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Research Article
Thermal Requirements and Life Table Parameters of Tomato Leaf Miner *Tuta absoluta* (Lepidoptera: Gelechiidae) in Egypt

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Abstract

Background and Objective: The tomato leaf miner, *Tuta absoluta* (Meyrick) is being a serious pest to tomato cultivations in Egypt since 2009. The present study was carried out to calculate the developmental parameters of insects based on temperature degree. **Materials and Methods:** The influence of 3 tested temperatures (20, 24, 28°C) were examined to evaluate its effect on the developmental stages of *T. absoluta*. Developmental thresholds and needed heat units for insect stages were mathematically calculated according to developmental rates. **Results:** Developmental threshold for egg stage and mean thermal units were calculated to be 7°C and 86.2 DD's. The developmental threshold for the larval stage was 10°C, while mean thermal units were calculated to be 310.8 DD's. Percentages mortality of larval stage were 52, 74, 74 and 100% at 20, 24, 28 and 32°C, respectively. For the pupal stage developmental threshold and mean thermal units required for completing the pupal stage was 11.2°C and 132.2 DD's. For an adult, zero of the developmental threshold female and of male were 11.2 and 9.8°C, respectively. The mean required heat units for female and male was 142.3 and 136.7 DD's Life table parameters such as net Reproduction Rate (R_o), Mean Generation Time (Gt), Intrinsic Rate of Increase (r_m), Finite Rate of Increase (λ) and Population Double Time (Dt) were calculated at three tested temperatures. **Conclusion:** Estimating thermal heat units of *T. absoluta* help in predicting the field generations of the insect and improve planning the integrated pest management.

Key words: *Tuta absoluta*, developmental threshold, life table, mortality, reproduction rate, thermal heat, pest management

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Egypt is considered the 5th producer of tomatoes in the world because of the high production of tomatoes and high quality. Tomato leaf miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is being one of the most destructive insect pests all over the world, that reduce crop yield and causes great economic losses[1]. It is considered to be one of the key pests attacking tomato fields in South America[2,3], spread fast to Europe in 2006[4]. Then, it invaded Africa in 2007[5,6]. *T. absoluta* was recorded in Egypt in 2009 in the governorates closest to Libya[7], it reached North Sudan in 2011[8]. It attacks not only tomatoes in all the developmental stages but it also attacks some solanaceous plants such as eggplant, pepper and potato[4]. Biondi *et al.*[1] showed that *T. absoluta* causes more than 60% loss in tomato plants which is considered the main host. Larval feeding cause 30% damage in Tunisia in greenhouses[9]. These losses reached to be 100% on tomatoes in Tanzania field[10]. Environmental weather factors are affecting the developmental growth rate of this insect, especially temperature which is considered limiting abiotic factor effect on growth population parameters[11]. High temperature reduces significantly egg hatching percent, survival and insect fecundity[12,13]. Recorded significant differences in sex ratio, where high rates of males were observed at low temperatures. The biological characters of insects are affected by changing temperatures, which affects population density, insect distribution and life parameters[14].

Physical factors directly affect the egg hatchability, growth development and insect behaviour, feeding, female fertility and fecundity[15]. Climatic factors also affect indirectly insect pests by changing some biochemical components and physiological activity in the host plant, therefore it affects insect abundance and behavior[16,17]. Variability in climatic factors leads to changes in biological characteristics of insects, such as developmental rate, duration of stages, insect survival, sex ratio, female fecundity and fertility[18,19]. Martins *et al.*[20] studied the thermal requirements for developing *T. absoluta*. Determination of temperature effects and calculating heat requirements models are based on developmental parameters. The models predict the lower developmental threshold (the development is disturbed when the temperature is below) and the upper developmental threshold (the development is disturbed when temperature above)[21,22].

Monitoring the accumulation of heat units can be used in expecting the pest activity, detect samples timing and pest management[23]. Calculating thermal units required for insect pests' development implicate significantly in pest control[24]. Life table characters are depending on biological parameters that are confirmed by survival, duration of development, fertility and sex ratio[25,26].

Therefore, this research aimed to assess the effect of temperature on different developmental stages of *T. absoluta* expressed by biological parameters. Determination of thermal units required help in forecasting the insect annual generations and expected time for insect fluctuations. This study may help in designing pest management.

MATERIALS AND METHODS

Study area: The study was carried out at the Ecological Studies Laboratory, Faculty of Agriculture, Ain Shams University, Egypt.

Experimental design: Experiments were carried out at the Ecological Studies Laboratory, Faculty of Agriculture, Ain Shams University, Egypt. Four incubators were used to provide constant temperatures of 20, 24, 28 and 32°C, fluctuations at each temperature were approximately ±1°C. Stages from egg to adult were kept under the constant temperature and 60-70% R.H. to determine the developmental rate and all biological aspects for all insect stages.

Rearing technique: The newly hatched larvae of *Tuta absoluta* were reared on an artificial diet mentioned by Bajonero and Parra[27] at 3 constant temperatures (20, 24 and 28°C) and 60-70% R.H. Artificial diet components of insect consist of white bean 75.0 g, wheat germ 60.0 g, soybean flour 30.0 g, casein 37.5 g, yeast 37.5 g, ascorbic acid 3.6 g, sorbic acid 1.8 g, methyl-p-hydroxybenzoate 3.0 g, tetracycline 113.0 mg, formaldehyde 3.6 mL, vitamin mixture 9.0 mL, agar 23.0 mL. Add tomato leaves powder (5%) is modified from Luna *et al.*[28].

