Effect of Temperature on the Population Growth of Tirathaba rufivena (Lepidoptera: Pyralidae) on Areca catechu (Arecaceae)

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Effect of temperature on the population growth of *Tirathaba rufivena* (Lepidoptera: Pyralidae) on *Areca catechu* (Arecaceae)

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Abstract

Tirathaba rufivena Walker (Lepidoptera: Pyralidae) is a major insect pest of Arecaceae such as *Areca catechu* L. (areca), *Cocos nucifera* L. (coconut), and *Elaeis guineensis* Jacq. (African oil palm). The larvae feed mainly on the palm flowers, fruits, and leaves, leading to the dropping of flowers and fruits, and they have caused economic damage and crop losses. In order to provide a foundation for the forecasting and scientific management of this pest, the effect of temperature on the development time, survival, and reproduction of *T. rufivena* reared on *A. catechu* was studied at 7 constant temperatures (16, 20, 24, 28, 32, 36, and 40 °C). The lower development threshold temperature and the effective accumulated temperature for the completion of the life cycle were 13.4 °C and 1,428.6 degree-days, respectively. The highest survival rate (30.0%) occurred at 28 °C. Eggs failed to survive at 16 and 40 °C. The population trend index (I = 19.04) and net reproductive rate (R_0 = 10.40) were highest at 28 °C. The net reproductive rate (R_0 = 4.13), intrinsic rate of increase (r_m = 0.0334), and finite capacity of increase (λ = 1.0340) were lowest at 20 °C. The mean generation time (T_0 = 18.70) was shortest at 36 °C. The population doubling time (PDT = 7.77) was shortest at 28 °C. Based on these results, we concluded that temperatures from 28 to 32 °C were most suitable for the development of *T. rufivena* reared on *A. catechu*.

Key Words: insect pest; development time; reproduction; survival; life table

Resumen

Tirathaba rufivena Walker (Lepidoptera: Pyralidae) es una plaga importante de insectos sobre palmas (Arecaceae) como *Areca catechu* L. (areca), *Cocos nucifera* L. (coco) y *Elaeis guineensis* Jacq. (palma de aceite africana). Las larvas se alimentan principalmente de las flores de palma, frutos y hojas de la palma, lo que lleva a la caída de flores y frutas, y han causado daños económicos y pérdidas de cosechas. A fin de proveer una base para el pronóstico y el manejo científico de esta plaga, se estudió el efecto de la temperatura sobre el tiempo de desarrollo, sobrevivencia y reproducción de *T. rufivena* criada sobre *Areca catechu* a 7 temperaturas constantes (16, 20, 24, 28, 32, 36 y 40 °C). El umbral mas bajo de la temperatura de desarrollo y la temperatura acumulada efectiva para completar el ciclo de vida fue 13,4 °C y 1.428,57 grados-día, respectivamente. La tasa de sobrevivencia más alta (30,0%) ocurrió a los 28 °C. Los huevos no sobrevivieron a los 16 y 40 °C. El índice de tendencia poblacional (I = 19,04) y la tasa neta de reproducción (R_0 = 10,40) fueron los más altos a 28 °C. La tasa neta de reproducción (R_0 = 4,13), la tasa intrínseca de aumento (r_m = 0,0334) y la capacidad finita de aumento (λ = 1,0340) fueron las más bajas a los 20 °C. El promedio del tiempo de generación (T_0 = 18,70) fue más corto a los 36 °C. El tiempo de duplicación de la población (PDT = 7.77) fue más corto a los 28 °C. En base a estos resultados, concluimos que las temperaturas de 28 a 32 ° C fueron las más adecuadas para el desarrollo de *T. rufivena*.

