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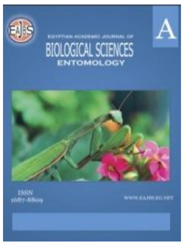

Threshold Temperatures and Thermal Requirements of Cotton Leafworm, *Spodoptera littoralis* Hb.

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ABSTRACT

The present investigation aimed to study the effect of four constant temperatures (17, 22, 27 and 32°C) on the developmental rates of different stages of cotton leafworm, *Spodoptera littoralis*. The incubation period, larval duration, pupal duration, pre-oviposition period and duration of generation were estimated. The time required for development was decreased as the temperature increased. The threshold temperatures were 11.8°C for egg, 7.56 °C for larvae, 12.27 °C for pupae, 12.58°C for the pre-oviposition period, and 10.5 °C for a generation. The average thermal requirements needed for completing the development were 40.1, 283.76, 149.5, 23.96 and 480.6 degree-days for egg, larvae, pupae, pre-oviposition period and generation; respectively.

INTRODUCTION

The Egyptian cotton leafworm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) is a native pest to Africa (Shonouda and Osman, 2000; El-Khawas and Abd El-Gawad, 2002), and distributed in many European countries (Pineda *et al*., 2007; Lanzoni *et al*., 2012; EPPO, 2019), Asia Minor and the Middle East countries (El-Aswad, 2007; El-Sabrout, 2013; Azzouz *et al*., 2014). Economically, it is a dangerous pest of many field crops and vegetables in North Africa, Middle East countries including Egypt (Kandil *et al*., 2003) and glasshouses plants and flowers production in Southern Europe (Roques *et al*., 2008; Abdel-Mageed *et al*., 2018), as well as various cash and traditional food crops in Africa (Capinera, 2008; Khedr *et al*., 2015). In Egypt, cotton cultivation is one of the main resources for the economy and *S. littoralis* represents a key pest on cotton (Ibrahim and Ali, 2018). In addition, it is considered the most destructive pest of more than 60 other crops, ornamentals and vegetables of economic importance (Dahi, 2005; Amin, 2007; Lanzoni *et al*., 2012; Abd El-Razik and Mostafa, 2013).

The temperature plays an important role among environmental factors for determining the rate of development, survival and any other biological and ecological aspects. Various investigations discussed different biological and ecological aspects of lepidopterous cotton insect pests, (Yones *et al.,* 2012).

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In this regard, threshold and thermal requirements have been determined for crop insect pests in order to predict their activities in the field and implement the control measures that match with target insect life stages (Padmavathi *et al*., 2013; Dahi *et al*., 2017; Yones *et al*., 2018)

This work was pointed mainly on the following aspects: (1) - Relationship between temperature and rate of development, which give a quantitative expression for this relationship, using thermal accumulation. (2)- Study the biological aspects of *S. littoralis* as a prior to determine its requirements of heat units that used through forecasting system for establishing IPM program against *S. littoralis*. (3)- Determine the thermal units required to complete the development of different stages for one generation, which help in the design of development indexes are used for determining the required times for these stages under field fluctuating temperatures in the field. These such points were previously studied by (Dahi, 2003, Dahi, 2005 and Ismail *et al.*, 2005).

In Egypt, El-Malki, K.G. (2000) reported that the mean developmental rate of immature *S. littoralis* stages and generation times at 4 constant temperature regimes over the range of 17.5 to 32.5 °C with increments of 5.0 °C was fitted to thermal summation (linear regression) and logistic curve. Eggs didn't hatch at 10 and 37.5 °C. The developmental rate of cotton leafworm stages increased with an increase in temperature over the range of 17.5 to 32.5 °C.

Predicting and monitoring population systems for lepidopterous pests by using light or pheromone traps based on heat- requirements were reported by (El-Mezayyen and Ragab, 2014).

MATERIALS AND METHODS

Egg masses of *S. littoralis* were collected from wild host plants at Assuit Governorate. The larvae reared on castor oil leaves, *Ricinus communis* for its highly nutritive content, under laboratory conditions at (27 ± 1 °C) to four generations to obtain susceptible strain.

The stages of *S. littoralis* were kept under four constant temperatures (17, 22, 27, and 32 °C) to determine the rate of development. The eggs were transferred in glass vials (2.0 X 7.5 cm), four replicates of 25 eggs / vail were used for each tested condition.