Eggs were collected from the breeding cages. Eggs were transferred to glass vials (2.0×7.5 cm). It was incubated under the required conditions of temperature and relative humidity. 20 eggs/glass with 5 replicates were used. Hatchability, incubation period and embryo developmental rates were recorded daily.

To investigate the larval development of *T. absoluta*, larvae were reared on an artificial diet (20 larvae/replicate) with 5 replicates, larvae were reared in a glass tube (7.5×2.5 cm), tubes were stuffed topically with clean cotton to prevent insects from escaping and to allow ventilation. Percentage of pupation, Larval duration were recorded.

Pupated larvae were transferred and placed individually in a glass tube (2.0×7.5 cm), 5 replicates were used

(20 pupa/replicate). Tubes were covered with a piece of cotton. Same conditions of temperature and relative humidity were achieved. Pupal duration and developmental parameters were observed and recorded.

Emerged moths were sexed on the same day (female abdomen is the width and male abdomen is narrow) and transferred to a glass mating cage. Five replicates were used. Each replicate consists of 2 adults, glass cages were placed at the same four tested temperatures. Adult longevity, pre-oviposition periods were estimated. Deposited eggs were collected with a soft brush and counted. Collected eggs were incubated at the same conditions in order.

Calculating the lower developmental threshold and thermal units of *Tuta absoluta* stages: The theoretical developmental threshold was calculated according to eq:

$$y = a+b\,x$$

where, (y) is expressed as a developmental rate of the tested stage, (a) Constant term, (b) Regression coefficient and (x) Temperature[29,30]. To estimate the thermal units needed for different stages to complete development, the following equation was utilized:

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

Where:
K = Thermal units (degree-days)
y = Duration of a developmental stage
T = Tested temperature
t_0 = Lower developmental threshold of tested stage[31]

Life table parameters of tomato leaf miner *T. absoluta*: Fixed numbers of *T. absoluta* eggs were incubated at 3 constant temperatures (20, 24 and 28°C) throughout 1 complete generation (100 eggs for each temperature). The life expectancy and actual population size, after excluding several dead individuals from different developmental stages, were recorded throughout the generation. The life table was constructed according to Nouri-Ganbalani *et al.*[32] based on the data obtained from the effects of the 3 constant temperatures as follows:

- Insect numbers in different developmental stages (x)
- Age-specific and survival rates (l_x)
- Age-specific fecundity (m_x) within a generation (No. of eggs/female)
- Apparent mortality percentage (A.M.%)
- Real mortality percentage (R.M.%)

Construction of life table: Life table for age-specific survival (l_x), the number of dead individuals (dx) during the age interval (x), rate of mortality (qx) during the age class (x to x+1) and for age-specific fecundity (mx) were estimated. Definitions and formulae used to calculate these parameters were summarized as the methods explained by to Damos and Savopoulou-Soultani[26], Bajonero and Parra[27] as follow:

$$R_o = \sum lx \times mx$$

where:
X = Age (in days)
l_x = Age-specific survival rates
m_x = Female fecundity
R_o = Net reproductive rate

$$Gt = \frac{lx \times mx \times x}{R_o}$$

Gt = Generation time:

$$r_m = \frac{\log e^{R_o}}{Gt}$$

r_m = Intrinsic rate of increase:

$$Dt = \frac{\text{Log } e^2}{r_m}$$

Where:
λ = Finite rates of increase ($\lambda = e^{rm}$)
Dt = Population double time

Statistical analysis: Data analysis was performed to determine the differences between biological parameters at tested temperatures by using the SAS Program, (one-way analysis of variance, ANOVA) (https://support.sas.com/documentation/onlinedoc/91pdf/sasdoc_91/stat_ug_7313.pdf). Significant differences were grouped by the Least significant differences tests in the SAS program.

RESULTS

Lower developmental threshold and thermal units for immature stages of *Tuta absoluta*

Lower developmental threshold and thermal units for the egg stage: Table 1 illustrated that the needed time for the incubation period decreased as the temperatures increased. The means of incubation periods were 6.8, 5.0, 4.0 and 3.5 days at 20, 24, 28 and 32°C, respectively. According to the

Table 1: Duration (days, Mean±SE) of immature stages of *Tuta absoluta* and thermal requirements recorded at constant temperatures

		Egg			Larva			Pupa	
Temperature (°C)	Incubation period	Hatchability (%)	Thermal DD's units	Larval duration	Thermal units DD's	Mortality (%)	Pupal duration	Thermal units DD's	Mortality (%)
20	6.8±0.18[d]	72±0.39[c]	88.4	30.9± 0.9[a]	309.0	52[c]	15.8±0.3[a]	138.6	10.0[a]
24	5.0±0.0[c]	89±0.38[b]	85.0	21.9±0.3[b]	306.6	74[b]	9.5±0.1[b]	121.5	5.0[b]
28	4.0±0.0[b]	97±0.39[a]	84.0	17.6±0.7[c]	316.8	74[b]	8.1±0.4[c]	136.6	1.0[c]
32	3.5±0.0[a]	95±0.32[a]	87.5	-	-	100[a]	-	-	-
Mean	4.8	86.2	23.5	310.8		11.1	132.2		
F-value	96.8	36.8	-	83.29	-	770.7	179.9	-	91.5
LSD	0.44	1.12	-	2.29	-	2.3	0.9	-	1.6

