Larvae can cause extensive and costly damage to fruit. Fruit damage is usually superficial, but the external damage may also create a suitable environment for pathogens to establish. Therefore, *A. orana* has a low damage threshold, and it should be monitored with pheromone traps (Kocourek & Stara, 2005). The summer fruit tortrix moth may have two to three generations per year in peach and apple orchards of Turkey (Pehlevan & Kovancı, 2014), whereas it has three generations in peach orchards of Greece and two generations in apple orchards in Europe (Milonas & Savopoulou-Soultani, 2006). Under laboratory conditions, the mean generation time of *A. orana* was found to be the longest on plum (35.7 d) compared with apple, peach and apricot (Lina et al., 2015). However, no specific information is available on the number of *A. orana* generations produced annually on plum grown in the field.

Pehlevan & Kovancı (2014) reported that emergence time and flight period of *A. orana* adults were different between host plants. The first moth flight was caught in apple and peach orchards in early or mid-May, coinciding with an average cumulative degree-days (DD) of 350-356 DD in Turkey. The second moth flight started at the end of June or at the beginning of July (1003-1027 DD) while the third moth flight began in early August (1600-1690 DD). Moth flights lasted for an average of 2305 DD until late September in Turkey (Pehlevan & Kovancı, 2014). However, it is not known if *A. orana* populations in plum orchards have similar flight patterns to those in apple and peach orchards. The ability to detect and predict the activity of *A. orana* in plum orchards may help farmers appropriately schedule pesticide application to correspond with the period of each flight peak of the pest.

Degree-day models are considered as a useful tool for forecasting the seasonal flight activity of many lepidopterous pests (Hrdý et al., 1996; Del Tio et al., 2001). These models have been used more effectively for making pest control decisions (Akotsen-Mensah et al., 2011). For example, models based on linear and nonlinear functions may help predict insect phenology such as emergence time of the codling moth *Cydia pomonella* (L., 1758) in the field (Demir & Kovancı, 2015). Similarly, Kocourek & Stara (2005) and Damos & Savopoulou-Soultani (2010) constructed different phenological models to predict the flight activity of *A. orana* in apple and peach orchards, respectively. To validate their temperature-based models in plum orchards, both Richards' function and logistic regression to predict flight emergence patterns of *A. orana* during the growing season were used in this study.

The main objective of this study was to monitor the population fluctuations of the summer fruit tortrix moth using pheromone traps in plum orchards in Turkey. In addition, moth phenology and cumulative catch data in plum orchards obtained between 2011 and 2013 were used to check and compare the reliability of previously developed degree-day models for *A. orana* adults in apple and peach orchards (Kocourek & Stara, 2005; Damos & Savopoulou-Soultani, 2010).

Materials and Methods

Study sites

Studies were carried out in plum orchards in İnegöl, Bursa (40°19´ N, 29°06´ E), northwestern Turkey in 2011, 2012 and 2013. Trials were conducted in three separate locations, where the occurrence of *A. orana* in plum orchards recorded for the first time in Turkey with this study. Each trial site consisted of a 0.5 ha orchard with three plots (0.17 ha each) of the late-ripening plum cultivar, President. Trees were 10 years old and about 2.5 m tall.

Three insecticide applications were made against insect pests each year. Chlorpyrifos-ethyl was applied once in early May at 100 ml in 100 l of water per 0.1 ha to control European fruit lecanium, *Parthenolecanium corni* (Bouché, 1844), and plum scale, *Sphaerolecanium prunastri* (Boyer de Fonscolombe, 1834). Aphid nymphs and adults were controlled with one application of imidacloprid at 20 ml in 100 l of water per 0.1 ha in early May. Spirodiclofen was used twice at a rate of 25 ml in 100 l of water per 0.1 ha to control spider mites in early May and mid-June.

Flight monitoring

Delta type traps loaded with a synthetic sex pheromone to monitor seasonal population fluctuation of the male *A. orana* moths. Each year, three traps per orchard were deployed at about 2 m above from the soil and at a distance of 45 m from each other to avoid trap interaction (Milonas & Savopoulou-Soultani, 2006). The traps were deployed on 1 May before night temperatures exceed 13-14°C, being the temperature threshold for the initiation of moth flight (Whittle, 1985). Traps were checked every day until the first flight was detected. The number of moths was recorded and moths were removed from traps every week. Pheromone capsules and the sticky surface were changed at six-week intervals (Pehlevan & Kovancı, 2013). At the end of the season, moth flight activity was considered to have ended after three consecutive zero captures.