The time of hatchability were recorded daily beside the estimation of incubation period and embryo development rates during experiment. Newly hatched larvae were confined in a test tube (7.5 X 2.5 cm) with adequate castor oil leaves for feeding. Sawdust was placed at the bottom of the tubes and the top was covered with muslin cloths and secured with a band then maintained in incubators running at 17, 22, 27, and 32 °C. The pupae were kept in similar tubes, under the same conditions, till moth emergence. After being sexed, the newly emerged moths of each group resulted from the same temperature were isolated in pairs, one pair for each kept in a separate tube (15 cm long 5 cm diam.) opened at each ends, contain a small piece of absorbent cotton wool previously soaked in 10% sucrose solution as adult feeding solution. The two ends of each tube were covered with muslin cloths, secured with band, and small branch of *Nerium oleander* as a suitable oviposition site.

Daily observations for each treatment were made to record the different durations of the embryo, larvae, pupae, pre-oviposition period, and generation of *S. littoralis* under selected conditions.

The rate of development for *S. littoralis* stages (incubation period, larval duration, pupal duration, pre-oviposition period, and period of one generation) were determined by the simple formula (1/t x 100) for the four constant temperatures.

Duration of different stages was recorded for each temperature degree. Data obtained in the present work were subjected to statistical analysis by regression.

Kajanshikov (1946) found that the linear relationship between temperature and speed of development in insects can be expressed by the formula Y= K (T – t_0) where (Y) is the speed of development, (T) is the given temperature, (t_0) the biological Zero and (K) is a constant, its value is the slope of the regression line for speed of development vs. temperature and equal to the reciprocal of summation heat units that required for the given stage. This constant, called the developmental thermolabaility coefficient. This biological constant is the best index for developmental thermolabaility for insects and plants.

The effects of the above-mentioned conditions were tested on the immature and adult stages of *S. littoralis,* the theoretical development thresholds were determined according to the following formula:

$$Y = a + bx$$

On the other hand, thermal units required for complete the development of each stage was determined according to the equation of thermal summation (Blunk, 1923):

$$K = y\,(T - t_0)$$

Where y = developmental duration of a given stage; T= temperature in degree centigrade; t_0 = lower threshold of development; and K = thermal units (degree-days).

RESULTS AND DISCUSSION

Egg Stage:

The relation between *S. littoralis* incubation period and constant temperatures from 17 to 32C (Table 1; Fig. 1) indicated that the required time for completion of egg development decreased as long as temperature increased. The means of incubation periods were 6.14, 4.56, 2.91 and 1.87 days at 17, 22, 27 and 32°C; respectively.

The threshold of egg development was calculated and illustrated in Fig. (1), it was found to be 11.8°C. The average of thermal units in degree – days required for the completion of development of this stage was 40.1 DD's. The expected rates of development were 13.30, 26.09, 38.89 and 51.68 respectively.

The four observed values of the egg's rate of development at the constant temperature range (17 - 32C), gave a remarkably good fit to the calculated temperature – velocity line having the formula Y= 2.6 X - 30 (Fig. 1).

Table 1: Development of *S. littoralis* eggs under different exposure of constant temperatures and its relation with thermal requirements.

Temp. (°C)	Incubation period (days) (mean ± S.E.)	Rate of development	Expected	Temp. threshold (°C)	Degree-Days (DD`s)
17	6.14±0.41 a	16.3	13.30		31.9
22	4.56±0.31 b	21.9	26.09		46.5
27	2.91±0.17 c	38.31	38.89	11.8	44.2
32	1.87±0.21 d	53.47	51.68		37.8
Average					40.1

