Thermal Requirements and Seasonal Abundance of Spiny Bollworm Based on Variable Field Temperature Derived from Satellite Images in Qaluobiya, Egypt

M.M. El Hoseny[1], H.F. Dahi[2*], A.M. El Shafei[1] and M.S. Yones[3]
Department of Entomology, Faculty of Science, University of Ain Shams, Egypt; (2) Plant Protection Research Institute, ARC, Dokki, Giza, Egypt; (3) National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt.
[*]Email address of the corresponding author: hassandahi@yahoo.com

Abstract

El Hoseny, M.M., H.F. Dahi, A.M. El Shafei and M.S. Yones. 2025. Thermal Requirements and Seasonal Abundance of Spiny Bollworm Based on Variable Field Temperature Derived from Satellite Images in Qaluobiya, Egypt. Arab Journal of Plant Protection, 43(1):25-32. https://doi.org/10.22268/AJPP-001295

The spiny bollworm (SBW), *Earias insulana* is one of the most serious cotton pests in Egypt and worldwide. The impact of temperature on this insect pest biology was investigated, with a focus on the duration length of the various developmental stages. The rate of development, the lower temperature threshold and the heat unit accumulations needed to complete each life stage (egg, larvae, pupa, pre-oviposition) and generation period of SBW were determined under laboratory conditions. The insect population, seasonal abundance and field generation forecasting were studied by using remote sensing techniques, especially satellite images, to investigate the impact of temperature on insect population growth in the field. Results obtained showed that SBW had four seasonal generations in addition to the overwintering generation for each of the three cotton seasons (2020, 2021 and 2022). The observed peaks and the predicted peaks of generations per season were detected and the predicted peaks were noticed earlier than the observed peaks, as the average deviation days were -3, -7 and -4 days for 2020, 2021 and 2022 cotton seasons, respectively. Earlier prediction of the SBW could be helpful in designing an integrated management program against this pest.

Keywords: *Earias insulana*, temperature, thermal requirements, lower temperature threshold, satellite images, prediction.

Introduction

Cotton is considered the most important industrial crop in the world, and Egypt remains one of the major producing countries of high-quality cotton (Abd-El Rahman *et al*., 2015). Cotton varieties vary greatly, in terms of insect pest infestation. In India over 166 insect's species have been identified as pests of cotton crops (Rajendran *et al*., 2018). Cotton bollworms are common among insects, inflicting significant economic losses in cotton production (Mamta & Narkhede, 2012). The spiny bollworm (SBW), is an important lepidopteran pest that has a wide distribution in cotton-growing countries, including several Mediterranean countries, in addition to Africa and Asia (Kumar *et al.*, 2014). This insect is considered as a serious cotton pest in Egypt (Moustafa, 2020).

The duration of SBW life cycle is temperature dependent and consequently fluctuates with the season. There is no diapause and the development is slowed in cold weather i.e. SBW can withstand a wide range of temperatures but does not adapt well (Said, 2020). Temperature played an important role in the development and growth rate of *E. vittella* and *E. insulana* (El-Sayed, 2014). Several studies discussed the biology and ecological aspects of lepidopterous cotton insect pests including SBW and the influence of temperature on its development rate (Dahi *et al*., 2020; Said, 2020). Field temperature varies and causes significant change in the growth stages and development of the insect and consequently in the approach of predicting the presence of this insect in the field (Adly *et al*., 2016; Moustafa *et al*., 2015).

Recently, remote sensing has gained popularity in agriculture for pest monitoring, yield forecasting and early warning to crop growers for proper timing in pest management (El Hoseny *et al*., 2022). The most significant benefits of remote sensing are accurate predictions of insect infestation and crop output forecasts. Numerous methods have been utilized to investigate ecological characteristics and collect useful information for better agricultural management. The country's cotton production will significantly rise if yield loss caused by pests is reduced through improved management. Pests prevalence forecast is based on the relationship between environmental variables and the rate of pest development (Hemming & Macneill, 2020; Yones *et al*., 2018). Management of pest outbreaks via early warning systems (EWSs) to forecast future climate change which affects pests that induce crop damage proved to be instrumental in improving pest management (Grace *et al*., 2019; Ogden *et al.*, 2019).

The bollworms seasonal variations and observed annual generations have been conducted in numerous studies based on the number of male moths gathered and captured by pheromone-baited traps (Amer *et al*., 2015; Yones *et al*., 2012). Information from satellite images were used for predicting seasonal abundance and field generation of *Spodoptera littoralis* (Boisd.), thus providing insight on the impact of temperature on insect development in the field (Yones *et al*., 2018). Information on the expected peaks and the corresponding expected generations of pink bollworm are helpful to develop IPM tactics.

The present study was initiated to determine the impact of consistent temperatures on some biological aspects of

https://doi.org/10.22268/AJPP-001295

SBW. The lower threshold of temperature and thermal needs have been evaluated and an effort has been made in this work to evaluate the potential use of remote sensing for predicting seasonal pest generations in cotton fields and determine its relation with the observed population peaks based on measuring the quantity of male moths caught in pheromone traps in order to forecast their field activities and devise control actions that match the life phases of the target insects.