Palabras Clave: insectos plagas; tiempo de desarrollo; reproducción; sobrevivencia; tabla de vida

Tirathaba rufivena Walker (Lepidoptera: Pyralidae) is a major insect pest of Palmaceae such as *Areca catechu* L. (areca), *Cocos nucifera* L. (coconut), and *Elaeis guineensis* Jacq. (African oil palm). This pest is distributed in China, Malaysia, Indonesia, Philippines, and Sri Lanka. Larvae feed on the palm flowers, fruits, and leaves, and at high densities, their feeding activity can result in frond skeletonization and death. In Hainan, China, damage to palm plants by *T. rufivena* has severely reduced crop production, with damage rates of 10 to 67% of areca plants and 10 to 40% of areca blossoms and fruit (Fan et al. 1986, 1991).

The biology of *T. rufivena* on oil palms and areca palms has been partially determined (Yang et al. 1986; Fan et al. 1991; Alouw et al. 2005), but the effect of temperature on the population growth of *T. rufivena* on areca is unknown. Population parameters (e.g., R_0, net reproductive rate; r_m, intrinsic rate of increase; etc.) are important indices to measure the potential population growth of a species under controlled conditions, as well as evaluate the potential distribution of the pest in new areas (Southwood & Henderson 2000). These parameters have been used to study the basic biology of insects on a particular host plant and to study the population dynamics models of insect pests at given temperatures (Kim et al. 2001; Martínez et al. 2002; Bonato et al. 2007; Par et al. 2010; Panassiti et al. 2013). Thus, it is useful to develop a process-based mathematical model involving parameters such as adult survival rate, oviposition, longevity, and stage-specific development rates and mortalities to assist palm growers in predicting when outbreaks might occur (Taylor 1982; Southwood & Henderson 2000; Medeiros et al. 2003a,b).

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It was the goal of this study to describe the development rate, survival, and fecundity of *T. rufivena* on *A. catechu* leaves under different temperatures to contribute to the development of integrated pest management programs in oil palm and areca plantations.

Materials and Methods

LABORATORY COLONY OF *T. RUFIVENA*

A laboratory population of *T. rufivena* was established by collecting larvae and pupae from infested palm trees at the Areca Germplasm Resources Garden located in Wenchang, Hainan Province, China (19.55°N, 110.77°E). The larvae were reared on *A. catechu* leaves at a constant temperature (28 ± 1 °C), 75 ± 5% RH, and in complete darkness (photoperiod of 0:24 h L:D). Within 24h of emergence, 1 male and 1 female were randomly selected and placed in a plastic container (30 × 30 × 30 cm) covered with a nylon mesh. During breeding, adult insects were provided with cotton wicks saturated with an 8 to 10% honey solution as a nutritional supplement. Containers were held under the same conditions as for the larvae, except the photoperiod was 14:10 h L:D. Eggs were typically deposited on the nylon mesh, and were removed daily.

DEVELOPMENT AND SURVIVORSHIP OF IMMATRURES AND GENERATIONS

The effects of different temperatures on the population growth of *T. rufivena* were evaluated in rearing chambers (PYX-300Q-B; Guangdong Shaoguan Keli Experimental Equipment, Guangdong Province, China) at the constant temperatures of 16, 20, 24, 28, 32, 36, and 40 °C, 75 ± 5% RH, and a 14:10 h L:D photoperiod.

Ten pairs of male and female *T. rufivena* adults were caged in a plastic container (30 × 30 × 30 cm) covered with a nylon mesh along with *A. catechu* leaves. Eggs were collected daily from the leaf surfaces, transferred to Petri dishes (12 cm diameter × 1.5 cm deep) with a moistened filter paper on the bottom, and incubated at the 7 constant temperatures. Each Petri dish containing 50 eggs was considered 1 replicate (3 replicates per temperature). The development time and the percentage of hatched eggs were recorded every other day.

To observe the development time and survival of the larval and pupal stages at different temperatures, all newly hatched larvae were collected and transferred to test tubes (1 cm diameter × 10 cm deep), 1 larva per tube, and these tubes had areca leaves placed in them in advance. The larvae and pupae were maintained at the same temperatures as the eggs until adult emergence.

