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Original article (Orijinal araştırma)

Creating a degree-day model of honeydew moth [*Cryptoblabes gnidiella* (Mill., 1867) (Lepidoptera: Pyralidae)] in pomegranate orchards[1]

Nar bahçelerinde Portakal güvesi [*Cryptoblabes gnidiella* (Mill. 1867) (Lepidoptera: Pyralidae)]'nin gün-derece modelinin oluşturulması

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Abstract

This study has been conducted in a pomegranate orchard in Tarsus, Mersin Province between 2008-2010 and 2012-2013. In this study, the sum of effective temperatures based on a degree-day (DD) model was determined to be successful for the scheduling control of honeydew moth [*Cryptoblabes gnidiella* (Mill.,1867) (Lepidoptera: Pyralidae)]. For this purpose, phenological stages, sex pheromone traps, the sum of effective temperatures (ETS), egg hatching time and fruit control were used. ETS values based on the DD model were 80 DD for hanging time of sex pheromone traps, 250 DD for first generation for egg hatching period, 800 DD for the second generation, 1375 DD for the third generation, 1930 DD for the fourth generation, and 2500 DD for fifth generation. However, the first generation of *C. gnidiella*, which had lower population having come from overwintering places, and fifth generation, which emerged at after harvest, should be monitored regularly so that control applications will be more beneficial.

Keywords: *Cryptoblabes gnidiella*, degree-day model, honeydew moth, pomegranate

Öz

Bu çalışma; 2008-2010 ve 2012-2013 yıllarında Mersin iline bağlı Tarsus ilçesindeki nar bahçesinde beş yıl süreyle yürütülmüştür. Çalışmada; Portakal güvesi [*Cryptoblabes gnidiella* (Mill.,1867) (Lepidoptera: Pyralidae)]'nin mücadelesinde daha etkin ve başarılı olabilmek için gün-derece modeline esas etkili sıcaklıklar toplamı değerleri belirlenmiştir. Bu amaçla fenolojik dönem, eşeysel çekici tuzak, etkili sıcaklıklar toplamı (EST), yumurta açılım zamanı ve meyve kontrolü kriterlerinden yararlanılmıştır. Bu çalışma sonuçlarına göre; *C. gnidiella*'nın gün-derece (g.d.) modeline esas EST değerleri; tuzak asım zamanı için 80 g.d., yumurta açılım zamanlarında birinci döl 250 g.d., ikinci döl 800 g.d., üçüncü döl 1375 g.d., dördüncü döl 1930 g.d. ve beşinci döl için ise 2500 g.d. olarak belirlenmiştir. Ancak, mücadele amaçlı yapılacak çalışmalarda *C. gnidiella*'nın kışlaktan gelen döl popülasyonu çok düşük olduğundan birinci döl, hasat sonrasına denk geldiğinden de beşinci dölün düzenli olarak takip edilmesinin ve uygulamanın da buna göre yapılmasının yararlı olacağı düşünülmektedir.

Anahtar sözcükler: *Cryptoblabes gnidiella*, gün-derece modeli, Portakal güvesi, nar

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Introduction

Pomegranate (*Punica granatum* L.) is one of the oldest fruit species mentioned in history and originated in the Middle East and the Caucasus. Considered as a tropical and subtropical climate fruit, pomegranate can be grown in range of soil and climatic conditions and it contains plenty of vitamin C, it protects the heart, reduces sugar and cholesterol, and strengthens the immune system against AIDS and cancer (Lansky et al., 1998). Pomegranate is generally consumed as table and fruit juice. In recent years it has become increasingly recognized as a fruit of interest due to its development in the field, food technology, storage and transportation. Pomegranate can be grown in places where the temperature does not fall below -10ºC and the altitude is up to 1000 m. World pomegranate production is about 2.5 Mt, and Turkey ranks third in the world with nearly 400,000 t produced annually (Anonymous, 2010a, b). The pomegranate production in Turkey is mainly carried out in the Mediterranean, Aegean and Southeastern Anatolia Regions, and new monoculture-pomegranate orchards are also being established in all the regions in recent years (Anonymous, 2010b).