Mean values followed by the same letter in a column are significantly not different at p = 0.05

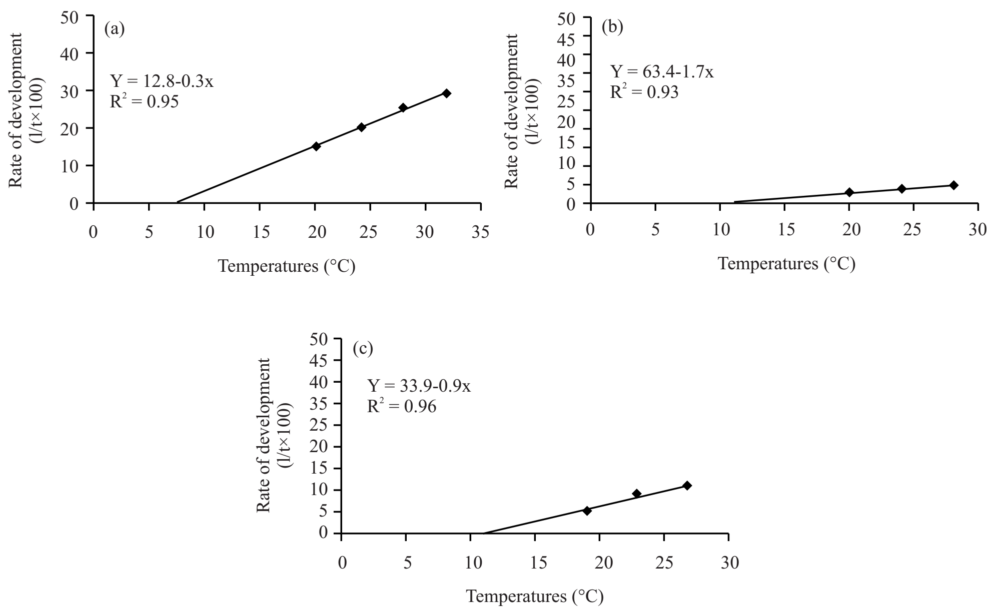

Fig. 1(a-c): Mathematical model between temperatures and developmental rate of *T. absoluta*, (a) Egg stage, (b) Larval stage and (c) Pupal stage

analysis of variance, highly significant differences between tested temperatures were recorded.

Data represented the percentage of hatchability where it recorded 72, 89, 97 and 95% under 20, 24, 28 and 32°C, respectively. Statistically, there are significant differences between the value of hatchability percent recorded at 20 and 24°C, whereas there are no significant differences between the recorded values at 28 and 32°C. It appears that the favourable temperature for the egg hatching ranged from (24-32°C). The average of thermal units required for the completion of the developmental incubation period was 86.2 DD's.

Data obtained for the egg incubation period at the four tested temperatures were used to estimate zero of development for the egg stage. Results are graphically illustrated in Fig. 1a showed that the value of zero development for egg stage was 7.0°C.

Lower developmental threshold and thermal units for the larval stage: The mean larval durations under 3 constant temperatures 20, 24 and 28°C, recorded 30.9, 21.9 and 17.6 days, respectively. The statistical analysis supported significant differences between three constant temperatures. Results are graphically illustrated in Fig. 1b whereas zero of development for the larval stage was 10°C. It could be stated that 28°C seemed to be the most favourable for the rearing larval stage. The mean needed thermal unit was calculated as 310.8 DD's. Data appeared that the highest percentage of mortality has occurred at 32°C. where it reached 100%, followed by 24 and 28°C it recorded 74%. while it recorded 52% at 20°C.

Lower developmental threshold and thermal units for the pupal stage: The needed time for the pupal stage of *T. absoluta* was recorded at 3 constant temperatures 20, 24

Table 2: Duration (days, Mean±SE) of pre-oviposition, oviposition, and post-oviposition periods of *T. absoluta* and thermal requirements recorded at constant temperatures

Temperature (°C)	Pre-oviposition Duration	Pre-oviposition Thermal units DD's	Oviposition Duration	Oviposition Thermal units DD's	Post-oviposition Duration	Post-oviposition Thermal units DD's
20	2.6±0.5[a]	13.0	9.2±0.3[a]	128.8	3.4±0.5[a]	16.3
24	2.2±0.2[a]	19.8	6.6±0.2[b]	108.0	2.6±0.2[b]	22.9
28	1.0±0.0[b]	13.0	5.8±0.2[b]	127.6	1.4±0.1[c]	17.9
Mean	1.9	15.2	7.2	121.2	2.5	19.03
F-value	6.9	-	39	-	10.8	-
LSD	0.97	-	0.94	-	0.78	-

Mean values followed by the same letter in a column are significantly not different at p = 0.05