The adults were placed in plastic containers (30 × 30 × 30 cm) covered with a nylon mesh and fed daily with an 8 to 10% honey solution. The adults were maintained at the same experimental temperatures until they died. Longevity and survival data of all development stages of *T. rufivena* were recorded daily. The life history was determined from the newly laid eggs at 7 constant temperatures with 3 × 50 eggs per tested temperature.

EXPERIMENTAL POPULATION LIFE TABLES

Life tables were constructed from fecundity data of adults and the sex ratio, in addition to all the aforementioned parameters. When the immatures became adults, the external morphological characteristics of the adults were observed carefully to determine the sex ratio. A male and a female of newly emerged *T. rufivena* adults were mated and kept in a separate plastic container (30 × 30 × 30 cm) containing areca leaves as the oviposition site and were fed daily with an 8 to 10% honey solution as a nutritional supplement. Twenty pairs of *T. rufivena* adults were evaluated daily until the females died. The leaves were replaced daily; the eggs on each leaf were collected every 24 h and counted, and egg viability was evaluated for each female (viable eggs from which larvae had hatched showed a hole in the eggshell, whereas non-viable eggs would shrink). Then, pre-oviposition, oviposition, and post-oviposition periods were calculated.

The numbers of eggs produced, the survival rates of immature stages, and the sex ratio were observed from the above experiments and a long-term observation. The predicted number of eggs laid in the next generation was determined by the number of female adults in the previous generation and the number of eggs per female. Using the methods of Tao et al. (2008) and Li et al. (2010), the population trend index (*I*) of *T. rufivena* was calculated as the expected number of eggs in the next generation divided by the initial number of eggs.

DATA ANALYSES

The development threshold temperatures (*C*) and effective accumulated temperatures (*K*) were calculated from the following formulae (Arbab et al. 2008):

$$K = (n\sum VT - \sum V\sum T)/[nN\sum V^2 - (\sum V)^2]$$

$$C = (\sum V^2\sum T - \sum V\sum VT)/[nN\sum V^2 - (\sum V)^2]$$

where *V* is the development rate, *T* is the treatment temperature, *N* is the development duration, and *n* is the number of temperature treatments.

The effect of temperature on the population growth of *T. rufivena* was estimated by constructing a life table including age-specific survival rate (*Lx*) and fecundity (*Mx*) for each age interval (*x*) per d (Bayhan et al. 2005). The net reproductive rate $R_0 = \sum L_x M_x$, the shortest mean generation time $T_0 = \sum xLxMx/R_0$, the intrinsic rate of increase $r_m = \ln R_0/T$, the finite capacity of increase $\lambda = \exp(r_m)$, and the population doubling time $PDT = \ln 2/r_m$ were calculated as described by Legaspi & Legaspi (2005) and Toapanta et al. (2005).

The effects of the treatments on eggs, larvae, pupae, and generations (i.e., development times) were determined using a 1-way analysis of variance in the SAS® software for Windows 9.0 (SAS Institute 2004). The significance of differences was evaluated by the Tukey honestly significant difference test (HSD; $P = 0.05$) (Ruxton & Beauchamp 2008). Differences at a probability level of $P < 0.05$ were considered significant.

Results

DEVELOPMENT AND SURVIVORSHIP OF IMMATURES AND GENERATIONS

Tirathaba rufivena completed development at all the temperatures except 16 and 40 °C, at which no oviposition or egg hatching occurred. Thus, the following analysis does not include data from 16 and 40 °C. The development time of *T. rufivena* at 5 constant temperatures is summarized in Table 1. As expected, different temperatures had significant effects on the development rate of *T. rufivena*. At the same stage, the development time decreased as the temperature increased from 20 to 36 °C. The development of eggs to adults required 43.5 d at 20 °C but was 29.5 d at 36 °C (Table 1). There were significant differences at all temperatures except for instar 2 at 24 and 28 °C and instar 3 at 32 and 36 °C (Table 1).

Table 1. Duration[a] (d; mean ± SE) of *Tirathaba rufivena* at constant temperatures under laboratory conditions (75 ± 5% RH and 12:12 h L:D photoperiod).

