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Original Article

Biology of *Corythucha gossypii* Fabricius, 1794 (Hemiptera: Tingidae) in *Ricinus communis* at different temperatures and thermal requirements

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(With 1 figure)

Abstract

We studied the biology of *Corythucha gossypii* in *Ricinus communis* under different temperatures in climatic chambers adjusted at 20, 23, 25, and 28 °C, 60 ± 10% relative humidity, and a 12-h photoperiod. The development period and viability of eggs, the development period and survival rate of nymphs, and egg-adult cycle of *C. gossypii* as well as the adult longevity and fecundity were estimated. The thermal requirements (K) and temperature-base (Tb) were estimated for each of the immature stages and for the eggs-adults period. The duration of the eggs and nymphs phases and the egg-adult cycle of the *C. gossypii* on castor bean leaves at 20-28 °C were 7.6-17 days, 10.2-27.5 days, and 16.9-44.5 days, respectively. The lower temperature inhibited the oviposition of *C. gossypii*, whereas the higher temperatures were most favorable for its development. The municipalities of the Bahia state of Brumado, Irecê, Itaberaba, Jacobina, and Senhor do Bonfim were estimated to have a high potential for the population growth of *C. gossypii*. However, a greater number of generations per year of *C. gossypii* were observed in the municipalities of Brumado and Itaberaba.

Keywords: castor bean, development time, lace bug, thermal threshold.

Biologia de *Corythucha gossypii* Fabricius, 1794 (Hemiptera: Tingidae) em *Ricinus communis* em diferentes temperaturas e exigências térmicas

Resumo

Estudamos a biologia de *Corythucha gossypii* em *Ricinus communis* sob diferentes temperaturas em câmaras climatizadas ajustadas as temperaturas de 20, 23, 25 e 28 °C, umidade relativa de 60 ± 10% e fotoperíodo de 12 horas. O período de desenvolvimento e a viabilidade dos ovos, o período de desenvolvimento e a taxa de sobrevivência de ninfas e do ciclo de ovo-adulto de *C. gossypii*, bem como a longevidade dos adultos e fecundidade foram estimados. As exigências térmicas (K) e as temperaturas-bases (Tb) foram estimadas para cada um dos estádios imaturos e para o ciclo de ovo-adulto. A duração das fases de ovos e ninfas e do ciclo de ovo a adulto de *C. gossypii* em folhas de mamona a 20-28 °C foram de 7,6-17 dias, 10,2-27,5 dias e 16,9-44,5 dias, respectivamente. A temperatura mais baixa inibiu a oviposição de *C. gossypii*, enquanto as temperaturas mais altas foram favoráveis ao seu desenvolvimento. Os municípios do estado da Bahia de Brumado, Irecê, Itaberaba, Jacobina e Senhor do Bonfim foram estimados para ter um alto potencial para o crescimento populacional de *C. gossypii*. No entanto, o maior número de gerações por ano de *C. gossypii* foi observado nos municípios de Brumado e Itaberaba.

Palavras-chave: mamona, tempo de desenvolvimento, percevejo de renda, limiar térmico.

1. Introduction

Brazil is the world's third-largest producer of castor bean (*Ricinus communis* L., Malpighiales: Euphorbiaceae) after China and India. The estimated castor production for 2015-2016 harvest in Brazil was 97,300 tons in 125,100-ha area, representing 52.4% growth in the national acreage as compared to the data from the previous year (CONAB, 2016). The northeast region comprises of >99% of the planted area, with a production of 96,800 tons in the

2015-2016 crop season. Among the states of this region, Bahia stands out with a production of around 95,000 tons, which accounted for over 98% of the castor oil production in Brazil (Costa et al., 2014).

Castor bean is highly adapted to the Brazilian soil and climatic conditions, especially in the semiarid region (Corrêa et al., 2006). In the northeast region, for example, planting this crop has been encouraged not only due to the low cost of implementation and production involved but also for its recognized tolerance to adverse conditions of climate and soil, such as in drought-related stress area (Severino et al., 2012). Nevertheless, the crop yield in Brazil is lower than in other countries due to the lack of information about the damages caused by species of insects and mites, which has compromised the economic exploitation of this crop (Ribeiro and Costa, 2008). Some species of Tingidae (Hemiptera, Heteroptera) have a great potential to become the major pests of this crop, among them, *Corythucha gossypii* (Fabricius, 1794) is notable (Varón et al., 2010).

Adults and nymphs of the lace bug *C. gossypii* feed on both sides of the castor bean leaves, causing injuries similar to the ones caused by other tingids. The damage is initially characterized by the formation of white punctuation that progresses to tanning, chlorosis, and, eventually, to premature dropping of the leaves (Li et al., 2007).

