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Orijinal araştırma (Original article)

Temperature-dependent development of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato plant *Lycopersicon esculentum* Mill. (Solanaceae)[1]

Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae)'nın domates bitkisi, *Lycopersicon esculentum* Mill. üzerinde sıcaklığa bağlı gelişmesi

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Summary

Laboratory studies on the temperature-dependent development of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) were performed at 10 constant temperatures ranging from 15 to 34±1°C. The duration of total development was measured for every temperature. Tayfun F1 tomato variety was used for larval feeding and all experiments were carried out at climatic cabinets where had long daylight period (16:8) and 65±5% constant humidity for every temperature. According to obtained data, developmental threshold (C) and thermal constant (K) were calculated by using linear regression, and lower (T_{min}), optimum (T_{opt}) and upper (T_{max}) temperature thresholds for total developmental period of pest were calculated by using Polynomial (4^{th}), Logan 6, Logan 10, Lactin 1, Briere 1 nonlinear regresyon models. Development time decreased with increasing temperature ranging from 78.17 days to 21.39 days within the range 15-29°C. Developmental threshold and thermal constant for total development of tomato leaf miner were estimated as 8.94°C and 419.46 degree-days respectively. Lower, optimum and upper temperature requests were estimated with different models and results obtained werein the range 8.9-12.5, 31.00-31.07 and 35.9-38.5, respectively.

Keywords: *Tuta absoluta*, temperature-dependent development, developmental threshold, thermal constant, optimum developmental

Özet

Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae)'nın sıcaklığa bağlı gelişmesi laboratuvar koşullarında 15-34±1°C arasında değişen 10 farklı sabit sıcaklıkta incelenmiştir. Her bir sıcaklıkta toplam gelişme süresi belirlenmiştir. Larvaların beslenmesi için Tayfun F1 domates çeşidi kullanılmıştır ve denemeler her bir sıcaklık için uzun gün aydınlatmalı (16:8), %65±5 orantılı nem koşullarına sahip iklim kabinlerinde yürütülmüştür. Elde edilen verilere göre zararlının gelişme eşiği (C) ve sıcaklık sabiti (K), doğrusal regresyon yöntemiyle ve en düşük, en iyi ve en yüksek sıcaklık eşikleri doğrusal olmayan regresyon modelleri Polynomial (4^{th}), Logan 6, Logan 10, Lactin 1, Briere 1 yardımıyla hesaplanmıştır. Gelişme süresi artan sıcaklığa bağlı olarak15-29°C sıcaklık aralığında 78.17 günden 21.39 güne azalmıştır. Domates güvesi'nin toplam gelişme süresi için gelişme eşiği 8.94°C ve sıcaklık sabitesi 419.46 gün-derece olarak tahmin edilmiştir. En düşük, en iyi ve en yüksek sıcaklık istekleri farklı modeller yardımıyla sırasıyla 8.90-12.50, 31.00-31.07 and 35.90-38.50 aralığında tahmin edilmiştir.

Anahtar sözcükler: *Tuta absoluta*, sıcaklığa bağlı gelişme, gelişme eşiği, sıcaklık sabiti, en iyi gelişme

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Introduction

The tomato leaf miner, *Tuta absloluta* (Meyrick) (Lepidoptera: Gelechiidae), originated in South America and feeds on many cultivars and weeds, which belong to the families of Solanacae and Fabacea. So far, 26 different plant species have been specified as host plants. It feeds mainly on tomatoes (*Lycopersicon esculentum* Mill.), potatoes (*Solanum tuberosum* L.), aubergines (*Solanum melongena* L.), peppers (*Capsicum annum* L.), some weeds (*Datura stramonium* L.*, Lycium chilense* Coralillo*, Solanum nigrum* L., and *Nicotiana glauca* Graham) (Solanaceae) and beans (*Phaseolus vulgaris* L.) (Fabaceae) (Harizanova et al., 2009; Abdul-Rassoul, 2014). Besides leaves of hosts, it also attacks the stalk, stem, fruit, and even flowers, and by this way it can cause damage of approximately 100% (Souza et al., 1992).