There are many pests that cause crop loss in pomegranates in Turkey and around in the world (Juan et al., 2004; Toledo & Albujer, 2005; Blumenfeld et al., 2007; Öztürk & Ulusoy, 2009). One of these species is the honeydew moth, *Cryptoblabes gnidiella* (Mill., 1867) (Lepidoptera: Pyralidae). This pest feeds on the pomegranate fruit and damages fruit before it ripens, causes rots and reduces market value (Öztop et al., 2002; Öztürk & Ulusoy, 2010). *Cryptoblabes gnidiella*, which is found in many countries i with subtropical growing conditions, is a harmful polyphagous insect (Ronald & Jayma, 1992; Silva & Mexia, 1999). So far, 11 hosts have been identified in Turkey (Öztürk & Ulusoy, 2011). Also *C. gnidiella* has been reported to have caused significant crop losses in recent years by reading high populations in the Mediterranean Region pomegranates (Öztop et al., 2002; Öztürk & Ulusoy, 2011).

Until the recent 10-15 years, chemical control against diseases and pests in Turkey pomegranates had not usually been conducted or recommended. Successful agricultural production, breeding, identification and control of diseases and pests, and development of adequate methods and models of control require adequate study of pest biology. The most important of these models is the degree-day (DD) model, also known as forecast-warning model. Although this model has been applied to many pests globally (Anonymous, 2011), it has been applied to European grapevine moth (*Lobesia botrana* Den-Schiff., 1775), codling moth [*Cydia pomonella* (L., 1758)], oriental fruit moth [*Grapholita molesta* (Busck.,1916)], peach twig borer (*Anarsia lineatella* Zell., 1839), carob moth [*Apomyelois* (=*Ectomyelois*) *ceratoniae* (Zell.,1839)] and olive moth (*Prays oleae* Bern.,1788) in Turkey (Kumral et al., 2005; Anonymous, 2008; Mamay et al., 2014). However, there appears to have been no studies on a DD model for *C. gnidiella*.

In this study, phenological stages, sex pheromone trap, effective temperatures sum (ETS), hatching time and fruit control were used to develop a DD model for providing a more effective control strategy against honeydew moth for the first time in pomegranate orchards. According to the model, ETS values of hanging time of sex pheromone traps, time of first adult emergence and egg hatching time for each generation were determined. Critical ETS values on phenological periods of pomegranate were also determined. According to the data collected, producers can be given a timely warning of the need to control *C. gnidiella,* so the effectiveness and success of insecticide applications will be increased. Thus, the number of insecticide applications will be reduced, benefiting the economy, ecological balance, human health and the environment.

Material and Methods

A pomegranate orchard infested with honeydew moth (*Cryptoblabes gnidiella* Mill.), delta type pheromone traps (Pherocon CAP, Trécé Inc., Adair, OK, USA) and a Hobo (Onset, MA, USA) temperature data logger were used for this study.

The study was conducted for five years (2008-2010 and 2012-2013) in Tarsus, Mersin Province where the pomegranate production is concentrated in the Eastern Mediterranean Region. Daily minimum and maximum temperatures (°C) data were recorded on site.

Degree-day model of honeydew moth

The orchard had 65 ha of 15-year old pomegranate cv. Hicaz and was located in the village of Akarsu, Tarsus, Mersin, Province. DD study of *C. gnidiella* was based on the hanging time of pheromone trap, the first adult emerging time, egg hatching time with ETS for each generation (Rice et al., 1982; Anonymous, 2008). In the calculation of ETS values, the lower threshold (12.0ºC), generation time (564.6 DD) and the egg hatching period from the adulthood (120.0 DD) were used (Ringenberg et al., 2005; Öztürk, 2010).