Temperature is a determining factor in the geographical distribution of species (Calosi et al., 2010; Kellermann et al., 2012a, b; Overgaard et al., 2014), particularly the metabolic activity and development time of insects (Damos and Savopoulou-Soultani, 2011; Pereira et al., 2011; Poncio et al., 2016). However, to understand the effect of temperature on the life cycle of insects, it is necessary to determine the base temperature and thermal constant of these arthropods (Damos and Savopoulou-Soultani, 2008, 2011). Therefore, the information on the thermal requirements in the development of insect pests have important implications in the control programs of such organisms, because the temperature determines the growth and size of the pest population and its variation in different environmental conditions. Thus, the insight to this information would provide support for the prediction of population dynamics and spatial and seasonal distributions of these organisms in the main castor-producing regions of Brazil.

In this study, we evaluated the biology of the lace bug *C. gossypii* in castor beans under different temperatures.

2. Material and Methods

2.1. Insects and plant

This study was conducted in the Laboratory of Entomology, Embrapa Cotton, Campina Grande, Paraíba, and Brazil (7°13’50”S, 35°52’52”W).

The specimens of castor bean cultivar “BRS Paraguaçú” were first planted in 4-L-plastic pots filled with soil collected from the experimental field, which was classified as a mixture of entisol eutrophic and manure (3:1 ratio), as recommended by the Soils Laboratory of the Embrapa Cotton. The plants were kept in the greenhouse until 55 days of age and then transferred to the laboratory for evaluate tingids infestation.

The *C. gossypii* specimens used in the experiment were collected from castor bean plants attacked in the Embrapa Cotton field. A total of 30 specimens (20 females and 10 males) of the lace bugs were collected using a brush, transferred to dry glass jars, and sent to Dr. Luiz Antônio Alves Costa (National Museum of the Federal University of Rio de Janeiro in Rio de Janeiro State, Brazil) for identification. These specimens were identified based almost exclusively on external morphology, because genital traits are not usually described (Monte, 1941) and deposited at the National Museum. For each temperature condition, two leaves of a castor plant were infested with 40 *C. gossypii* females, which continued laying eggs for 24 h. The infested leaves were wrapped with voile to prevent the insects’ escape. At the end of this period, the females were removed and their positions were marked with black paint to facilitate stereoscopic microscope inspections until the emergence of the nymphs.

2.2. Biology and thermal time bioassays

A castor bean plant containing 250 newly laid eggs inside the leaves by *C. gossypii* females were maintained in the biochemical oxygen demand (BOD) chambers adjusted at 20, 23, 25, and 28 °C under a relative humidity of 60 ±10% for a 12-h photoperiod. The eggs were observed daily. The total number of eggs hatched at each temperature and the duration of each egg development (incubation period) was recorded.

To evaluate the nymphal stage at each temperature, the newly emerged first-instar nymphs were kept individually in rearing units consisting of 25-mL, transparent, plastic containers (3 × 4 cm). Inside these units, a filter paper disk measuring 3.0 cm in diameter was placed and moistened with distilled water. On this disk, a disk of a castor bean leaf was placed, with the ventral side facing upward. Then, the rearing units were covered with a transparent plastic film and maintained at a given temperature until the insects emerged as adults. The castor bean leaf disks were replaced every 2 days, and the filter paper was moistened on a daily basis.

The development time and viability of eggs and the survival of nymphs and adults of *C. gossypii* as well as the adult longevity and fecundity were estimated. The longevity of males and females was determined by considering the couples. To determine the fertility and the sex ratio of the offspring at each temperature condition, the adults were divided into couples, and the newly emerged males were transferred separately to new arenas containing newly emerged female. The eggs laid in these areas were quantified daily by two observations made at 08:00 AM and 04:00 PM.

2.3. Data analysis

The differences in the development periods between *C. gossypii* males and females were compared by F test at 5% probability using the System of Statistical Analysis and

Genetics (SAEG) (Ribeiro Júnior, 2001). The threshold temperature (*Tb*) and thermal constant (*K*) were estimated by the hyperbole method (Haddad et al., 1999) based on the duration of the immature stages and the life cycle (egg-adult) of *C. gossypii*. The annual accumulation of degree-days and the likely number of generations (*NG*) of the lace bug in five castor-producing municipalities of Bahia state were calculated based on the thermal constant (Wilson and Barnett, 1983). The NG was calculated using the following Equation 1:

$$NG = T\left(Tm - Tb\right) / K \qquad (1)$$

where: K = thermal constant; Tm = average temperature for each location studied; Tb = lower temperature threshold; and T = time (in days).

3. Results

The insect was identified as *C. gossypii* (Figures 1A-C).

The viability of *C. gossypii* eggs in castor bean leaves did not vary between the four studied temperatures (Table 1); however, the survival of the nymphal phase ranged from 26% to 60%. The maximum survival was observed at 25 °C and the minimum at 20 °C. Among the nymphal instars, the survival rates for the first, second, third, fourth, and fifth instars for the four temperatures studied were 50-82%, 75.6-100%, 76.5-89.2%, 76.9-93.8%, and 80-100%, respectively (Table 2).

The developmental time of eggs and nymphs phases, and the egg-adult cycle of *C. gossypii* with castor bean leaves gradually decreased with the increase in the temperature (Table 1), but did not differ between the sexes. The incubation periods of eggs and development period of the nymphal phase and egg-adult cycle were 7.6-17 days, 10.2-27.5 days, and 16.9-44.5 days, respectively, at 20-28 °C.