The pest was first reported to have been transmitted from Chile to Argentina in 1964, and then it was occurred in Valencia, Spain in 2007 (Vieira, 2008), in Cosenza, Italy in 2008 spring, and then in autumn of the same year in the south France (EPPO, 2009). It has appeared in Turkey since 2009 and caused considerable damage by spreading rapidly over suitable areas. It was occurred in North Africa, in the Middle East, and in some Asian countries in the same year and the following years. It became one of the greatest troubles of tomato growers in a short time by spreading rapidly all over the areas where tomato was grown. Besides host suitability, suitable temperature is one of the most important reasons why the pest spreads and causes damage. Temperature is one of the most important abiotic factors affecting the biology of insects (Chapman, 1998). Determining the appropriate temperature conditions for the pest is essential in terms of the studies of population dynamics. One of the main reasons why this pest, which is of Neotropical origin, can mainly be seen more at northern latitudes and why it causes damage is that these regions have the appropriate temperature zone for the pest. This study was conducted in order to determine the temperature ranges in which tomato leaf minercan grow best, and in which it can endure most. The most appropriate growth curves were determined in relation to the developmentrates obtainedat various constant temperatures. Thus, the temperature values having the potential for the pest to spread and create an epidemic, best developmental temperature, lower and upper temperature requests, and thermal constant were all obtained for total developmental period.

Material and Methods

Tomato leaf miner adults were collected from tomato fields in Antalya and reared on potted Tayfun F1 tomato variety, *Lycopersicon esculentum*, within sealed Plexiglas cages covered with tulle (40 cm x 50 cm x 50 cm) at 25ºC temperature, 65±5% relative humidity and day light period (16:8 h). Experiments were initiated with adults of tomato leaf miner taken from stock culture. Three potted plants were put in each cage and 10 adults oftomato leaf miner were released for one day to lay eggs on seedlings. Then, potted plants having eggs were taken to climate cabinets whose temperature, humidity, and light had been adjusted before. In the study,10 different experimental groups, which had ranged 10 and 79 larvae, were created in the climate cabinets adjusted to 15, 20, 23, 25, 27.5, 29, 30, 31, 33 and 34ºC (Table 1). Relative humidity was 65±5% and day light period was16:8 h for each temperature. Developmental and survival data were recorded daily. Generation numbers of the pest in the most important tomato growing areas of Turkey were calculatedtheoretically based on obtained development threshold and temperature constant with average daily temperature.

Table 1. The development periods (days) of *Tuta absoluta* at ten different temperature conditions

Temperatures(°C)	n	Development periods (days) ± Std. Dev
15	10	78.17±4.222
20	25	40.24±1.022
23	67	29.24±0.474
25	79	26.75±0.297
27.5	18	22.67±0.642
29	38	21.39±0.398
30	50	21.48±0.276
31	38	20.49±0.344
33	70	21.39±0.216
34	15	23.93±0.372

Statistical analyses

A linear and six non-linear regression models were used for data analysis. The developmental threshold (C) and the thermal constant (K) of tomato leaf minerin relation to total developmental time were calculated by means of linear regression, and lower (T_{min}), optimum (T_{opt}) and upper (T_{max}) temperature thresholds for total developmental period of tomato leaf miner were calculated theoretically by means of nonlinear models; Polynominal (4^{th}), Logan 6, Logan 10, Lactin 1, and Briere 1. The curves were fitted with nonlinear regression using by CurveExpert Pro, SPSS (v.20), and MS Excel software.

Linear regression model

The thermal constant (K) and developmental threshold (C) can be estimated only by the linear equation (Campbell et al., 1974; Obrycki & Tauber, 1982; Kontodimas et al., 2004).