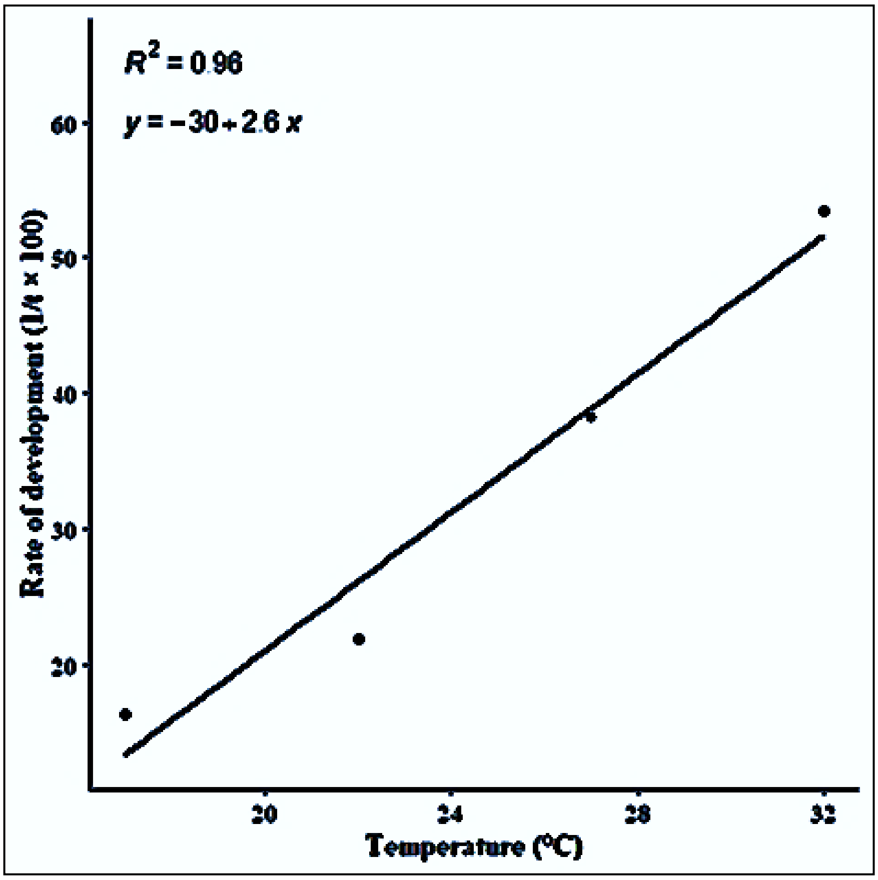

Fig. 1. The regression line of the relationship between the rate of the development incubation period of *S. littoralis* at different constant temperatures

Larval Stage:

The average larval duration (Table 2) varied from 30.65, 18.70, 15.22 and 11.45 days at 17, 22, 27 and 32°C. The lower threshold of development (t_0) for the larval stage **(Fig. 2)** was 7.56°C and **t**he average thermal units required for larval developmental till pupation was 283.76. DD's determined by the thermal summation equation K= y (T-7.56). However, the expected rates of development were 3.32, 5.09, 6.85 and 8.62; respectively. The four observed values for the larval rate of development at the four tested temperature degrees, gave remarkably good fit to the calculated temperature – velocity line having the formula Y = 0.35 X -2.7 (Fig.2).

Table 2: Development of *S. littoralis* larvae under different exposure of constant temperatures and its relation with thermal requirements.

Temp. (°C)	larval duration (days) (mean ± S.E.)	Rate of development	Expected	Temp. threshold (°C)	Degree-Days (DD`s)
17	30.65±1.90 a	3.26	3.32		289.23
22	18.70±0.52 b	5.34	5.09		270.02
27	15.22±0.64 c	6.57	6.85	7.56	295.87
32	11.45±0.80 d	8.73	8.62		279.83
Average					283.76