Materials and Methods

Laboratory studies

The biology of *Earias insulana* and the impact of various temperatures (20, 25 and 30°C) on the duration of various stages and their rate of development were studied, to determine the average developmental time, zero development and thermal degree days units for *E. insulana*. Insects were collected from Qaluobiya Governorate cotton fields, and four generations were reared in laboratory to obtain a susceptible strain at 27±1°C and 65±5% R.H on artificial diet according to Rashad & Ammar (1985). Eggs laid in the same day (< 24 h old) were transferred in a glass jar and incubated at three different constant temperatures (20, 25 and 30°C) with 65±5% R.H. For each temperature, four replicates of 25 eggs/each treatment were used. The number of hatched eggs were counted daily, and the duration of incubation period was determined. The first larval instar developed from eggs that had previously undergone treatment were moved out individually into glass tubes measuring 3×10 cm and with 3 g of artificial diet. After being carefully closed with absorbent cotton, each tube was placed in an incubator with the prescribed conditions. For each temperature treatment, four replicates of 25 larvae were employed. To measure the period of the larval stage, each larva was checked every day until pupation. Pupae were moved to clean glass tubes, where they were checked every day until moth emergence to determine pupal duration. The newly emerged females were monitored, sexually tested, and then kept in glass bell shape cages to begin egg-laying, with 10% honey solution provided to the moths. The cages were checked every day until the moths died. For each female, the pre-oviposition period was calculated until the first egg was laid. The mean generation times were calculated as the sum of the mean durations of various developmental stages, including the incubation period, larval, pupal, and pre-oviposition period (Adly *et al*., 2016). The data conducted from this study were analyzed statistically using the t-test.

The simple formula (1/t x 100) was used to calculate the rate of development for the *E. insulana* stages (incubation period, larval duration, pupal duration, pre-oviposition period, and the full period of one generation) for the three constant temperature treatments. The gathered information related to the effects of various constant temperature levels on *E. insulana* immature and adult stages was statistically analyzed, and the theoretical development thresholds (t_0) were calculated according to the regression formula:

$$Y = a + b \times \qquad t_0 = -a/b$$

Where (y) is a developmental rate of the tested stage, (a) constant term, (b) regression coefficient, and (x) Temperature (Anguelov *et al*., 2017; Estay *et al*., 2009).

Also (t_0) can be determined graphically by using Microsoft excel sheet, the rate of development was plotted against temperature (T) in °C, and the point at which the velocity line crosses temperature axis is the threshold of development (t_0) in degree centigrade (Davidson, 1944).

The accumulated thermal units (K) were calculated from a previously developed equation (Campbell & Mackauer, 1975) as follows:

$$K = 1/b \times 100$$

The thermal units necessary for the full growth of each stage were also calculated using the thermal summation equation (Blunk, 1923) as follows:

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

Where y is the duration of development, T is temperature, t_0= lower threshold of development, and K is thermal units in degree-days (DD's).

Field determination of seasonal generations by using sex pheromone traps

The experiments were conducted in the field at the Qaha Farm in Qaha, Qaluobiya Governorate, Egypt (30°17'19.2"N and 31°12'46.9"E) as shown in (Figure 1), during the 2020, 2021 and 2022 cotton seasons, where the cotton variety Giza 97 was commonly cultivated, and planted during the first half of April. The experimental area was exposed to normal agricultural practices.

During the three successive cotton seasons, five funnel traps baited with pheromone capsules at the rate of 1 trap/acre were installed in cotton fields over a period that ranged from the first week of May to the first week of October (Amer *et al*. 2015), as the sex pheromone traps more preferable than other traps (Abdelmaksoud *et al*., 2020; Whitfield *et al*., 2019). Traps were checked every two weeks, and the pheromone capsules were replaced. Every 3 nights, the number of SBW male moths caught were counted. The synthetic pheromone formulation in polyethylene vials was used as bait in the traps inside the center of the plastic roof. Each vial contained one mg of the active components of the particular pheromone for *Earias insulana*, i.e. (E, E)-10, 12-Hexadecadienal (Hall *et al*., 1980). Trapping strips from Russell IPM Corporation were used to kill the captured males.

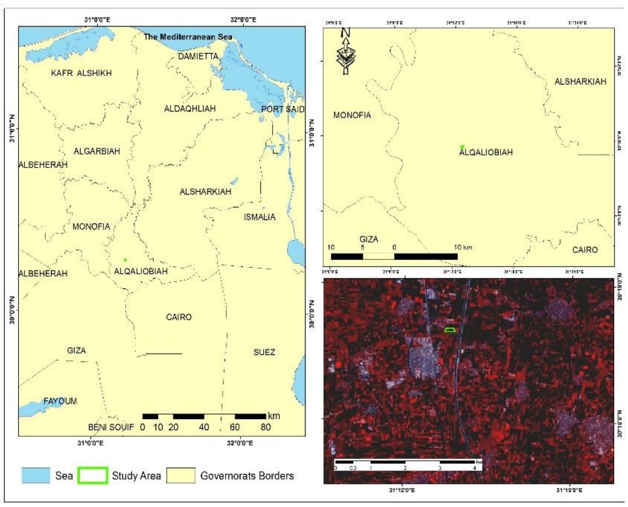

Figure 1. Qaha farm, Qaluobiya Governorate, Egypt.