$d(T) = a + b.t \qquad K = \frac{1}{b} \qquad C = \frac{-a}{b}$

Where $d(T)$ is the rate of development at temperature T (°C) (days-1), and *a*and *b* are constants. Constant parameters were calculated based on the values obtained between 15 °C and 29 °C where developmentrate increased linearly. Outside of this range, the relationship between developmental time and temperature was nonlinear (Mills, 1981). The linear relationship between development time and temperature was used for degree-days model:K: thermal constant (day-temperature); C: developmental threshold (°C) (Wigglesworth, 1953; Campbell et al., 1974; Mills, 1981).

Non-linear regression models

Polynomial model (4th)

$y = a + b.x + c.x^2 + d.x^3 + e.x^4$

Logan 6 model

$d(T) = \psi.\left[e^{\rho.T} - e^{(\rho.T_{max} - \frac{T_{max}-T}{\Delta}}\right]$ (Logan et al., 1976; Logan, 1988)

Where $d(T)$ is the rate of development at temperature T (°C) (days^{-1}), ψ is the maximum development rate, ρ is a constant defining the rate of optimal temperature, T_{max} is the high temperature threshold, and Δ is the temperature range over which physiological breakdown becomes the overriding influence.

Optimum temperature for development (T_{opt}) was calculated by the equations of Logan et al. (1976).

$$T_{opt} = T_{max}.\left(1 + \varepsilon.\frac{ln\ (\varepsilon.b_0)}{1 - \varepsilon.b_0}\right)$$

Where $\varepsilon = \frac{\Delta T}{T_{max}}$ and $b_0 = \rho.T_{max}$ (Palyvos, 2009).

Logan10 model

$d(T) = \alpha.\left[\frac{1}{1+k.e^{-\rho.T}} - e^{(\frac{T_{max}-T}{\Delta}}\right]$ (Logan et al., 1976; Logan, 1988)

Whereα and k are the empirical constants, and $\rho,\ T_{max}$ and Δ are as in Logan 6 model.

Janish model

$d(T) = \frac{T_{min}}{2}.\left[e^{k.(T-T_{opt})} + e^{-\lambda.(T-T_{opt})}\right]$ (Janisch, 1932; Analytis, 1981)

Where T_{min} is the lower temperature and T_{opt} is optimum temperature, λ and k are the empirical constants.

Lactin1 model

$d(T) = e^{\rho.T} - e^{(\rho.T_{max} - \frac{T_{max}-T}{\Delta}} + \lambda$ (Brie`re & Pracros, 1998; Tsai & Liu, 1998)

Where ρ, T_{max} and Δ are as in Logan 6 model and λ forces the curve to intercept the *y*-axis at *a* value below zero and thus allow estimation of a low temperature threshold.

Briere1 model

$d(T) = \alpha.T.(T - T_{min}).\sqrt{T_{max} - T}$ (Brie`re et al., 1999)

Where T is the rearing temperature (°C), a is an empirical constant, T_{min} is the low temperature development threshold and T_{max} is the lethal temperature threshold.

Results and Discussion

Development time and survival

All experimental cohorts of tomato leaf miner were able to complete their developmentin every temperatures conditions, except 35°C. Total development period from egg hatching toadult exclusionsharply decreased ranging from 78.17 days at 15 °C to 21.39 days at 29°C, and then smoothly increased ranging from 21.48 days at 30°C to 23.93 days at 34°C (Table 1). Like most ectothermic organisms, temperature affects developmental time of tomato leaf miner significantly. Findings obtained in this study are consistent with results ofother insects including tomato leaf miner (Estay, 2000; Uygun & Atlıhan, 2000; Atlıhan & Özgökçe, 2002; Pereyra et al., 2006; Andrew et al., 2013; Mahdi & Doumandji, 2013).

Survival rate from egg to adult of tomato leaf miner obtained at different temperaturesare shown in Figure 1. The survival rates obtained at temperatures ranged 23 - 27.5°C were higher than those of other temperatures tested, andit was the lowest at 15 and 34°C. Survival rates of insects are under effects of temperature as stated in different studies (Aldyhim & Khalil, 1993; Kersting et al., 1999; Atlıhan & Chi, 2008; Andreadis et al., 2013).