Stage	20 °C	24 °C	28 °C	32 °C	36 °C
Egg	5.38 ± 0.07 a	5.10 ± 0.04 b	4.56 ± 0.07 c	3.28 ± 0.06 d	2.94 ± 0.03 e
Instar 1	2.76 ± 0.06 a	2.50 ± 0.07 b	2.22 ± 0.06 c	1.96 ± 0.03 d	1.74 ± 0.06 e
Instar 2	2.84 ± 0.05 a	2.46 ± 0.07 b	2.30 ± 0.07 b	2.08 ± 0.04 c	1.82 ± 0.05 d
Instar 3	3.28 ± 0.07 a	2.86 ± 0.05 b	2.54 ± 0.07 c	2.28 ± 0.06 d	2.12 ± 0.05 d
Instar 4	4.48 ± 0.07 a	4.28 ± 0.06 b	3.14 ± 0.05 c	2.82 ± 0.05 d	2.54 ± 0.07 e
Instar 5	4.74 ± 0.06 a	4.46 ± 0.07 b	4.08 ± 0.04 c	3.80 ± 0.06 d	3.48 ± 0.07 e
Pupa	16.26 ± 0.10 a	14.30 ± 0.07 b	12.24 ± 0.06 c	9.38 ± 0.07 d	7.52 ± 0.07 e
Egg to adult	43.46 ± 0.08 a	39.54 ± 0.08 b	34.36 ± 0.11 c	32.62 ± 0.07 d	29.48 ± 0.08 e

[a]There were 3 replicates for each temperature, and the initial number of eggs for each replicate was 50. Means within a row followed by the same letter are not significantly different (Tukey HSD; $\alpha = 0.05$).

There were different development threshold temperatures for every stage of *T. rufivena* reared on areca leaves (Table 2). The lower development threshold temperatures of eggs and instar 1 were the lowest, 4.1 and 4.6 °C, respectively (Table 2). The development threshold temperature and cumulative degree-day requirements for the entire development period (egg to adult) were 13.4 °C and 1428.6 degree-days, respectively.

The survival rates of *T. rufivena* eggs, larvae, pupae, and adults over the full life cycle were also affected by temperature (Fig. 1). From 20 °C to 28 °C, the survival rates for each stage increased with increasing temperature. Of the 5 constant temperatures considered, the lowest mortality for each life stage of *T. rufivena* occurred at 28 °C (Fig. 1).

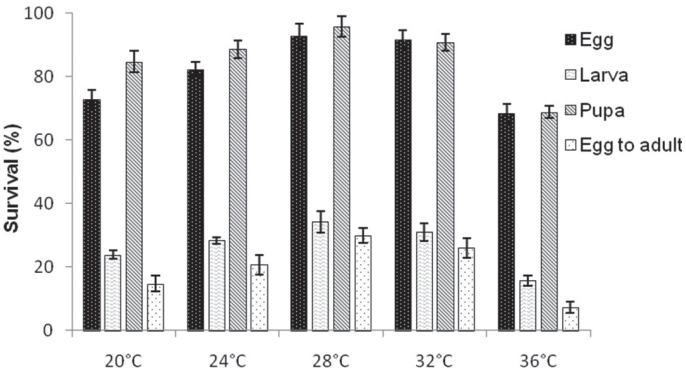

Fig. 1. Survival rates for immature stages and the entire development period (egg to adult) of *Tirathaba rufivena* at 5 constant temperatures. Each value represents the mean of 3 replicates for each temperature, and bars indicate the standard error.

EXPERIMENTAL POPULATION LIFE TABLES

Fecundity was affected by temperature, with peak egg production at 28 °C. The mean number of eggs laid per *T. rufivena* female was 35.2, 89.4, 113.1, 107.1. and 26.3 eggs at 20, 24, 28, 32, and 36 °C, respectively (Fig. 2).