Sex pheromone traps: Traps were used to monitor the first adult emergence time and adult population changes of *C. gnidiella*. Traps: [(Z)-11-hexadecenal (Z,11-16:Ald), (E)-11-hexadecenal (E,11-16:Ald), (Z)-13-octadecenal (Z,13-18:Ald), (E)-13-octadecenal (E,13-18:Ald)] were hung at the orchard at the end of March every year at a height of 1.5-2 m above the ground in the south facing side of a tree (Anshelevich et al., 1993; Öztürk, 2010). The trap was checked 2-3 times per week until the first adults were caught, after which they were checked weekly and butterflies counted individually. Pheromone-containing capsules were changed every 4-6 weeks according to the manufacture's instructions, and the roof and adhesive tabs were changed as needed. Adult population data for *C. gnidiella* was obtained in each year, and egg hatch and the time of spraying for each generation with hanging time of traps were correlated with the phenological stages of the pomegranates (Rice et al., 1982; Anonymous, 2008; 2011).

Effective temperatures sum: ETS (DD) values used to determination of appropriate spraying times and trapping times for *C. gnidiellia* were calculated according to the formula (Anonymous, 2008).

$$\text{ETS} = \frac{\text{Minimum temperature + Maximum temperature}}{2} - \text{Lower threshold (12.0ºC)}$$

The ETS value, equivalent to about 7-10 d prior to the 5-year average ETS value of the first adults captured in traps from 1 January, was considered as the first trapping time for monitoring purposes. After the first butterfly was caught in the trap, the hatching of the first emerging of eggs was followed and the average ETS values corresponding to the day when the first larvae were determined to be the appropriate spraying time for the first generation of *C. gnidiella*. Control was continued for the other generation of the pest and the average ETS values corresponding to the days in which each egg hatching was detected and calculated separately. In the calculations, development threshold, ETS value corresponding to generation period (Ringenberg et al., 2005; Öztürk, 2010) and the peak point of the *C. gnidiella* flight curve for each offspring was taken into account (Rice et al., 1982; Önder & Zümreoğlu, 1986; Anonymous, 2008, 2011).

Egg hatching time: Theoretically egg laying of the pest occurs within 1-3 d of catching the first butterfly in the trap, which is used to determine the spraying time for control of the first and second generation of *C. gnidiella*. Eggs were monitored on the fruit (stamens), where the great majority of eggs are deposited, on 10 trees for this were selected randomly. Critical phenological development in 5 fruits on 4 sides of the trees (i.e., 25 fruits/tree and a total 250 fruit), were checked 2-3 times a week and egg hatching or larvae emergence were monitored (Öztürk, 2010). The insecticide spraying time for the first generation was when 5% of eggs had hatched of the fruit, and ETS value was determined following the first larvae hatched. When egg had hatched in 5% of the fruit, ETS value were calculated according to required conditions for the first generation insecticide applications. Monitoring of the traps continued to determine the start of the drop in peak flight due to the density of the population, and when the DD value for each generation when 5% of the fruit were infested. The necessary conditions for the timing of spraying against *C. gnidiella* were accepted (Rice et al., 1982; Önder & Zümreoğlu, 1986; Toledo & Albujer, 2005; Anonymous, 2008, 2011).

ETS values obtained annually were calculated from 1 January according to the lower threshold of *C. gnidiella*. One-way ANOVA and Duncan's multiple range test was used for analysis of the data. According to results, difference between years were determined for adult emergence and egg hatching for each generation.

Results and Discussion

Honeydew moth degree-day model

In the first year (2008), the pheromone traps were hung on 19 March (62.1 DD) on the basis of plant phenology and *C. gnidiella* adults were first caught on 4 April (138.7 DD). In 2009, 2010, 2012 and 2013, traps were hung on 25, 26, 31 and 29 March (69.4, 116.8, 23.2 and 80.5 DD) and adults caught on 9 April, 31 March, 18 and 1 April (121.5, 134.7, 121.9 and 117.0 DD), respectively.

The population development curves of *C. gnidiella* according to the numbers of butterflies captured in the sex pheromone traps for the five years are given in Figure 1.

