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Population Ecology

Temperature- and Relative Humidity-Dependent Life History Traits of *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) on *Hibiscus rosa-sinensis* (Malvales: Malvaceae)

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ABSTRACT *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), a worldwide distributive invasive pest, originated from the United States, and it was first reported in Guangdong province, China, in 2008. The effects of temperature and relative humidity (RH) on the life history traits of *P. solenopsis* on *Hibiscus rosa-sinensis* L. (Malvales: Malvaceae) were studied at seven constant temperatures (15, 20, 25, 27.5, 30, 32.5, and 35°C) and three RHs (45, 60, and 75%). The results showed that temperature, RH, and their interactions significantly influenced the life history traits of *P. solenopsis.* First instar was the most sensitive stage to extreme temperatures with very low survival rates at 15 and 35°C. At 25–32.5°C and the three RHs, the developmental periods of entire immature stage were shorter with values between 12.5–18.6 d. The minimum threshold temperature and the effective accumulative temperature for the pest to complete one generation were 13.2°C and 393.7 degree-days, respectively. The percentage and longevity of female adults significantly differed among different treatments. It failed to complete development at 15 or 35°C and the three RHs. Female fecundity reached the maximum value at 27.5°C and 45% RH. The intrinsic rate for increase (r), the net reproductive rate (R_0), and the finite rate of increase (λ) reached the maximum values at 27.5°C and 45% RH (0.22 d^{-1}, 244.6 hatched eggs, and 1.25 d^{-1}, respectively). Therefore, we conclude that 27.5°C and 45% RH are the optimum conditions for the population development of the pest.

KEY WORDS temperature, humidity, *Phenacoccus solenopsis*, biological characteristic

Phenacoccus solenopsis Tinsley (Hemiptera: Pseudococcidae), a worldwide distributive invasive pest, originated from the United States (Tinsley 1898), has been reported in 35 global locations of various ecological regions (Sahayaraj et al. 2014). As a polyphagous pest, it is reported that its hosts have been >200 plant species (Fand and Suroshe 2015), including crops, weeds, medical and horticultural plants (Culik and Gullan 2005, Hodgson et al. 2008, Huang et al. 2014). Nymphs and female adults mainly attack leaves, and also infest flowers, fruits, main stems, and branches (Hodgson et al. 2008, Aheer et al. 2009), resulting in chlorosis, stunting, deformation, and death of plants (Sahayaraj et al. 2014). It has become a serious and invasive pest on cotton (Hodgson et al. 2008), and caused 30–60% yield losses (*Gossypium hirsutum* L., Malvaceae) in Pakistan and India during 2005–2009 (Fand and Suroshe 2015).

In China, *P. solenopsis* was first reported in Guangdong province in 2008, whereafter it spread to other eight provinces in the following two years (Wang et al. 2014). The widely potential distribution (Wang et al. 2010) makes it to be a notoriously invasive pest in China (Lu et al. 2008). *Hibiscus rosa-sinensis* L. (Malvales: Malvaceae) is an important valuable horticultural plant in southern China, and it is also one of the favorite hosts of *P. solenopsis* (Abbas et al. 2010b, Sreedevi et al. 2013). Because the hosts of *P. solenopsis* exist throughout the year, a persistent spread source has been provided for the mealybug between cotton and other crops (Arif et al. 2009, Sreedevi et al. 2013).

Temperature and humidity are the basic and key environmental factors that influenced an insect in nature. Many studies have shown that temperature, relative humidity (RH), and their interactions significantly affected the survival, developmental time, longevity, progeny sex ratio, and fecundity of an insect (Gautam et al. 2010; Zhou et al. 2010a,b; Yanik and Unlu 2011; Tamiru et al. 2012). As an important insect pest, the biology of *P. solenopsis* has been reported in a few previous studies (Guan et al. 2012, Prasad et al. 2012, Sreedevi et al. 2013, Wang et al. 2014). Meanwhile some studies have preliminarily described how temperature or humidity affected the development, survival, reproduction, or other biological characteristics of *P. solenopsis* (Ali et al. 2012, Kumar et al. 2013). On the other hand, temperature-dependent biology and fitness

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of an insect were also often affected by geographical environments (Suman et al. 2011, Chen et al. 2014) and host plant species (Serrano and Lapointe 2002, Abbas et al. 2010b). Therefore, there may be a significant difference in the ecological and biological characteristics of an insect among geographical populations and host-feeding populations.