The traps were fastened in the fields on steel stands which were positioned above the cotton plants canopy at a height of around 20 cm, as the growth of the plant increased, the level of the traps was constantly adjusted, and they were maintained until the end of the season (Ali Shah *et al*., 2011). The average number of male spiny bollworm moths for each three days per traps was accumulated for each season (2020, 2021 and 2022) and was presented graphically to identify the populations peaks (observed peaks).

Temperature data from satellite images

Earlier work had shown that there was no noticeable difference between degree days acquired from daily maximum and minimum air temperatures determined from satellite images and thermograph (Yones *et al*., 2013), so daily maximum and minimum air temperatures determined from satellite images appeared to be a reliable method for predicting and computing the average of thermal units in degree-days (dd's) needed to complete the development of *E. insulana* generations (Yones *et al*., 2018). Consequently, daily maximum and minimum air temperatures derived from satellite images were acquired and recorded from NASA/POWER CERES/MERRA2 Native Resolution Daily Data, Elevation from MERRA-2: Average for 0.5×0.625-degree lat/lon region = 31.5 meters or obtained from satellite images (Landsat 8 collection 1 level-1) (Figure 2).

As the primary process to assess the prediction potential in relation to heat unit accumulations, the temperature data was converted into heat units and then used as a tool to study insect population dynamics and predict the presence of spiny bollworm in the field at Qaluobiya Governorate during three seasons of 2020, 2021, and 2022. Each cotton season started during the first week of April lasted until early October.

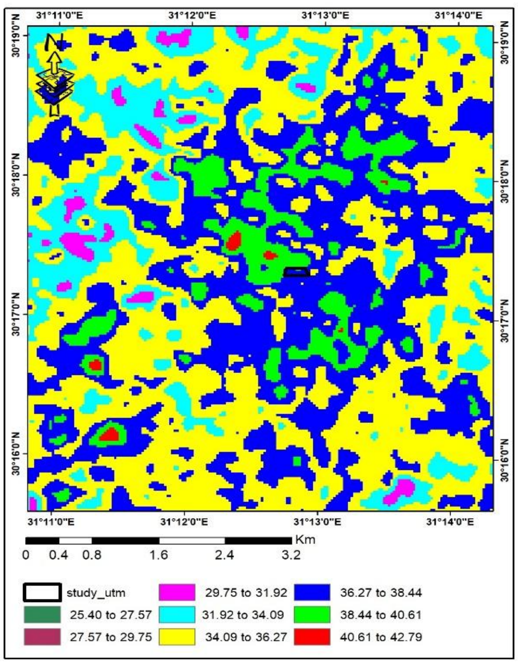

Figure 2. Satellite image from Landsat 8 (collection 1 level-1) showing the variation in temperature at study area.

Degree-days (dd's) were determined using the daily maximum and minimum temperatures (°C) obtained from satellite image as well as the developmental threshold (t_0) and the accumulated heat units for one generation development was calculated under laboratory constant conditions. The degree-days (dd's) were calculated using the following formula according to Richmond *et al*. (1983), and based on temperature fluctuations.

$$H= \Sigma HJ$$

Where, H = number of accumulated heat units, C= threshold temperature, HJ = [(max. + min.)/2]-C, if max.>C and min.>C., HJ = (max.- C)2/(max.-min.), if max.>C and min<C. and HJ= 0 if max.< C and min.< C.

Results and Discussion

The impact of constant temperatures on the biological aspects of *E. insulana*

Data summarized in Table 1 showed that in the egg stage, the necessary time to complete the *E. insulana* embryogenesis period was 5.36, 4.02, and 2.67 days and the rate of development (RD%) was 18.65, 24.87 and 37.45% at 20, 25, and 30^{o}C, respectively, and the means were significantly different. The mean larval durations were 22.78, 15.55, and 12.74 days and the rate of development (RD%) was 4.39, 6.43 and 7.84% at 20, 25, and 30°C, respectively, and the means were significantly different.

The mean pupal durations were 16.44, 10.83 and 7.28 days and the rate of development (RD%) was 6.08, 9.23 and 13.37% at 20, 25 and 30°C, respectively, and the means were significantly different. The developmental duration of the pre-oviposition periods were 3.81, 2.11, and 1.90 days and the rate of development (RD%) was 26.24, 47.39 and 52.63% at 20, 25 and 30°C, respectively.

The average pre-oviposition period at 20°C differed significantly from all other treatments, and no significant difference was found between means at 25 and 30°C. The mean duration of generation at different constant temperature regimes could be calculated as the total of mean durations of different developmental stages (incubation period, larval stage, pupal stage and pre-oviposition period) according to Dahi *et al*. (2020). The mean generation duration for spiny bollworm *E. insulana* were 48.39, 32.51 and 24.59 days and the rate of development (RD%) was 2.06, 3.07 and 4.06% at 20, 25 and 30°C, respectively (Table 1), with significant differences among the means. The lower thresholds of development (t_0) for SBW were 10.64, 6.97, 12.34, 9.05 and 9.68°C for egg stage, larval stage, pupal stage, pre oviposition period and complete generation, respectively (Table 1, Figure 3).