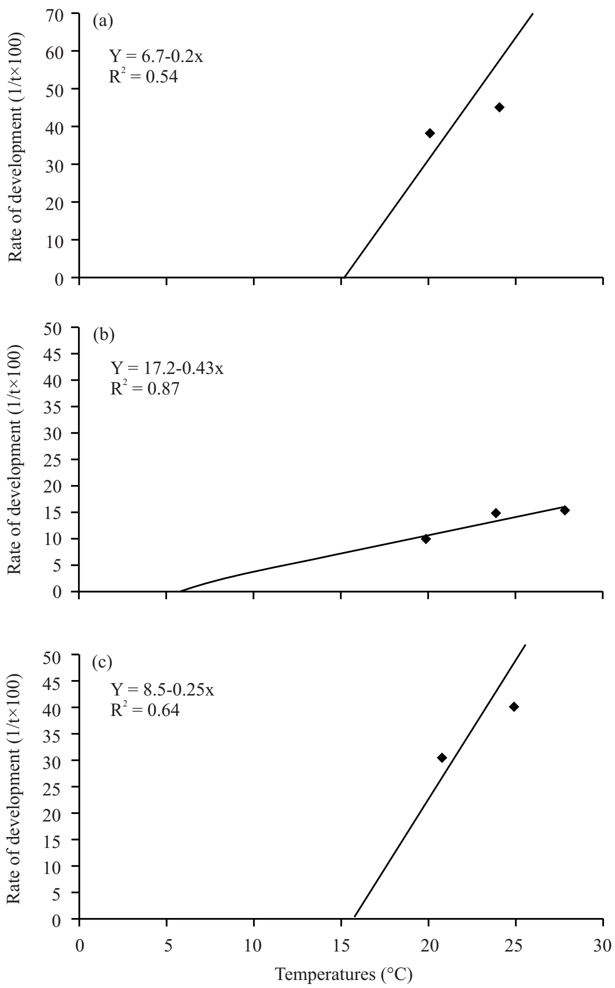

Fig. 2(a-c): Mathematical model between temperatures and developmental rate of *T. absoluta*, (a) Pre-oviposition period, (b) Oviposition period and (c) Post-oviposition period

and 28°C, which seems to be 15.8, 9.5 and 8.1 days, respectively. Significant differences were investigated as shown in Table 1. Developmental zero of the pupal stage is graphically illustrated in Fig. 1c, is estimated to be 11.2°C. Results revealed the mean thermal units required for the pupal stage of *T. absoluta* were 132.3.5 DD's.

The highest percentage mortality of pupal stage was calculated at 20°C to be 10.0%, while it recorded 1.0% at 28°C which is considered the lowest percentage mortality. From these results, it could be stated that 28°C seemed to be the most favourable temperature where the lowest percentage of mortality occurred throughout the pupal stage.

Lower developmental threshold and thermal units for the adult stage of *Tuta absoluta*

Pre-oviposition, oviposition and post-oviposition period: Table 2 showed the pre-oviposition, oviposition and post-oviposition period. The pre-oviposition period decreased as the temperature increased, where it recorded 2.6, 2.2 and 1.0 days at 20, 24 and 28°C, respectively. The threshold of development needed for this period is illustrated graphically in Fig. 2a, it is estimated to be 15°C. Notably, the rising of temperature expedites the rate of development of the female's ovaries. The mean thermal units required for the development of ovaries was calculated as 15.2 DD's.

The oviposition period was found to be the longest period. The longest mean duration was recorded at 20°C to be 9.2 days, followed by those reared at 24 and 28°C to be 6.6 and 5.8 days. The estimated threshold of development was 6°C as shown in Fig. 2b. The mean thermal units required for the oviposition period were calculated as 121.12 DD's.

The statistical analysis supported that temperature had a highly significant effect on pre-oviposition, oviposition and post- oviposition period at the tested constant temperatures. Mean duration of post- oviposition period of *T. absoluta*. The longest mean duration was occurred at 20°C to be 3.4 days, followed by those at 24 and 28°C, where it recorded 2.6 and 1.4 days. The threshold of development was 15.2°C (Fig. 2c). The mean thermal units required for the post-oviposition period were calculated as 19.03 DD's.

Female and male longevity: The longevity of females and males are represented by the time elapsed between an adult's

Table 3: Duration (days, Mean±SE) of female and male longevity of *T. absoluta* and thermal requirements recorded at constant temperatures

	Female			Male		Generation	
Temperature (°C)	Female longevity	Thermal units DD's	Fecundity	Male longevity	Thermal units DD's	Generation period	Thermal units DD's
20	15.6±0.5[a]	137.3	57.8±5.8[c]	12.8±0.4[a]	130.6	56.1±1.6[a]	533
24	11.8±0.4[b]	151	79.3±5.8[b]	10.2±0.4[b]	144.8	38.6±0.3[b]	521.1
28	8.2±0.4[c]	137.8	145.3±2.9[a]	7.4±0.3[c]	134.7	30.7±0.4[c]	537.3
Mean		142.3	94.13	10.13	136.7	41.8	529.4
F-value	52.16	-	83.2	64.4	-	392.8	530.4
LSD	1.5	-	17.3	1.04	-	2.3	-

Mean values followed by the same letter in a column are significantly not different at p = 0.05

