Heat Unit's Applications for Forecasting of Emergence and Population of The Different Developmental Stages of The Pink Bollworm, *Pectinophora gossypiella* (Saund.)

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ABSTRACT: The influence of constant temperatures (20, 25, 30 and 35 ℃) as accumulated heat units (day degrees) on the emergence and stages of development of the pink bollworm (PBW) (*Pectinophora gossypiella*).has been studied under laboratory conditions of the constant temperatures of 20, 25, 30 and 35℃ The observed incubation periods, rate of development, the theoretical lower threshold of development (t_0) and the degree days (DD_S) of each stage were estimated. Generally, the obtained results showed a negative relationship between incubation temperatures (℃) and lengths of incubation periods for all PBW stages. Referring to the constant temperatures, the PBW stage periods were varied between 20℃ and 35℃, hence, They ranged from 7.2 to 2.87, 30.89 to 7.76, 24.4 to 9.83, 4.28 to 1.26, 6.3 to 2.8 and from 6.1 to 2.6 days for eggs, larvae, pupae, pre-oviposition period, oviposition period, post-oviposition period , consequently. The estimated lower threshold temperature (t_0) has been differed according to the developmental stage. The (t_0) values were 10.63, 14.82, 9.28, 12.19, 8.44 and 7.53 ℃ for eggs, larvae, pupae, pre-oviposition, oviposition, post-oviposition periods, respectively. The thermal units as degree days (DD's) were also calculated for each immature and mature stages. The heat unit's accumulations as a part of IPM could be of benefit for forecasting population of the different PBW stages, which were highly important for the predicting pest population and applying insecticides at the optimum time to obtain timely insect control.

Keywords: Heat Unit, Pink Bollworm, Prediction, Accumulated degree days (dd's), Lower threshold (t0).

INTRODUCTION

The Pink bollworm, *Pectinophora gossypiella* (Saund.) [Lepidoptera:Gelechiidae] is one of the most important pests that attacks cotton squares and bolls in Egypt and many countries in the worldwide . Many of the full –grown larvae spend late autumn, winter and early spring in the form of diapausing larvae inside cotton seeds and dry bolls. The emerging moths are considered as a source of renewing infestation to the new cotton crop next year Rashad (1992).

The timing of emergence is a critical point in the life history of any pest; It is the beginning of the life cycle that seriously cause crop damage and to yield loss. The influence of temperature in determining the emergence and development of insect Population was well established (Eckenrode and Chapman, 1972; Lves, 1973; Aliniazee 1976; Riedl *et al*., 1976 and Toscano *et al* ,1979). Thermal unit or effective day-degrees accumulation system has implications for pest management well as well as areas of applied entomology. The degree – days system is a fundamental basis for temperature–dependent population models, which have been widely used for prediction of population events of many insect species (Whalon and Smilowitz ,1979).

Application of heat unit accumulations and the pink bollworm were discussed by several authors (Gutierrez *et al*; 1977 ; Watson 1980; Gutierrez *et al;*1981 and Metwally *et al* ;1996).

A method of heat summation reported by Sevacherian *et al;* (1977) was utilized to predict the spring pattern emergence of the pink bollworm by monitoring daily maximum and minimum temperatures and summing heat unit (i.e., degree – days). Accumulating degree- days has been proved to be the accurate means for forecasting cumulative pink bollworm moth emergence under both cage and field conditions in Imperial Valley, California, USA, for four years (Sevacherian *et al.,* 1977). Toscano *et al*. (1979) mentioned that no significant difference at the 90% level in PBW population peaks between insecticides treated and untreated fields, thus treated and untreated field were compared and used for peak prediction by thermal summation.

In Egypt, many authors' applied the heat unit applications for forecasting the emergence of many insect pests, some of those are: (Al-beltagy, 1999(1,2) and Yones *et al*., 2011). The present work as a part of series of studies that had been subjected to the forecasting of PBW emergence and population dynamics and to related study the effectiveness of different constant temperature degrees on both immature and adult stages of *P. gossypiella* for estimating their theoretical development thresholds (t0) and the accumulated thermal units (K) required to complete development of each stage.