Degree-days and phenological models

Weekly average temperature data for the trial season periods during 2011-2013 in İnegöl, Bursa is given in Figure 1. Weather data was acquired from the meteorological station. DD were calculated based on the following equation of Baskerville & Emin (1969):

$$\frac{t_{min} + t_{max}}{2} - \mathrm{MTT}$$

where $t_{\min}$ and $t_{\max}$ for lower and higher day temperature and MTT is the minimum temperature threshold of the insect development. According to the results of previous studies, a developmental threshold of 7.2°C was adopted to calculate DD (Pehlevan & Kovancı, 2013). Temperatures above the degree of developmental threshold were accumulated from 1 February when larval diapause was found to be terminated by Milonas & Savopoulou-Soultani (2006).

The fitness of Richards' function model by Kocourek & Stara (2005) for predicting flight emergence patterns of *A. orana* was compared with that of logistic regression model by Damos & Savopoulou-Soultani (2010). The cumulative percentages of the flights of each generation and DD were fitted to a curve using three-parameter Richards' function and four-parameter logistic regression function. Both equations are S-shaped cumulative distribution functions. Three-parameter Richards' function:

$$y = \frac{100}{(1 + c_3 \, \mathrm{X} \, e^{-c_1(x-c_2)}) \, \mathrm{X} \, 1/c_3}$$

where y is the cumulative percentage, x is the cumulative DD *and* c_1, c_2, and c_3 are parameters. c_1 is the slope of the curve, c_2 is the time when 50% of the population were caught, and c_3 is the upper limit of the curve (Kocourek & Stara, 2005). Four-parameter logistic regression function:

$$g(x) = d + \frac{a}{1 + \left(\frac{x}{c}\right)^b}$$

where g is the cumulative percentage, x is the cumulative DD, and a, b, c and d are constant numerical parameters that regulate the shape of the curve. Moreover, c indicates the DD at which 50% moth emergence occurs (Damos & Savopoulou-Soultani, 2010).

Statistical analysis

Moth catch data were transformed using √(x+1) before analysis of variance to normalize the data distribution. Least squares means comparisons were used to determine interaction effects. Parameter estimation values both in the Richards' function and in the logistic model were obtained through JMP (Schlotzhauer, 2007). Computations of the percent emergence of populations were calculated with Microsoft Excel. The accuracy of each model was tested based on the adjusted coefficient of determination (Adj. R^2), as well as the Akaike's information criteria (Damos & Savopoulou-Soultani, 2010).

$$\text{Adj } R^2 = 1 - \frac{(\frac{\text{RSS}}{n} - (Q+1))}{\frac{\text{SS}}{n} - 1}$$

$$\text{AIC} = n[\text{In}(\text{RSS})] - [n - 2(Q-1)] - n\ln(n)$$

where RSS is the residual sum of squares, SS is the total sum of squares, Q is the number of parameters, and n the number of observations. To find out the probability of the ith model that minimizes the information loss, we used the following formula, $\exp((\text{AIC}_{min} - \text{AIC}_i)/2)$ (Burnham & Anderson, 2002).