The first adults of *C. gnidiella* were caught in the sex pheromone trap between 31 March and 18 April 18 in the 5 years (Figure 1). However, it was determined that the population of the pest adults generally continued at low density for about 3 months until the second half of July, then started to increase from that date and continued at high density for about 4 months till the middle of November. According to the trap counts, adult flight graphs show that *C. gnidiella* populations had 4-5 peak points during the year and the adult flight ended at the end of November to the beginning of December. Yehuda et al. (1992) reported, for a study carried out in Israel, that *C. gnidiella* were first caught in March-April, the population was low in March-June, did not cause damage in first generation and adult flights ended in late October to early November. In another study carried out in Portugal, *C. gnidiella* adults emerged in the second half of the March, the population gradually increases from the beginning of June until the end of August, generations overlapped with each other and adults were active from the second half of March until the beginning of December (Silva & Mexia, 1999).

Öztürk & Ulusoy (2012) carried out a study in 2008-2009 in pomegranate orchards in the Eastern Mediterranean Region (Adana, Mersin and Osmaniye). They reported that the first adults were caught at the beginning of April, the population showed an increase from the second half of July, reached the highest level in October-November and the moth flight ended at the end of November to the beginning of December. Similarly, a study conducted on pomegranates in Hatay Province (2010-2011) found that *C. gnidiella* population was low in May and November, and increases in June-October, giving four generations per year, May-June, July, August-September and October-November, with mature flight ending in December (Demirel, 2016).

