Article

Temperature dependent development of poinsettia, *Euphorbia pulcherrima*, and its parasite sweetpotato whitefly, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae)

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Abstract
The present study demonstrated that development of the ornamental plant poinsettia *Euphorbia pulcherrima* Willd Ex Koltz was determined by temperature. The expected lower temperature threshold, optimal temperature, and upper temperature threshold for leaf sprouting of poinsettia was 19.2, 32.8, and 37.6℃, respectively. The effective cumulative day degrees for the development of single leaf of poinsettia were 21.8. The dynamic models for the number of leaves per poinsettia plant, the total foliage area per poinsettia plant, and the height of poinsettia plant were developed as follows: N=-1.86+0.05D, A=-80.60+2.12 D, H=-0.71+0.04D, where D is the effective cumulative day degrees, N, A, and H are the number of leaves per plant, the total foliage area per plant (cm^2), and the height of plant (cm), respectively. The development and fecundity of the sweetpotato whitefly *Bemisia tabaci* Genn., the insect pest of poinsettia, are greatly determined by temperature. The present study revealed that the expected lower temperature threshold for development of egg, 1^{st} to 4^{th} instar nymphs, pupae, and immature of *B. tabaci* fed on poinsettia was 12.6, 12.2, 8.4, 6.9, 9.5, 12.6, and 9.8℃, respectively; the optimal temperature for development was 30.8, 31.5, 29.7, 31.4, 30.3, 31.3, and 31.0℃, respectively; the upper temperature threshold for their development was 39, 36.9, 36.7, 36.4, 36.5, 36.2, and 36.6℃, respectively. The temperature range for development of *B. tabaci* was between 6 to 39℃, and the favorable temperature range was between 29 to 32℃. The egg had the strongest tolerance to high temperature. The effective cumulative day degrees for development of egg, 1^{st} to 4^{th} instar nymphs, pupae, and immature stage were 74.1, 56.5, 64.1, 44.4, 29.9, 16.8, and 204.1, respectively. The effective cumulative day degrees for development generally decreased from egg to pupae. The favorable temperature for egg laying was in the range of 27 to 36℃. The expected maximum number of eggs laid daily per adult in unlimited living space could be reached at 30.8℃. The stronger density dependence of fecundity was found in female adults of *B. tabaci*. Fecundity of *B. tabaci* was comprehensively affected by temperature and adult density on host plant poinsettia. Temperature dependence was more important than density dependence in the determination of fecundity. The expected maximum number of eggs laid daily per adult in unlimited living space was 0.57, 4.53, 11.23, 15.32, and 13.10 at the temperature 12.0, 16.0, 21.0, 27.0, and 36.0℃, respectively.

Keywords poinsettia; *Bemisia tabaci*; temperature; development; adult density; fecundity.

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1 Introduction

Poinsettia (*Euphorbia pulcherrima* Willd Ex Koltz) is an important ornamental plant (Chong et al., 2014; Olberg and Lopez, 2016). It is even called Christmas Star by people. Moreover, it is a Chinese medicinal plant (Zhang, 2017a-d). So far many research have been made to exploit the growth and development of poinsettia (Chong et al., 2014; Olberg and Lopez, 2016). However, we still lack of detailed studies on temperature dependent growth relationships and parameters of poinsettia in the whole range of temperature (between lower temperature threshold and upper temperature threshold).

Sweetpotato whitefly, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae), is a significant foliar insect pest damaging on cotton, tomoto, poinsettia and some other crops (Mound, 1965;Sundaramurthy, 1992; Minkenberg et al., 1994; McKenzie et al., 2014). Temperature dependent development and fecundity of this insect pest have been partially approached on such plants as cotton and tabacco. Compared the previous reports, it can be found that there were certain differences among development rates of *B. tabaci* on different host plants tested (Bethke et al. 1991). For example, the life cycle of *B. tabaci* was 27.3 days on tomato but only 21.7 days on cotton, which was a significant difference (Coudriet et al., 1985). Significant differences of fecundity on different host plants and at different temperatures were also found, e.g., the total number of eggs laid was 81 at 26.7℃ and, was 72 at 32.2℃ (Butler et al., 1983). Up till now, temperature dependent developments and density dependent fecundity of *B. tabaci* in the whole range of temperature, especially when feeds on host plant poinsettia, have not yet been studied in detail.

The present study aimed to exploit the detailed development – temperature relationship and biological parameters of poinsettia and *B. tabaci* in the whole range of temperature, in order to provide valuable data for further studies and application.