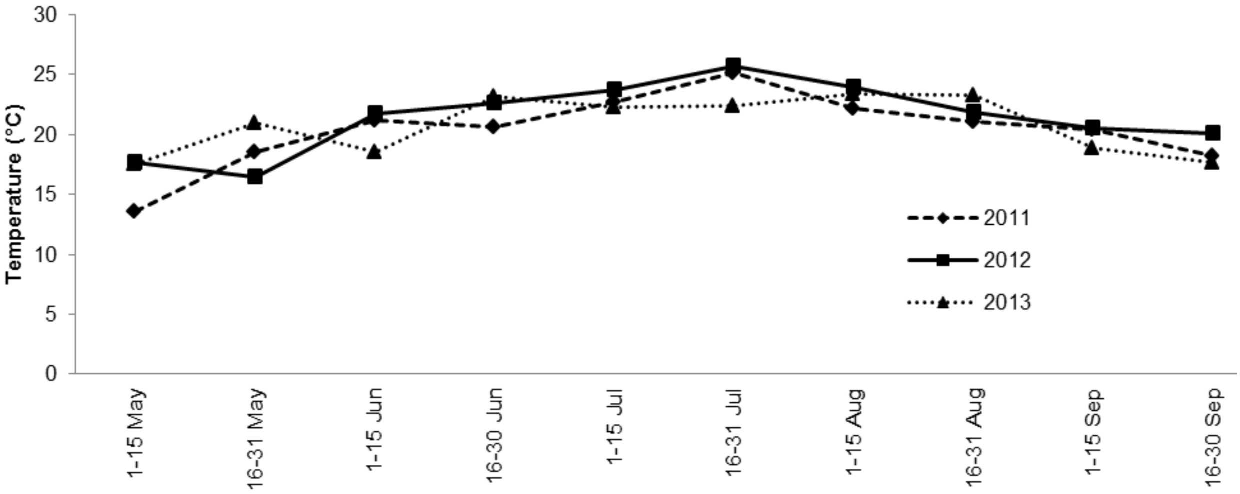

Figure 1. Weekly average temperature data in İnegöl, Bursa, Turkey during 2011-2013.

Results

Moth flight activity in plum fruits

A total of 1835 adults of *A. orana* was caught in traps during the three-year study period. There were significant differences in total moth catches between the 2011 (172), 2012 (887) and 2013 (776) growing seasons ($F_{2, 681} = 17.7$, $P < 0.01$). Moth pressure was low during 2011. The peak catches of moths occurred on 27 July, 8 July and 27 June in 2011 to 2013, respectively (Figure 2). Significant differences were observed between weeks in the number of moths caught in 2011 ($F_{16, 187} = 6.44$, $P < 0.01$), 2012 ($F_{19, 220} = 12.0$, $P < 0.01$), and 2013 ($F_{19, 220} = 4.16$, $P < 0.01$) in all orchards. The total number of moths caught in traps did not significantly differ between locations ($F_{2, 675} = 1.54$, $P = 0.22$), but they were significantly different between years ($F_{2, 675} = 17.8$, $P < 0.01$). Numbers of captured moths during the first, second and third flights were significantly different in 2011 ($F_{2, 152} = 2.60$, $P = 0.08$), 2012 ($F_{2, 213} = 51.0$, $P < 0.01$) and 2013 ($F_{2, 213} = 8.50$, $P < 0.01$).

Adult emergence times and total flight period showed significant variation among years. The first adults were caught on 25 May, 6 May and 2 May in 2011 to 2013, respectively (Figure 2), corresponding to the accumulation of 391, 325 and 377 DD, respectively, starting from 1 February. The second flight began on 13 July (1065 DD), 24 June (957 DD) and 20 June (976 DD) in 2011 to 2013, respectively. The third flight began on 7 September (1943 DD), 12 August (1806 DD) and 15 August (1767 DD) in 2011 to 2013, respectively. Moth captures continued until mid-September, and the total flight period ended at 1955, 2316 and 2311 DD in 2011 to 2013, respectively (Figures 2 & 3).

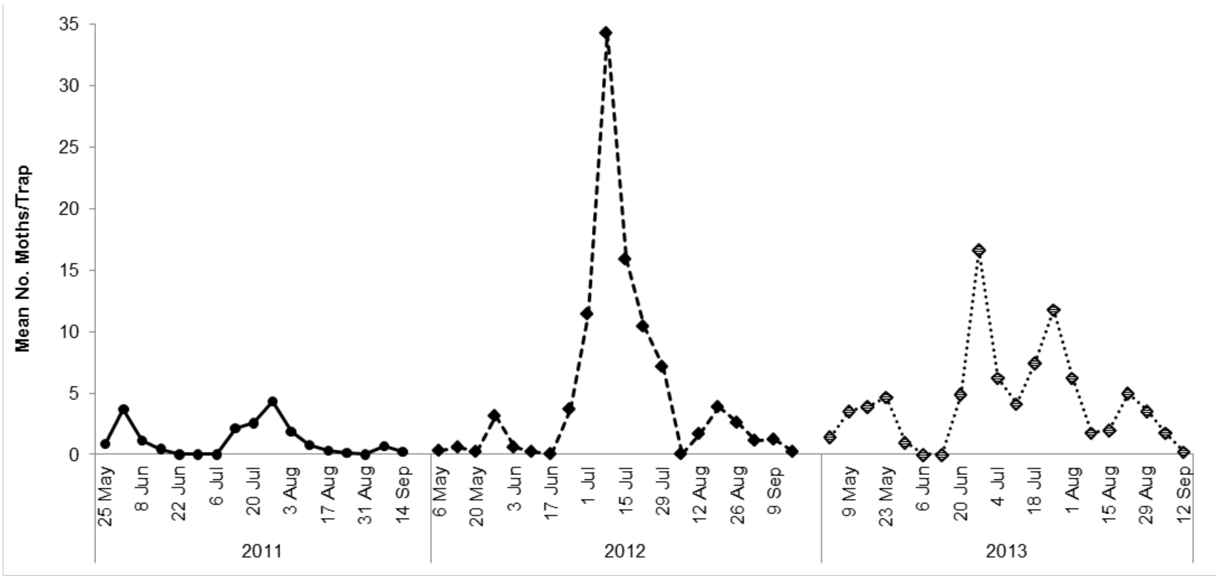

Figure 2. Seasonal flight patterns of *Adoxophyes orana* in three respective plum production regions of Turkey in 2011, 2012 and 2013.