MATERIAL AND METHODS

Eggs of the pink bollworm *P. gossypiella* were obtained from the Division of Bollworms, Plant Protection Research Institute, Agric. Res. Center, Egypt resulting from susceptible strains reared in the laboratory for at least twenty generations on an artificial diet.

The pink bollworm (PBW) stages were kept under the four constant temperatures of 20, 25, 30 and 35 °C to determine the rate of development. Eggs were transferred to glass vials (2.0 X 7.5 cm); four replicates of 25 eggs / each were used for each of the assigned temperatures. Observations were made daily to record the time of hatchability. To study the larval development, 100 newly hatched larvae were transferred, each in a separate glass tube (7.5 x 2.5 cm.) 25 larvae/replicate as (4 replicates). The larvae were left in the vials until pupation. Daily observations were made to count the pupated larvae, larval developmental rate and duration and recorded.

Newly formed pupae were collected on the same day of pupation and placed in glass tubes (one pupa for each) and plugged tightly with a piece of cotton wool. Four replicates (25 pupae, each) were placed at each of the tested temperature and observed daily till adult 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 end, provided with a small piece of absorbent cotton wool previously soaked in 20% sucrose solution for adult feeding. The two ends of each tube were covered with a piece of cotton, secured rubber band, and a small strip of muslin cloth was put as a suitable site of oviposition. Five replicates, each has 2 adults (1 male +1 female), were tested at each tested temperature. Daily observations were made to record the adult survival.

Duration of different stages and other biological aspects were recorded for each temperature degree. Data obtained in the present work were subjected to the statistical analysis by t-test.

The rate of development for *P. gossypiella* stages (eggs, larval, pupae and adults) and other biological aspects { pre-oviposition period, oviposition period, and post- oviposition period} were also determined by the simple formula (1/t ×100) for the considered temperatures .

To determine the threshold of development (zero of development) of the different stages of *p. gossypiella,* the duration of those stages at 20,25, 30 and 35℃ were calculated . Threshold of development (t0) for each immature and mature stages, was established as the point at which the extended velocity – temperature line meets the abscissa. This line was previously gained by regressing development velocity against temperature according to the regression formula:

$$Y = a + b\,x$$
$$(t0) = -a / b \quad \& \quad K = 1 / b$$

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

$$K = y\,(T - t0)$$

Where y = developmental duration of a given stage; T= temperature in degree centigrade; t0 = lower threshold of development and K = thermal units (Degree-Days (DD's).

Statistical analysis:

Replicates means were computed and the obtained data were statistically analyzed, using the analysis of variance (ANOVA) to know the significance of differences among treatments. The least significant differences between treatments (L.S.D.) were determined according to Duncan (1955).

Regression equation and confidence limits were calculated according to probit analysis computer program (Finney 1971). Regression equations was also applied to predict mortality percentages (Y) for any applied concentration (X), whereas (a) was the intercept from (Y) axis and (b) slop of the linear regression

RESULTS AND DISCUSSION

Effect of certain constant temperatures on *P. gossypiella*, with reference to its requirements and developmental stages:

1. Egg stage

The presented data shown in Table (1) indicated the effect of 4 constant temperatures and their thermal requirements on the egg stage of the *P. gossypiella.* Figure, (1) also illustrated the regression line that represented the relationship between temperature degrees (℃) and corresponding incubation periods (day) for PBW eggs.

Results revealed that the embryogenesis periods of PBW eggs varied from 7.2 days at 20℃ to 2.87 days at 35℃, with an average of 4.67 days. Additionally, the corresponding rate of development varied from 13.89% to 34.84%, respectively.

The obtained data showed that there was a negative relationship between embryogenesis periods and degrees of temperatures (℃), while the relationship between temperatures (℃) and rate of development (%) was positive. These relationships were calculated by applying the regression equation between temperatures (℃) (X-axis) and rate of development (Y- axis), which has been obtained by (Y= 1.44(X)-15.28).