2 Materials and Methods

2.1 Experimental design

Five temperature treatments, i.e., 16.0, 22.0, 25.0, 28.0, and 36.0℃, two to three replicates for each treatment, were used to determine the temperature dependent development of *B. tabaci*. For density dependent fecundity, five temperature treatments, i.e., 12.0, 16.0, 21.0, 27.0, and 36.0℃, were designed. At 27.0℃, nine adult density treatments, i.e., 0.26, 0.39, 0.53, 0.66, 1.06, 1.19, 1.32, 3.18, and 3.31 whitefly adults per square centimeter leaf, and at other temperatures, seven density treatments, i.e., 0.26, 0.44, 1.32, 2.2, 3.08, 3.96, and 4.85 whitefly adults per square centimeter leaf, were used.

Four temperature treatments, i.e., 21.0, 24.0, 26.0, and 36.0℃, three replicates for each treatment, were used to determine temperature dependent development of poinsettia. The plant poinsettia were raised from 4-5 leaves of seedlings in the pots, then moved into laboratory with 50%-80% RH and temperature treatments as indicated, and received artificial lights (40 watt Gro-Lux plant florescent tubes).

In the experiment for temperature dependent development of *B. tabaci*, plants were received 10-20 whitefly adults to deposit eggs. On one leaf of each plant, adults were limited with clip cage. After 12 hs of egg depositing, all adults and clip cages were removed from plants. Thereafter, record the development time of every life stage of *B. tabaci* at each temperature treatment every day until the adults emerge. For density dependent fecundity, on one leaf of each plant, whitefly adults were limited with clip cage to lay eggs. After 24 hs, all adults were removed from the plants, and started to record the number of eggs laid on each plant.

In another experiment for poinsettia growth, record the number of leaves per plant, total foliage area per plant and plant height at each temperature treatment every other day.

2.2 Data analysis

Various models for insect development, such as Stinner et al. (1975) model, Logan et al. (1976) models, Sharpe and DeMichele (1977) model, Wang et al. (1982) model, and Lactin et al. (1995) model can be used to describe the development-temperature relationship (Lee et al. 2000). According to the criteria described by Got et al. (1997) and Briere and Pracros (1998), Wang et al. (1982) model was used in present analysis. This nonlinear model is biologically meaningful and included more useful temperature parameters. The equation is described as

$$v=[K/(1+e^{-r(T-T0)})](1-e^{-(T-Tl)/\delta})(1-e^{-(Th-T)/\delta}) \quad (1)$$

where T: temperature (°C), v: development rate which is the reciprocal of development time (1/day), r: growth rate of development rate with the temperature, Tl, $T0$, and Th: lower temperature threshold, optimal temperature, and upper temperature threshold, respectively, K and δ: constants.

A non-linear SIMPLEX algorithm was used to solve the parameters in eq. (1) (Zhang et al. 1989; Zhang et al., 1997).

Linear regression was used to describe the effective cumulative day degrees for development and density dependence of *B. tabaci*, and the temperature dependence of poinsettia. The effective cumulative day degrees for every life stage in normal temperature range, i.e., the daily cumulation of temperatures equaling to or less than the optimal temperature, can be calculated from the formula:

$$v=-c/s + T/s \quad (2)$$

where v, T: development rate and temperature, respectively, s: effective cumulative day degrees, c: lower temperature threshold.

In the analysis on adult density and temperature dependent fecundity, multi-variable regression was also used.

3 Results

3.1 Temperature dependent development of poinsettia

Calculating the average development time between the two dates that generate new leaves, the development rate of poinsettia leaf can be obtained (Fig. 1).