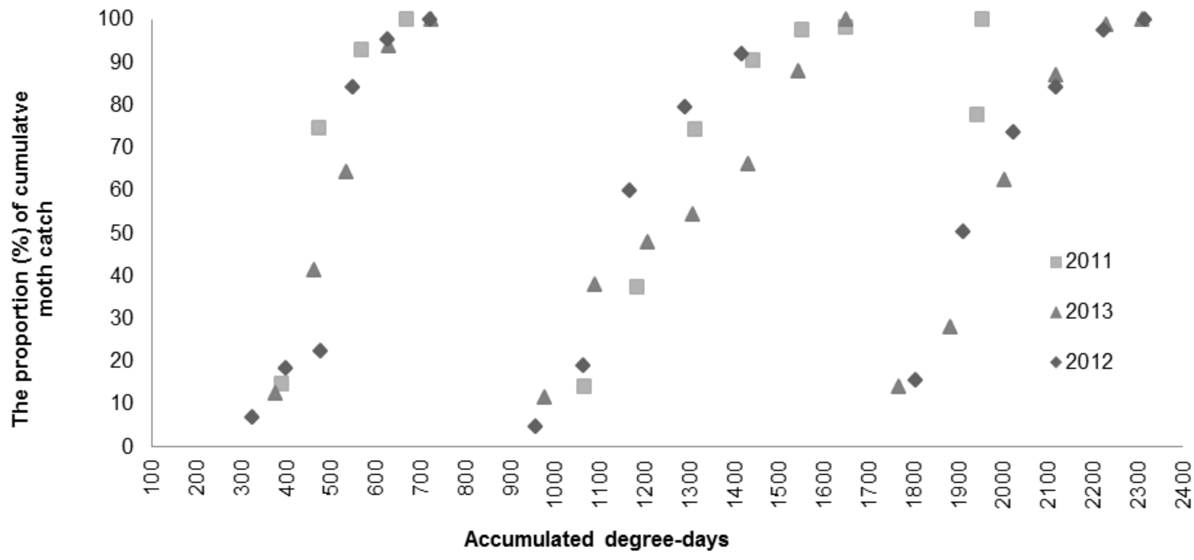

Figure 3. The proportion (%) of cumulative male moths caught in pheromone traps and cumulative degree-days during the first, second, and the third flight of *Adoxophyes orana* in 2011, 2012 and 2013 in plum orchards in Bursa, Turkey.

Forecasting models

Data on the cumulative proportion of *A. orana* adults caught in plum orchards during 2011-2013 were subjected to nonlinear regression analysis. Generated models using the relationship between cumulative catches of the first, second and third flight of *A. orana* males and DD are shown in Figure 4.