The development time of the nymphal phase of *C. gossypii* in castor bean leaves varied within each instar stage and between the instars and sexes (Table 2), according to the

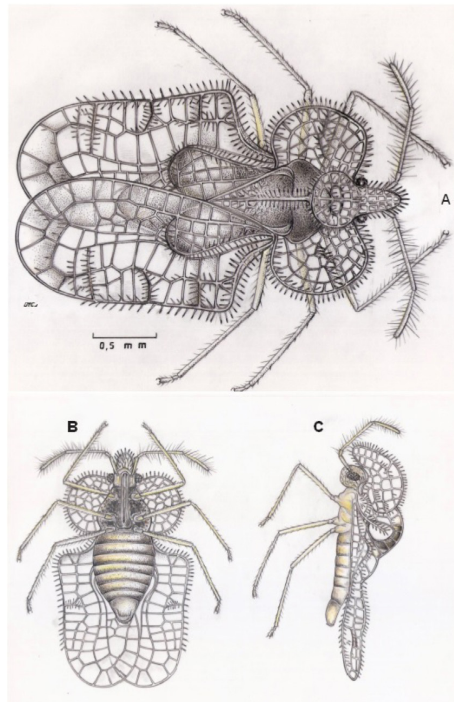

Figure 1. Adult cotton lace bug, *Corythucha gossypii* (Fabricius, 1794) (Heteroptera: Tingidae) in dorsal (A), ventral (B) and lateral view (C).

Table 1. Survival and development time of the egg and nymph phases and egg-adult cycle of *Corythucha gossypii* (Hemiptera: Tingidae) with castor leaves at temperatures 20 °C, 23 °C, 25 °C and 28 °C, relative humidity of 60 ± 10% and photophase of 12 hours.

Stage/ cycle	Temp. (°C)	Ind.	Sur. (%)	Development time (days) ± SE					
				Female	(N)	Male	(N)	Female + Male	(N)
Egg	20	50	100	17.38 ± 0.43	4	16.67 ± 0.17 N.S	3	17.03 ± 0.28	7
	23	50	100	10.95 ± 0.05	11	11.00 ± 0.00 N.S	8	10.97 ± 0.03	19
	25	50	100	9.13 ± 0.06	15	9.43 ± 0.13 N.S	15	9.28 ± 0.07	30
	28	50	100	7.33 ± 0.17	5	7.80 ± 0.20 N.S	9	7.57 ± 0.16	14
Nymph	20	13	26	27.13 ± 0.80	4	27.83 ± 0.60 N.S	3	27.48 ± 0.51	7
	23	19	38	16.77 ± 0.40	11	17.13 ± 0.51 N.S	8	17.05 ± 0.31	19
	25	30	60	11.13 ± 0.16	15	11.47 ± 0.14 N.S	15	11.30 ± 0.11	30
	28	16	32	9.83 ± 0.60	5	10.60 ± 0.51 N.S	9	10.22 ± 0.20	14
Egg-adult	20	13	100	44.50 ± 0.96	4	44.50 ± 0.50 N.S	3	44.50 ± 0.55	7
	23	19	100	27.73 ± 0.39	11	28.13 ± 0.51 N.S	8	27.93 ± 0.30	19
	25	30	100	20.27 ± 0.16	15	20.90 ± 0.22 N.S	15	20.58 ± 0.15	30
	28	16	100	16.80 ± 0.30	5	16.94 ± 0.27 N.S	9	16.87 ± 0.20	14

N.S = Not significant for the duration of development between female and male by F test (P = 0.05); Temp = temperature; Ind = number of individuals per instar at each temperature; Sur = Suvival; SE = standard error; N = number of individuals that achieved the adult stage.

Table 2. Survival and development time (day, mean ± standard error) of nymphs in the different instar of *Corytucha gossypii* in castor leaves, at 20 °C, 23 °C, 25 °C and 28 °C, relative humidity of 60 ± 10% and photophase of 12 hours.