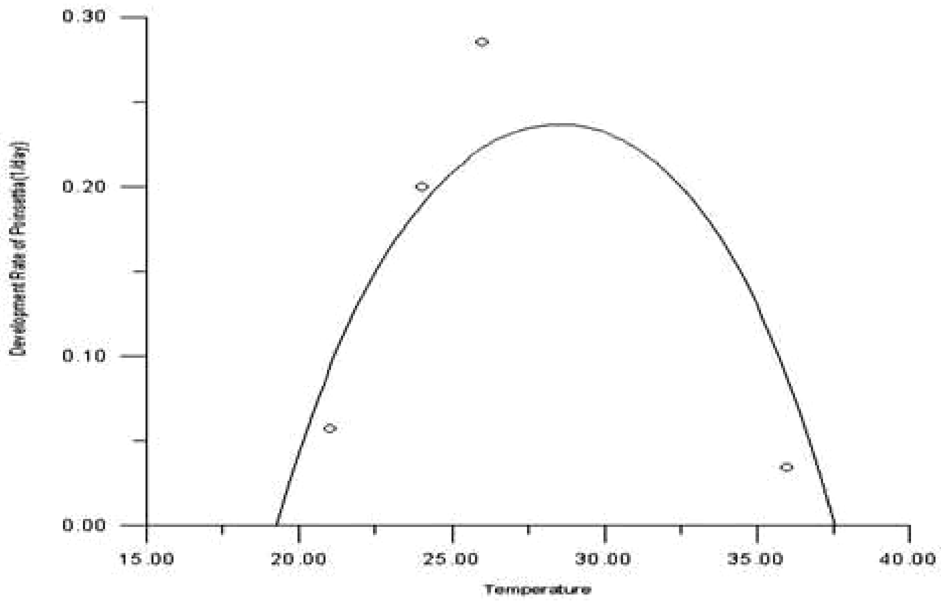

Fig. 1 Relationship between temperature (℃) and development rate (1/day) of poinsettia leaf. Real line is the simulated relationship based on eq. (1), where K=0.7, r=0.0058, $T0$=32.83, Tl=19.23, δ=5.21, and Th=37.56.

Based on eq. (1), the expected lower temperature threshold, optimal temperature, and upper temperature threshold for leaf sprouting of poinsettia is estimated as 19.2, 32.8, and 37.6℃, respectively (Fig. 1). It is suggested that the poinsettia is a plant with high temperature tolerance. The temperature range for leaf producing is approximately between 19 and 38℃. The effective cumulated day degrees for the development of single leaf of poinsettia, calculated from eq. (2), are 21.8. Comparing these parameters to that of *B. tabaci*, we can find the close coincidence of temperature requirements for developments of poinsettia and *B. tabaci*.

In the indoor temperature range, the dynamic models for the number of leaves per plant (eq. (3)), the total foliage area per plant (eq. (4)), and the height of plant (eq. (5)) are developed as follows

$$N = -1.86 + 0.05\,D \qquad r^2=0.94,\ \mathrm{df}=47,\ F=748.3,\ p<0.01 \qquad (3)$$

$$A = -80.60 + 2.12\,D \qquad r^2=0.94,\ \mathrm{df}=47,\ F=748.3,\ p<0.01 \qquad (4)$$

$$H = -0.71 + 0.04\,D \qquad r^2=0.89,\ \mathrm{df}=47,\ F=435.1,\ p<0.01 \qquad (5)$$

where D: effective cumulative day degrees; N, A, and H: number of leaves per plant, the total foliage area per plant (cm^2), and the height of plant (cm), respectively.

As a preliminary test, we achieve an additional set of observed data on the number of leaves per poinsettia plant over effective cumulative day degrees which have not been used in developing eq. (3). The observed and predicated (eq. (3)) values, as indicated in Fig. 2, exhibit a better coincidence.