The three values obtained for each stage rate of development at temperatures ranging from 20 to 30°C, were used to estimate temperature-velocity line using the formula: Y = a + bx. By knowing a and b, the rate of development at any temperature applied can be determined.

Table 1. Mean duration, rate of development, lower threshold of development (t_0) and degree-days (DD's) for live stages of *E. insulana* at different constant temperatures.

Stage	Temp. regime (ºC)	Duration (Days ± S.E.)	Rate of development %	t_0 (ºC)	Degree-days (DD's) At each temp.	Degree-days (DD's) Average
Egg	20	5.36±0.14 a	18.65	10.64	50.16	53.19
	25	4.02±0.06 b	24.87		57.72	
	30	2.67±0.14 c	37.45		51.69	
Larvae	20	22.78±0.44 a	4.39	6.97	296.82	290.19
	25	15.55±0.22 b	6.43		280.36	
	30	12.74±0.16 c	7.84		293.4	
Pupae	20	16.44±0.16 a	6.08	12.34	125.93	130.53
	25	10.83±0.11 b	9.23		137.10	
	30	7.28±0.21 c	13.73		128.56	
Pre-oviposition period	20	3.81±0.31 a	26.24	9.05	41.71	38.38
	25	2.11±0.07 bd	47.39		33.65	
	30	1.90±0.07 cd	52.63		39.80	
Generation	20	48.39±0.94 a	2.06	9.68	499.38	499.03
	25	32.51±0.53 b	3.07		498.05	
	30	24.59±0.16 c	4.06		499.66	

Values followed by the same letters in the same column are not significantly different at P=0.01.

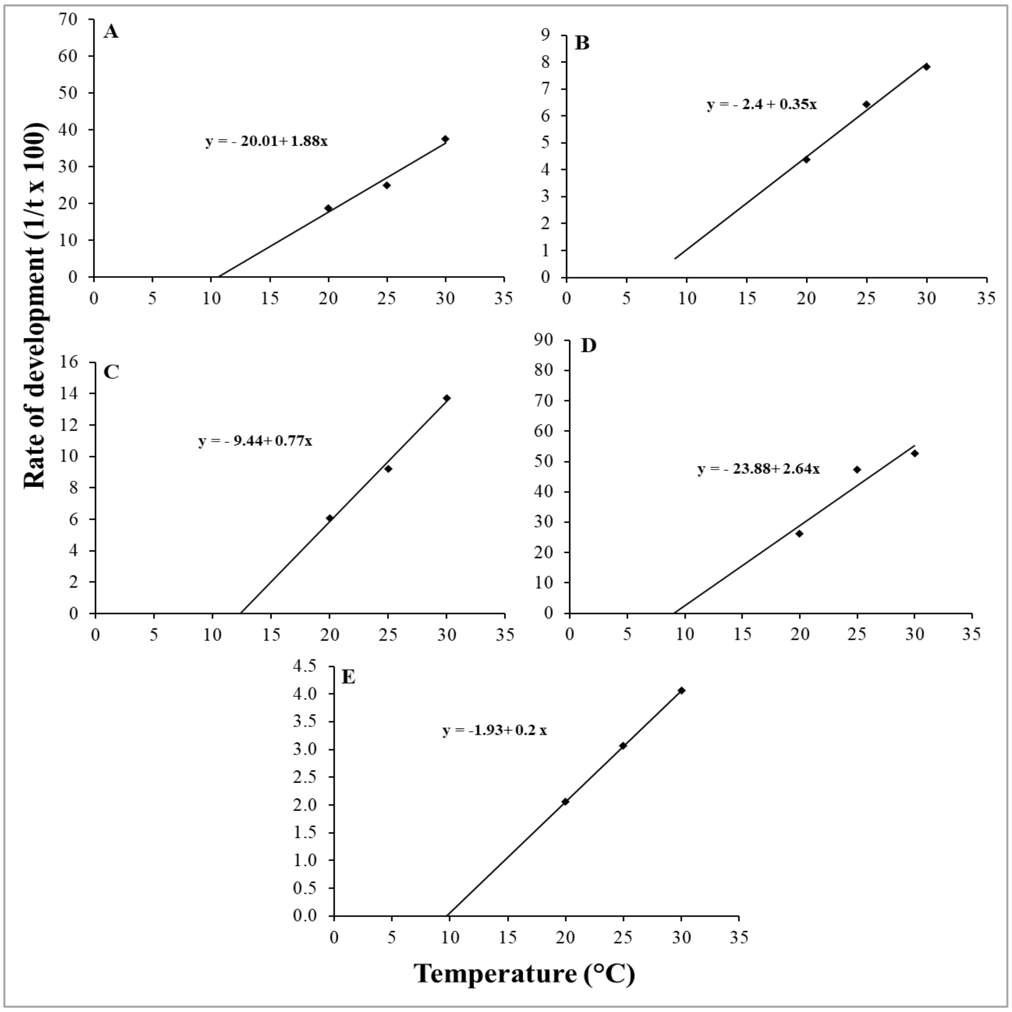

Figure 3. The regression line of the incubation period of egg (A), larval duration (B), pupal duration (C), pre oviposition period (D) and duration of generation (E) for *E. insulana* at different constant temperatures.