Nymphal stage	Temp. (°C)	Ind.	Sur. (%)	Development time (days) ± standard error			
				Fêmea	(N)	Macho	(N)
1st instar	20	25	50.00	6.75 ± 0.66	4	6.83 ± 0.73$^{N.S}$	3
	23	41	82.00	2.86 ± 0.20	11	3.13 ± 0.26$^{N.S}$	8
	25	37	74.00	2.67 ± 0.06	15	2.57 ± 0.05$^{N.S}$	15
	28	40	80.00	2.00 ± 0.00	5	2.17 ± 0.17$^{N.S}$	9
2nd instar	20	19	76.00	3.50 ± 0.29	4	5.00 ± 0.20*	3
	23	31	75.61	2.56 ± 0.26	11	2.41 ± 0.16$^{N.S}$	8
	25	37	100.00	1.63 ± 0.06	15	1.63 ± 0.06$^{N.S}$	15
	28	34	85.00	1.50 ± 0.00	5	1.44 ± 0.10$^{N.S}$	9
3rd instar	20	16	84.21	4.25 ± 0.14	4	5.67 ± 0.33*	3
	23	24	77.42	3.50 ± 0.31	11	3.14 ± 0.14$^{N.S}$	8
	25	33	89.19	1.80 ± 0.07	15	1.63 ± 0.06$^{N.S}$	15
	28	26	76.47	1.50 ± 0.12	5	1.50 ± 0.00$^{N.S}$	9
4th instar	20	15	93.75	5.63 ± 0.38	4	5.00 ± 0.50$^{N.S}$	3
	23	21	87.50	3.86 ± 0.21	11	3.88 ± 0.31$^{N.S}$	8
	25	30	90.91	2.03 ± 0.08	15	2.20 ± 0.07$^{N.S}$	15
	28	20	76.92	2.20 ± 0.20	5	2.11 ± 0.25$^{N.S}$	9
5th instar	20	13	86.67	5.50 ± 0.20	4	6.83 ± 0.67$^{N.S}$	3
	23	19	90.48	4.50 ± 0.28	11	4.06 ± 0.11$^{N.S}$	8
	25	30	100.00	3.17 ± 0.14	15	3.27 ± 0.10$^{N.S}$	15
	28	16	80.00	3.10 ± 0.10	5	3.22 ± 0.24$^{N.S}$	9

$^{N.S}$ = Not significant and *significant for the duration of development between female and male by F test (P = 0.05); Temp = temperature; Ind = number of individuals per instar at each temperature; Sur = Suvival; N = number of individuals that achieved the adult stage.

Table 3. Longevity (day, mean ± standard error) and fecundity (total eggs, mean ± standard error) of *Corytucha gossypii* in castor bean leaves at 20 °C, 23 °C, 25 °C and 28 °C, relative humidity of 60 ± 10% and photophase of 12 hours.

Temp. (°C)	Sex	(N)	Longevity	Fecundity
20	Female	3	14.17 ± 1.48	-
	Male	3	13.50 ± 1.00	-
23	Female	6	46.82 ± 2.18	146.33 ± 31.17
	Male	6	42.31 ± 2.54	-
25	Female	6	34.53 ± 1.80	148.00 ± 32.80
	Male	6	34.47 ± 4.16	-
28	Female	5	24.30 ± 3.61	167.00 ± 28.00
	Male	5	21.28 ± 2.56	-

N = individuals number.

temperature. Within each instar, the duration gradually decreased with increasing temperature. On the other hand, longer periods between instars were observed for the fifth-instar nymphs and shorter periods for the second- and third-instar nymphs, except for similar amount of days for the first- and fifth-instar nymphs at 20 °C. Among the second- and third-instar nymphs at 20 °C, the nymphs that originated males showed a longer development time than those that originated females.

The longevity of *C. gossypii* adults in castor bean leaves were 24.3-46.8 days and 21.3-42.3 days for females and males nymphs, respectively (Table 3). The greatest longevity period was observed for females nymphs at 23 °C, followed by those kept at 25 °C. The smallest longevity of *C. gossypii* adults was observed for those kept at 28 °C.

The fecundity of *C. gossypii* in castor bean leaves varied with temperature (Table 3), with a better performance demonstrated at higher temperatures. At 20 °C, the females did not lay any eggs. Similarly, the sex ratio in castor bean leaves varied with the temperature, with values of 0.57, 0.58, 0.50, and 0.38 at temperatures of 20, 23, 25, and 28 °C, respectively.

The development rate to the egg and nymph stages and the egg-adult cycle of *C. gossypii* with castor bean leaves

Table 4. Linear regression equations between the rates of development $r(T)$ and temperature (20 °C, 23 °C, 25 °C and 28 °C) to determine the base temperature (*Tb*) and thermal constant (*K*) for egg and nymph stages and egg-adult cycle of development of *Corytucha gossypii* in castor leaves.

Phase	Instar	*Tb* (°C)	*K*	*a*(1) ± standard error	b(2) ± standard error	$Pr>\chi^2$	R^2
Egg	-	15.14	86.81	-0.17446 ± 0.02121	0.01152 ± 0.00088	0.0057	0.98
	First	15.26	26.70	-0.57176 ± 0.17614	0.03746 ± 0.00729	0.0358	0.89
	Second	16.74	15.90	-1.03640 ± 0.15045	0.06291 ± 0.00622	0.0096	0.97
	Third	16.95	16.15	-1.04962 ± 0.37136	0.06193 ± 0.01536	0.0564	0.84
	Fourth	15.92	23.72	-0.67116 ± 0.28193	0.04215 ± 0.01166	0.0687	0.80
	Fifth	11.92	47.55	-0.25070 ± 0.12738	0.02103 ± 0.00527	0.0574	0.83
Nymphal	-	15.40	123.46	-0.12477 ± 0.03222	0.00810 ± 0.00133	0.0260	0.92
Egg-adult	-	15.36	208.33	-0.07375 ± 0.00866	0.00480 ± 0.00036	0.0055	0.98

(1)The base temperature or low development threshold (*Tb*) is calculated as $Tb = 2a/b$; (2)The thermal constant, *k* (day-degrees) is calculated as $k = 1/b.a$ is the intercept, and b is the regression line slope. The values of *Tb* and *k* were calculated for each instar and nymph stage (from hatching to the adult stage).