Life tables were principally constructed from the survival rate and fecundity data (Table 3). The survival rates of immature stages and the numbers of eggs produced are observed values. A sex ratio of 1.27 (♀:♂) was obtained from long-term observation. The predicted number of eggs laid in the next generation was determined by the number of female adults in the previous generation and the number of eggs per female. The population trend index (*I*) was calculated as the expected number of eggs in the next generation divided by the initial number of eggs (Tao et al. 2008; Li et al. 2010). Based on the analysis of the population trend index (*I*), we concluded that 28 °C was the optimum temperature. After each generation, the population of *T. rufivena* would increase by 19.04 times if there were no extrinsic mortality factors at this temperature (Table 3).

Table 2. Development threshold temperature (mean ± SE)[a] and effective accumulated temperature (mean degree-days ± SE)[a] of *Tirathaba rufivena.*

Stage	Threshold temperature (°C)	Accumulated temperature (degree-days)
Egg	4.1 ± 0.26	96.2 ± 8.20
Instar 1	4.6 ± 0.31	71.4 ± 5.45
Instar 2	10.0 ± 0.63	85.5 ± 3.61
Instar 3	9.1 ± 0.52	94.3 ± 4.44
Instar 4	11.6 ± 0.85	87.0 ± 11.82
Instar 5	23.3 ± 0.91	208.3 ± 13.96
Pupa	7.8 ± 0.41	222.2 ± 20.96
Egg to adult	13.4 ± 0.88	1,428.6 ± 18.25

[a]There were 3 replicates for each temperature, and the initial number of eggs for each replicate was 50.

The population parameters of *T. rufivena* were affected by temperature (Table 4). The net reproductive rate (R_0), intrinsic rate of increase (r_m), and finite capacity of increase (λ) were lowest at 20 °C. The mean generation time (T_0) was shortest at 36 °C. The population doubling time (*PDT*) was shortest at 28 °C. The eggs could not survive at 16 and 40 °C, which indicated that a *T. rufivena* population will experience extinction at 16 and 40 °C.

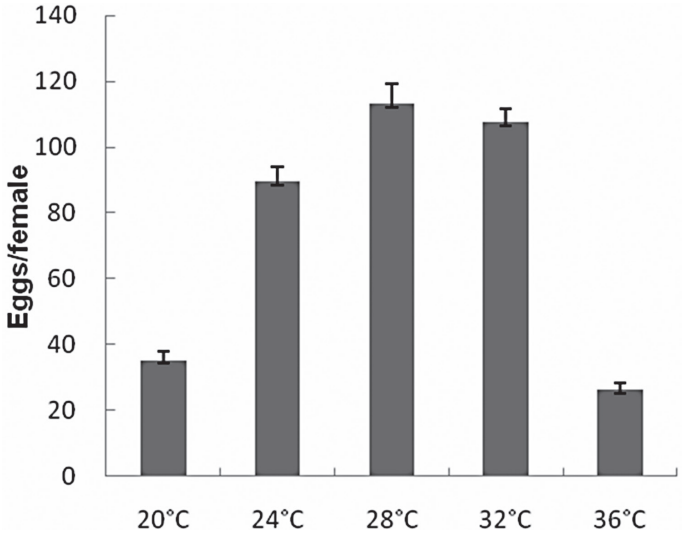

Fig. 2. Mean numbers of eggs deposited per *Tirathaba rufivena* female at 5 constant temperatures. Each value represents the mean of 3 replicates for each temperature, and bars indicate the standard error.

Table 3. Experimental population life table of *Tirathaba rufivena* at 7 constant temperatures.