Heat units in degree-days (DD's) necessary to complete development of each SBW stage at each constant temperature was calculated (Table 1). The results obtained showed that heat units necessary for the SBW to complete the development of egg stage, were 50.16, 57.72 and 51.69 DD's at 20, 25 and 30°C, respectively, with an average 53.19 DD's determined by the thermal summation equation K = y (T – 10.64). The values of thermal units required for larval development until pupation were 296.82, 280.36, and 293.4 degree-days at 20, 25 and 30°C, respectively with an average of 290.19 degree-days determined by the thermal summation equation K = y (T – 6.97). The thermal units required for pupal duration completion until adult emergence were 125.93, 137.10, and 128.56 degree-days, for the three constant temperatures, respectively, with mean of 130.53 degree-days, according to the thermal summation equation K = y (T - 12.34). The thermal units (DD's) needed for complete the pre oviposition period at the studied temperature 20, 25, and 30°C were 41.71, 33.65, and 39.80 degree-days, respectively, with an average of 38.38 degree-day according to the thermal summation equation k= y (T- 9.05). Based on these data, the development of SBW generation required 499.38, 498.05 and 499.66 degree-days (DD's) at 20, 25 and 30°C, respectively, with an average of 499.03, as calculated by the equation: k = y (T - 9.68).

Results of the present study revealed that as the temperature increased, the duration length for all SBW life stages decreased and the rate of development increased until reaching the upper heat threshold, which is in agreement with previous findings (Dahi *et al*., 2020; Said, 2020).

Prediction and observed seasonal presence of SBW generations in the field

During the first season (2020), there were 4 generations in addition to the overwintering generation for the SBW in the field. The observed peaks for the overwintering, the first, the second, the third and the fourth generation were on 25th May, 21th June, 18th July, 14th August and 10th September, respectively, when the average number of male moths per trap was 16, 26, 44, 46 and 23 moths/day, respectively. On the other hand, the expected peaks for the same generations were on 25th May, 24th June, 19th July, 12th August and 5th September for the overwintering, the first, the second, the third and the fourth generation, respectively, with average deviation of 3 days earlier than the observed peaks (Table 2, Figure 4-A).

For the second season (2021), there were 4 generations in addition to the overwintering generation for the SBW in the field. The observed peaks for the overwintering, the first, the second, the third and the fourth generation were on 31th May, 27th June, 21th July, 17th August and 10th September, respectively, when the average number of male moths per trap was 33, 54, 33, 61 and 31 moths/trap, respectively. Whereas, the expected peaks for the same generations were on 31th May, 28th June, 21th July, 13th August and 6th September, respectively, with deviation of 7 days earlier than the observed peaks (Table 2, Figure 4-B).

For the third season (2022), there were four SBW generations in addition to the overwintering generation for the SBW in the field. The observed peaks for the overwintering, the first, the second, the third and the fourth generation were at 28th May, 24th June, 18th July, 11th August and 7th September, respectively, when the average number of moths per trap was 23, 55, 59, 44 and 31 moths/day, respectively. Alternatively, the expected peaks for the same season were on 28th May, 23th June, 18th July, 11th August and 4th September, respectively, with deviation intervals of 3 days earlier than the observed peak (Table 2, Figure 4-C). The deviation between observed and expected seasonal generations of *E. insulana* during cotton seasons 2020, 2021, 2022 are shown in Figure 4-D.

Table 2. Observed and expected *E. insulana* generations monitoring by sex pheromone traps and accumulated degree-days (dd's) derived from satellite images at Qaluobiya during cotton seasons 2020, 2021 and 2022.

Seasons	Generations	Generation dates		Deviation (days)	Degree-Days (dd's)
		Observed	Expected		
2020	Overwintering	25/5	25/5	0	503.4
	1st	21/6	24/6	+3	505.4
	2nd	18/7	19/7	+1	497.3
	3rd	14/8	12/8	-2	506.2
	4th	10/9	5/9	-5	498.1
	Average			-3	502.1
2021	Overwintering	31/5	31/5	0	492.7
	1st	27/6	28/6	+1	509.4
	2nd	21/7	21/7	0	493.0
	3rd	17/8	13/8	-4	504.5
	4th	10/9	6/9	-4	495.1
	Average			-7	498.9
2022	Overwintering	28/5	28/5	0	503.7
	1st	24/6	23/6	-1	503.8
	2nd	18/7	18/7	0	495.3
	3rd	11/8	11/8	0	498.7
	4th	7/9	4/9	-3	495.7
	Average			-4	499.4

In general, for a successful forecast to occur, there should be enough period between the prediction and the actual observation, and the period should also be as short as possible to get a high prediction accuracy based on dd's of SBW, because it permits early preparation of pest control materials. Results obtained in this study were in agreement with previous studies (Ismail *et al*., 2007; Salman *et al.*, 2022).

It can be concluded from this study that the knowledge about the threshold of development (t_0) per generation, accumulated thermal units (dd's) per generation, T_{max}, T_{min} and numbers of moths caught are the foundations upon which spiny bollworm field management is based. In addition, monitoring pest generations via satellite images is crucial for the development of appropriate prevention and control strategies.