Table 5. Annual accumulation of degree-days and probable number of generations of *Corythucha gossypii* in five regions with castor bean crops in the State of Bahia, based on the thermal constant(1).

Municipality	Egg to adult period	
	Annual degree-days	Number of generations per year
Brumado	3447.3	16.5
Irecê	3007.3	14.4
Itaberaba	3642.7	17.5
Jacobina	3073.1	14.8
Senhor do Bonfim	2996.1	14.4

(1)The daily maximum and minimum temperatures in the municipalities listed in the table were obtained from the INMET (2016) and used for degree-day calculation for the year 2015.

showed a linear and positive correlation with temperatures between 20 °C and 28 °C (Table 4). Within this temperature range, the second- and third-instar nymphs showed higher development rate, which could be confirmed by larger angular coefficients of the regression equations estimated for these instars.

Thermal constants for the egg and nymph stages and the egg-adult cycle of *C. gossypii* with castor leaves showed a linear and positive correlation with the temperature of 20-28 °C (Table 4).

The likely number of generations of *C. gossypii* throughout the year in the municipalities of Brumado, Irecê, Itaberaba, Jacobina, and Senhor do Bonfim (the largest castor bean producers in Brazil; Bahia state) ranged from 14.4 to 17.5 (Table 5). The municipalities of Itaberaba and Brumado, two of the hottest cities in the region, possess the greatest potential of annual generations of *C. gossypii*, while municipalities with cooler temperatures such as Irecê, Jacobina, and Senhor do Bonfim are predicted to yield fewer numbers of generations per year.

4. Discussion

The high viability rate of eggs with castor bean leaves is similar to the >90% value observed for the viability of *C. ciliata* eggs (Ju et al., 2011a) in the studied temperature range with hybrid plane leaves of *Platanus* × *acerifolia* (Aiton). This observation can be attributed to *C. ciliate's* oviposition behavior. The females often lay their eggs on both the sides of the leaf and next to the midvein or lateral veins, inserted partially in the leaf parenchyma; this site of oviposition protects the eggs from abiotic stress factors such as water loss and extreme temperatures and biotic ones such as attack by natural enemies (Southwood, 1973).

The shorter incubation period of *C. gossypii* eggs at temperature between 20 °C and 28 °C as compared to those of 12-19 days by *C. cydoniae* on leaves of *Crataegus phaenopyrum* (L.f.) Medik. (Neal Junior and Douglass, 1990), 11.3-26.5 days by *C. cydoniae* on leaves of *Cotoneaster dammeri* (Braman and Pendley, 1993), and 8.8-20 days by *C. ciliata* on hybrid plane leaves (Ju et al., 2011b) can be attributed to differences among the oviposition sites in the plant tissue of the host leaves. The oviposition of *C. gossypii* is endophytic, while those of *C. cydoniae* and *C. ciliata* are pseudo-endophytic and exophytic, respectively. In the endophytic posture, the eggs are inserted into the spongy mesophyll with only the operculum left outside the vegetable tissue, while, in the pseudo-endophytic posture, the eggs are partially inserted in the plant tissue. In the exophytic posture, the eggs are deposited on the surface of the plant tissue (Guidoti et al., 2015).

The differences in the development time of the second- and third-instar nymphs of *C. gossypii* at 20 °C that originated males and females may be attributed to the reduced number of individuals used to calculate this development period of this lace bug at this temperature. However, the development time of the phases of egg, nymph, and egg-adult did not differ between the sexes at all temperatures, indicating that nymphs at a more advanced instar stage of development can compensate for the possible differences between the sexes in the development time of initial instars. The duration time of nymph stage and egg-adult cycle of *C. gossypii* at 20-28 °C were similar to that of 12.1-29.3 days and 22.8-55.6 days observed for the nymph stage and egg-adult cycle of *C. cydoniae* on the leaves of *Cotoneaster dammeri* (19-30 °C) (Braman and Pendley, 1993), respectively, and of 11.3-27.6 days and 20.0-47.6 days for the same development period of *C. ciliata* on the hybrid plane leaves (19-30 °C) (Ju et al., 2011a). Moreover, the durations were greater, ranging from 14.7 to 23.4 days and 26.6 to 42.5 days for the nymph stage and the egg-adult cycle of *C. cydoniae* on the leaves of *Crataegus phaenopyrum* (Neal Junior and Douglass, 1990).

The survival rates for the first-, second-, third-, fourth-, and fifth-instars for the four temperatures studied were less than those in survival from 63% to 90%, 95% to 100%, 96% to 99%, 96% to 97.5%, and 85% to 95% observed for the respective instars of *C. ciliata* on hybrid plane leaves (19-30 °C). On the other hand, the improved survival of *C. gossypii* at 25 °C and its reduction at 20 °C indicates that these nymph species preferably survive in warmer temperatures.

