J. of Plant Protection and Pathology, Mansoura Univ., Vol. 15 (9):283 - 291, 2024

Journal of Plant Protection and Pathology

Journal homepage & Available online at: www.jppp.journals.ekb.eg

Number of Generations Expected to Appear in 2050 to 2100 for the Spiny Bollworm, *Earias insulana* (Boisd.) Based on Variations in Temperature

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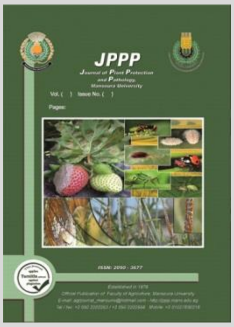

ABSTRACT

The study set out to ascertain how the number of generations of *Earias insulana* (Boisd.) moths would be affected by rising temperatures in 2050, 2075, and 2100. The Sharkyia Governorate was the site of a four-year comparative field research conducted between 2019 and 2022 in order to achieve this goal. There were nine field generations recorded. The generations and peak-to-peak, general average durations were 39.0±17 and 36±11 days, respectively, with a coefficient variance CV of 43.0 and 30.4 days. The overall average for thermal heat units was 507± 6 and 520± 19 units, while the CV values were 1.2 and 3.6 days. The estimated average duration of a generation for the years 2050–2100 was 32–34 days, with 11–13 day standard deviation. Compared to the field study, the CV values were 34.9–37.2 days lower. Due to a shorter generation growth period in the anticipated years than in the field research, the generations will occur earlier. The thermal constant remained nearly constant throughout generations and from peak to peak, even though the year's thermal units increased from 4595 units in the average of four years of field study to 5207, 5418, and 5595 units in the anticipated years 2050, 2075, and 2100, respectively. Nine generations of *E. insulana* moths were recorded in 2019–2022, rising to ten in 2050, remaining at ten in 2075, and reaching eleven in 2100. The number of days required to complete the generation growth is clearly correlated with temperature; the generation period decreases with increasing temperature.

Keywords: *Earias insulana,* cotton**,** Climate change, Light trap, Accumulated heat units.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change's Fourth Assessment Report, there is no longer any doubt about the warming of the climate system or its consequences (IPCC, 2007). The average annual temperature of Earth is predicted to increase by two to four Celsius degrees by the end of the twenty-first century. Climate change forecasts indicate that average temperature in Egypt will rise by 1.07 to 3.1°C. The environment has been greatly impacted by carbon dioxide and global warming over the past thirty years, which has affected every facet of agriculture (Stern, 2007). A major direct effect of climate change on agricultural productivity is shown in the way it impacts crops and their pests, including diseases, insects, and other pathogens. Temperature variations have a significant effect on the growth rate and geographic distribution of insects. In temperate settings, rising temperatures may encourage more insect species to attack more crops because insect species diversity tends to decrease with latitude (Bale *et al.*, 2002; Thomson *et al.*, 2010 and Sutherst *et al.*, 2011)). Growth is also impacted, and the reaction varies based on the type of latitude and region. These impacts the number of generations generated annually or during the crop season. The effects of extreme heat on insect generations are significant because higher surface temperatures may enable certain species to produce a larger number of young each year. However, there may be a closer link between this trait and climate change (Srinivasa *et al.*, 2014; Nada *et al.*, 2018; Skendžic *et al.*, 2021 and El-Sayed *et al.*, 2024). The spiny bollworm, *Earias insulana* (Boisd.), causes significant damage to cotton and other cultivated plants in Egypt. The larvae attack okra *Abelmoschus esculentus* L., cotton fruits *Gossypium barbadense* L. and roselle Hibiscus sabdariffa L. according to El-Mezayen *et al*., (1997). According to Taher, (1983) and El-Zanan, (1987), temperature is the main factor that determined how long each stage of this pest took. Furthermore, it has been observed that the insect thrives at temperatures between 15 and 31 ºC. Understanding seasonal patterns of insect populations is crucial to an integrated pest management program, which uses a multifaceted approach to reduce pest populations. As a result, many mathematical models have been created (Clement *et al.*, 1979 and Richmond *et al.*, 1983). The moths *E. insulana* recorded five to eight overlapping field generations during the three cotton growing seasons tested, and the numbers of actual and expected field generations were estimated using both lower developmental threshold (13.1°C) and accumulated heat units (590 dd's) according to Abdullah *et al.* (2004).). Under laboratory conditions, El-Sayed (2014) reported that in the same context, the field strain generation of *E. insulana* recorded a lower developmental threshold of 12.26 °C and 402.94 cumulative thermal units. In contrast, Abdullah (2005) stated that the lower developmental threshold and thermal units for the generation was 11.04 °C and 512.82 dd's for the laboratory strain of *E. insulana*. Little research has been conducted on using temperature accumulation to predict with the different phases of insect, *E. insulana* (Arnold, 1960; Allen, 1976 and Sevacherian *et al.*, 1976). With the help of corresponding thermal units needed to complete one generation, the current study aims to estimate how long it will take the spiny bollworm to complete its development.

MATERIALS AND METHODS

In Sharkyia Governorate, the study was carried out for four years in a row (2019, 2020, 2021, and 2022). This covered the period from January 1, 2019, to December 31, 2022, when a light trap was installed on the roof of a single-story home

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DOI: 10.21608/jppp.2024.313733.1252

inside a 150-feddan area. Maize *Zea mays* (L.), okra *Abelmoschus esculantus* (L.), cotton *Gossypium barbadense* (L.), and clover *Trifolium Alexandrinum* (L.) are the four crops grown in around 80 feddans annually, amounting to 20, 5, 35, and 20 feddans, respectively. The remaining fields were planted with a variety of crops (the four crops' growth seasons spanned four years, from the final third of 2018 to the final third of 2022). Every three days, *E. insulana* moths captured in the trap are brought in paper bags to the laboratory for examination.