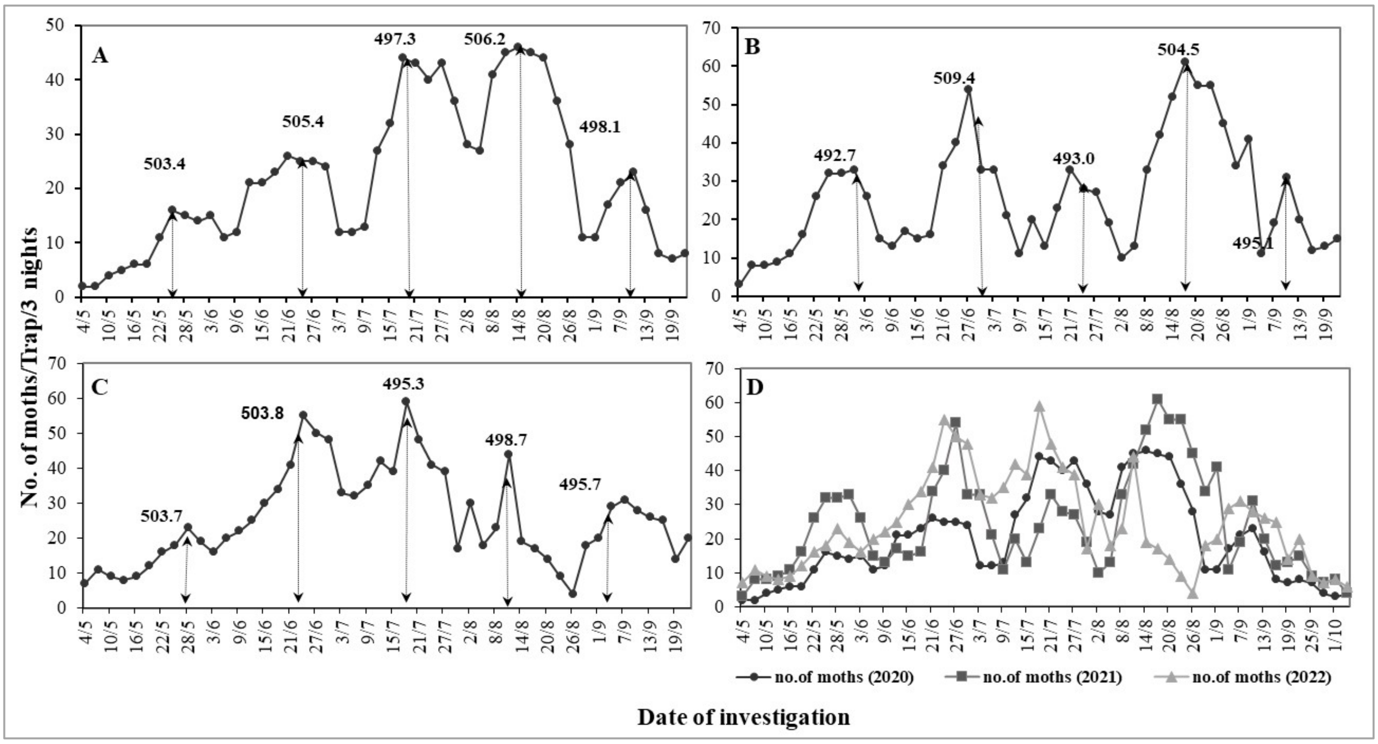

Figure 4. Deviation between observed and expected seasonal generations of *E. insulana* at Qaluobiya during cotton season 2020 (A), 2021 (B), 2022 (C) and all seasons consolidated (D).

الملخص

الحسني، منى، حسن ضاحي، عقيلة الشافي ومنى يونس. 2025. الاحتياجات الحرارية والوفرة الموسمية لدودة اللوز الشوكية بناءً على حرارة الحقل المتغيرة المأخوذة من صور الأقمار الصناعية في محافظة القليوبية، مصر. مجلة وقاية النبات العربية، 43(1):25-32.
https://doi.org/10.22268/AJPP-001295

تعدّ دودة اللوز الشوكية (*Earias insulana*) من أخطر آفات القطن في مصر والعالم. تمّت دراسة تأثير درجة الحرارة على حياتية هذه الآفة الحشرية، مع التركيز على مدة مراحل النمو المختلفة. تمّ تحديد معدل التطور وعتبة درجة الحرارة المنخفضة والوحدات الحرارية المتراكمة اللازمة لإكمال كل مرحلة من مراحل الحياة (البيض واليرقات والعذارى وما قبل وضع البيض) لدودة اللوز الشوكية تحت ظروف المختبر. تمّت دراسة أعداد الحشرات والوفرة الموسمية والتنبؤ بالتكاثر الحقلي باستخدام تقنيات الاستشعار عن بعد، وبخاصةٍ الصور الفضائية، لمعرفة تأثير درجة الحرارة على نمو أعداد الحشرات في الحقل. أظهرت النتائج أن لدودة اللوز الشوكية أربعة أجيال موسمية بالإضافة إلى جيل البيات الشتوي خلال ثلاثة مواسم لمحصول القطن (2020، 2021 و 2022). تمّ الكشف عن القمم المرصودة والقمم المتوقعة للأجيال في الموسم الواحد، وتمّت ملاحظة القمم المتوقعة في وقت أبكر من القمم المرصودة، إذ بلغ متوسط أيام الانحراف -3، -7 و -4 أيام، لمواسم القطن 2020، 2021 و 2022، على التوالي. وبذلك يمكن للتنبؤ المبكر بدودة اللوز الشوكية أن يكون مفيداً في تصميم برنامج الإدارة المتكاملة ضدّ هذه الآفة.