The obtained lower threshold temperature for egg stage development (t_0) was (10.63 ℃). The thermal units (resembled by K) of the degree days (DD's) that required for egg development had been obtained by applying its equation (K = 1/b). Meanwhile, the average of these thermal units (DD's) was 69.60. Where, (t_0) = -a/b for the lower threshold temperature and K= 1/b for the degree days (DD's). The least DD's was 67.43 resulting from the incubation temperature of 20℃. Accordingly, the required thermal units for egg stage were 67.43, 73.26, 67.78 and 69.93 for 20, 25, 30 and 35 ℃, consequently, with an average of 69.60 ℃.

Table (1). Development of *P.* gossypiella egg's stage under the different constant temperatures and thermal requirements.

Temp. (℃)	Observed		Expected		(t_0˚C)	Degree Days (DD´s)
	Incubation Period (days)	Rate of Development %	Incubation period (days)	Rate of development %		
20	7.2^{a}	13.89	7.43	13.45		67.43
25	5.1^{b}	19.61	4.85	20.64	**10.63**	73.26
30	3.5^{c}	28.57	3.59	27.82		67.78
35	2.87^{c}	34.84	2.86	35.00		69.93
Average	**4.67**	**24.23**	**4.68**	**24.23**		**69.60**
L.S.D 0.05	**0.716**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

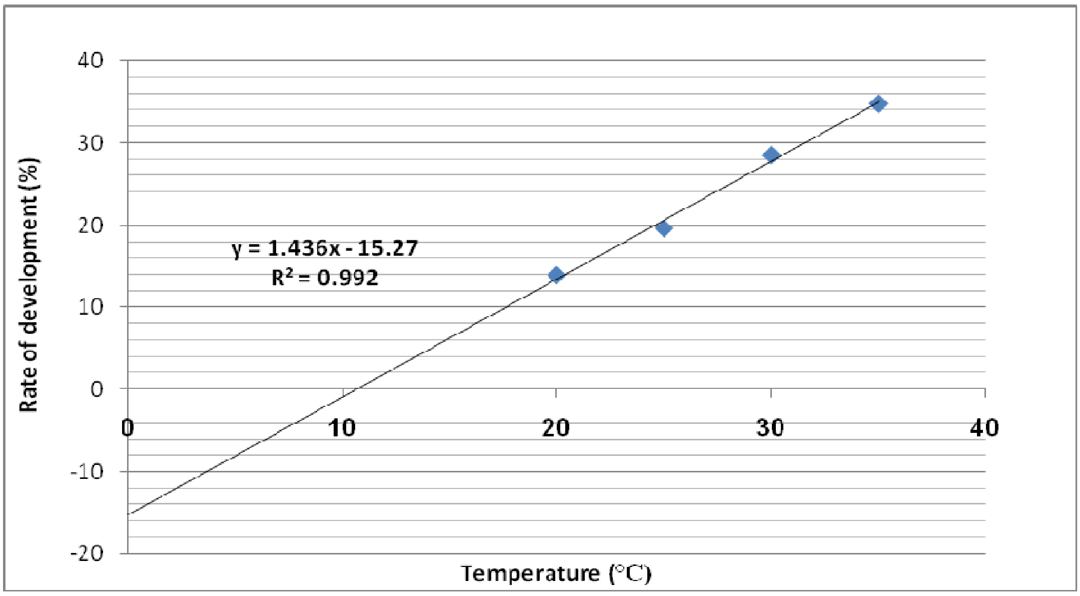

Figure (1). Regression line of the relationship between Temperature (°C) and the corresponding rate of development (%) for PBW eggs.

2. Larval stage

Results in Table (2) included the effect of the constant temperatures on the duration period of PBW larval stage and its thermal requirements. Figure (2) illustrate also the regression line representing the relationship between temperature degrees (°C) and corresponding incubation periods (day) for PBW larvae.

The data revealed that the periods of PBW larvae varied from 30.89 days at 20°C to 7.76 days at 35°C, with an average of 16.14 days. Correspondingly the rate of development varied from 3.24 % to 12.89 %, in respect.

Furthermore, the data approved that there was a negative relationship between larval stage periods and degrees of temperatures (°C). Conversely, the relationship between temperatures (°C) and rate of development (%) was positive that resulted statistically from applying the obtained regression equation (Y= 0.63 X -9.34) between temperatures (°C) (X-axis) and rate of development (Y- axis.).