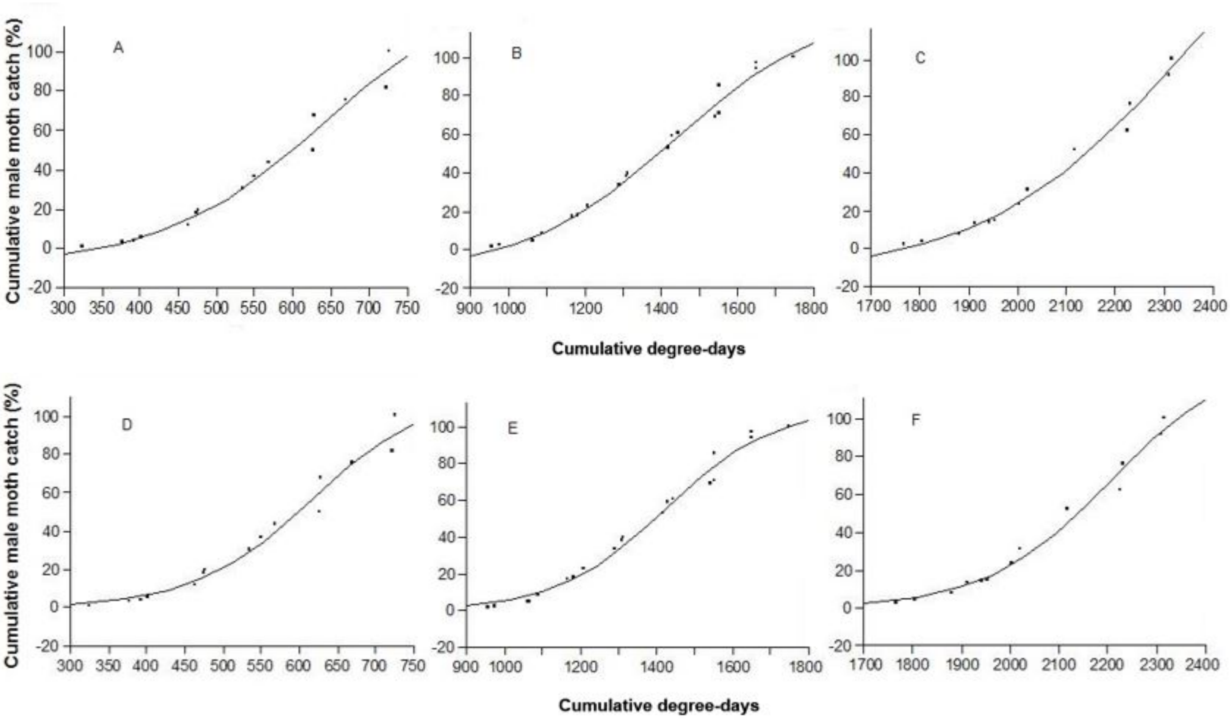

Figure 4. Developed models for logistic regression function (A, B and C) and Richards' function (D, E and F) in describing first, second and third flight cumulative male moth catches of *Adoxophyes orana* in relation to degree-days.

The flight curve of the first, second and third flight was fitted into a plot using both Richards' function and logistic regression function. There was a significant correlation between logistic regression function and Richards' function (Figure 5).

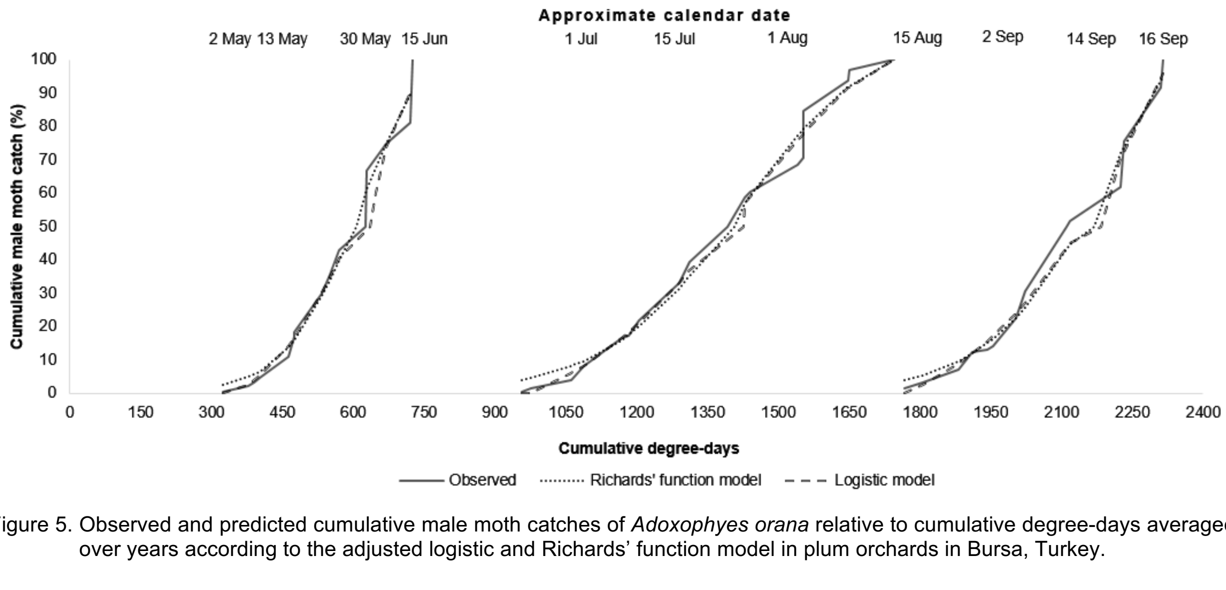

Figure 5. Observed and predicted cumulative male moth catches of *Adoxophyes orana* relative to cumulative degree-days averaged over years according to the adjusted logistic and Richards' function model in plum orchards in Bursa, Turkey.