Stage	16 °C	20 °C	24 °C	28 °C	32 °C	36 °C	40 °C
Initial no. of eggs	150	150	150	150	150	150	150
Egg mortality (%)	100	27.3	17.7	7.3	8.2	31.7	100
No. of larvae, instar 1	0	109	123	139	138	103	0
Instar 1 mortality (%)	—	19.5	22.8	15.3	22.2	23.8	—
No. of larvae, instar 2	—	89	95	116	108	78	—
Instar 2 mortality (%)	—	44.6	29.5	23.7	27.0	51.4	—
No. of larvae, instar 3	—	49	67	89	79	38	—
Instar 3 mortality (%)	—	20.5	22.6	29.2	27.9	18.4	—
No. of larvae, instar 4	—	39	52	63	57	31	—
Instar 4 mortality (%)	—	13.3	19.3	6.4	10.5	25.8	—
No. of larvae, instar 5	—	34	42	59	51	23	—
Instar 5 mortality (%)	—	23.5	16.7	20.3	15.7	30.4	—
No. of pupae	—	26	35	47	43	16	—
Pupae mortality (%)	—	15.4	11.4	4.3	9.3	31.3	—
No. of adults	—	22	31	45	39	11	—
No. of females (♀:♂=1.27:1)	—	12	17	25	22	6	—
Eggs laid per female	—	35	89	113	108	26	—
Expected no. of eggs in next generation	—	433	1,554	2,856	2,347	162	—
Population trend index (I)	—	2.89	10.36	19.04	15.65	1.08	—

A dash means not applicable.

Discussion

Although insects are not typically naturally subjected to constant temperatures, controlled laboratory conditions can provide useful information for the study of population dynamics (Bayhan et al. 2005). Under controlled conditions, *T. rufivena* completed its development from 20 to 36 °C, but no larvae hatched at 16 and 40 °C, indicating that temperature gradients of <20 °C and >36 °C are unfavorable for the development of this insect. Extreme temperatures are harmful to insect development (Logan et al. 1976; Briere et al. 1999; Keena 2006). In our study, the data for *T. rufivena* reared on areca leaves clearly showed the effect of temperature on development, survival, fecundity, and mortality.

The development time of *T. rufivena* stages decreased as the temperature increased from 20 to 36 °C. The development from egg to adult required 43.5 d at 20 °C but was 29.5 d at 36 °C. Alouw et al. (2005) showed that the total development period from egg deposition to adult emergence was 25.1 d under laboratory conditions. This is different from the results of this study, which may be due to the geographical differences and the food sources. We also observed that the activity and feeding of larvae at low temperatures was reduced as compared with those at high temperatures, probably because of changes in their metabolism. This phenomenon is also found in other lepidopteran insects, such as *Eriogaster lanestris* L. (Lasiocampidae), *Stenoma impressella* Busck (Elachistidae), *Stenoma catenifer* Walsingham (Elachistidae), and *Anticarsia gemmatalis* Hübner (Noctuidae) (Ruf & Fiedler 2002; Martínez et al. 2002; Hoddle & Hoddle 2008; Da Silva et al. 2012), and these insects can adapt to thermal changes by changing their activity level.

Minimum threshold and effective accumulated temperatures can provide useful information for forecasting potential occurrence and distribution of insects (Zhou et al. 2010). In this experiment, the development threshold temperature of 13.4 °C and cumulative temperature of 1428.6 degree-days were required for *T. rufivena* to complete development (egg to adult). The larvae live inside the flowers and fruit bunches of areca. The temperatures experienced by the insect in the host plant are somewhat different than air temperatures. Therefore, the effect of microclimatic temperatures for *T. rufivena* on its hosts needs to be further studied.

Table 4. Estimated population parameters[a] of *Tirathaba rufivena* at different temperatures.

Parameters	20 °C	24 °C	28 °C	32 °C	36 °C
R_0	4.13	6.24	10.40	5.78	4.12
r_m	0.0334	0.0465	0.0892	0.0710	0.0648
λ	1.0340	1.0476	1.0933	1.0736	1.0670
T_0	42.36	39.37	26.26	24.71	18.70
PDT	20.70	14.90	7.77	9.76	10.70

[a]R_0, net reproductive rate; r_m, intrinsic rate of increase; λ, finite capacity of increase; T_0, shortest mean generation time; *PDT*, population doubling time.

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