The obtained lower threshold of larval development (t_0) was (14.82 °C) as obtained from the regression line of the relationship between temperature (°C) and corresponding incubation periods (day) for PBW larvae in Fig. (2), where (t_0)=-a/b. The degree days (DD's) required for development were also estimated using its equation (K= 1/b). The average of these thermal units (DD's) was 158.70 (Table, 2 and Figure, 2).

Table (2). Development of *P.* gossypiella larvae and thermal requirements under different constant temperatures.

Temp.(°C)	Observed: Larval duration (days)	Observed: Rate of Development %	Expected: Larval duration (days)	Expected: Rate of development %	(t_0°C)	Degree Days (DD´s)
20	30.89[a]	3.24	30.60	3.27		160.15
25	15.05[b]	6.64	15.58	6.42		153.28
30	10.85[c]	9.22	10.45	9.57	**14.82**	164.75
35	7.76[d]	12.89	7.86	12.72		156.63
Average	**16.14**	**8.00**	**16.12**	**8.00**		**158.70**
$L.S.D_{0.05}$	**2.483**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

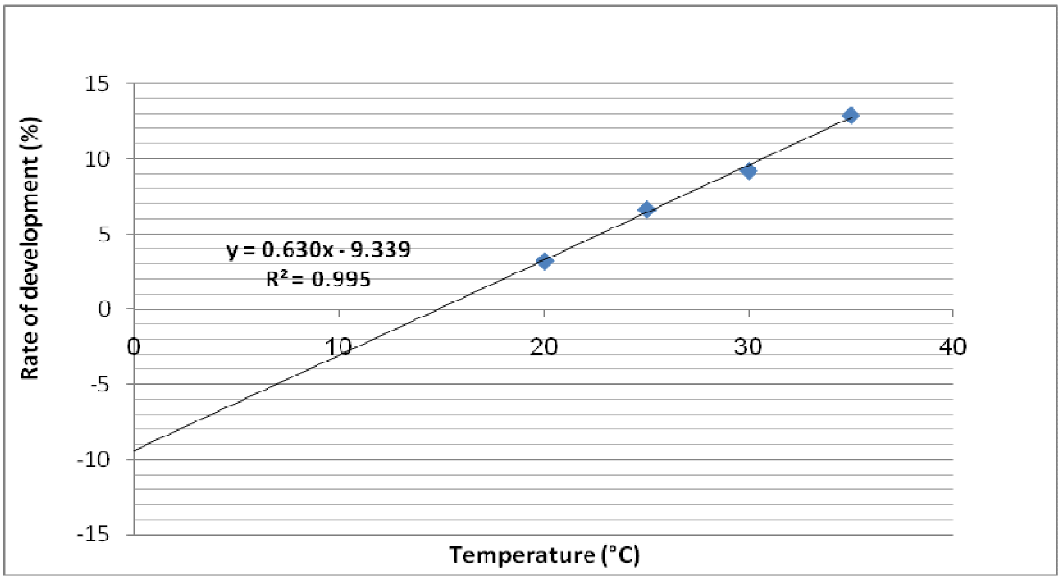

Figure (2). Regression line of the relationship between temperature (°C) and the corresponding rate of development (%) for PBW larvae.

3. Pupal stage

Table (3) exhibited the pupal periods of PBW that varied from 24.4 day at 20°C to 9.83 days at 35°C, with an average of 15.21 days. Likewise, the corresponding rate of development varied from 4.10 % to 10.17%, respectively.

Employing the obtained regression equation (Y= 0.41(X) - 3.77) between temperatures (°C) and rate of development indicated that there was a negative relationship between incubation periods of pupal stage and the constant temperature degrees (°C), while the relationship between temperatures (°C) and rate of development (%) was positive.

Moreover, the developmental zero (t_0) for this stage was (9.28 °C). Also, the required average of these thermal units as degree days (DD's) for development was 247.56 (Table, 3 and Figure, 3).

Table (3). Development of *P. gossypiella* pupae and its relation with thermal requirements under different constant temperatures.