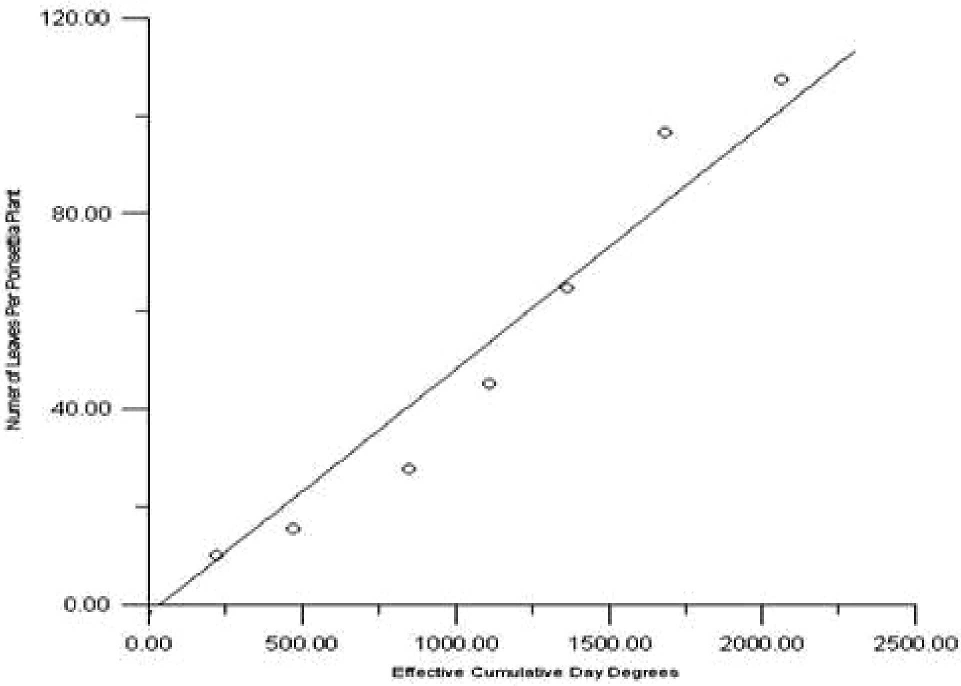

Fig. 2 Comparison between observed and predicted number of leaves of poinsettia over effective cumulative day degrees. Real line is the simulated relationship based on eq. (5).

3.2 Temperature dependent development of *B. tabaci*

The relationship between temperature and development rate for every life stage of *B. tabaci* is a skewed and bell shaped curve in the temperature range tested, which can be fitted with eq. (1).

The parameters fitting to eq. (1) is indicated in Table 1. The expected lower temperature threshold for development of egg, 1^{st} to 4^{th} instar nymphs, pupae, and immature of *B. tabaci* is 12.6, 12.2, 8.4, 6.9, 9.5, 12.6, and 9.8℃, respectively; the corresponding optimal temperature for development is 30.8, 31.5, 29.7, 31.4, 30.3, 31.3, and 31.0℃, respectively; and the upper temperature threshold for their development is 39, 36.9, 36.7, 36.4, 36.5, 36.2, and 36.6℃, respectively. It can be concluded that the temperature range for development is between 6 to 39℃, and the favorable temperature range is between 29 to 32℃. *B. tabaci* has a strong tolerance to high temperature. Among these life stages, the egg has a strongest tolerance to high temperature because of its relative inactive status.

Table 1 Relationships between temperature (℃) and development rate (1/day) of egg, 1st to 4th instar nymph, pupae, and immature of *B. tabaci*.

Stages	*K*	*r*	*T0*	*Tl*	δ	*Th*	df	*F*	*p*
Egg	0.59	0.11	30.84	12.59	5.67	39.03	3	130.2	<0.01
1st	0.83	0.09	31.52	12.22	5.63	36.98	3	34.4	<0.01
2nd	0.9	0.1	29.66	8.4	5.65	36.72	3	152.7	<0.01
3rd	1.47	0.08	31.42	6.97	5.82	36.35	3	88.5	<0.01
4th	1.77	0.09	30.27	9.47	6.42	36.45	3	55.5	<0.01
Pupae	2.4	0.06	31.26	12.6	6	36.2	3	19.8	<0.05
Immature	0.23	0.09	31.05	9.76	6.31	36.56	3	106.5	<0.01

F is the *F*-value for the linear regression between the simulated and observed development rates, df1=1, df2=df.

Table 2 Expected effective cumulative day degrees and lower temperature thresholds for egg, 1st to 4th instar nymphs, pupae, and immature stage of *B. tabaci*.

Stages	Egg	1st	2nd	3rd	4th	Pupae	Immature
s	74.1	56.5	64.1	44.4	29.9	16.8	204.1
c	12.7	12.5	8.2	6.6	9.2	12.6	10.4
r^2	0.98	0.96	0.94	0.98	0.96	0.94	0.98
df	2	2	2	2	2	2	2
F	98.5	48.5	31.8	98.5	48.5	31.8	98.5
p	0.01	<0.05	<0.05	0.01	<0.05	<0.05	0.01

Biological meanings of parameters s and c were indicated in eqn. (2). *F* is *F*-value, df1=1, df2=df.

Table 3 Parameters for the relationship between the adult density of *B. tabaci* and the number of eggs laid daily per adult based on eq. (3).

Temp. (℃)	12	16	21	27	36
a	0.57	4.53	11.23	15.32	13.1
b	-0.07	-0.54	-1.21	-2.21	-2.33
r^2	-0.83	-0.58	-0.53	-0.4	-0.88
df	3	5	5	7	5
F	14.5	6.8	5.7	4.6	37.9
p	<0.05	<0.05	<0.10	<0.10	<0.01

a, *b* are the regression constant and regression coefficient in eqn. (3). *F* is *F*-value, df1=1, df2=df.