We obtained the daily temperature data, both maximal and minimum, from the Central Laboratory of Agricultural Climatology at Dokki, Giza. Within the criteria set by the Intergovernmental Panel on Climate Change, SRES scenarios were used to predict changes in air temperature at the same location for the years 2050, 2075, and 2100. El-Sayed (2014) determined that the lower threshold temperature (T_0) for *E. insulana* is 12.26°C. Based on the previously listed literature, the lower threshold temperature of 37.07 °C was determined using the regression line equation D = a + bT, where a and b are the constant parameters of the regression line. The lower developmental threshold was equal -a/b.

Number of field generations of the spiny bollworm, *E. insulana*

The investigated years:-

The total thermal units were calculated for the duration of the investigation and the anticipated periods. By using the preceding lower and upper temperature limitations, the daily maximum and minimum temperatures were converted to thermal units, according to Seaver *et al*., (1990). The biological constant was taken into account in the computation of cumulative daily heat units as of January1. Every six days, the number of moths collected and accumulated heat units were tabulated during the four years of the investigation periods, which ran from January 1, 2019, to December 31, 2022. Also, accumulated heat units were tabulated every six days for the anticipated periods.

The anticipated years:-

To determine the number of *E. insulana* moths in the anticipated years 2050, 2075, and 2100:

First, find the relationship between the average number of spiny bollworm moths (Y) and the accumulated thermal units (X) for the study seasons 2019-2022 (field studies) using the multiple regression equation (X^{10}) COSTAT (2005). Since degree 10 multiple regressions yielded the highest value for the coefficient of determination R^2 and the lowest values of RMSE (is the square root of the average of the squared differences between prediction and actual observation or Root Mean Square Error (RMSE) is a standard way to measure the error of a model in predicting quantitative data, Montgomery *et al*., 2012).

Second, the parameters of the multiple regression equation for the field study years were applied in the predicted years according to the following: 1- The equation's values for the field study years are based on the cumulative thermal unit value for the anticipated year. 2- The accumulated thermal units for the anticipated year and the average number of moths observed during the field study years are combined in a multiple regression equation X^{10}. 3- The predicted number of moths in each of the study years and the forecasted year's thermal units make up the third regression equation (Tables, 1 and 2).

Table 1.The effect of expected changes in accumulated thermal units for the anticipated years 2050,2075, and 2100 on the population of spiny bollworms moths, *E. insulana* using multiple regression analysis (grade X^{10}), comparing with the average moths yielded from 2019 to 2022 years in Sharkyia Governorate.

Measurements	Y expected of 2019-2022	2050			2075			2100		
		Y^1	Y^2	Y^3	Y^1	Y^2	Y^3	Y^1	Y^2	Y^3
R^2	0.946	0.946	0.941	0.999	0.946	0.939	0.999	0.946	0.938	0.998
RMSE	0.980	15.161	1.025	0.100	36.870	1.039	0.134	71.047	1.051	0.177
The increase		15.465	1.046	0.102	37.607	1.060	0.137	72.469	1.072	0.180

Y Expected for 2019-2022= Observed for 2019-2022 (Y) + cumulative thermal units of 2019-2022 (X).
Expected for 2050: Y1 = Equation parameters of 2019-2022+ cumulative thermal units of 2050 (X),
Y2= Observed for 2019-2022 (Y) + cumulative thermal units of 2050 (X)and Y3= Expected for 2019-2022 (Y) + cumulative thermal units of 2050 (X)
Expected for 2075: Y1= Equation parameters of 2019-2022 + cumulative thermal units of 2075 (X),
Y2= Observed for 2019-2022 (Y) + cumulative thermal units of 2075 (X) and Y3= Expected for 2019-2022 (Y) + cumulative thermal units of 2075 (X).
Expected for 2100:Y1 = Equation parameter of 2019-2022 + cumulative thermal units of 2100 (X)
Y2= Observed for 2019-2022 (Y) + cumulative thermal units of 2100 (X) and Y3= Expected for 2019-2022 (Y) + cumulative thermal units of 2100 (X).
RMSE:is the square root of the average of the squared differences between prediction and actual observation and the increase= value of RMSE in year /value of RMSE in 2019-2022 as reference.

Table 2. Multiple regression equation parameters (X^{10}) to evaluate the impact of changes in the anticipated cumulative thermal units on the number of spiny bollworm moths (*E. insulana* in Sharkyia Governorate in 2050, 2075, and 2100 years relative to the average population from 2019 to 2022

Parameters	2019-2022 Y expected for Equation parameters Y* + X**	*** P	2050 Y^3 expected for Y expected 2019-2022+X 2050	*** P	2075 Y^3expected for expected 2019-2022+X 2075	*** P	2100 Y^3 expected for expected 2019-2022+X 2100	*** P
Intercept	-0.9609206643	ns	-1.6470454434	ns	-1.8129110589	***	-1.9865099335	ns
x^1	0.0451845506	**	0.0469944458	. ***	0.0464227648	***	0.0460521865	***
x^2	-0.0002235708	**	-0.0001894238	***	-0.0001753010	***	-0.0001644258	***
x^3	0.0000004352	***	0.0000003045	***	0.0000002641	***	0.0000002345	***
x^4	-0.0000000004	**	-0.0000000002	***	-0.0000000002	***	-0.0000000002	***
x^5	0.0000000000	**	0.0000000000	***	0.0000000000	***	0.0000000000	***
x^6	0.0000000000	*	0.0000000000	***	0.0000000000	***	0.0000000000	***
x^7	0.0000000000	ns	0.0000000000	***	0.0000000000	***	0.0000000000	***
x^8	0.0000000000	ns	0.0000000000	***	0.0000000000	**	0.0000000000	ns
x^9	0.0000000000	ns	0.0000000000	**	0.0000000000	ns	0.0000000000	ns
x^10	0.0000000000	0	0.0000000000	0	0.0000000000	0	0.0000000000	0
RMSE	0.980		0.100		0.134		0.177	
R^2	0.946		0.999		0.999		0.998	

RMSE: is the square root of the average of the squared differences between prediction and actual observation.
***: Y= observation , **: X=cumulative thermal units and ***; P = Probability. COSTAT (2005)**

RESULTS AND DISCUSSION

Results

The field study years:-

The seasonal fluctuations:-

Over the course of four years, from 2019 to 2022, the data in Figure, 1 showed the seasonal fluctuations in the average number of *Earias insulana* (Boisd) moths, recording nine field generations and peaks, from the beginning of their appearance in the light trap on January 1st to the end of December. Figure, 2: The number of annual generations and approximate dates of field generations of *E. insulana* moths, arranged as averages over four consecutive years from 2019 to 2022 in Sharkyia Governorate, using the Gauss' scale as described by Audemard and Milaire (1975) and Jacob (1977).