Temp. (°C)	Observed		Expected		(t_0°C)	Degree Days (DD´s)
	Pupal duration (days)	Rate of Development %	Pupal duration (days)	Rate of development %		
20	24.4[a]	4.10	22.97	**4.35**	**9.28**	261.64
25	15.1[b]	6.62	15.67	**6.38**		237.42
30	11.5[c]	8.70	11.89	**8.41**		238.31
35	9.83[c]	10.17	9.58	**10.44**		252.86
Average	**15.21**	**7.40**	**15.03**	**7.40**		**247.56**
L.S.D$_{0.05}$	**4.472**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

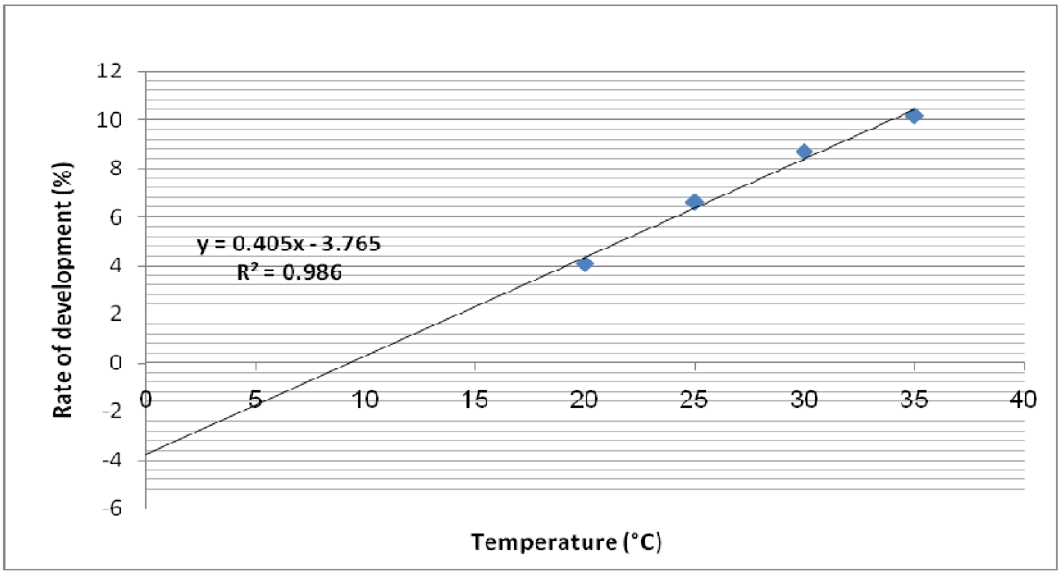

Figure (3). Regression line of the relationship between temperature (°C) and the corresponding rate of development (%) for PBW pupal stage.

4. Adult stage

4.1. Pre-oviposition period

Results in Table (4) reffered to the pre-oviposition period which varied from 4.38 day at 20°C to 1.26 days at 35°C, with an average of 2.24 days. The corresponding rate of development varied also from 22.83 % to 79.37%, respectively.

The data indicated that there was a negative relationship between periods and degrees of temperatures (°C), while the relationship between temperatures (°C) and rate of development (%) was positive in case as using the regression line equation:

(Y=3.67(X) – 44.8).

The theoretical lower threshold of development (t_0) was 12.19 ℃. In addition, the highest degree days (34.20 DD's) required for the pre-oviposition period was resulted from using incubation temperature of 20 ℃. However, he average of these thermal units (DD's) was 28.13 (Table, 4 and Figure, 4).

Table (4). Duration periods of *P. gossypiella* pre-oviposition and its thermal requirements under different constant temperatures.

Temp.(℃)	Observed		Expected		(t_0 °C)	Degree Days (DD´s)
	Pre-oviposition period (days)	Rate of development %	Pre-oviposition period (days)	Rate of development %		
20	4.38[a]	22.83	3.48	28.70	12.19	34.20
25	1.84[b]	54.35	2.12	47.07		23.57
30	1.46[bc]	68.49	1.53	65.45		26.00
35	1.26[c]	79.37	1.19	83.82		28.74
Average	**2.24**	**56.26**	**2.08**	**56.26**		**28.13**
L.S.D$_{0.05}$	**0.491**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