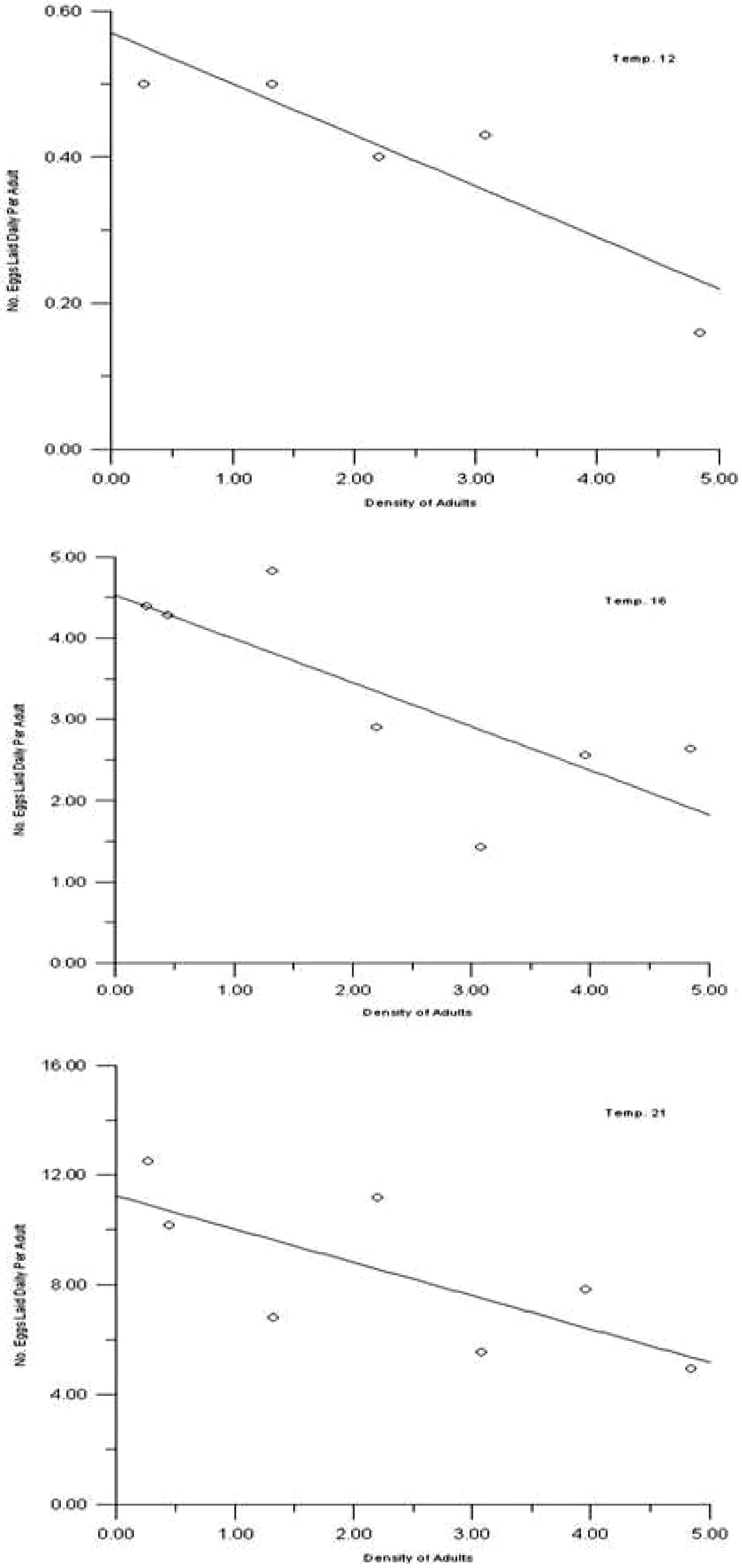

Fig. 3 Relationship between the number of eggs laid daily per adult of *B. tabaci* and adult density (the number of adults per square centimeter leaf) on poinsettia at different temperatures. Real lines represent the fitted relationship based on eq. (3).

According to the prediction given by eq. (1) and Table 1, the development time of egg, 1st to 4th instar nymphs, and pupae of *B. tabaci* is 10.3, 6.5, 4.9, 2.8, 2.7, and 1.8 days, respectively at 20℃, and is 4.7, 3.8, 3.2, 2.2, 1.9 and 1.4 days at 30℃.