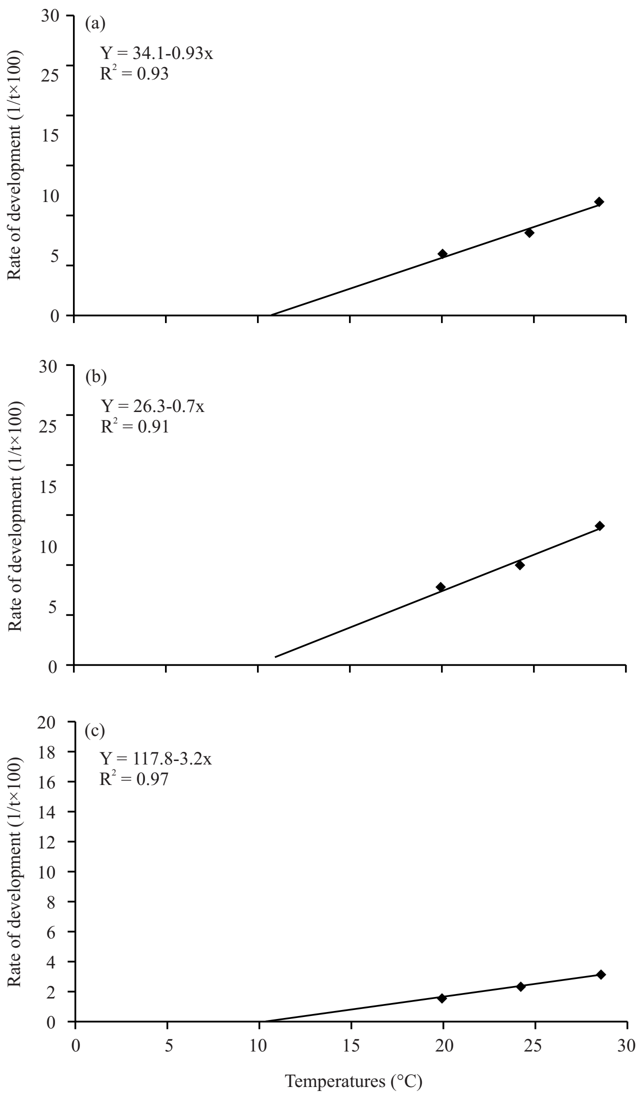

Fig. 3(a-c): Mathematical model between temperatures and developmental rate of *T. absoluta*, (a) Female longevity, (b) Male longevity and (c) Generation

emergence from pupae until death. Data obtained about the effect of the 3 constant temperatures on the longevity of both females and males of *T. absoluta* are given in Table 3. Results of the statistical analysis proved that 3 constant temperatures had highly significant effects on the means longevity of both sexes.

The female longevity was estimated to be longer than male longevity at the 3 tested temperatures. Means longevity were 15.6, 11.8 and 8.2 days at 20, 24 and 28°C, respectively.

The threshold of development was indicated by extrapolation Fig. 3a, this value was 11.2°C. The mean thermal units required for adult females was 142.3 DD's.

Male longevities were recorded to be 12.8, 10.2 and 7.4 days, at 20, 24 and 28°C, respectively. The threshold of development was indicated by Fig. 3b to be 9.8°C. The average thermal units needed for adult males were calculated as 136.7.

Female fecundity and egg fertility: The reproductive potentiality is expressed as the total number of deposited eggs per female during its longevity. Data obtained of female fecundity of *T. absoluta* which was reared at the 3 constant temperatures are given in Table 3.

By increasing temperature, the female ability to lay eggs is increased. That is confirmed by statistical analysis as recorded highly significant differences. The highest mean fecundity was occurred at 28°C to be 145.3 eggs/female, followed by those reared at 24 and 28°C to be 79.3 and 57.8 eggs/female, respectively.

Egg fertility is expressed by egg hatchability, highly significant differences were observed when utilizing statistical analysis. The highest mean of egg hatchability was 97%, which occurred at 28°C, while the lowest fertility recorded was 72% at 20°C.

Total generation duration: Table 3 indicated duration of generation of *T. absoluta* under 3 constant temperatures had highly significant means generations duration (F = 392.8 sig. at 0.001 and L.S.D. = 2.3 days) whereas the shortest duration of generation was achieved at 28°C to be 30.7 day,

Table 4: Life table parameters of *T. absoluta* from egg to adult stage reared on 3 constant temperatures

Temperature (°C)	Stage	Number of individuals dead (dx)	Apparent mortality (%)	Real mortality (%)
20	Egg	28	28	28.00
	Larva	52	72.2	52.0
	Pupa	10	50	10.0
	Total	90		
	Adults (male and female)	10	-	-
24	Egg	3	3	3.0
	Larva	74	76.3	74.0
	Pupa	5	21.7	5.0
	Total	82		
	Adults (male and female)	18	-	-
28	Egg	11	11	11.0
	Larva	74	83.1	74.0
	Pupa	1	6.7	1.0
	Total	86		
	Adult (male and female)	14	-	-

followed by 38.6 days at 24°C., while the longest occurred at 20°C recorded as 56.1 days. On the other hand, the threshold of development was indicated by Fig. 3c, this value was 10.5 °C. The average thermal constant required for completing the development of generations was 530.4 DD's.