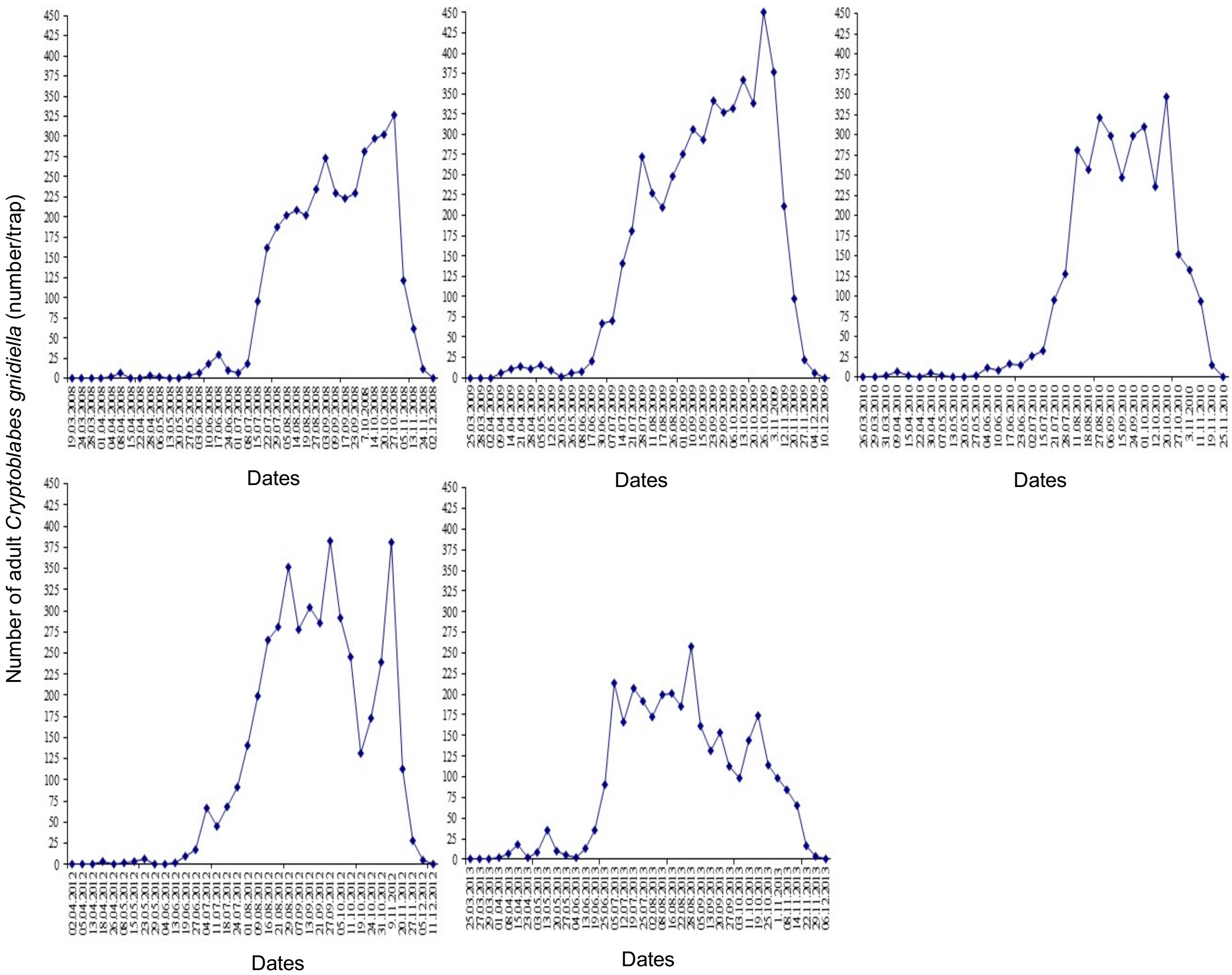

Figure 1. Adult population variation of *Cryptoblabes gnidiella* between 2008-2010 and 2012-2013 at the pomegranate orchard in the village of Akarsu, Tarsus, Mersin Province, Turkey.

For the first generation of *C. gnidiella,* first egg laying and ETS values were on 21 April 2008 and 253.8 DD, 1 May 2009 and 238.9 DD, 24 April 2010 and 253.5 DD, 1 May 2012 and 243.8 DD, and 23 April 2013 and 237.1 DD. During the first egg laying period in the five assessment years, the fruit were still quite small, i.e. walnut sized.

For the second generation, first adult emergence from larvae were on 9, 14, 11, 14 and 6 June (708.2, 685.4, 699.5, 699.7 and 686.8 DD) and the egg hatching on 18, 22, 19, 21 and 17 June (820.2, 796.1, 809.8, 807.4 and 805.2 DD), respectively for 2008-10 and 2012-13. In this period, the great majority of the fruit were about 70 mm in size.

For the third generation in 2018, first adult emergence larvae were on July 17 (1269.3 DD) and the egg hatching on 22 July 22 (1389.7 DD). In the four subsequent years of assessment, these dates were 21 and 28 July (1241.8 and 1361.9 DD) in 2009, 22 and 30 July (1260.9 and 1391.5 DD) in 2010, 19 and 26 July (1248.0 and 1374.9 DD) in 2012, and 18 and 26 July (1247.0 and 1368.1 DD) in 2013, when the majority of the fruit had reached 50% of the mature size.

For the fourth generation in 2018, adult emergence was on 20 August (1834.9 DD) and egg hatching on 27 August in 2008 (1952.2 DD). In the subsequent assessments, these dates were on 25 August (1807.0 DD) and 2 September (1930.6 DD) in 2009, on 24 and 31 September (1825.9 and 1941.8

DD) in 2010, 19 and 27 September (1822.9 and 1929.4 DD) in 2012, and 24 and 31 September 24 (1814.6 and 1919.8 DD) in 2013, when the fruit had start to sweeten and 50% were fully grown.

For the fifth generation in 2018, adult emergence was on 27 September (2398.4 DD) and the egg hatching on 7 October (2514.6 DD). In the subsequent assessments, these dates were 8 and 18 October (2378.4 and 2497.3 DD) in 2009, 30 September (2393.8 DD) and 12 October 12 (2516.3 DD) in 2010, 26 September (2390.2 DD) and 4 October (2509.5 DD) in 2012, and 11 and 27 October (2370.7 and 2495.4 DD) in 2013, when 85-90% of the fruit have matured and where ready for harvest.