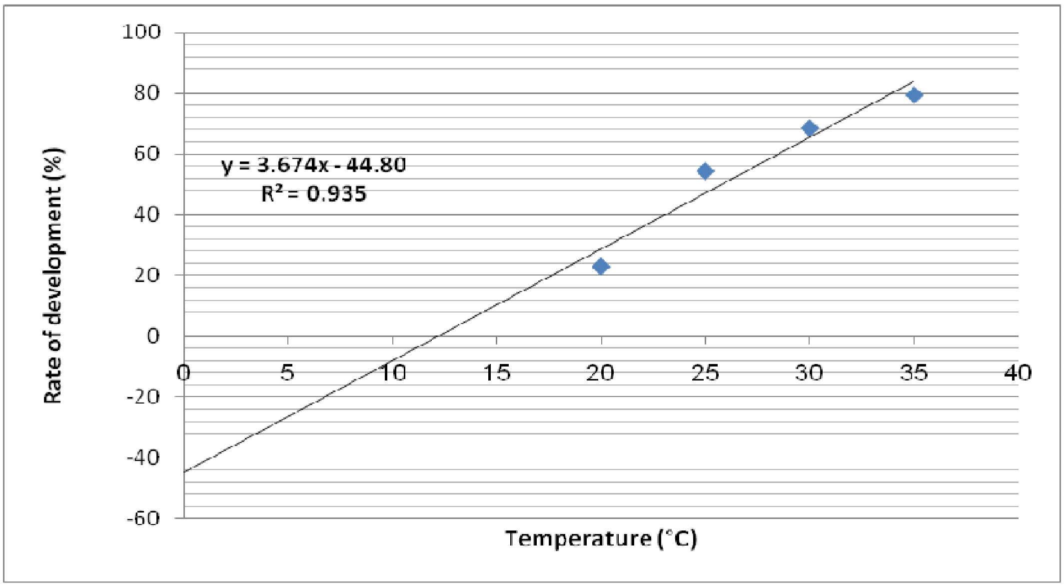

Figure (4). Regression line of the relationship between temperature (℃) and the corresponding rate of development (%) for PBW pre-oviposition adult stage.

4.2. Oviposition period

Table (5) concluded that the oviposition periods of PBW significantly varied from 6.3 days at 20℃ to 2.8 days at 35℃, with an average of 4.18 days. The corresponding rate of development varied from 15.87 % to 35.71%, respectively. These data indicated that there was a negative relationship between oviposition period and the assigned degrees of temperatures (℃), while the relationship between temperatures (℃) and rate of development (%) was positive, which determined from the regression line equation: Y= 1.39 (X) – 11.74.

The estimated lower threshold of development (t_0) was 8.44 °C. The least (66.84) and highest (74.52) degree days were recorded by the incubation temperatures of 30 and 25°C, respectively. Consequenctly, the average of these thermal units (DD's) was 72.14 (Table, 5 and Figure, 5).

Table (5). Duration of *P. gossypiella* -oviposition period and its thermal requirements under different constant temperatures.

Temp.(°C)	Observed		Expected		(t_0˚C)	Degree Days (DD´s)
	oviposition period (days)	Rate of development %	oviposition period (days)	Rate of Development %		
20	6.3[a]	15.87	6.22	16.08	8.44	72.83
25	4.5[b]	22.22	4.34	23.04		74.52
30	3.1[c]	32.26	3.33	29.99		66.84
35	2.8[c]	35.71	2.71	36.95		74.37
Average	**4.18**	**26.52**	**4.15**	**26.52**		**72.14**
$L.S.D_{0.05}$	**0.953**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