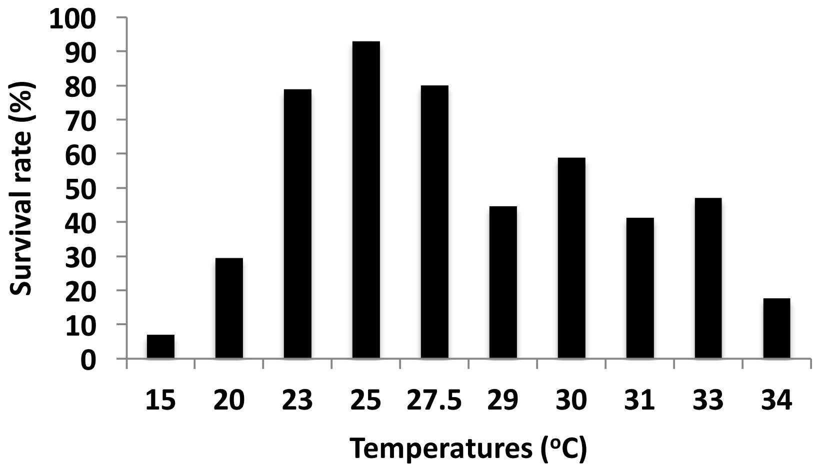

Fig. 1. Survival rate from egg to adult of tomato leaf miner, *Tuta absoluta* at different temperatures.

The developmental threshold, thermal constant, optimum development, lower and upper development requests

The developmental threshold (C), thermal constant (K), optimum (T_{opt}) development temperature, lower (T_{min}) and upper (T_{max}) temperature requests for total immature development of tomato leaf miner are presented in Table 2 and Figure 2. The development rate increased linearly with increasing temperature from 15 to 29 °C withthe highestcoefficient of determination (r^2) of 0.851. The developmental threshold and thermal constant were found 8.94°C and 419.46 Degree-days, respectively. The development threshold of tomato leaf miner was reported as 9.8 °C by Mahdi & Doumandji (2013) and 8.1 °C by Estay (2000). Our result is between these two results mentioned. Differences from literature might be due to host plants used for experiments.

Table 2. Values of the fitted coefficients and measurable parameters, the adjusted coefficient of determination of linear and five nonlinear models for describing total development of *Tuta absoluta*

Models		Parameters± Std. Dev.
Linear	*a*	-2.1E-02±2.4E-03
	b	2.4E-03±9.1E-05
	K	419.460±
	C	8.940
	r	0.851
	SE	4.5E-03
Polynomial (4th)	*a*	-2.7E-01±1.3E-01
	b	4.9E-02±2.3E-02
	c	-3.1E-03±1.4E-03
	d	9.4E-05±3.9E-05
	e	-1.0E-06±3.8E-07
	r	0.867
	T_{min}	12.500
	T_{opt}	31.000
	T_{max}	38.500
	SE	4.3E-03
Logan 6	*ψ*	8.1E-02±6.5E+02
	ρ	1.4E-01±4.4E+00
	T_{opt}	31.070
	T_{max}	38.173±6.4E-01
	Δ	7.1E+00±2.2E+02
	r	0.865
	SE	0.004
Logan 10	*α*	5.6E-02±2.9E-03
	k	5.7E+01±2.2E+01
	ρ	1.9E-01±2.2E-02
	T_{opt}	31.070
	T_{max}	35.891±5.3E-01
	Δ	1.1E+00±3.1E-01
	r	0.869
	SE	4.3E-03
Lactin 1	*ρ*	2.4E-03±1.4E-04
	T_{min}	9.500
	T_{opt}	31.000
	T_{max}	38.000±1.7E+00
	Δ	2.4E+00±4.4E-01
	λ	-1.0E+00±3.4E-03
	r	0.868
	SE	4.3E-03
Briere 1	*a*	2.7E-05±1.5E-06
	T_{min}	8.893±7.3E-01
	T_{opt}	31.000
	T_{max}	37.597±2.9E-01
	r	0.866
	SE	4.3E-03