كلمات مفتاحية: دودة اللوز الشوكية، الاحتياجات الحرارية، الحرارة الدنيا الحرجة، صور الأقمار الصناعية، التوقع.

عناوين الباحثين: منى الحسني[1]، حسن ضاحي[2*]، عقيلة الشافي[1] ومنى يونس[3]. (1) قسم الحشرات، كلية العلوم، جامعة عين شمس، مصر؛ (2) معهد بحوث وقاية النبات، مركز البحوث الزراعية، الدقي، الجيزة، مصر؛ (3) الهيئة القومية للإستشعار عن بعد وعلوم الفضاء، القاهرة، مصر. *البريد الإلكتروني للباحث المراسل: hasandahi@yahoo.com

References

Abd-El Rahman, T.A., H.Z. Moustafa, M.S. Salem, R.A.A. Dar and N.S.A. Hiekel. 2015. Residual effect of profenofos on cotton bollworm *Earias insulana* (Boisd.) using two ground motor sprayer. International Journal of Advanced Research, 3(5):886-893.

Abdelmaksoud, N.M., N.F. Abdel-Aziz, E.A. Sammour, E.A. Agamy, A.M. El-Bakry and M.A. Kandil. 2020. Influence of insect traps and insecticides sequential application as a tactic for management of tomato leaf miner, *Tuta absoluta* (Meyrick), (Lepidoptera: Gelechiidae). Bulletin of the National Research Centre, 44:123. https://doi.org/10.1186/s42269-020-00376-y

Adly, A.M., A.S.M. Ibrahim and A.F. Ahmed. 2016. Thermal units' requirements for development of the American bollworm, *Helicoverpa armigera* (Hubner.). Journal of Plant Protection and Pathology, 7(2):115-122. https://doi.org/10.21608/JPPP.2016.50084

Ali Shah, M., N. Memon and A.A. Baloch. 2011. Use of sex pheromones and light traps for monitoring the population of adult moths of cotton bollworms in Hyderabad, Sindh, Pakistan. Sarhad Journal of Agriculture, 27(3):435-442.

Amer, A.E.A., A.A.A. El-Sayed and M.S. Hashem. 2015. Seasonal fluctuation of the spiny bollworm, *Earias insulana* (Boisd.) On some host plants. Journal of Plant Protection and Pathology, 6(10):1415-1425. https://doi.org/10.21608/JPPP.2015.75338

Anguelov, R., C. Dufourd and Y. Dumont. 2017. Mathematical model for pest-insect control using mating disruption and trapping. Applied Mathematical Modelling, 52:437-457. https://doi.org/10.1016/j.apm.2017.07.060

Blunk, M. 1923. Die Entwicklung Von Dytiscus marginalis L.Vom. Ei bis Zur Imago, 2 Teil. Die Metamorphase Zracht-Wiss. Sool, 121-171.

Campbell, A. and M. Machauer. 1975. Thermal constants for the development of the pea aphid and some of its parasites. Canadian Entomologist, 107(4):419-423. https://doi.org/10.4039/Ent107419-4

Dahi, H.F., S.A.R. Salem, W.E. Gamil and H.O. Mohamed. 2020. Heat requirements for the fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) as a new invasive pest in Egypt. Egyptian Academic Journal of Biological Sciences, 13(4):73-85. https://doi.org/10.21608/eajbsa.2020.120603

Davidson, J. 1944. On the relationship between temperature and rate of development of insects at constant temperatures. Journal of Animal Ecology, 13(1):26–38. https://doi.org/10.2307/1326

El Hoseny, M.M., H.F. Dahi, A.M. El Shafei and M.S. Yones. 2022. Spectroradiometer and thermal imaging as tools from remote sensing used for early detection of spiny bollworm, *Earias insulana* (Boisd.) infestation. International Journal of Tropical Insect Science, 43:245-256. https://doi.org/10.1007/s42690-022-00917-0

El-Sayed, A.A.A. 2014. Thermal units for the spiny bollworm, *Earias insulana* (Boisd) in Sharkia and Kafr El-Sheikh governorates. Egyptian Journal of Agricultural Research, 92(1):81-89. https://doi.org/10.21608/ejar.2014.154431

Estay, S.A., M. Lima and F.A. Labra. 2009. Predicting insect pest status under climate change scenarios: Combining experimental data and population dynamics modelling. Journal of Applied Entomology, 133(7):491-499. https://doi.org/10.1111/j.1439-0418.2008.01380.x

Grace, M.A., T-F.E. Achick, B.E. Bonghan, M.E. Bih, N.V. Ngo, M.J. Ajeck, G.T.B. Prudence and F.C. Ntungwen. 2019. An overview of the impact of climate change on pathogens, pest of crops on sustainable food biosecurity. International Journal of Ecotoxicology and Ecobiology, 4(4):114-124. https://doi.org/10.11648/j.ijee.20190404.15

Hall, D.R., P.S. Beevor, R. Leser and B.F. Nesbit. 1980. (E,E)-10,12-hexadecadienal: a component of the female sex pheromone of spiny bollworm *Earias insulana* (Boisd.) (Lepidoptera: Noctuidae). Experientia, 36:152-154.