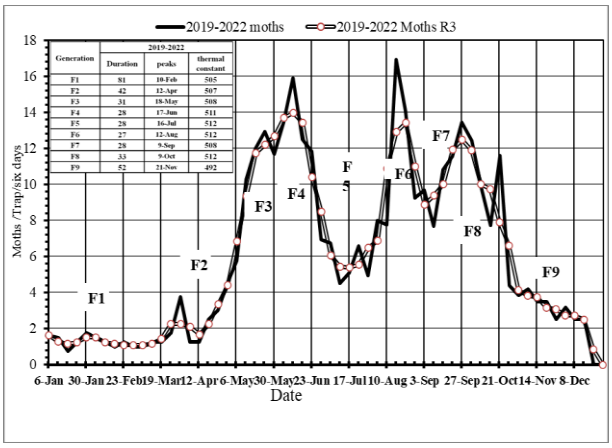

Figure 1. Average numbers of *E. insulana* moths at Shrkiya Governorate for four years, from 2019 to 2022 population fluctuation of generations, duration, peaks, and thermal constant .

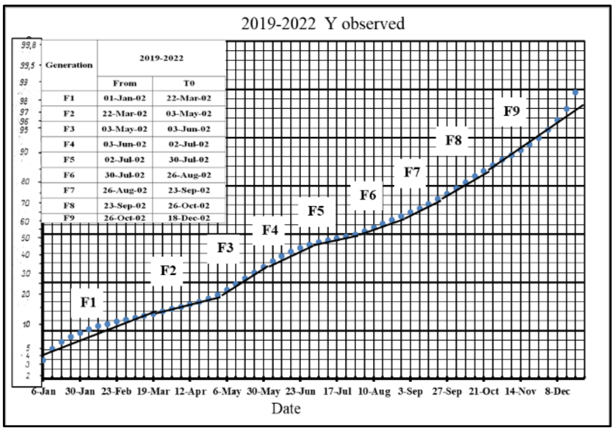

Figure 2. The number of annual generations and approximate dates of field generations of *E. insulana* moths, arranged as averages over four consecutive years from 2019 to 2022, using the Gauss' scale as described by Audemard and Milaire (1975) and Jacob (1977) in Sharkyia Governorate.

Accumulated Julian days and duration in day:-

For each of the nine generations throughout the course of the four field research years, the approximate dates, total Julian days, and average days are displayed in Table, 3. January 1 to May 3 was the approximate range of dates for the first and second generations. For the ninth generation, the estimated date was moved from the last week of October 26 to the third week of December 18. This is the final generation. The growth of the first and second generations took 82 ± 11 Julian days on average to finish. The ninth generation's average number of days accrued was 299±9.

Table 3. The Sharkyia Governorate's annual generations, estimated dates of occurrence, averages of cumulative Julian days, heat units, duration in days, and thermal constant are displayed for *Earias insulana* during the course of four consecutive years, 2019–2022.

Generation	approximate dates		accumulated Julian days				Duration in day		accumulated heat units				Thermal constant	
	From	To	From		To		Days	Sd	From		To		heat units	Sd
			Day	Sd	Day	Sd			heat units	Sd	heat units	Sd		
F1	1-Jan	22-Mar	1	0	82	11	81	11	6	4	511	18	505	14
F2	22-Mar	3-May	82	11	123	12	42	3	511	18	1018	29	507	11
F3	3-May	3-Jun	123	12	155	12	31	1	1018	29	1526	48	508	19
F4	3-Jun	2-Jul	155	12	183	12	28	1	1526	48	2037	67	511	20
F5	2-Jul	30-Jul	183	12	211	9	28	3	2037	67	2548	76	512	11
F6	30-Jul	26-Aug	211	9	238	8	27	1	2548	76	3060	85	512	10
F7	26-Aug	23-Sep	238	8	266	8	28	1	3060	85	3569	97	508	12
F8	23-Sep	26-Oct	266	8	299	9	33	1	3569	97	4080	114	512	17
F9	26-Oct	18-Dec	299	9	351	3	52	10	4080	114	4572	138	492	33
F10														
Average			173		212		39		2039		2547		507	
Sd			89		81		17		1316		1314		6	
CV			51.3		38.3		43.0		64.5		51.6		1.2	

From the first week of May to the last week of October 26, the remaining six generations, from the third to the eighth, took about 217 days, with a standard deviation ranging between 8 and 12 days. The duration in days of the nine field generations was divided into two groups: The long-term generations and the lower generations. The first, second, and ninth generations had lengths of 81 ± 11, 42 ± 3, and 52 ± 10 days, respectively. The others, three to eight generation groups had duration of 27 to 33 days, with a standard deviation of one to three. The overall average was 39 ± 17 days, and the CV was 43.0 days.

The accumulated heat units and the thermal constant:-

The dates of the nine generations are usually associated with these temperatures. For the first generation, the average amount of accumulated heat units increased gradually from 6±4 to 511±18 units, and for the ninth generation, it increased from 4080±114 to 4572±138 units. The overall average varied between 2039±1316 and 2547±1314 units and C.V varied between 64.5 and 51.6 units. The average thermal constant for the first generation was 505±14 units, while the ninth generation's was 492±33 units. The general average was 507±6 units, and the C.V. was 1.2 units, Table, 3.