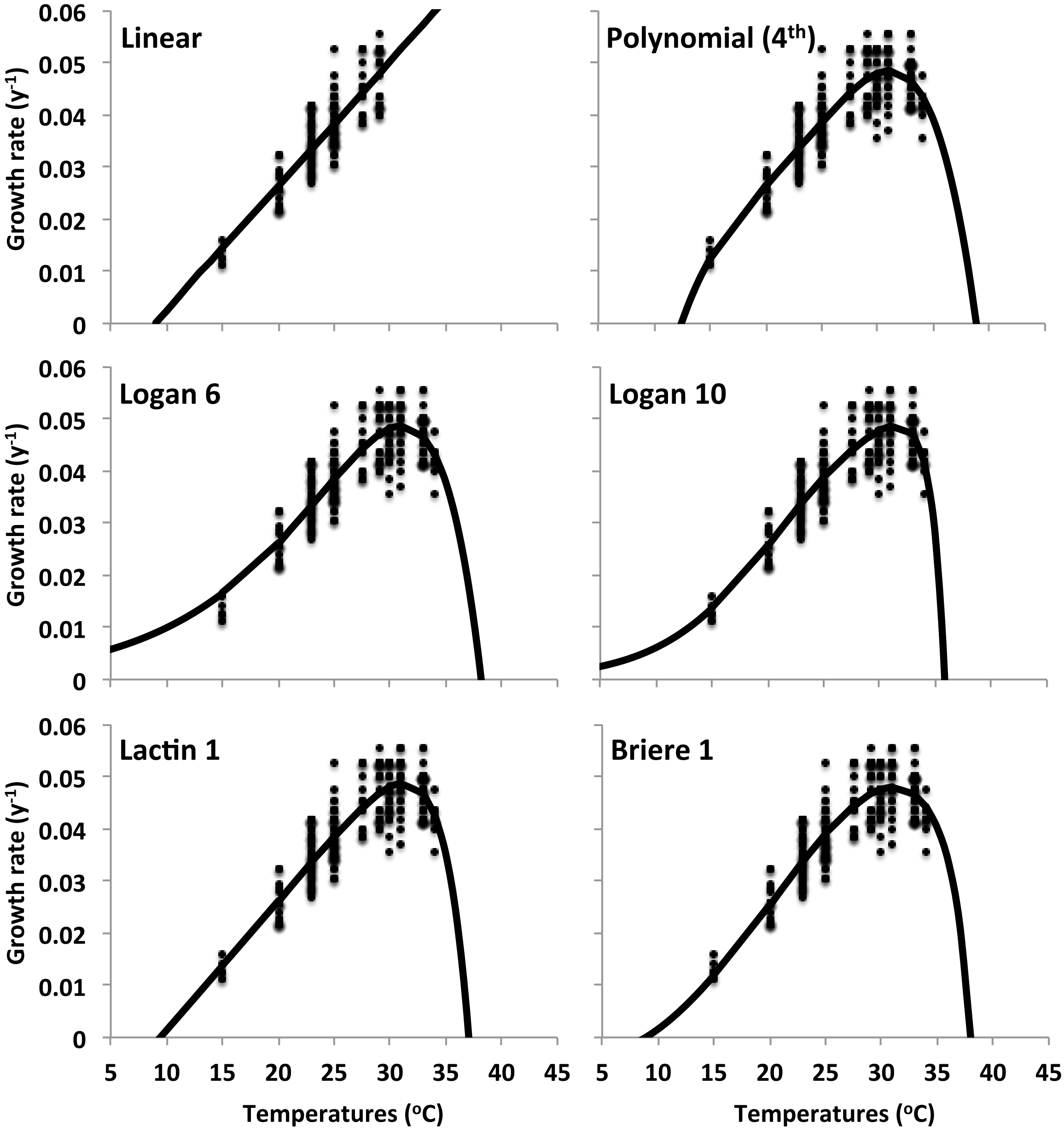

Fig 2. Fitting a linear and five nonlinear models, relationship of development rate of *Tuta absoluta* with temperature described by the total preadult period.