Hemming, D. and K. Macneill. 2020. Use of meteorological data in biosecurity. Emerging Topics in Life Sciences, 4(5):497-511. https://doi.org/10.1042/ETLS20200078

Ismail, I.I., M.Y. Hashem, S.A. Emara and H.F. Dahi. 2007. Predicting the annual generations of the spiny bollworm *Earias insulana* (Boisd.) (Lepidoptera: Arctiidae) by sex pheromone trap catches and heat unit accumulations at delta region. Bulletin of the Entomological Society of Egypt, 84, 88-97.

Kumar, U., D.V. Singh, S.K. Sachan, A. Bhatnagar and R. Singh. 2014. Insect pest complex of okra and biology of shoot and fruit borer, *Earias vittella* (F.). Indian Journal of Entomology, 76(1):29-31.

Mamta, S. and S.D. Narkhede. 2012. Role of fenvalerate on growth and yield of cotton *Gossypium hirsutum* L. Science Research Reporter, 2(3):281-285.

Moustafa, H.Z. 2020. Non-traditional approaches against spiny bollworm *Earias insulana* (Lepidoptera: Noctuidae) infesting cotton in Egypt. Egyptian Journal of Plant Protection Research Institute, 3(3):873-882.

Moustafa, H.Z., A.M. Rizk and K.A. El-Lebody. 2015. Biological studies of *Earias insulana* (Boisd.) Field strains at different constant Temperature Degrees. Egyptian Academic Journal of Biological Sciences (A.Entomology), 8(3):127-135. https://doi.org/10.21608/eajbsa.2015.12876

Ogden, N.H., L.R. Lindsay, A. Ludwig, A.P. Morse, H. Zheng and H. Zhu. 2019. Weather-based forecasting of mosquito-borne disease outbreaks in Canada. Canada Communicable Disease Report, 45(5):127-132. https://doi.org/10.14745/ccdr.v45i05a03

Rajendran, T.P., A. Birah and P.S. Burange. 2018. Insect pests of cotton. Pp. 361-411. *In:* Pests and Their Management. O. Bidkar (ed.), Springer, Singapore. http://doi.org/10.1007/978-981-10-8687-8_11

Rashad, A.M. and E.D. Ammar .1985. Mass rearing of the spiny bollworm *Earias insulana* (Boisd.) on semi artificial diet. Bulletin of the Entomological Society of Egypt, 65:239-244.

Richmond, J.A., H.A. Thomas and H.B. Hattachargya. 1983. Predicting spring flight of Nantucket pine tip moth (Lepidoptera: Olethreutidae) by heat unit accumulation, Journal of Economic Entomology, 76(1):269-271. https://doi.org/10.1093/jee/76.2.269

Said, S.M. 2020. Influence of temperature on the development, growth rate, and life table parameters of *Earias insulana* Boisd. (Lepidoptera: Noctuidae) under laboratory conditions. Egyptian Academic Journal of Biological Sciences (A.Entomology), 13(3):37-46. https://doi.org/10.21608/eajbsa.2020.102002

Salman, A.M.A., H.F. Dahi, H.A. Fouad and A.M.H. Elgeddawy. 2022. Heat accumulations and sex pheromone traps as a tool for predicting the cotton leafworm *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) field generations at Assiut Governorate. Journal of Sohag Agriscience (JSAS), 7(1):1-8. https://doi.org/10.21608/jsasj.2022.245695

Whitfield, E., E. Lobos, A. Cork and D. Hall. 2019. Comparison of different trap designs for capture of noctuid moths (Lepidoptera: Noctuidae) with pheromone and floral odor attractants. Journal of Economic Entomology, 112(5):2199-2206. https://doi.org/10.1093/jee/toz093

Yones, M.S., H.F. Dahi, H.A. Abdel Rahman, A.F. Abou Hadid and S.M. Arafat. 2012. Using remote sensing. technologies and sex pheromone traps for prediction of the pink bollworm, *Pectinophora gossypiella* (Saund.). Nature and Science, 10(7):6-10.

Yones, M.S., S.M. Arafat, H.F. Dahi, A.F. Abou Hadid, H.A. Abd Elrahman, M.S. Mostafa and R. AlGendy. 2013. Best timing of controlling application for *Pectinophora gossypiella* (Saund.) using remote sensing. Pp. 2737-2745. *In:* Proceedings of the 34th Asian Conference on Remote Sensing (ACRS). October 20-24 2013, Bali, Indonesia.

Yones, M., H. Dahi and M. Aboelghar. 2018. Remote sensing technologies as a tool for cotton leafworm, *Spodoptera littoralis* (Boisd.): prediction of annual generations. European Chemical Bulletin, 7(1):20-22. https://doi.org/10.17628/ecb.2018.7.20-22

Received: April 19, 2023; Accepted: February 5, 2024

تاريخ الاستلام: 2023/4/19؛ تاريخ الموافقة على النشر: 2024/2/5