Life table parameters of *Tuta absoluta*: This study aimed to investigate the biotic potential of insects, expressed as duration, survival and developmental rate for all tested stages. Table 4 revealed that both apparent and real mortalities are different according to stage and temperature. One hundred eggs were incubated for each tested temperature. At 20°C, 10 adults were obtained at the end of the generation, while at 24°C and 28, 18 and 14 adults were obtained, respectively.

The percentage of eggs mortalities (apparent & real) at three tested temperatures were recorded. The highest percentage of mortalities were occurred at 20°C to be 28%, followed by 11% at 28°C, while the lowest value was occurred at 24°C to be 3%. It seemed that 24°C seemed to be the most favourable for egg stage incubation. For larval stage, the percentages of apparent mortalities and real mortalities were 72.2 and 52% at 20°C, 76.3 and 74% at 24°C and 83.1 and 74% at 28°C, respectively. These results indicated that the larval stage is considered a critical stage for this insect, where it showed the highest apparent and real mortalities. The apparent and real mortalities of the pupal stage were 50 and 10% at 20°C, 21.7 and 5% at 24°C and 6.7 and 1% at 28°C, respectively. Obtained results indicated that the highest percentage of egg hatchability and the lowest percentages of mortalities of most different stages occurred at 24°C. The biological parameters of tomato leaf miners *T. absoluta* expressed as survivors (l_x) and female fecundity rates (m_x) at three constant temperatures 20, 24, 28°C were tabulated in Table 5-7.

Survival and female fecundity rates: Obtain data from previous biological studies of *T. absoluta* were used to calculate biological parameters at 3 tested temperatures as summarized in Table 8. Life table parameters were calculated as follow:

- **Net reproduction rate (R_o):** Results of net reproduction rate indicated that *T. absoluta* female can give the highest birth average being 10.03 at 28°C, followed by 6.29 at 24°C and 2.85 at 20°C while the lowest birth average was 2.85 at 20°C
- **Mean generation time (Gt):** Results of generation time showed that the generation time of *T. absoluta* varied at the 3 tested temperatures. The shortest generation time was obtained at 28°C being 33.92, followed by those at 24°C being 41.37 days while the highest was being 59.58 days at 20°C
- **Intrinsic rate of increase (r_m):** The intrinsic rate of increase refers to the rate of daily population growth and is considered an important index of potential population performance. The calculated values of the intrinsic rate of increase showed that these rates for *T. absoluta* adult were affected by the tested temperatures. The highest intrinsic rates individual/day were obtained at 28°C being 0.13 individual/day, followed by 24°C beings (0.07 individual/day), while the lowest was being 0.02 individual/day at 20°C
- **Finite rate of increase (λ):** The finite rate of increase (λ) or (e^{rm}) is considered the discrete version of (r_m). The calculated values of finite rate of increase of *T. absoluta* followed the same trend which occurred for the intrinsic rate of increase. The highest values were 1.14 female/day at 28°C, followed by those at 24°C being 1.07 females/day, while the lowest value was 1.02 females/day at 20°C

Table 5: Age specific of *T. absoluta* survivors (l_x) and female fecundity rates (m_x) at constant temperature 20°C

Stage	Age/days (x)	No. of observations	Survivors (l_x)	Fecundity (m_x)	$l_x \times m_x$	$l_x \times m_x \times x$
Egg	6.8	100	1.00			
Larva	30.9	72	0.72			
Pupa	15.8	20	0.2			
Female	54.5	6	0.06	0.00	0.00	0.00
	55.5	6	0.06	0.00	0.00	0.00
	56.5	6	0.06	0.00	0.00	0.00
	57.5	5	0.05	20.00	1.00	57.50
	58.5	5	0.05	3.00	0.15	8.78
	59.5	5	0.05	16.40	0.82	48.79
	60.5	5	0.05	4.00	0.20	12.10
	61.5	4	0.04	4.00	0.16	9.84
	62.5	4	0.04	8.60	0.34	21.25
	63.5	4	0.04	2.80	0.11	6.99
	64.5	4	0.04	1.00	0.04	2.58
	65.5	3	0.03	1.00	0.03	1.97
	66.5	3	0.03	0.00	0.00	0.00
	67.5	2	0.02	0.00	0.00	0.00
	68.5	2	0.02	0.00	0.00	0.00
	69.5	1	0.01	0.00	0.00	0.00
Total					2.85	169.8

Table 6: Age specific of *T. absoluta* survivors (l_x) and female fecundity rates (m_x) at constant temperature 24°C

Stage	Age/days (x)	No. of observations	Survivors (l_x)	Fecundity (m_x)	$l_x \times m_x$	$l_x \times m_x \times x$
Egg	5	100	1.00			
Larva	21.9	97	0.97			
Pupa	9.5	23	0.23			
Female	37.4	10	0.10	0.00	0.00	0.00
	38.4	10	0.10	0.00	0.00	0.00
	39.4	10	0.10	10.25	1.03	40.58
	40.4	9	0.09	19.25	1.73	69.89
	41.4	9	0.09	13.00	1.17	48.44
	42.4	8	0.08	17.50	1.40	59.36
	43.4	7	0.07	9.50	0.67	29.08
	44.4	5	0.05	5.75	0.29	12.88
	45.4	4	0.04	0.00	0.00	0.00
	46.4	3	0.03	0.00	0.00	0.00
	47.4	1	0.01	0.00	0.00	0.00
Total					6.29	260.23