The generation's peaks:-

The field study conducted from 2019 to 2022 found that there were nine average peaks for the nine generations prior. And these were the estimated dates: February 10 through April 12, May 18, June 17, July 16, August 12, September 9, October 9, and November 21. In that order, the average number of days accumulated was 42 ± 5, 103 ± 12, 139 ± 12, 169 ± 12, 197 ± 11, 225 ± 9, 252 ± 8, 283 ± 9, and 325 ± 5. The average number of days accumulated from peak to peak; the first, second, and ninth peaks, was at 62 ± 6, 37 ± 2, and 43 ± 5, respectively, had the largest duration of days from peak to peak. The remaining six peaks, ranging in average from 28 to 31 days with a standard deviation between 0 and 2, began to peak from the third peak and continued until the eighth peak, Table, 4.

The cumulative heat units:-

For the first peak was 235±14 units and this value progressively grew up to nine peaks, with an average of 4399±123 units. The average value was 2089±1412, with a CV of 67.6 units. The average thermal constant from peak to peak, for the first peak was 505±17 units, whereas the ninth peak had an average of 561±18 units. Furthermore, for the final seven peaks, which corresponded to the second through eighth peaks, the heat unit average varied from 496 to 532 units, with a standard deviation ranging from 8 to 24 units. The overall average was 520±19 units, and the C.V. was 3.6 units, Table, 4.

Table 4. The yearly generations, estimated peak dates, average cumulative Julian days, heat units for peaks, and heat units from peak to peak for E. insulana moths during the course of four consecutive years, starting on January 1st, 2019–2022, in Sharkyia Governorate

Generation	Date	Accumulated days and heat units				From peak to peak			
		Days	Sd	Heat units	Sd	Days	Sd	Thermal constant	Sd
F1	10-Feb	42	5	235	14				
F2	12-Apr	103	12	740	30	62	6	505	17
F3	18-May	139	12	1254	37	37	2	514	8
F4	17-Jun	169	12	1786	60	30	0	532	24
F5	16-Jul	197	11	2297	72	29	2	511	14
F6	12-Aug	225	9	2792	83	28	2	496	21
F7	9-Sep	252	8	3317	87	28	1	525	12
F8	9-Oct	283	9	3838	106	31	1	521	24
F9	21-Nov	325	5	4399	123	43	5	561	18
F10									
F11									
Average		178		2089		36		520	
Sd		92		1412		11		19	
CV		52.0		67.6		30.4		3.6	

During the study period, nine field generations from the past were recorded and split into two groups. First, second, and ninth generation are the ones that require a significant amount of time to finish their growth. The other six generations, who require lower days, make up the second group. In the nine generations before this one, nine peaks were noted. The peaks were split into two groups as well, with the generations following the same pattern. The thermal constant and accumulated heat units were the maximal of the thermal units, which roughly corresponded to the nine generations. From the first to the ninth generation, the collected heat units grew progressively. Throughout the nine generations, the average thermal constant was 507±6 units, with a 1.2 unit coefficient of variation. The cumulative heat units of the nine peaks showed behavior similar to the generations from the first to the ninth peak with respect to the peaks. The C.V. unit was 67.6, and the total average was 2089±1412. The thermal constant averaged 520 ± 19 units and the CV was 3.6 units across the eight-period period from peak to peak. The number of days required to complete growth generation is inversely connected with temperature; that is, the higher the temperature, the shorter the generation period must be.

Predicted years:-

Based on data from four consecutive years (2019–2022) and anticipated years (2050, 2075, and 2100), Figure, 3 displays the average number of accumulated heat units (AcHUs) from the fixed date, January 1st, to the end of December. Over the course of the four years, the average number of ACHUs climbed steadily from the established date to the end of December, totaling 4595 units. With 5207, 5418, and 5595 units of residential space, ACHUs progressively grew for the predicted years 2050, 2075, and 2100, respectively.

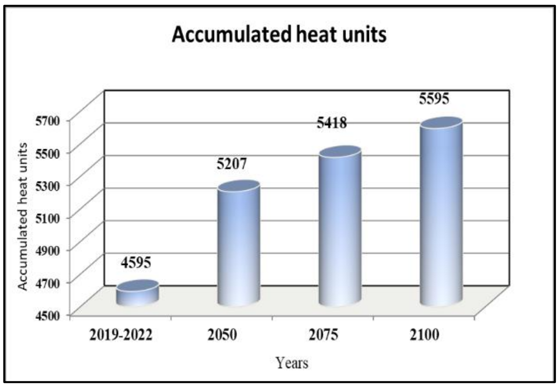

Figure 3. The increase in predicted heat units owing to potential temperature increases in the years 2050, 2075, and 2100 relative to the average 2019–2022, using *E. insulana's* lower and upper threshold temperatures

The data in Figures, 4 and 5 compared the average annual number of adult moths since they appeared in the light trap from January 1 to the end of December during the four consecutive years that spanned from 2019 to 2022 to the predicted annual population fluctuations of adult moths *E. insulana* that will be predicted during 2050, 2075, and 2100 years.

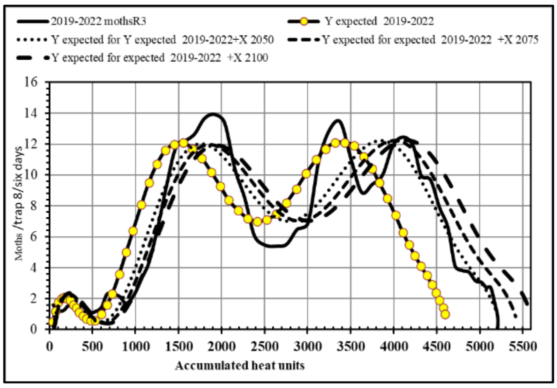

Figure 4. Projected changes in populations of *E. insulana* moths due to probable temperature increases in the years 2050, 2075, and 2100, as compared to the average number observed and forecasted between 2019 and 2022.