In 2008, the pomegranate harvest started on 22 September, and on 25 September, 25 September and 5 October and 27 September in the subsequent assessment years, and was completed in about 15-20 d.

The 5-year pentad temperature (five consecutive days) and DD values based on a DD model of *C. gnidiella* are given in Table 1 and Figure 2.

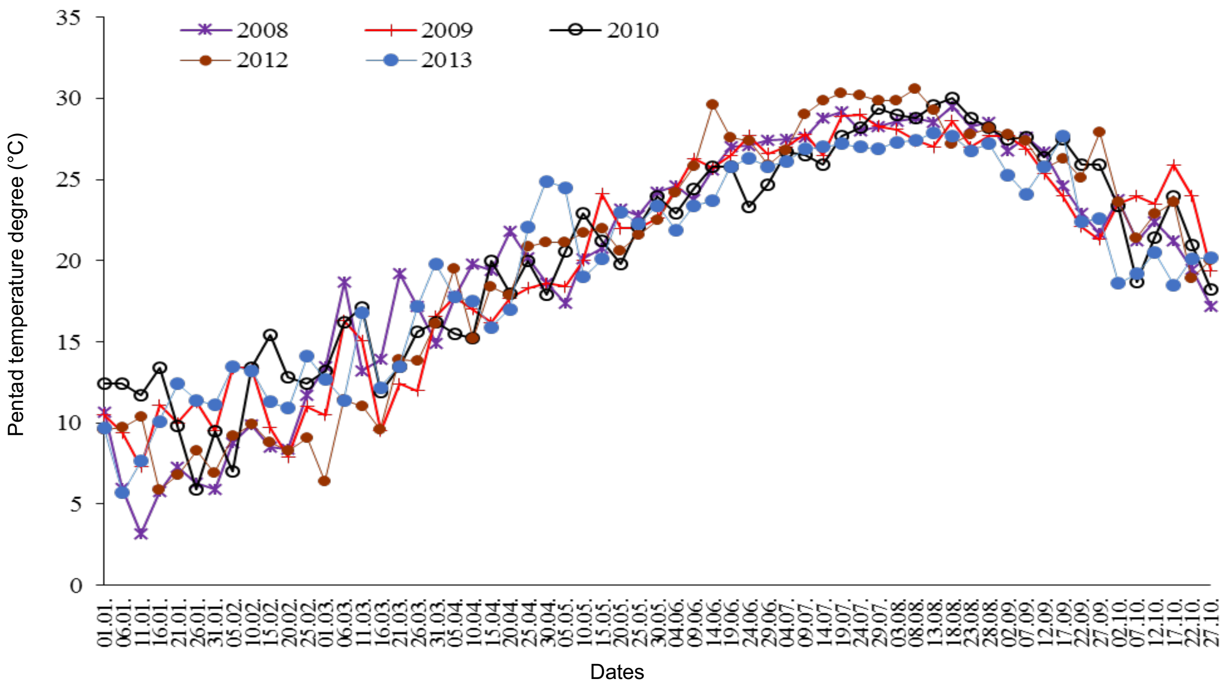

Figure 2. Pentad temperature values in 2008-2010 and 2012-2013 at the pomegranate orchard in Akarsu village in Tarsus/Mersin.

The 5-year pentad temperature values of the pomegranate orchard in Akarsu village ranged between 3.2 and 29.5ºC in 2008 in Figure 2. In the subsequent assessment years, the temperature ranges were 7.3-29.0ºC, 7.0-30.0ºC, 5.9-30.6ºC and 5.7-27.9ºC. The pentad temperatures at the time of the first adult of *C. gnidiella* caught were 14.9, 17.8, 16.2, 18.4 and 19.8ºC for the five years. Therefore, it was concluded that the first adults of *C. gnidiella* could be trapped when the average temperature was about 17.4ºC (15-20ºC).