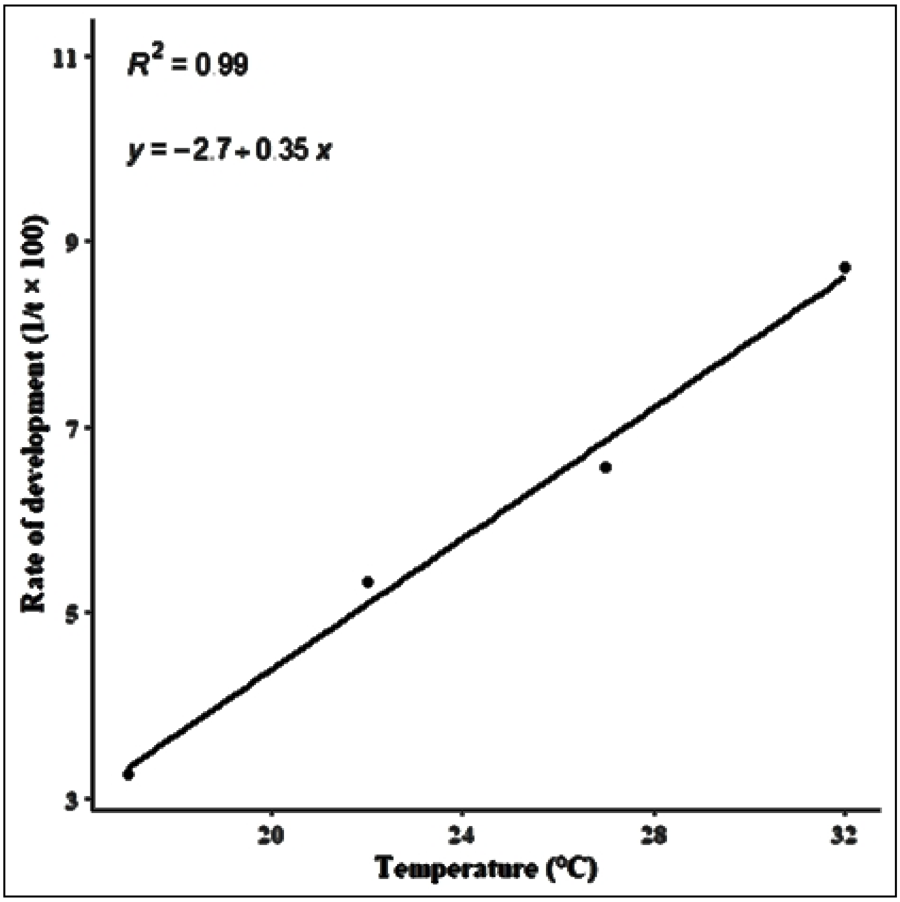

Fig. 2. The regression line of the relationship between the rate of development larval stage of *S. littoralis* at different constant temperatures.

Pupal Stage:

Concerning the effects of the four tested constant temperatures on the pupal duration of *S. littoralis,* it was noticed generally that the pupal period decreased as temperature increased where the average durations were 31.64, 15.36 10.14 and 7.57 days at 17, 22, 27 and 32° C, respectively (Table 3).

The developmental zero for this stage was 12.27°C as illustrated graphically by extrapolation in Fig. (3). Data in the same table refer that the average of thermal heat units for *S. littoralis* pupae was 149.5 DDs as estimated by the thermal summation equation K = y (T – 12.27). The expected rates of development were 3.16, 6.19, 9.89 and 13.21 % respectively.The four observed values for the pupal rate of developmental gave a remarkably good fit to the calculated temperature – velocity line having the formula Y = 0.67 X– 8.2 Fig. (3).

Table 3: Development of *S. littoralis* Pupae under different exposure of constant temperatures and its relation with thermal requirements.

Temp. (°C)	Pupal duration (days) (mean ± S.E.)	Rate of development	Expected	Temp. threshold (°C)	Degree-Days (DD`s)
17	31.64±1.97 a	3.16	3.16		149.7
22	15.36±0.60 b	6.51	6.19		149.5
27	10.14±0.72 c	9.86	9.89	12.27	149.4
32	7.57±0.82 d	13.21	13.21		149.3
Average					149.5

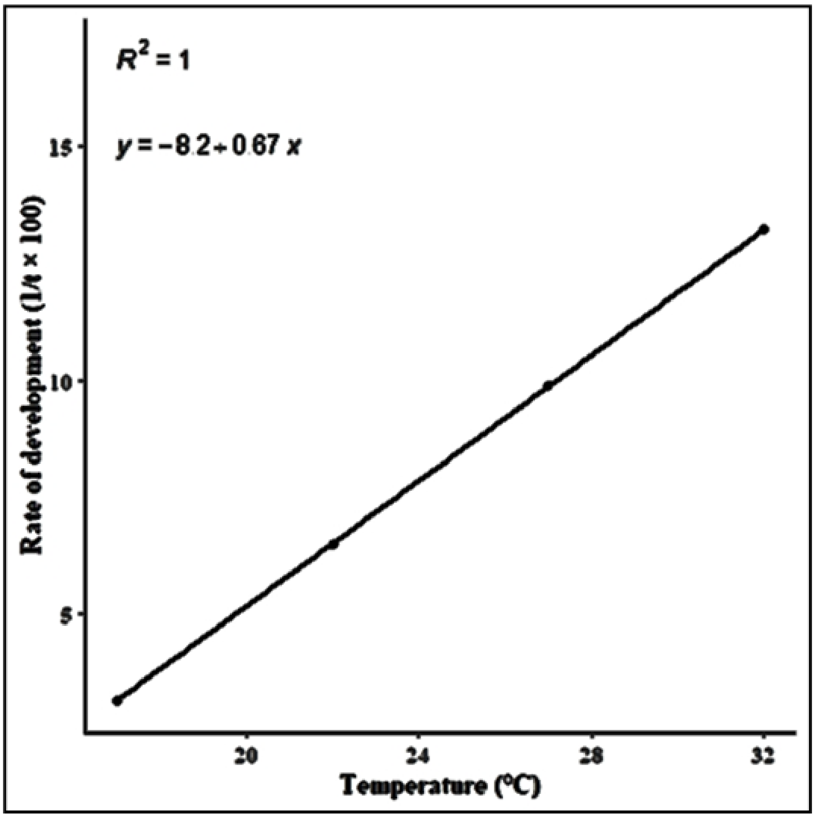

Fig. 3. The regression line of the relationship between the rate of development pupae stage of *S. littoralis* at different constant temperatures