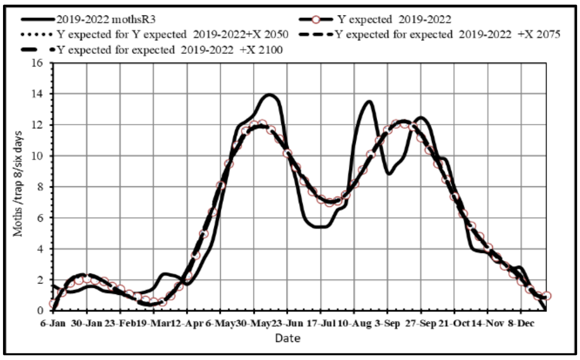

Figure 5. Projected fluctuations in populations of *E. insulana* moths due to probable temperature increases in the years 2050, 2075, and 2100, in comparison to the average number observed and forecasted between 2019 and 2022.

The duration in days:-

The information displayed in Tables, 3 and 5 and Figures, 6 and 7 illustrates how the annual number, periods in days, and thermal constant of *E. insulana* moths in the anticipated years 2050, 2075, and 2100 differ from those of the same generations with averages of 2019–2022 years (as reference data) across generations. The field investigation recorded nine generations for the duration in days. The longest generations were the first, second, and ninth, with the remaining six ranging from 28 to 33 days, for a total of 350 days, with varying durations of 16 days less than the annual days. The number of generations rose from nine to ten, compared to the projected year 2050. Compared to the reference data, the first, second, and tenth generation periods had shorter periods. The remaining seven generations varied in length from 25 to 31 days, totaling 344 days, with 21 days fewer than the number of days in a year. Their respective lengths were 67, 42, and 45 days. Within the anticipated year 2075, there were fewer than ten generations. The intervals of ten generations kept getting shorter, falling short of the field research years and the projected 2050. It took 66, 43, and 41 days, respectively, for the first, second, and ten generations. With a total of 339 days and varying 26 days, the remaining seven generations had duration of 25 to 32 days. This time was 10 days longer than the field study years and 5 days shorter than 2050 days. The days have increased by roughly 26, yet neither the number of generations nor their duration has altered from ten to one. There will be eleven generations instead of ten in the anticipated year 2100. The first, second, and eleventh generations' periods kept getting smaller than the reference data and the anticipated years 2050 and 2075. With a difference of 15 days, the last eight generations totaled 350 and varied from 23 to 30 days. Within the field study, the average duration in days for the generations fell between 32 and 39 days, with a standard deviation ranging from 11 to 17 days and CV values between 34.9 and 43.0. In the field study, the generations lasted 39 days, but the values started to drop from 2050 and kept going down to 34 days in 2075 and 2100. That is to say, depending on the temperature and the time of year the generation occurs, there was a variation in the total number of days needed to finish the growth generation.

Table 5. The thermal constant, number of yearly generations, and length of time in days for *E. insulana* generation in Sharkyia Governorate in 2019–2022 as well as in the anticipated years 2050, 2075, and 2100

Generation	Duration in day							Thermal constant for generation						
	2019-2022		2050	2075	2100	Average 2050-2100		2019-2022		2050	2075	2100	Average 2050-2100	
	Days	Sd				Days	Sd	Heat units	Sd				Heat units	Sd
F1	81	11	67	66	59	64	3.6	505	14	513	534	512	520	10
F2	42	3	42	43	43	43	0.5	507	11	519	515	514	516	2
F3	31	1	31	32	30	31	0.8	508	19	507	534	502	514	14
F4	28	1	27	27	26	27	0.5	511	20	519	530	502	517	11
F5	28	3	26	26	25	26	0.5	512	11	515	533	516	521	8
F6	27	1	25	25	23	24	0.9	512	10	516	533	499	516	14
F7	28	1	25	25	23	24	0.9	508	12	518	532	502	517	12
F8	33	1	26	25	24	25	0.8	512	17	527	521	517	522	4
F9	52	10	30	29	24	28	2.6	492	33	511	524	501	512	9
F10			45	41	30	39	6.3			512	527	513	517	7
F11					43	43						507	507	
*Total	350		344	339	350			4566		5157	5283	5585		
Different	15		21	26	15			29		50	135	10		
Average	39		34	34	32			507		516	528	508		
Sd	17		13	12	11			6		5	6	6		
CV	43.0		37.2	36.6	34.9			1.2		1.0	1.2	1.3		
Total **	365		365	365	365			4595		5207	5418	5595		

*** :Total days or heat units for generations ** :Total days or heat units per year**

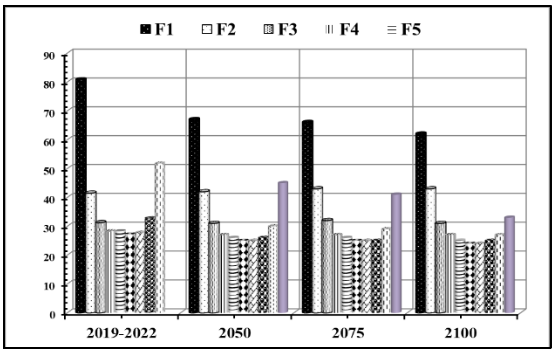

Figure 6. In Sharkyia Governorate, annual generations and duration in days for *E. insulana* over the years 2019–2022, as well as the anticipated years 2050, 2075, and 2100

The thermal constant:-

According to Table, 5; from the first generation to the ninth, the reference data for 2019–2022 showed that the thermal constant varied between 492 and 512 units, with an average of 507±6 units and CV by 1.2 units; this difference was 29 units less than the total heat units each year. There will be ten generations instead of just nine in the anticipated year 2050. The ten generations' thermal constants varied from 507 to 527 units, with the latter being 50 units lower than the total. 516±5 units and a CV of 1.0 were the general avenge. The number of generations did not rise above ten in the projected year 2075. The difference between the 10 generations' thermal constants, which was 135 units less than the total, was between 515 and 534 units. The average across the board was 528±6 units and CV by 1.2 units. The cumulative total heat units of 5283 were less than the 135 units for the year 5418; nevertheless, the units did not complete a generation, and the number of generations remained constant at ten. There will be eleven generations instead of just ten in the anticipated year 2100. The eleven generations' thermal constant varied by 10 units, with the total for the year 5595 units being between 499 and 517 units. The overall average was 508 ± 6 units and CV by 1.3 units. The overall average for the reverence data (the years 2019–2022) and the projected years (2050, 2075, and 2100) varied from 32 to 39 days and 507 to 528 heat units, respectively, in terms of thermal constant. There was a range of 11 to 17 days for the standard deviation and 5 to 6 units for heat units. The range of CVs was 34.9–43.0 days, and the range of heat units was 1.0–1.3 units. The discrepancy between the total number of generations and the total number of days and heat units for the year was found to be between 15 and 26 days. The heat units ranged from 10 to 135 units.