Results of parameter estimation of Polynomial (*4^th^*), Logan 6, Logan 10, Lactin 1 and Briere 1 models for development rates of tomato leaf miner are presented in Table 2. At all models, r^2 was calculated as around 0.87. While Logan 6 and Logan 10 models provide optimum (T_{opt}) and upper (T_{max}) temperatures, Polynomial (4^{th}), Lactin 1 and Briere 1 models provide lower (T_{min}), temperatures, additionally. The lower temperatures for development were estimated as 8.89, 9.50 and 12.50°C with Briere 1, Lactin 1 and Poynomial (4^{th}), respectively. First two results are more close to the developmental threshold. The optimum temperature of the pest was estimated as 31 °C withall models. The upper temperature of pest was estimated very close to eachother with models used, except Logan 10, and results are as follows; 38.5 °C (Polynomial 4^{th}), 38.17 °C (Logan 6), 38,00 °C (Lactin 1), 37.60 °C (Briere 1) and 35.89 °C (Logan 10).

As an invasive species, potential of tomato leafminer to spread to more extensive areas within the years to come is very high due to atmospheric movements or other reasons. Thus, knowing well the environmental conditions affecting the pest's life would be essential in terms of the measures that could be taken. The minimum and maximum temperature requests of the pest would allow us to predict the probable areas that it would spread as well as the periods when the pest would start causing damage. The number of generations of any insect can be estimated theoretically by using development threshold and temperature constant with average daily temperature. Based on parameters mentioned above, theoretically calculated generation number of the pest in Turkey was presented in Table 3. Mersin and Antalya were located in Mediterranean coast but the number of generations of the pest in Mersin is higher than that of Antalya. Our results indicated that generation number of tomato leaf miner could change even in the same region because of climatic differencesas mentioned in literature (Mahdi & Doumandji, 2013).

Table 3. Estimated generation numbers of *Tuta absoluta* in the most important tomato produced areas in Turkey after infestation

	Years				
	2010	2011	2012	2013	2014
Ankara	6.12	4.75	6.23	5.43	5.42
Antalya	8.51	7.55	8.62	8.16	8.06
Bursa	7.01	5.46	6.83	6.43	6.64
Çanakkale	7.27	5.95	7.32	6.83	6.69
İzmir	9.59	7.96	9.01	8.66	8.66
Manisa	8.74	7.06	8.51	7.95	7.79
Mersin	10.87	9.59	9.96	10.32	10.28
Muğla	6.84	6.06	7.08	6.56	6.14
Samsun	6.98	5.29	6.51	6.19	6.39
Şanlıurfa	10.38	8.47	9.65	9.34	9.59
Tokat	6.21	4.92	5.81	5.17	5.66

Biology and the development periods of tomato leaf minerat different temperatures were examined in previous studies (Haji et al., 1988; Coelho & France, 1987; Estay, 2000; Pereyra et al., 2006; Andrew et al., 2013; Mahdi & Doumandji, 2013). However, they studied at temperatures that development rate increased linearly. Temperatures at which development rate stopped and declined were not examined yet. In this study, the best temperature values for development of tomato leaf miner and maximum temperature for the pest to resist were also calculated. The temperature range for tomato leaf miner to grow best was 29.5-32.0°C, and maximum temperature range for it to resist was 34.18-40.5°C.

Results obtained here can be used to estimate population development, and the regions where the pest can spread. Additionally, greenhouse conditions can be arranged based on results obtained in this study to control the pest.

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