Adult Stage:

1. Pre-Oviposition Period:

The mean time required for maturation of the ovaries and starting to egg-laying decreased, while the temperature increased from 5.0, 2.6, 1.8 and 1.2 days at 17, 22, 27 and 32°C, respectively (Table 4). The lower threshold of development was 12.58°C. Meanwhile, the average of total thermal units was 23.96 DD's which calculated by thermal summation equation K = y (T – 12.58). The expected rates of development were 18.27, 38.98, 59.68 and 80.39 %, respectively. The four observed values of temperature for this period rate of development from 17 to 32°C, which resulted a remarkably good fit to the calculated temperature – velocity line having the formula Y = 4.1 X -52 (Fig.4).

Table 4: Development of *S. littoralis* Pre –oviposition period under different exposure of constant temperatures and its relation with thermal requirements.

Temp. (°C)	Pre-oviposition period (days) (mean ± S.E.)	Rate of development	Expected	Temp. threshold (°C)	Degree-Days (DD`s)
17	5.0±0.76 a	20	18.27		22.1
22	2.6±0.55 b	38.46	38.98		24.49
27	1.8±0.18 c	55.55	59.68	12.58	25.95
32	1.2±0.16 c	83.33	80.39		23.50
Average					23.96

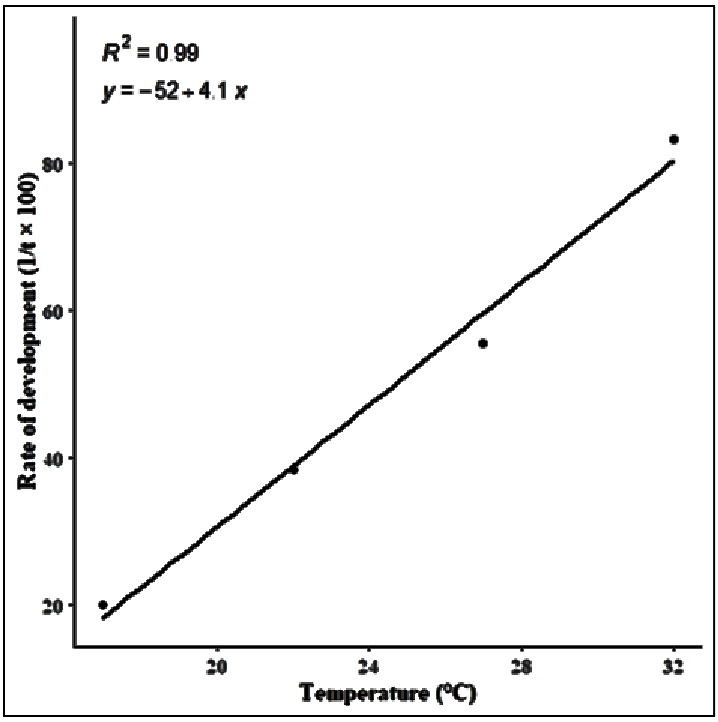

Fig. 4. The regression line of the relation between the rate of development pre. oviposition period of *S. littoralis* at different constant temperatures

The generation:

The mean duration of the total period of generation at different constant temperature regimes calculated using the total mean duration of different developmental stages (i.e., incubation period, larval stage, pupal stage and pre-oviposition period). Theoretically, the result obtained from this method shows an approximate value for the mean duration of generation at different constant temperature regimes.

The means of generation duration (Table 5) were 73.43, 41.22, 30.07 and 22.07 days at 17, 22, 27 and 32°C, respectively. Data revealed that the increase of temperature accelerated the developmental rates of *S. littoralis*, where it reached to the maximum velocity at 30 °C.

Thermal summation method, represents the hyperbolic relationship between temperature and developmental times given by equation: Y (T – 10.50) = 480.6 DD's, that drive from the linear regression equation: Y = 0.21 X – 2.2 (r = 1). The expected rates of development were 1.34, 2.38, 3.42, and 4.46; respectively. The lower threshold of development (t_0) that could be estimated graphically by extrapolation from the Fig. (5), was 10.50°C.