Both models were good at estimating the first emergence time and each flight period of *A. orana*. Parameter *b* of the Richards' model and parameter *m* of the logistic model represented the 50% of cumulative moth emergence. Parameters in the Richards' function (606 DD) and the logistic model (636 DD) were similar to each other. Estimated regression parameters of the models for all three years are listed in Table 1. Across years, the first male moths were caught between 325 and 391 DD. The second moth flight began between 957 and 1065 DD, while third moth flight occurred between 1767 and 1943 DD. Total flight periods lasted between 1955 and 2316 DD for all three years, starting from 1 February. Despite the standard errors that lead to deviations in model predictions, predicted moth phenology remained within acceptable limits.

Table 1. Parameter estimates (SE) and coefficient of determinations of Richards' and logistic- regression function models in defining moth phenology of *Adoxophyes orana* in plum orchards

Flight	Parameter Estimates			
	Richards' function		Logistic regression function	
First	*a*	0.013 (0.002)	*a*	-7.8 (10.8)
	b	606 (15.2)	*b*	0.01 (0.004)
	c	1.10 (0.20)	*c*	141 (52.8)
	-	-	*m*	636 (60.4)
	R^2	0.975	R^2	0.977
	Adjusted R^2	0.973	Adjusted R^2	0.975
	Regression equation	y = 1.81 + 0.96x	Regression equation	y = 0.82 + 0.98x
	F	508	F	554
	AIC*	60.0	AIC	62.2
	df	12	df	11
Second	*a*	0.007 (0.001)	*a*	-12.3 (7.90)
	b	1407 (14.3)	*b*	0.005 (0.001)
	c	1.10 (0.10)	*c*	138 (20.5)
	-	-	*m*	1427 (33.0)
	R^2	0.986	R^2	0.989
	Adjusted R^2	0.985	Adjusted R^2	0.989
	Regression equation	y = 1.88 + 0.97x	Regression equation	y = 0.44 + 0.99x
	F	1333	F	1769
	AIC	65.4	AIC	62.6
	df	17	df	16
Third	*a*	0.008 (0.001)	*a*	-13.3 (16.3)
	b	2169 (28.7)	*b*	0.005 (0.003)
	c	1.40 (0.30)	*c*	233 (217)
	-	-	*m*	2341 (317)
	R^2	0.983	R^2	0.986
	Adjusted R^2	0.982	Adjusted R^2	0.985
	Regression equation	y = 1.5 + 0.97x	Regression equation	y = 0.5 + 0.99x
	F	674	F	816
	AIC	50.7	AIC	53.6
	df	10	df	9

* Akaike's information criterion (AIC) was used to compare the quality of each model relative to each other.

Models for estimating flight times were tested according to the adjusted R^2 (Table 1). Both models defined first, second and third flights of *A. orana* with high accuracy. Based on the adjusted coefficient of determination values (>0.97) for all flights, there were only minor differences between the two models. Moreover, these models were assessed based on the Akaike's information criteria. Logistic regression model was 0.33 and 0.24 times as probable as the Richards' function model to minimize the information loss in predicting the first and third moth flights. In contrast, the probability of estimated information loss for the second flight by Richards' function model was 0.25 times the logistic regression model. Thus, both models yielded similar predictions despite subtle differences between flights. The differences in the accuracy of each model for predicting each moth flight can be explained by the climate variables such as temperature, directly affecting insect phenology (Damos & Savopoulou-Soultani, 2010).

First emergence time and flight periods of *A. orana* across over the years were forecasted by both models. Estimated regression equations of the two nonlinear models for all three years are given in Table 2. The adjusted R^2 values were used to evaluate the model performance of each function (Table 2). Good accuracy in describing the first, second and third flights of *A. orana* was obtained by both models

Table 2. Estimated regression equations of the two nonlinear models for all years and regression statistics of moth phenology for *Adoxophyes orana*