The expected effective cumulative day degrees and lower temperature thresholds for development of *B. tabaci* were shown in Table 2. Generally, the effective cumulative day degrees for development reveal a decreasing trend from egg to pupae. The lower temperature thresholds calculated from eq. (2) show little differences compared with the threshold values derived from eq. (1). However the overall trend is similar with each other.

3.3 Temperature and density dependent fecundity of *B. tabaci*

At different temperatures, the number of eggs laid daily per adult on poinsettia is negatively correlated with the density of the adult, as shown in Fig. 3, which produces an approximate linear relationship as

$$y= a + bx \qquad (6)$$

where x and y are the density of adults (adults per square centimeter leaf) and the number of eggs laid daily per adult, respectively. Parameters of eq. (6) are shown in Table 3.

From the data of Table 3, it can be concluded that the number of eggs laid daily per adult is largely controlled by density of the adult on poinsettia. Results revealed a stronger density dependence of fecundity of *B. tabaci*. The expected maximum numbers of eggs laid daily per adult in unlimited living space are from 0.57 to 13.1 at the temperatures indicated in Table 3. The expected maximum number of eggs laid daily will be reached between the 27 to 36℃ and the favorable temperature of egg laying is in the range 27 to 36℃. It seems that the density dependence of fecundity decreases around the favorable temperatures, just as indicated by the determinant coefficients (r^2) in Table 3. At the temperatures indicated in Table 3, the threshold density of adult for laying eggs is 8.1, 8.4, 9.3, 6.9, and 5.6 adults/cm^2, respectively. The lower threshold at high temperature reveals a higher sensitivity of adult to give birth at higher temperature. The density threshold is also a point at which the whitefly population will stop its growth.

As an additional conclusion, we may estimate the adult whitefly density to achieve the largest number of eggs to augment its natural enemy, such as *Eretmocerus sp.* The largest number of the eggs laid, based on eq. (6), is $x(a+bx)$. Therefore the required adult density ($-a/(2b)$) is 4.1, 4.2, 4.6, 3.5, and 2.8 adults/cm^2, respectively at the temperatures in Table 3.

The mixed effect produced by temperature and adult density can be described by a stepwise multi-variable regression equation:

$$y=-21.47+2.47t-0.06tx-0.04\,t^2 \qquad (7)$$

$$R^2=0.85,\ \mathrm{df}=31,\ P<0.01$$

where x, t, y: density of adult whitefly (adults per square centimeter leaf), temperature, and the number of eggs laid daily per adult, respectively. According to eq. (7), there is an interaction between temperature and adult density. The fecundity was comprehensively affected by temperature and adult density on host plant. It may be concluded from the factorial composition in eq. (7) that the temperature dependence is more significant than density dependence in the determination of fecundity of *B. tabaci*. The maximum number of eggs laid daily per adult in unlimited living space could be reached at 30.8℃, with the maximum number of 16.65.

4 Discussion

As for the development time of egg of *B. tabaci*, Bulter et al. (1983) observed the values of 5 days at 32.5℃, 22.5 days at 16.7℃, and 7.6 days at 25℃ on cotton. The lower temperature threshold for development of egg, calculated from their three data sets by us, was 12.1℃, which is similar to our result. The expected values, derived from eq. (1), are 4.7, 19.2, and 6.0 days respectively on poinsettia. These results suggested some similarities between cotton and poinsettia for development of egg because the egg is a relative inactive stage and can't feed on host plants. Azab et al. (1972) discovered that the development time on sweetpotato at 28.4℃ was 3 days for egg, 1 day for 2nd instar nymph, 2 days for 3rd instar nymph; and at 14.3℃ it was 29 days for egg, 5 days for 2nd instar nymph, and 7 days for 3rd instar nymph. Estimated from their two data sets' result, the lower temperature threshold for development of egg, 2nd to 3rd instar nymph was 12.7, 10.8, and 8.7℃, respectively, which showed 0-2℃ differences compared with our results. Using the eq. (1), however, the expected development time of egg, 2nd and 3rd instar nymph on poinsettia at 28.4℃ is 4.9, 3.2, and 2.1 days, respectively, and is 47.3, 9.9, and 4.8 days at 14.3℃ respectively. The results show certain differences in development times. Calculated results from Sharaf et al. (1985) suggested a more significant difference in lower temperature threshold for development of 1st instar nymph (9.0℃ compared with 12.2℃ in the present study), but showed a little difference (1.7℃) in lower temperature threshold for 2nd instar nymph compared with the present study. It should be noted that these differences may be produced from different host plants tested, different number of data sets for developing regression models, and different temperature ranges tested, etc.

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