Variations in the development time of *C. gossypii* within each instar and between instars and sexes according to the temperature confirm that temperature is an important climatic factor that influences the development of these insects. The developmental period gradually decreases with increasing temperature conditions. On the other hand, the longest period observed for the fifth-instar nymphs and shortest for the second- and third-instar nymphs, except for similar durations for the first- and fifth-instar nymphs at 20 °C, are in concordance with the previous results observed for other species of Tingidae (Vogt and McPherson, 1986; Neal Junior and Douglass, 1988, 1990; Braman et al., 1992; Braman and Pendley, 1993; Cividanes et al., 2004; Silva, 2004; Aysal and Kivan, 2008; Ju et al., 2011a; Zhang et al., 2011; Carr and Braman, 2012; Moreira et al., 2013; Sánchez-Ramos et al., 2015), thereby confirming this to be the pattern of development for the nymphal stages of lace bugs, as proposed by Sanchez-Ramos et al. (2015).

In this study, adult longevity and fecundity were prolonged and increased with decreasing temperature. At 25 °C, the life spans of the male and female *C. gossypii* were found to be similar to the life spans of 33.2 days and 34.7 days for the male and female *C. ciliate*, respectively, on hybrid plane leaves at 26 °C (Ju et al., 2011a).

The positive linear correlation between the development rate and the temperature and between the thermal constant and the temperature for the egg, nymph, and egg-adult stages of *C. gossypii* at 20-28 °C indicated the thermophilic nature of Tingidae species. The number of degree-days required for the development of egg and nymph stages and the egg-adult cycle were similar to those observed for the Tingidae species *Monosteira unicostata* on the leaves of *Phyllostachys nigra* (Sánchez-Ramos et al., 2015) to those observed for *Gargaphia torresi* on cotton leaves (Silva, 2004) and for *C. cydoniae* on the leaves of *Cotoneaster dammeri* (Braman and Pendley, 1993). On the other hand, the number of degree-days required for the three developmental stages were superior to the lower limits of 10.5, 10.9, and 11.2 °C obtained for the respective stages of *C. ciliata* (Ju et al., 2011a).

The largest number of annual generations estimated for *C. gossypii* in the warm municipalities of Itaberaba and Brumado as compared to those in the colder municipalities of Irecê, Jacobina, and Senhor do Bonfim indicate that the municipalities of Itaberaba and Brumado are most susceptible to population outbreaks and, consequently, to damage caused by castor bean lace bug.

5. Conclusion

From this study, it can be concluded that temperature influences the development time of the egg and nymph stages and the egg-adult cycle as well as the longevity and fecundity of *C. gossypii* on the leaves of castor beans. The temperatures of 25 °C and 28 °C were found to be the most favorable for the development of this lace bug. The study indicated that the municipalities of the Bahia state of Brumado, Irecê, Itaberaba, Jacobina, and Senhor do Bonfim have a greater potential for the population growth of *C. gossypii*. However, the greater number of generations per year of *C. gossypii* observed in Brumado and Itaberaba indicated that *C. gossypii* has more potential to be a pest in these municipalities.

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References

AYSAL, T. and KIVAN, M., 2008. Development and population growth of *Stephanitis pyri* (F.) (Heteroptera: Tingidae) at five temperatures. *Journal of Pest Science*, vol. 81, no. 3, pp. 135-141. http://dx.doi.org/10.1007/s10340-008-0198-9.

BRAMAN, S.K. and PENDLEY, A.F., 1993. Temperature, photoperiod, and agregation effects on development, diapause, reproduction, and survival in *Corythucha cydoniae* (Heteroptera: Tingidae). *Journal of Entomological Science*, vol. 28, no. 4, pp. 417-426. http://dx.doi.org/10.18474/0749-8004-28.4.417.

BRAMAN, S.K., PENDLEY, A.F., SPARKS, B. and HUDSON, W.G., 1992. Thermal requirements for development, popultion trends, and parasitism of azalea lace bug (Heteroptera: Tingidae). *Journal of Economic Entomology*, vol. 85, no. 3, pp. 870-877. http://dx.doi.org/10.1093/jee/85.3.870.

CALOSI, P., BILTON, D.T., SPICER, J.I., VOTIER, S.C. and ATFIELD, A., 2010. What determines a species' geographical range? Thermal biology and latitudinal range size relationships in European diving beetles (Coleoptera: Dytiscidae). *Journal of Animal Ecology*, vol. 79, no. 1, pp. 194-204. http://dx.doi.org/10.1111/j.1365-2656.2009.01611.x. PMid:19761459.

CARR, E.R. and BRAMAN, S.K., 2012. Phenology, abundance, plant injury and effect of temperature on the development and survival of *Leptodictya plana* (Hemiptera: Tingidae) on *Pennisetum* spp. grasses. *Journal of Entomological Science*, vol. 47, no. 2, pp. 131-138. http://dx.doi.org/10.18474/0749-8004-47.2.131.

CIVIDANES, F.J., FONSECA, F.S. and GALLI, J.C., 2004. Biologia de *Leptopharsa heveae* Drake & Poor (Heteroptera: Tingidae) e a relação de suas exigências térmicas com a flutuação populacional em seringueira. *Neotropical Entomology*, vol. 33, no. 6, pp. 685-691. http://dx.doi.org/10.1590/S1519-566X2004000600005.

COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB, 2016 [viewed 5 February 2016]. *Mamona: série histórica* [online]. Brasília: CONAB. Available from: http://www.conab.gov.br

CORRÊA, M.L.P., TÁVORA, F.J.A.F. and PITOMPEIRA, J.B., 2006. Comportamento de cultivares de mamona em plantio consorciadas com caupi e sorgo granífero. *Revista Ciência Agronômica*, vol. 37, no. 2, pp. 200-207.

COSTA, A.G.F., SOFIATTI, V., MACIEL, C.D.G., POLETINE, J.P. and SOUSA, J.I., 2014. Weed management strategies for castor bean crops. *Acta Scientiarum, Agronomy*, vol. 36, no. 2, pp. 135-145. http://dx.doi.org/10.4025/actasciagron.v36i2.17090.

DAMOS, P.T. and SAVOPOULOU-SOULTANI, M., 2008. Temperature-dependent bionomics and modeling of *Anarsia lineatella* (Lepidoptera: Gelechiidae) in the laboratory. *Journal of Economic Entomology*, vol. 101, no. 5, pp. 1557-1567. http://dx.doi.org/10.1093/jee/101.5.1557. PMid:18950037.

DAMOS, P.T. and SAVOPOULOU-SOULTANI, M., 2011. Temperature-driven models for insect development and vital thermal requirements. *Psyche*, vol. 2012, pp. 1-13. http://dx.doi.org/10.1155/2012/123405.

GUIDOTI, M., MONTEMAYOR, S.I. and GUILBERT, E., 2015. Lace bugs (Tingidae). In: R. PANIZZI and J. GRAZIA, eds., *True bugs (Heteroptera) of the neotropics*. Dordrecht: Springer, pp. 395-422. http://dx.doi.org/10.1007/978-94-017-9861-7_14.

HADDAD, M.L., PARRA, J.R.P. and MORAES, R.C.B., 1999. *Métodos para estimar os limites térmicos inferior e superior de desenvolvimento de insetos*. Piracicaba: FEALQ, 29 p.

INSTITUTO NACIONAL DE METEOROLOGIA – INMET, 2016 [viewed 23 April 2016]. *Dados meteorológicos* [online]. Brasília: INMET. Available from: http://www.inmet.gov.br

JU, R.T., CHEN, G.B., WANG, F. and LI, B., 2011a. Effects of heat shock, heat exposure pattern, and heat hardening on survival of the sycamore lace bug, *Corythucha ciliata. Entomologia Experimentalis et Applicata*, vol. 141, no. 2, pp. 168-177. http://dx.doi.org/10.1111/j.1570-7458.2011.01180.x.

JU, R.T., WANG, F. and LI, B., 2011b. Effects of temperature on the development and population growth of the sycamore lace bug, *Corythucha ciliata. Journal of Insect Science*, vol. 11, no. 16, pp. 1-12. http://dx.doi.org/10.1673/031.011.0116. PMid:21526932.

KELLERMANN, V., LOESCHCKE, V., HOFFMANN, A.A., KRISTENSEN, T.N., FLOJGAARD, C., DAVID, J.R., SVENNING, J.-C. and OVERGAARD, J., 2012a. Phylogenetic constraints in key functional traits behind species' climate niches: patterns of desiccation and cold resistance across 95 drosophila species. *Evolution*, vol. 66, no. 11, pp. 3377-3389. http://dx.doi.org/10.1111/j.1558-5646.2012.01685.x. PMid:23106704.

KELLERMANN, V., OVERGAARD, J., HOFFMANN, A.A., FLOJGAARD, C., SVENNING, J.-C. and LOESCHCKE, V., 2012b. Upper thermal limits of *Drosophila* are linked to species distributions and strongly constrained phylogenetically. *Proceedings of the National Academy of Sciences of the United States of America*, vol. 109, no. 40, pp. 16228-16233. http://dx.doi.org/10.1073/pnas.1207553109. PMid:22988106.

LI, C.R., XIA, W.S. and WANG, F.L., 2007. First record of *Corythucha ciliata* (Say) (Hemiptera:Tingidae), in China. *Dong Wu Fen Lei Xue Bao*, vol. 32, no. 4, pp. 944-946.

MONTE, O., 1941. Quatro novos Tingitídeos da América do Sul. *Revista Brasileira de Biologia=. Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 1, no. 4, pp. 373-378.

MOREIRA, D.C., REDAELLI, L.R., GUIDOTI, M. and BARCELLOS, A., 2013. Compared nymphal development of *Tingis americana* (Hemiptera, Tingidae) in two *Handroanthus* species (Bignoniaceae) and reproductive parameters in seedlings of *Handroanthus heptaphyllus. Iheringia*, vol. 103, no. 2, pp. 195-199. http://dx.doi.org/10.1590/S0073-47212013000200015.

NEAL JUNIOR, J.W. and DOUGLASS, L.W., 1988. Development, oviposition rate, longevity, and voltinism of *Stephanitis pyrioides* (Heteroptera: Tingidae), an adventive pest of azalea, at three temperatures. *Environmental Entomology*, vol. 17, no. 5, pp. 827-831. http://dx.doi.org/10.1093/ee/17.5.827.