Flight	Year	*N*	Richards' function			Logistic regression function		
			Regression equation	R^2	Adj R^2	Regression equation	R^2	Adj R^2
First	2011	4	y = 0.57 + 0.99*x*	0.995	0.993	y = 20.1 + 0.67*x*	0.948	0.922
	2012	6	y = -6.64 + 1.07*x*	0.979	0.974	y = 0.43 + 0.99*x*	0.992	0.990
	2013	5	y = 0.67 + 0.99*x*	0.996	0.995	y = 0.17 + 1.00*x*	0.997	0.996
Second	2011	7	y = -0.02 + 1.00*x*	0.999	0.999	y = 0.06 + 1.00*x*	0.999	0.999
	2012	6	y = 1.89 + 0.97*x*	0.989	0.986	y = 0.54 + 0.99*x*	0.990	0.988
	2013	7	y = 3.32 + 0.95*x*	0.961	0.953	y = 1.03 + 0.97*x*	0.971	0.966
Third	2011*	-	-	-	-	-	-	-
	2012	6	y = 2.70 + 0.97*x*	0.986	0.982	y = 2.57 + 0.96*x*	0.998	0.997
	2013	6	y = -0.75 + 1.00*x*	0.998	0.997	y = 0.02 + 1.00*x*	0.999	0.999

*Not calculated.

The parameters of the Richards' and logistic equation used to fit the curve are shown in Table 3. Observed and predicted data revealed a good fit for *A. orana* moth phenology for all three flight periods. Combined regression statistics were also calculated for predicted and observed cumulative percentages of moth catches in each generation.

Table 3. Observed and predicted times (month and day) of 50% moth emergence of first, second and third *Adoxophyes orana* flight relative to degree-days using Richards' function and logistic regression function in plum orchards in 2011, 2012 and 2013

			Richards' function	Logistic regression function
Flight	Year	Observed	Predicted	Predicted
First	2011	391 (25.5)	389 (23.5)	283 (15.5)
	2012	325 (06.5)	335 (06.5)	323 (05.5)
	2013	377 (02.5)	375 (01.5)	376 (01.5)
First	Pooled data for all years	325	316	319
First flight 50%		626	606	636
Second	2011	1065 (13.7)	1065 (13.7)	1064 (13.7)
	2012	957 (24.6)	936 (22.6)	950 (23.6)
	2013	1008 (20.6)	930 (14.6)	945 (15.6)
Second	Pooled data for all years	957	930	948
Second flight 50%		1393	1407	1427
Third	2011*	1943 (07.9)	-	-
	2012	1806 (12.8)	1746 (08.8)	1744 (08.8)
	2013	1797 (08.8)	1783 (08.8)	1765 (05.8)
Third	Pooled data for all years	1767	1716	1745
Third flight 50%		2110	2169	2341

*Not calculated.

Discussion

Flight activity

In this study, the presence of *A. orana* in plum orchards in Turkey were reported for the first time. Previously the only known hosts of this introduced pest in Turkey were apple, pear, peach and sweet cherry (Pehlevan & Kovancı, 2014). *Adoxophyes orana* larvae have been recorded to feed on pome fruit such as pear and apple in Europe (Stamenkovic et al., 1999), whereas stone fruit like peach and sweet cherry were more heavily attacked in southern Europe (Savopoulou-Soultani et al., 1985). The high levels of moth catch in plum orchards in this study clearly showed that stone fruit are suitable alternative hosts of the summer fruit tortrix moth.

Pheromone traps were successfully used to detect and monitor the flight activity of male moths during the growing season as in other countries such as Greece and the Czech Republic (Kocourek & Stara, 2005; Damos & Savopoulou-Soultani, 2010). However, degree-day and nonlinear regression models developed by Kocourek & Stara (2005) in apple orchards and by Damos & Savopoulou-Soultani (2010) in peach orchards to predict emergence time and flight activity periods of *A. orana* adults may improve the success of monitoring activities in plum orchards as well, enabling more appropriately timed sprays.

There were three flight peaks in plum orchards in May, late June or mid-July and mid-August. The number of flight peaks recorded in this study is consistent with the results of Pehlevan & Kovancı (2014) in apple, pear, peach and sweet cherry orchards. Nevertheless, there were subtle differences between the emergence time of *A. orana* males in plum orchards compared with pome and other stone fruit. However, emergence time and flight peak periods were possibly unrepresentative in 2011 due to the low population density in that year. Temperatures above the upper larval development threshold of 30°C in August may have been responsible for the late detection of summer generation moths in 2011 (Milonas & Savopoulou-Soultani, 2000).

Adoxophyes orana completed three generations in plum orchards in Turkey based on flight monitoring data in all years. This finding is consistent with earlier field studies conducted in Thessaloniki, northern Greece, where three to four generations were reported in peach orchards (Charmillot & Brunner, 1990; Milonas & Savopoulou-Soultani, 2006). Unlike southern Europe, two generations of *A. orana* occurred in apple orchards in central and northern Europe (Charmillot & Brunner, 1990; Cross et al., 1997).