Accumulated Julian days for generations' peaks:

According to Table, 6 and Figure, 7; the number of peaks rose from nine to 10 for the anticipated year 2050. With an average of 190±86 and a CV of 45.1 days, the total number of days varied from 35 to 324. There were ten peaks for the anticipated year 2075. With an average of 188±85 and a CV of 45.3 days, the total number of days varied from 33 to 319. The number of peaks rose from ten to eleven for the anticipated year 2100. The average number of accumulated days for the expected years 2050–2100 was 33±2 days at F1 and rose to 330 days at F11; in contrast, the average number of accumulated days for the field study was 42±5 days at F1 and increased to 325±5 days at F9. With standard deviations between 85 and 87 days and a CV between 45.1 and 45.9 days, the average number of days accrued from F1 to F11 for the projected years 2050–2100 fell between 188 and 190 days. In comparison with the average accumulated days for generations' peaks in the field study 2019–2022. The number of accumulated days required for generations' peaks in the expected years, 2050, 2075, and 100 decreased. The largest decrease reached its highest value in the expected generation's peaks in the predicted year 100.

Accumulated heat units for generations' peaks:

The number of peaks for the expected year 2050 increased from nine to 10. With an average of 2570±1497 and a CV of 58.3 units; the cumulative heat units varied from 245 to 4937. There were ten generations that peaked in the projected year 2075. With an average of 2652±1533, and a CV of 57.8 units, the total heat units varied from 256 to 5062. The number of peaks for generations rose from ten to eleven for the anticipated year 2100. With an average of 2791±1465 and a CV of 52.5 units, the accumulated heat units followed the same trend in the anticipated years 2050 and 2075. The average cumulative heat units for the four years of 2019–2022 field study were 235 ±14 at F1 and grew to 4399±123 units at F9. In contrast, the average cumulative heat units for the forecasted years 2050–2100 was between 250±5 units at F1 and increased to 5371 units at F11. For the anticipated years 2050 to 2100, the average cumulative heat units from F1 to F11 ranged from 2570 to 2791 units, with standard deviations between 1465 and 1533 units. The CVs varied from 52.5 units to 58.3 units, as shown in Table, 6 and Figure, 7.

Table 6. The Sharkyia Governorate's yearly generations, accumulated Julian days, and heat units for the *E. insulana* generation's peaks in 2019–2022 as well as the projected years 2050, 2075, and 2100

Generation	Accumulated Julian days for generation's peaks							Accumulated heat units for generation's peaks						
	2019-2022		2050	2075	2100	Average 2050-2100		Average 2019-2022		2050	2075	2100	Average 2050-2100	
	Days	Sd				Days	Sd	Days	Sd				Heat units	Sd
F1	42	5	35	33	31	33	2	235	14	245	256	249	250	5
F2	103	12	89	88	82	86	3	740	30	733	759	732	742	13
F3	139	12	127	125	118	123	4	1254	37	1270	1326	1262	1286	28
F4	169	12	156	155	146	152	4	1786	60	1783	1854	1772	1803	36
F5	197	11	182	181	172	178	4	2297	72	2309	2396	2280	2328	49
F6	225	9	208	207	196	204	5	2792	83	2817	2921	2785	2841	58
F7	252	8	233	232	219	228	6	3317	87	3339	3456	3286	3360	71
F8	283	9	258	257	242	252	7	3838	106	3872	3982	3807	3887	72
F9	325	5	286	284	266	279	9	4399	123	4392	4505	4320	4406	76
F10			324	319	293	312	14			4937	5062	4834	4944	93
F11					330	330						5371	5371	
Average	193		190	188	190	198		2295		2570	2652	2791	2838	
Sd	85		86	85	87	90		1338		1497	1533	1465	1638	
CV	44.0		45.1	45.3	45.9	45.3		58.3		58.3	57.8	52.5	57.7	

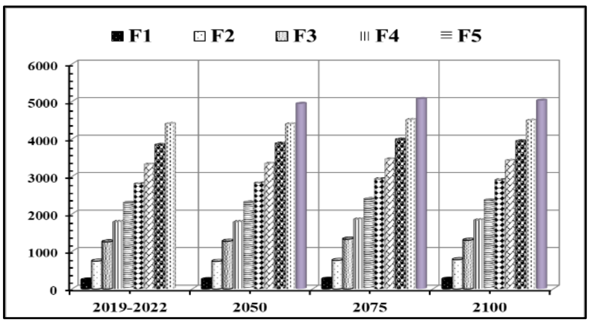

Figure 7. In Sharkyia Governorate, annual generations and cumulative heat units for peaks of *E. insulana* during 2019–2022 and projected years of 2050, 2075, and 2100

Duration in day from peak to peak: -

For the nine preceding generations, the field survey documented eight time intervals, measured in days, between peaks. Eight periods' worth of days is displayed in Tables, 4 and 7 with an average of 36±11 and CV of 30.4 days. There are now nine periods instead of just eight for the anticipated year 2050. Days followed the same pattern in the field study, with an average of 32.4±9.3 and a CV of 28.5 days. There were nine periods for the anticipated year 2075. The duration in days was 25–55, with an average of 32±9.2 and a CV of 28.8 days. There will be ten phases instead of nine for the anticipated year 2100. Days followed the same pattern in the anticipated year 2075, averaging 30.1±8.5 and CV 28.3 days Table, 7.