The number of moths caught in the five years at the highest average temperature values during were 30.7ºC/235 moths (21 August 2008), 30.2ºC/273 moths (23 July 2009), 31.1ºC/321 moths (21 August 2010), 32.1ºC/91 moths and 140 moths (19 and 28 July 2012), and 28.6ºC/186 moths (18 August 2013). The highest number of caught at the mean temperature values were 20.2ºC/326 moths (27 October 2008), 22.5ºC/451 moths (26 October 2009), 22.8ºC/347 moths (20 October 2010), 25.8ºC/383 moths (27 September 2012) and 27.2ºC/258 moths (28 August 2013) (Figures 1 and 2). The adult population of *C. gnidiella* was not negatively affected by temperatures above 30ºC and biological activity (egg, larva, pupa and adult) continued throughout the entire study. According to these results, the most suitable temperature for development of *C. gnidiella* was 25-30ºC and upper threshold for development was 40ºC. The optimum temperature for development was previously reported as 25-30ºC by (Anonymous, 2016), and Salama (2008) reported that development continued at 35°C. However, the mortality on egg embryo was 100% at 5, 10 and 40ºC.

As shown in Table 1, the average effective temperature calculated from 1 January over the 5 years, and used in *C. gnidiella*'s DD model, were 70.4 DD for hanging traps, 126.76 DD for the first adult emergence, and 245.42 DD for the first egg hatching. In addition, the value for egg hatching in the second to fifth generations were 807.74, 1377.22, 1934.76 and 2506.58 DD, respectively.

Table 1. Degree-day (DD) values of *Cryptoblabes gnidiella* based on a DD model for years 2008-2013

Application periods	ETS values (DD±SE) for each year*										Average ETS value (DD±SE)	Recommended ETS value (DD)
	2008		2009		2010		2012		2013			
Traps hanging	62.1±2,1	b**	69.4±2,4	b	116.8±0,8	c	23.2±2,2	a	80.5±3,5	d	70.40±15.08	80.0
First adult emergence	138.7±2,7	c	121.5±4,5	ab	134.7±4,7	bc	121.9±5,4	ab	117.0±1	a	126.76±4.19	120.0
Egg hatching	253.8±1,8	b	238.9±2,9	a	253.5±3,5	b	243.8±1,2	a	237.1±0,9	a	245.42±3.53	250.0
2nd generation adult emergence	708.2±2,2	b	685.4±0,6	a	699.5±1,7	b	699.7±3,7	b	686.8±3,2	a	695.92±4.31	700.0
Egg hatching	820.2±1,2	c	796.1±3,9	a	809.8±3,8	bc	807.4±2,4	abc	805.2±5,2	abc	807.74±3.88	800.0
3rd generation adult emergence	1269.3±4,3	c	1241.8±2,8	a	1260.9±1,9	b	1248.0±2	ab	1247.0±7	ab	1253.40±5.06	1250.0
Egg hatching	1389.7±3,7	bc	1361.9±1,9	a	1391.5±1,5	c	1374.9±4,9	abc	1368.1±2,1	abc	1377.22±5,84	1375.0
4th generation adult emergence	1834.9±4,9	c	1807.0±2,0	a	1825.9±4,1	bc	1822.9±3,1	bc	1814.6±4,6	ab	1821.06±4.78	1820.0
Egg hatching	1952.2±4,2	b	1930.6±2,6	a	1941.8±3,2	b	1929.4±3,6	a	1919.8±2,8	a	1934.76±5.53	1930.0
5th generation adult emergence	2398.4±2,4	c	2378.4±4,6	ab	2393.8±4,2	bc	2390.2±1,2	bc	2370.7±2,7	a	2386.30±5.11	2385.0
Egg hatching	2514.6±3,6	b	2497.3±0,7	a	2516.3±2,3	b	2509.5±3,5	b	2495.4±0,6	a	2506.58±4.34	2500.0

* ETS: Indicates effective temperatures sum (DD) and calculated from 1 January;
** values within a column followed by the same letters are not significantly different (Duncan, P=0.05).