In this study, the first flight of moths emerged between 2 and 25 May, the second between 20 June and 13 July and the third between 7 August and 14 September depending on the year. These flight periods differed markedly between years due to weather conditions. In the Czech Republic, the time interval for the first capture of the first flight of moths differed by more than one month from 11 May to 15 June during 1992 to 2003. Similarly, there was also one month difference at the beginning of the flight of the second flight varying from 8 July to 7 August between years (Kocourek & Stara, 2005). Two flight periods observed from late May to early July, and from early August to mid-September in apple orchards in western Serbia (Stamenkovic et al., 1999). Over the same time span, *A. orana* had three flights in Turkey. This variation may be caused by an adaptation to phenology of different hosts, as well as by the colder temperatures and shorter photoperiods in central and northern Europe than in southern Europe. Particularly, day lengths below a critical photoperiod of 12 h can stimulate diapause in the third instar larvae (Ankersmit, 1968).

Degree-day calculations

Estimation of first moth emergence is crucial for successful control of *A. orana*. Hence, the seasonal flight activity of *A. orana* was monitored using pheromone traps.

DD accumulations can be used as a tool for forecasting emergence time of adults in each flight period (Damos & Savopoulou-Soultani, 2010). For this purpose, we examined the interaction among temperature data and moth catch in plum orchards in 2011, 2012 and 2013. DD calculations for the first flight of *A. orana* were similar in all years at each locality. However, they were significantly different for the second and third flights according to year and locality. Based on these results, the first adult emergence began between 325 and 391 DD, the second between 957 and 1065 DD and the third between 1797 and 1943 DD during 2011 to 2013 (Table 3). Except for the delayed onset of the third flight, these findings were consistent with those of Pehlevan & Kovancı (2014) in apple, pear, peach and sweet cherry. Apparently, it takes more time for *A. orana* to develop on plum in the field as previously observed by Lina et al. (2015) under laboratory conditions.

We recorded 50% moth emergence of the first, second and third flights of *A. orana* at 626, 1393 and 2110 DD, respectively, in plum orchards. Whereas, Damos & Savopoulou-Soultani (2010), who used the same threshold value, reported 406, 1260 and 2141 DD for the first, second and third flights of *A. orana* in peach orchards in Greece. Apart from the third flight, there was a considerable delay in 50% moth emergence period in plum orchards when compared with DD calculations in peach orchards in Greece.

Nonlinear regression models

DD values have been used to test nonlinear regression models to forecast moth phenology in a more accurate way (Kocourek & Stara, 2005; Damos & Savopoulou-Soultani, 2010). Richards' function and logistic regression models were applied to compare predicted and observed DD values. Also, the predictions obtained by Richards' function and logistic regression models were compared with each other.

First emergence and subsequent flight activity of *A. orana* for each flight were well described by both models. For the first *A. orana* flight, parameter b in the Richards' function (606 DD) and parameter m in the logistic model (636 DD), which defines the 50% of cumulative moth emergence, were very similar to each other. Both models also provided a similar prediction for the second *A. orana* flight of 1407 and 1427 DD in the same order. Whereas, divergence in predictions were higher for the third flight, 2169 and 2341 DD, respectively. Kocourek & Stara (2005) also applied Richards' function to estimate 50% of moth catch for the first flight in apple orchards based on the sum of DD above an 8°C development threshold. Unlike our prediction of 606 DD, this model with a higher base temperature predicted 300 DD in the

Czech Republic. Damos & Savopoulou-Soultani (2010) used a three-parameter Boltzmann-type and a four-parameter logistic regression function to predict 50% of moth catch of the first, second and third flights of *A. orana* in peach orchards in Greece. However, their models gave predictions of 404 and 406 DD for the first flight, 1253 and 1260 DD for the second, and 2136 and 2141 DD for the third, which distinctly differs from our findings in plum orchards.

In all three flight periods, the observed and predicted data fit well with *A. orana* moth phenology. The coefficient of determination (R^2) showed that both models had very high prediction competence, although variation increased in succeeding generations.

Clearly, this study indicated three distinct flights of *A. orana* in plum orchards, with the last flight occurring later than in pome and other stone fruits orchards. Previously developed forecasting models for the summer fruit tortrix moth in other crops can offer a means of achieving timely pest control, thus reducing the number of pesticide applications in plum orchards. Finally, further field studies in plum orchards are needed to validate the parameter estimates of the Richards' function and logistic model for *A. orana* flight activity in other regions of Turkey as well in other parts of the world.

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