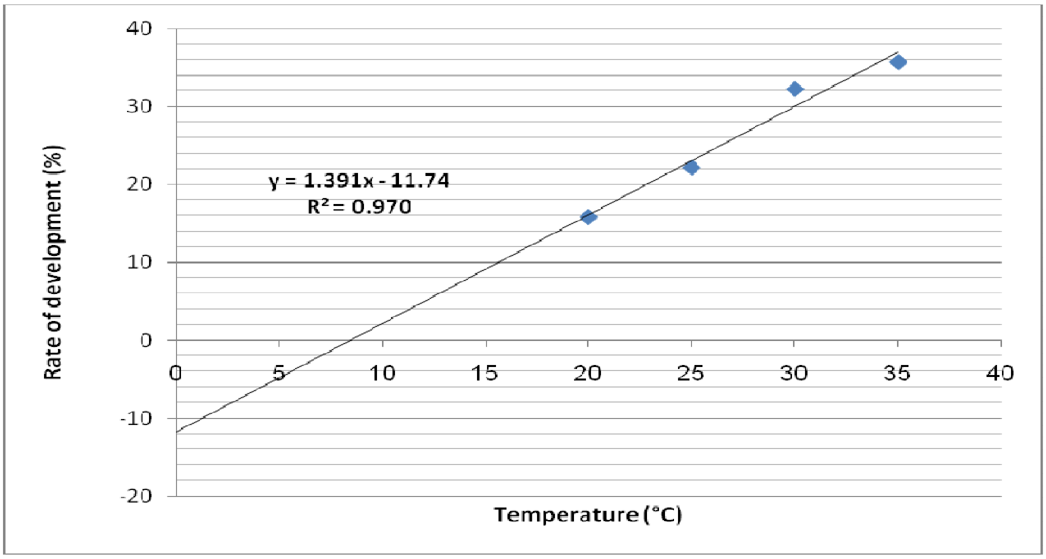

Figure (5). Regression line of the relationship between temperature (°C) and the corresponding rate of development (%) for PBW oviposition adult stage.

4.3. Post-oviposition period

The listed results in Table (6) revealed that the post-oviposition periods of PBW varied from 6.1 days at 20°C to 2.6 days at 35°C, with an average of 3.88 days. Furthermore, the corresponding rate of development varied from 16.39 % to 38.46%, respectively.

The data clarified that there was a negative relationship between the post-oviposition periods and the degrees of temperatures (°C), while the relationship between temperatures (°C) and rate of development (%) was positive by utilizing the regression equation of Y= 1.43 (X) – 10.75 (Figure, 6).

These findings cleared that the lower threshold of development (t_0) was 7.53 ℃. On the other hand, the thermal requirements as expressed in degree days changed with the change of incubation temperatures. Consequently, the average of the DD's was 70.46.

Table (6). Duration of *P. gossypiella* post-oviposition period and its thermal requirements under different constant temperatures.

Temp.(℃)	Observed		Expected		(t_0°C)	Degree Days (DD´s)
	Post-oviposition period (days)	Rate of development %	Post-oviposition period (days)	Rate of development %		
20	6.1[a]	16.39	5.61	17.82	7.53	76.08
25	3.7[b]	27.03	4.01	24.96		64.65
30	3.1[c]	32.26	3.11	32.11		69.67
35	2.6[c]	38.46	2.55	39.25		71.43
Average	**3.88**	**28.54**	**3.82**	**28.54**		**70.46**
L.S.D$_{0.05}$	**0.580**					

* Means followed by the same letter(s) in each column are not significantly different at P ≤ 0.05 level.