NEAL JUNIOR, J.W. and DOUGLASS, L.W., 1990. Seasonal dynamics and the effect of temperature in *Corythucha cydoniae* (Heteroptera: Tingidae). *Environmental Entomology*, vol. 19, no. 5, pp. 1299-1304. http://dx.doi.org/10.1093/ee/19.5.1299.

OVERGAARD, J., KEARNEY, M.R. and HOFFMANN, A.A., 2014. Sensitivity to thermal extremes in Australian *Drosophila* implies similar impacts of climate change on the distribution of widespread and tropical species. *Global Change Biology*, vol. 20, no. 6, pp. 1738-1750. http://dx.doi.org/10.1111/gcb.12521. PMid:24549716.

PEREIRA, F.F., ZANUNCIO, J.C., OLIVEIRA, H.N., GRANCE, E.V., PASTORI, P.L. and GAVA-OLIVEIRA, M.D., 2011. Thermal requirements and estimate number of generations of *Palmistichus elaeisis* (Hymenoptera: Eulophidae) in different *Eucalyptus* plantations regions. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 71, no. 2, pp. 431-436. http://dx.doi.org/10.1590/S1519-69842011000300012. PMid:21755160.

PONCIO, S., DEQUECH, S.T.B., BOLZAN, A., GÜTHS, C., WALKER, M.P., STURZA, V.S. and NAVA, D.E., 2016. Effect of temperature on immatures of *Stiretrus decastigmus* (Hemiptera: Pentatomidae). *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 76, no. 2, pp. 495-499. http://dx.doi.org/10.1590/1519-6984.21914. PMid:26983086.

RIBEIRO JÚNIOR, J.I., 2001. *Análises estatísticas no SAEG*. Viçosa: UFV, 301 p.

RIBEIRO, L.P. and COSTA, L.C., 2008. Ocorrência de *Erinnyis ello* e *Spodoptera marina* na cultura da mamona no Rio Grande do Sul. *Ciência Rural*, vol. 38, no. 8, pp. 2351-2353. http://dx.doi.org/10.1590/S0103-84782008000800040.

SÁNCHEZ-RAMOS, I., PASCUAL, S., FERNÁNDEZ, C.E., MARCOTEGUI, A. and GONZÁLEZ-NÚÑEZ, M., 2015. Effect of temperature on the survival and development of the immature stages of *Monosteira unicostata* (Hemiptera: Tingidae). *European Journal of Entomology*, vol. 112, no. 4, pp. 664-675. http://dx.doi.org/10.14411/eje.2015.087.

SEVERINO, L.S., AULD, D.L., BALDANZI, M., CÂNDIDO, M.J.D., CHEN, G., CROSBY, W., TAN, D., HE, X., LAKSHMAMMA, P., LAVANYA, C., MACHADO, O.L.T., MIELKE, T., MILANI,

M., MILLER, T.D., MORRIS, J.B., MORSE, S.A., NAVAS, A.A., SOARES, D.J., SOFIATTI, V., WANG, M.L., ZANOTTO, M.D. and ZIELER, H., 2012. A review on the challenges for increased production of castor. *Agronomy Journal*, vol. 104, no. 4, pp. 853-880. http://dx.doi.org/10.2134/agronj2011.0210.

SILVA, C.A.D., 2004. Efeitos da temperatura no desenvolvimento, fecundidade e longevidade de *Gargaphia torresi* Lima (Hemiptera, Tingidae). *Revista Brasileira de Entomologia*, vol. 48, no. 4, pp. 547-552. http://dx.doi.org/10.1590/S0085-56262004000400018.

SOUTHWOOD, T.R.E., 1973. The insect/plant relationship an evolutionary perspective. In: H.F. VAN EMDEN, ed. *Insect/plant relationships*. London: Blackwell, pp. 3-30.

VARÓN, E.H., MOREIRA, M.D. and CORREDOR, J.P., 2010. Effect of *Corythucha gossypii* on castor oil plant leaves: Sampling criteria and control by insecticides. *Corpoica Ciencia y Tecnología Agropecuaria*, vol. 11, no. 1, pp. 41-47.

VOGT, T.E. and MCPHERSON, J.E., 1986. Life history and laboratory rearing of *Corythuca juglandis* (Hemiptera: Tingidae) with descriptions of immature stages. *Great Lakes Entomologist*, vol. 19, pp. 221-233.

WILSON, L.T. and BARNETT, W.W., 1983. Degree-day: an aid in crop and pest management. *California Agriculture*, vol. 37, no. 1, pp. 4-7.

ZHANG, Y., HANULA, J.L., HORN, S., BRAMAN, S.K. and SUN, J., 2011. Biology of *Leptoypha hospita* (Hemiptera: Tingidae), a potential biological control agent of Chinese Privet. *Annals of the Entomological Society of America*, vol. 104, no. 6, pp. 1327-1333. http://dx.doi.org/10.1603/AN11042.