In a DD-model study in Turkey, to determine the first emergence of the codling moth sexual attractant traps were hung when ETS reaches 40-80 DD from 1 January and when ETS reached 250 and 800 DD, the first and second generations egg hatching occurred, respectively. Traps were hung for the European grapevine moth when the sum of the maximum temperatures reached to 1000°C from 1 January, and when ETS reach to 120, 520 and 1047 DD, the first, second and third generations egg hatching occurred, respectively. Sex pheromone traps were hung when the ETS reached 150 DD from 1 January for the peach twig borer (*A. lineatella*). Following the first adult emergence, egg hatching occurred when the ETS reached 250 DD, consequently spraying should be performed. The calculation of development thresholds for DD values are accepted as 10.0ºC for *C. pomonella*, 12.0ºC for *L. botrana* and 10.0ºC for *A. lineatella* (Anonymous, 2008). Similarly, sex pheromone traps were hung at the end of March and when ETS reached 400 DD, first spraying should be performed, and according to insecticide efficacy second and third spraying should be performed for oriental fruit moth. The average first adult emergence ETS values of carob moth were found to be 403.86 and 294.48 DD in pomegranate orchards in Central and Siverek Regions of Şanlıurfa. Adults were found to have four peaks during the year with ETS values of 1642.19, 2374.25, 2754.76 and 3107.46 DD in the Center Region, and 1218.45, 1595.80, 2109.57 and 2409.71 DD in the Siverek Region of Şanlıurfa. According to these results, development threshold was determined 10.0ºC for *C. pomonella*, *A. lineatella and G. molesta,* 10.85ºC for *P. olea*, and 12.0ºC for *L. botrana* (Kumral et al., 2005; Anonymous, 2008; Mamay et al., 2014).

Regression models and R square values were obtained for mean DD values and mean temperatures of five different generations adult emergence (Table 2).

Table 2. Regression models, parameters between mean degree-day values and mean temperatures for different generations adult emergence in 2008-2013.

Generations	Equations	R^2 values	F values	p values
1st generation	y= 0.0636 x - 19.601	0.490	2.958	0.184
2nd generation	y= 0.0425 x - 4.8642	0.041	0.129	0.743
3rd generation	y=-1.2334 x + 1289.145	0.047	0.149	0.725
4th generation	y= 0.095 x - 144.44	0.890	26.014	0.015
5th generation	y= 0.1147 x - 250.13	0.550	3.667	0.151
Mean	y= 0.0007 x - 25.084	0.130	0.457	0.547

In studies conducted on a DD model for *A. lineatella* in peach orchards in the USA, it is reported that *A. lineatella* has a development threshold of 10.0ºC, a generation completed at 600.0 DD, traps can be hung when ETS reaches 183.3 DD from 1 January, when ETS value from the first adult emergence the traps reach to 222.2-277.7 DD for first generation and 811.0 DD for the second generation the spraying can be applied (Anonymous, 1999; Reding & Alston, 2001). Similarly, studies on the DD model of oriental fruit moth in California (USA) peach orchards revealed that *G. molesta* has a developmental threshold at 7.2ºC, a generation is completed at 535 DD, and when the ETS value reaches at 126.1 DD from 1 January, the first adult are caught at traps, following the catch of the first adult, 175 DD, first spraying, 350 DD second spraying are carried to control the first generation. For the second generation could be controlled by the first spraying when ETS values of 1150-1200 and 1500 DD second spraying, and for the second generations when ETS reach at 2100-2200 DD first spraying and at 2500 DD second spraying can be applied (Croft et al., 1980; Polk et al., 1995).

In conclusion, values for the DD model of *C. gnidiella* from the 5 years of data, taking into account standard errors in the values obtained with literature information, were 80.0 DD for hanging time of trap, and 250.0, 800.0, 1375.0, 1930.0 and 2500.0 DD for first, second, third, fourth and fifth generations egg hatching, respectively. However, when scheduling insecticide applications, first generation of *C. gnidiella*, which had a low population density, having emerged from overwintering places, and the fifth generation, whose time was after harvest, should be controlled. If insecticides are applied according to above information, the applications will be more effective.

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