Table 7: Age specific of *T. absoluta* survivors (l_x) and female fecundity rates (m_x) at constant temperature 28°C

Stage	Age/days (x)	No. of observations	Survivors (l_x)	Fecundity (m_x)	$l_x \times m_x$	$l_x \times m_x \times x$
Egg	4	100	1.00			
Larva	17.6	89	0.80			
Pupa	8.1	15	0.15			
Female	30.7	8	0.08	0.00	0.00	0.00
	31.7	8	0.08	19.75	1.58	50.09
	32.7	8	0.08	37.75	3.02	98.75
	33.7	8	0.08	16.75	1.34	45.16
	34.7	7	0.07	20.75	1.45	50.32
	35.7	7	0.07	17.00	1.19	42.48
	36.7	5	0.05	24.25	1.21	44.41
	37.7	3	0.03	8.00	0.24	9.05
	38.7	1	0.01	0.00	0.00	0.00
	39.7	0	0.00	0.00	0.00	0.00
Total					10.03	340.26

Table 8: Summary of life table parameters for *Tuta absoluta* reared under 3 constant temperatures (20, 24 and 28°C) and laboratory conditions

Temperature (°C)	Net reproductive rate (R_o)	Generation time/day (Gt, days)	Intrinsic rate of increase (r_m, day^{-1})	Finite rate of increase (λ, day^{-1})	Population double time (Dt)
20	2.85	59.58	0.02	1.02	43.43
24	6.29	41.37	0.07	1.07	12.41
28	10.03	33.92	0.13	1.14	6.68

- **Population double time (Dt):** Results investigated that the population of *Tuta absoluta* reared at 20°C had the longest double generation value 43.43 days, followed by 24°C beings (12.41 days). The shortest double generation value was (6.68 days) which occurred at 28°C

From these results, it could be concluded that 28°C seemed to be the optimum degree for rearing *T. absoluta* on tomatoes. At this degree, both female fecundity and net reproductive rate, intrinsic rate of increase and finite rate of increase recorded their maximum values and population doubling time recorded its minimum value.

DISCUSSION

Observed results revealed that both rates of development and thermal constant units for all stages were affected by the prevailing temperatures. The rate of development was increased gradually as the temperature increased from 20-32°C [33,34]. About 32°C is a fetal high degree temperature to the larval stage of *T. absoluta* especially for first instars whereas, all 1st instars are dead. The obtained results for immature stages were in harmony with Lakshmi *et al.*[35] who recorded that the incubation period of *T. absoluta* egg was 4.6±0.05 days at (24.5-31.2°C). The larval period of *Tuta absoluta* was 11.9±0.15 days 31.2°C, while for pupa, the time needed for this stage was 6.5±0.33 days at 24.5-31.2°C. Erdogan and Babaroglu[36] in Turkey found that the incubation period of *Tuta absoluta* egg was 4.1 days at 25±1°C and 65±5 R.H% under long daylight (16L: 8D). The total period needed for the larval stage of *T. absoluta* was 10.97 days at 25°C. They also recorded the period of pupae to be 9.53 days at 25°C.

Cuthbertson *et al.*[25] in the UK, recorded only 17% of egg hatchability at 10°C but no larvae developed at this temperature, in addition, no recorded hatchability at 7°C. they investigated 52% survival of *Tuta absoluta* from egg to adult at 19°C. It is concluded to investigate that 28°C is considered as the optimum degree for eggs hatchability.

The obtained results were agreed with Marchioro *et al.*[37] who calculated the lower threshold temperature for *T. absoluta* egg as 6.9°C., while the thermal constant for this stage was 103.8 DD's. For the larval stage, they recorded slightly different results, where the lower threshold temperature for the larval stage was 7.6°C and the thermal constant was 238.5 DD's. For the pupal stage, they calculated the lower threshold temperature of *Tuta absoluta* pupae to be 9.2°C and estimated the thermal units required for the pupal stage as 117.3 DD's.

The study assured the highest recorded mortality of this insect occurred during the larval stage, because of the temperature condition. The tomato leaf miner *T. absoluta* lives in a tunnel during the larval stage. Microclimatic conditions in tunnels are favourable for insect feeding and development. The temperature inside these tunnels is warmer than outside[38,39]. So, it may record high mortality at extreme temperatures.

Pre-oviposition, oviposition and post-oviposition periods are significantly influenced by changing temperature, where it affects the needed time for development. Pre-oviposition, oviposition and post-oviposition periods were significantly longer at 20°C than other temperatures. Krechemer and Foerster[11] in Brazil, studied the effect of temperature on the oviposition period at four constant temperatures. Egg fertility was the highest at 20 and 25°C. They recorded that the pre-oviposition period at 10°C was longer at the other tested temperatures. They mentioned that the oviposition period of *T. absoluta* was similar at all the tested temperatures. They also demonstrated that the post-oviposition period was 5.52 days at 25±1°C, relative humidity 65±5% and under long daylight (16L:8D). The researchers recorded no differences in longevity for both sexes.