These results agreed with the findings obtained by Kajanshikov (1946) who found that the linear relationship between temperature and rate of development can be expressed by the formula K = y (T – t_0). Gergis *et al.,* (1994) investigated the relationship between temperature and developmental rates for the cotton leafworm under field and laboratory conditions. They reported that the different stages of *S. littoralis* completed their development at the range of temperatures from 15- 32.5 ºC, under these conditions where the threshold of development and thermal units were also estimated.

Table 5: Development of *S. littoralis* Generation under different exposure of constant temperatures and its relation with thermal.

Temp. (°C)	Generation period (days) (mean ± S.E.)	Rate of development	Expected	Temp. threshold (°C)	Degree-Days (DD`s)
17	73.43±3.44 a	1.36	1.34		477.29
22	41.22±1.93 b	2.42	2.38		474.03
27	30.07±3.80 c	3.32	3.42	10.50	496.15
32	22.07±1.59 d	4.52	4.46		474.93
Average					480.6

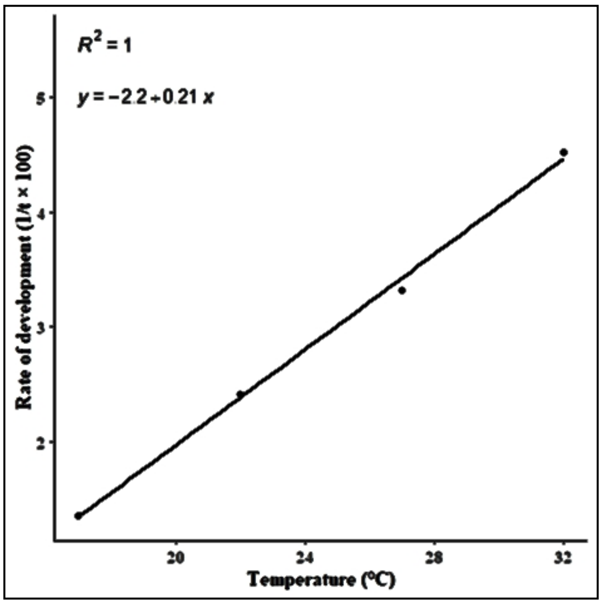

Fig.5. The regression line of the relation between the rate of development generation period of *S. littoralis* at different constant temperatures

Insects are selected for slow development (but relatively fast growth) in spring, but faster development occurred in summer. These contrasting selection pressures explains five puzzling effects of temperature on insects: growth and development rates increase almost linearly with temperature; genetic variability in development rate is reduced at high (27°C) temperatures; genetic variability in growth rate is reduced at low temperatures (15°C); development is very slow at the time of emergence after diapause regardless of the temperature threshold for emergence; and growth is slow at low temperatures with slower development rates. Insects use temperature to indicate time-of-season for different insect species which geared differently in high temperatures. Insect predators and parasitoids become more effective at high temperatures; and insect population dynamics are not stable in the conventional sense, (Gilbert and Raworth, 2012).

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ARABIC SUMMARY

عتبة النمو والاحتياجات الحرارية لدودة ورق القطن

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2- قسم وقاية النباتات – كلية الزراعة-جامعة اسيوك- اسيوك- مصر
3- الهيئة القومية للاستشعار عن بعد وعلوم الفضاء ، القاهرة ، مصر.

يهدف هذا العمل الي دراسة تأثير اربع من درجات الحرارة الثابتة داخل منطقة الحرارة الفعالة وهي(**17** ، **27،22** ، **23** م (علي نمو وتطور الاطوار المختلفة لدودة ورق القطن .اوضحت الدراسة ان الوقت الازم لنمو وتطور الاطوار المختلفة يقل بزيادة درجة الحرارة من 17 الي 32° م ، حيث بلغ صفر النمو البيولوجي° 11.8 م للبيض و ° 7.56م لليرقات و° 12.27 م للعذارى و° 12.58 م لمرحلة ما قبل العذراء و° 10.50 م للجيل الكامل .وبلغ عدد الوحدات الحرارية الازمة لاتمام النمو والتطور 40.1 ، 283.76 ، 149.5 ، 23.96 ، 480.6 وحدة حرارية يومية لكل من البيض واليرقات والعذارى ومرحلة ما قبل العذراء والجيل الكامل علي التوالي .