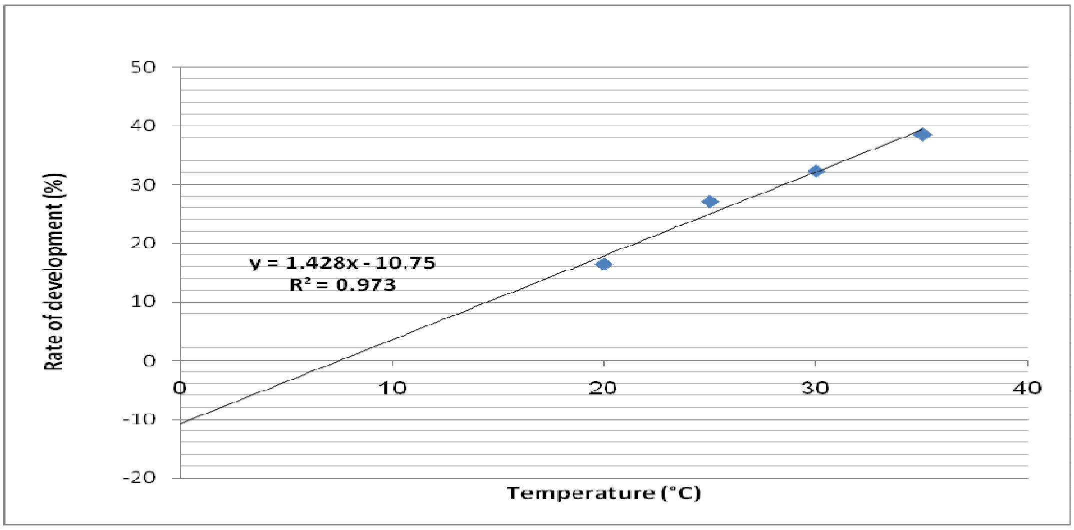

Figure (6). Regression line of the relationship between temperature (℃) and the corresponding rate of development (%) for post-oviposition adult stage.

CONCLUSION

We conclude from that study that there is the effect of temperature on some biological aspects of the pink bollworm, expressed as the amount of accumulated thermal units. Conducted this study to calculate the zero growth phases the theoretical threshold of development (t0)) to bollworm, pink as well as the necessary heat units each phase separately. The lower thresholds of development (t0) were 10.63, 14.82, 9.28, 12.19, 8.44 and 7.53 ℃ for eggs, larvae, pupae, pre-oviposition period, Oviposition period and post- Oviposition period respectively. The average accumulated heat units required for development was 69.60, 158.70, 247.56, 28.13, 72.14 and70.46 degree-days for egg, larvae, pupae, pre-oviposition period, Oviposition period and post-Oviposition period respectively. The lower threshold of development (t0). The time required for embryogensis, larval duration and pupal duration decreased as the temperatures increased from 20 to 35℃ and thus can be expected to predict when or application control means or different strategies to combat the scourge.

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الملخص العربى

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١- كلية الزراعة سابا- باشا – جامعة الاسكندرية

٢- معهد وقاية النباتات – الدقي – الجيزة

تهدف هذه الدراسة المعملية الى دراسة تاثير اربع من درجات الحرارة الثابتة (٢٠، ٢٥ ، ٣٠ ، ٣٥)°م على ظهور ومراحل تطور دودة اللوز القرنفلية من خلال هذه الدراسة تم تحديد الاحتياجات الحرارية المطلوبة لنمو وتطور كل طور على حدة و عتبة النمو الاقتصادي (صفرالنمو البيولوجى) للاطوار المختلفة لدودة اللوز القرنفلية (مرحلة البيض – اليرقة – العذراء- مرحلة ماقبل وضع البيض – مرحلة وضع البيض – مرحلة مابعد وضع البيض على التوالى).وانتهت الدراسة الى تحديد الاحتياجات الحرارية اللازمة لنمو وتطور كل الاطوار وبلغت (٦٩.٦، ١٥٨.٧، ١٤٧.٥٦، ٢٨.١٣، ٧٢.١٤، ٧٠.٤٦) وحدة حرارية يومية لكل من (مرحلة البيض – اليرقة – العذراء- مرحلة ماقبل وضع البيض – مرحلة وضع البيض – مرحلة مابعد وضع البيض على التوالى) وكذلك بلغ الحد الحرج للنمو (عتبة النمو الاقتصادى او صفر النمو البيولوجى) (١٠.٦٣، ١٤.٨٢، ٩.٢٨، ١٢.١٩، ٨.٤٤، ٧.٥٣) °م لكل من مرحلة (البيض – اليرقة – العذراء- مرحلة ماقبل وضع البيض – مرحلة وضع البيض – مرحلة مابعد وضع البيض على التوالى)

عموما، أظهرت النتائج المتحصل عليها وجود علاقة سالبة بين درجات حرارة الحضانة وفترات الحضانوة لجميع المراحل.

تعتبر الوحدات الحرارية المتراكمة التى تستخدم فى التنبؤ بالمراحل المختلفة للأفة والتى تعتبر من الاعتبارات المهمة فى برامج المكافحة المتكاملة فيما يخص توقع اوالتنبؤ بموعد تطبيق وسائل المكافحة او الاستراتيجيات المختلفة لمكافحة الافة.