Thermal constant from peak to peak:

From 2019 to 2022, eight thermal constants, with an average of 520±19 and a CV of 3.6 units, were observed from peak to peak during the field investigation, as shown in Tables, 4 and 7. There were nine thermal constants instead of just eight in the year 2050 that was projected. The nine thermal constants followed the same pattern, with an average of 521 ± 16 CV 3.0 units, in the reference data for the period 2019–2022. Nine thermal constants were projected for the year 2075. With an average of 534 ± 18 and a CV of 3.4 units, the nine thermal constants varied from 503 to 557. The thermal constant number grew from nine to ten for the anticipated year 2100. With an average of 512 ± 14 and a CV 2.8 unit, the ten thermal constant followed the same pattern in the anticipated years 2050 and 2075. The thermal constant averages varied from 512 to 534 units, with standard deviations ranging from 14 to 18 units. The CVs were found to be between 2.7 and 3.0 units, in contrast to the previous data, which showed an average of 520±19 and a C.V. of 3.6 units.

Table 7. In Sharkyia Governorate, the number of yearly generations, duration in days, and thermal constant of E. insulana from peak to peak in 2019–2022 and anticipated years of 2050, 2075, and 2100

Generation	Duration in day from peak to peak							Thermal constant from peak to peak						
	2019-2022		2050	2075	2100	average 2050-2100		2019-2022		2050	2075	2100	average 2050-2100	
	Days	Sd				Days	Sd	heat units	Sd				heat units	Sd
F1														
F2	62	6	55	55	51	54	1.9	505	17	488	503	483	491	8.5
F3	37	2	38	38	37	38	0.5	514	8	537	567	530	545	16.0
F4	30	0	29	30	28	29	0.8	532	24	513	528	510	517	7.9
F5	29	2	27	27	26	27	0.5	511	14	525	542	507	525	14.3
F6	28	2	26	26	24	25	0.9	496	21	508	525	505	513	8.8
F7	28	1	25	25	23	24	0.9	525	12	522	535	502	520	13.6
F8	31	1	26	25	24	25	0.8	521	24	533	526	520	526	5.3
F9	43	5	28	27	24	26	1.7	561	18	520	523	513	519	4.2
F10			38	35	27	33	4.6			544	557	514	538	18.0
F11					37	37						536	536	
Average	36		32.4	32.0	30.1	32		520		521	534	512	523	
Sd	11		9.3	9.2	8.5	9		19		16	18	14	14	
CV	30.4		28.5	28.8	28.3	27.2		3.6		3.0	3.4	2.8	2.7	

Discussion

The effects of global climate change on agriculture and agricultural insect pests are significant. Both directly and indirectly, these changes affect crops and the pests that feed on them. The development of their host plants as well as the growth, survival, and reproduction of insects are significantly influenced by temperature. The synthesis of secondary chemicals and the structural characteristics of plants that aid in their defense against herbivores are also influenced by temperature. Climate change has led to a rise in the number and danger of insect pests due to their increased abilities for adaptability, survival rates, and spread. (Skendžic *et al.*, 2021 and Subedi *et al.*, 2023). Nine generations' worth of *E. insulana* moth peaks was noted throughout the field research. The periods for them were the cumulative Julian days, increasing gradually from the first generation and their peak to the ninth. Days were used to describe the duration for generations and from peak to peak, they were divided into two groups. The first were the generations and their peaks, which took long period to complete its growth. That's the first, second, and ninth ones. The second group consisted of the six generations that were left and required fewer days. The overall averages were 39.0 and 30.4 days for the coefficient variance and 39±17 and 36±11 days from peak to peak. The cumulative heat units for the first through the ninth generations increased gradually and from peak to peak. Tables, 3 and 4 displays the average values of the thermal constant for generations and from peak to peak at 507±6 and 520±19 units, and the overall CV by 1.2 and 3.6 units, respectively. The *E. insulana* moth population peaked in 2050 after increasing over nine to ten generations. After that, it remained at ten in 2075 and increased to eleven in 2100. Over the course of the generations and their peaks, the total Julian days climbed progressively from the first generation to the last. Compared to the field research, which had 39±17 days and a CV of 43.0 days, the average duration in days for generations and from peak to peak in the anticipated years 2050 to 2100 was 32–34 days, with a standard deviation of 11–13 days and CV values at 34.9–37.2 days. Similarly, the field study discovered a 15-day difference between the generations; values began to decline by 2050 and dropped to 21 days; they continued to decline at 2075 and 2100, reaching 26 and 15 days, respectively. The results showed that, similar to the field study, the average number of days from peak to peak was between 30.1 and 32.4 days, with standard deviations ranging from 8.5 to 9.3 days and CVs between 28.3 and 28.8 days. The average duration in days from peak to peak was 36±11 and the CV was 30.4 Tables,5, 6, and 7. This suggests that depending on the temperature and the season, in which the generation took place, different numbers of days were required to complete the growth generation. Temperature is one significant meteorological component that influences the phenology of insects. It is predicted that the remarkable trend of global warming will increase insect pest populations, hence jeopardizing food production (Gutiérrez and Wilson, 2021). The distribution of crop pests, especially invasive ones, can change, which can affect crop productivity. Thermal units are used to indicate the eleven generations' predicted dates and maxima. From the first to the eleventh generation, the cumulative heat units for the projected years increased gradually. For all eleven generations, the average values of the thermal constant were 516±5, 528±6, and 508±6, with corresponding CV values of 1.2, 1.0, and 1.3 units. Overall, as indicated in Tables 5 and 7, the averages from peak to peak were 521±16, 534±18, and 512±14, with corresponding CV values of 3.0, 3.4, and 2.8 units are the result of calculating the total amount of heat accumulation over the course of a year. Add together the daily maximum and minimum temperature differences to find it (Premanandh, 2011). The average thermal unit of the *Spodoptera littoralis* (Boisd.) generation was 523.27 DDU, according to EL-Mezayyen, *et al.* (2019). It takes fewer days in the expected years to finish the generation's growth than it does in the four field study years. The total heat units rose from 4595 units during the four field study years to 5207, 5418, and 5595 units in 2050, 2075, and 2100, the anticipated years. But during the course of the generation, the thermal constant essentially stays the same. With four years of field study, the average number of generations was therefore nine; but, in the projected years 2050 and 2100, that number increased to ten and eleven, respectively. Temperature is the main factor influencing the growth and development of crop plants, and temperature fluctuations have a significant effect on these activities. A variety of effects are expected to result from climate change for insect pests, including increases in population size, growth rate, number of generations, distribution range, and migratory patterns; the host pests expanded simultaneously (Florentine *et al*.,2020). Since temperature significantly affects an insect's development and metabolism, it is thought to be an important environmental component governing insect growth and survival (Hallmann and Denlinger, 1998). Given their considerable influence on insect growth rate, geographic dispersion, and species diversity, higher temperatures may lead to an increase in the number of bug species attacking crops in temperate regions. The number of generations that an insect generates in a year or throughout a crop season is another important aspect of insect growth. Responses vary throughout insect species and geographical areas (Srinivasa *et al*., 2014; Nada *et al*., 2018 and El-Sayed *et al.,* 2024). The projected three years 2050, 2075, and 2100 had less of an impact from climate changes on the periods by days necessary for generations' growth than did the four field study years 2019–2022, which experienced a steady drop from 2050 to 2100. This suggests that the length of time fluctuated in days based on the number of days required to complete the growing generation, which was dictated by the temperature and the generation's timing within the year. There exists an inverse relationship between temperature and the number of days required to complete growth generation; a greater temperature corresponds to a shorter generation period. Climate change may increase the quantity of insecticides needed as well as the number of insect generations of important insect pests per season. Because there are more generations in each season or year due to year-round temperature changes, population expansion might be accelerated (Thomson *et al.,* 2010 and Sutherst *et al*., 2011). Temperature is one of the key environmental factors influencing how insect populations behave. More generations are expected to be born as global temperatures rise, and the effects are expected to disperse over a greater geographic region (Skendžic *et al*. ,2021).