Our results were closely related to the finding of Erdogan and Babaroglu[36], the pre-oviposition period of *T. absoluta* was 1.28 days at 25±1°C. Oviposition period recorded 7.88 days at 25±1°C, relative humidity 65±5%. They demonstrated fecundity of *T. absoluta* was found 141.16 eggs/female in a climate chamber at 25±1°C, relative humidity 65±5% and under long daylight (16L:8D)

Temperatures correlated inversely with female and male longevity. The life cycle tends to be shorter at low temperatures because the biological and physiological parameters is being faster at high temperatures. Osman *et al.*[40] in Egypt, mentioned that the longevity of males or females of *T. absoluta* decreased as temperature increased. They recorded the daily average fecundity of females to be 15.78, 18.19, 34.65 and 28.26 eggs at 15, 20, 25 and 30°C, respectively. Moreover, they reported *T. absoluta* failed to survive at 35°C due to the high mortality that occurred in reared insects. Obtained results showed congruity with Guimapi *et al.*[41] who found the duration of *T. absoluta* for females ranges between 10 and 15 days, while for males it takes 6-10 days. Torres *et al.*[42] found that female longevity of *T. absoluta* needs 10-22 days. From the results, it could be stated that temperature 28°C seemed to be the most favourable condition for rearing *T. absoluta* under laboratory conditions. The reported results are close to Marchioro *et al.*[37] who stated the life cycle of *T. absoluta* takes 76.3 days at 14°C and 23.8 days at 27°C. Abolmaaty *et al.*[43] in Egypt, found that needed time from egg to adult of *T. absoluta* recorded 61 days at 17°C. Cuthbertson *et al.*[25] in the UK, determined the longest developmental life cycle to be 72 days at 13°C but the shortest estimated recorded was 35 days at 25°C. Tadele and Emana[44], calculated lower and upper temperatures by mathematical models, it ranged 8.9-12.5 and 35.9- 38.5°C, respectively. Developmental zero and heat units required for completing generation are estimated to be 8.94°C and 419.46 degree-days. Salama *et al.*[45] in Egypt, investigated corresponding results, where they recorded the needed time for insect generation reared at 26.03°C as 38.49 days while this period increased to be to 79.5 days at 15.32°C. Saeedeh *et al.*[46] estimated the thermal requirements for *T. absoluta*, the researchers reported that rising global temperatures developed the growth rates of pests, by changing the life cycle activity and the population growth rates.

Knowledge about life table parameters is very important due to reflecting the main effect of temperature on the survival and reproduction of insects[47]. When considered the influence of temperature on the developmental growth rates, the results in being crucial[48].

The results are agreed with the obtained by Nouri-Ganbalani *et al.*[32] who recorded that the total population mortality of tomato leaf miner was 92.3%, where it reached the highest mortality for the larval stage to be 79.8%. The mortality of the pupal stage was the lowest (0.6%) due to malformation. Martins *et al.*[20] investigated the significant effect of temperature on net reproductive Rate (R_0), Generation Time (T) and Intrinsic Rate Increase (rm). Pereyra and Sanchez[49] found that Net Reproductive Rate (R_o), Intrinsic Rate of Increase (r_m) and Generation Time (T_o) of *T. absoluta* were: R_o = 48.92, T_o = 27.98, r_m = 0.14. Erdogan and Babaroglu[36] in Turkey, found that, the Intrinsic Rate of Increase (r_m), Finite Population Increase (λ), Net Reproductive Rate (R_o) and Mean Generation Time (Dt) of *T. absoluta* were 0.13, 1.14 days, 42.01 and 28.25 days, respectively. Torres *et al.*[42]. In Egypt, recorded that life table analysis of the population of *T. absoluta* reared at 30°C had the highest intrinsic rate of increase (0.75), net reproductive rate (28.28), shortest population doubling time (0.93 days) and mean generation time (4.49 days), comparing to populations reared at 15, 20 and 25°C. Therefore, the optimum temperature for the population growth of *Tuta absoluta* ranged between 20-30°C. It could be conducted that life table parameters are reflecting the effect of temperatures on different developmental stages of the insect. Rostami *et al.*[50] demonstrated that the net Reproduction Rate (R_0) of *T. absoluta* on 3 tomato cultivars was determined to be 15.73, 17.66 and 10.03 eggs. Different hosts, different varieties and different areas play an important role in the survival, developmental rate and insect reproduction. Silva *et al.*[51] clarified that solanaceous host plant effect on the oviposition potentiality, therefore effect on the developmental parameters[25,52].

Realizing more information about insect life cycle duration and survival rate at different temperatures is very important to perceive insect behaviour and biology. These data will help not only the distribution but also the invasive potential of pests. In addition, taking up the biological control strategy at a suitable time instead of excess using chemical insecticides.

CONCLUSION

The researchers clarified the influence of temperatures on the biological developmental parameters of tomato leaf miner *T. absoluta*. The obtained results elucidated that the developmental zero of this insect is 10.5°C. The average of thermal heat units needed for completing the development of generations was recorded as 530.4 DD's. The provided data help in forecasting the annual generation, the timing of insects appearing in the field, timing of pesticides application and therefore improve planning strategies of management for this destructive insect pest.

SIGNIFICANCE STATEMENT

This study discovers the heat units required for different developmental stages of *T. absoluta* that can be beneficial for predicting the insect infestation, annual generations, when and how to control. This study will help the researcher to uncover the critical areas of utilizing thermal units in controlling pests, that many researchers were not able to explore. Thus, a new theory of using the mathematical formulas for insect management may be arrived at.

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