CONCLUSION

Crop growth, survival, reproduction, and host plant development are all impacted by climate change, which also has a substantial impact on agricultural insect pests. The production of secondary chemicals in plants, their ability to fend off herbivores, and the growth and survival of insects are all significantly influenced by temperature. As a result of climate change, insect pests have increased in number and danger. The peak durations of nine generations of ***E. insulana*** moths were recorded in a field research and expressed in days. The average accumulated days increased steadily for generations and from peak to peak from the first to the ninth. For the projected years 2050–2100, the average generational duration and peak–to–peak duration in days were 32–34, with a standard deviation of 11–13 days and CV values of 34.9–37.2 days. From nine to ten generations, the number of ***E. insulana*** moths rose; it peaked in 2050, stayed at ten in 2075, and reached eleven in 2100. In the anticipated years 2050 to 2100, the impact of climate change on the number of days required for the growth of generations was less. The number of days required to complete the growing generation, which was based on the temperature and the generation's timing within the year, varied depending on the duration in days. Climate change may result in an increase in the number of insect generations of important insect pests per season as well as the amount of pesticides needed. Variations in temperature throughout the year can increase the number of generations each season or year, which can speed up population expansion.

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حساب عدد الأجيال السنوية المتوقعة في المستقبل لدودة اللوز الشوكية، *Earias insulana* (Boisd.)، نتيجة للتغيرات في درجات الحرارة

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الملخص

هدفت الدراسة إلى تحديد تأثير ارتفاع درجات الحرارة في أعوام 2050 و2075 و2100 على عدد أجيال فراشات *Earias insulana* (Boisd.) ، وذلك من خلال إجراء دراسة حقلية مقارنة لمدة أربع سنوات في محافظة الشرقية من عام 2019 إلى عام 2022. تم تسجيل تسعة أجيال للتعداد خلال الدراسة. كان المتوسط العام لفترات الجيل ومن الذروة إلى الذروة 39±17 و36±11 يومًا ومعامل التباين 43.0 و30.4 يومًا على التوالي. كان المتوسط العام للوحدات الحرارية 507±6 و520±19 وحدة ومعامل التباين 1.2 و3.6 وحدة على التوالي. كان متوسط مدة الجيل في السنوات المتوقعة 2050-2100 32-34 يومًا، مع انحراف معياري 11-13 يومًا. كانت قيم معامل التباين أقل بمقدار 34.9-37.2 يومًا مما كانت عليه في الدراسة الحقلية. من المتوقع ان تتواجد الأجيال مبكرًا لأن فترة نمو الجيل في السنوات المتوقعة كانت أقل من سنوات البحث الحقلى. وبينما ارتفعت الوحدات الحرارية في العام من 4595 وحدة في متوسط أربع سنوات من الدراسة الحقلية إلى 5207 ، 5418 و5595 وحدة في السنوات المتوقعة 2050 و2075 و2100 على التوالي، ظل الثابت الحراري ثابتًا تقريبًا لمدد الأجيال ومن الذروة إلى الذروة. سجلت فراشات *E. insulana* تسعة أجيال في الفترة 2019-2022؛ وارتفع هذا العدد إلى عشرة في عام 2050، وظل عند عشرة في عام 2075، ووصل إلى أحد عشر في عام 2100. هناك علاقة مباشرة بين درجة الحرارة وعدد الأيام اللازمة لإكمال نمو الجيل؛ أي أنه كلما ارتفعت درجة الحرارة، كلما كان وقت الجيل أقصر.

الكلمات الدالة: *Earias insulana*، *Gossypium barbadense*، تغير المناخ، المصيدة الضوئية، الوحدات الحرارية المتراكمة AcHU's