P. solenopsis has successfully invaded and established its population for 6 yr in south China since 2008. Therefore, it has adapted to the climates of the invasive areas in south China. To understand the effects of temperature and humidity on life history traits of *P. solenopsis* feeding on *H. rosa-sinensis*, we observed development, survival, and fecundity of the mealybug under different temperatures and humidities. A better understanding of life history parameters of *P. solenopsis* on its key off-season host will be helpful to improve its prediction on cotton during the cropping season (Sreedevi et al. 2013). Therefore, the results of this study will offer valuable insights into the climatic applicability of *P. solenopsis* covering geographically wide regions, and understanding an optimum condition for its growth and development.

Materials and Methods

Host Plants. *H. rosa-sinensis* seedlings were transplanted to a well-drained greenhouse with loose and fecund loam, and were then watered and fertilized once every 2 and 15 d separately. When they grew up to about 50 cm high, the fully expanded healthy leaves were cut and washed with distilled water. The petioles were individually wrapped around with wet cotton balls and placed in plastic cups (6 cm base diameter, 8 cm crown diameter, 10 cm high) prior to the release of insects.

Insects. Adults of *P. solenopsis* were collected from *H. rosa-sinensis* in Nanning City, Guangxi Zhuang Autonomous Region, China (22° 58′27″ N, 108° 11′34″ E), and then were reared on *H. rosa-sinensis* in greenhouse located in Institute of Plant Protection, Guangxi Academy of Agricultural Sciences (22° 50′56″ N, 108° 14′37″ E). The first-instar healthy nymphs (≤24 h old) were chosen for the following experiments.

Experimental Setup. Development and survival of *P. solenopsis* was assessed at seven constant temperatures (15, 20, 25, 27.5, 30, 32.5, and 35 ± 0.6°C) and three RHs (45, 60, and 75 ± 8%). This study was focused on the biology of female *P. solenopsis* based on the dominated parthenogenesis (Kumar et al. 2010, Vennila et al. 2010), the negligible role in reproduction, and longevity of male adults (Nikam et al. 2010, Vennila et al. 2010). For each treatment, 40 first-instar healthy nymphs were used in one replication, and they were separately placed in 40 plastic cups (see above) covered with 100 mesh using an artist's fine brush (size 000), and the plastic cups were then placed in an environmental chamber (LRH-550-GSI; Shaoguan Taihong Medical Equipment Co. Ltd., Guangdong, China) with a photoperiod of 14:10 (L:D) h and a light intensity of 10,000 LX. *H. rosa-sinensis* leaves with nymphs and cotton balls in plastic cups were examined daily for shed exuviae which marked the successful completion of the current instar duration. Sex of each nymph was determined at the time of the second molt. From this point onwards, the developmental times of females and males were recorded separately. Daily instar survival in each replication was recorded to calculate the percentage of surviving individuals at the start of each instar. Survival from first instar to adult emergence was recorded to calculate the survival rate of entire immature stage. The percentage of female adults was calculated as a secondary sex ratio estimated by the numbers of female and male. The period from the start of one instar to the emergence of another instar of surviving individuals was recorded to calculate the developmental time. Period from first instar or third instar to adult emergence was recorded to calculate the developmental time of entire immature stage or third instar. Cotton balls were watered timely, and leaves were changed every 2 or 3 d until all nymphs developed into adults.

To measure the longevity, fecundity, and prelarviposition period of female adult, 10 healthy newly emerged female adults (≤24 h old) as one replication were carefully placed in 10 plastic cups covered with 100 mesh using an artist's fine brush (size 000) separately, and the plastic cups were then kept in the same environmental chambers as above. *H. rosa-sinensis* leaves with nymphs and cotton balls in plastic cups were also examined daily for counting the number of progeny (i.e., first instar nymphs due to the ovoviviparous reproduction of *P. solenopsis*), while newly counted nymphs were then removed. Cotton balls were watered timely, and leaves were changed every 2 or 3 d until all females died. Each treatment was repeated five times.

Statistical Analysis. Data were checked for normality as appropriate ($P > 0.05$) and, if needed, were arcsine square-root or log-transformed. The data for the biological parameters at different temperatures and RHs were run a two-way ANOVA via OriginPro 9.0; the differences between means were run a one-way ANOVA via OriginPro 9.0 (LSD test, $P = 0.05$; OriginLab, Northampton, MA).

Linear regression was used to describe the relationship between temperature (T) and developmental rates ($V = 1$/developmental period) for the nymph stage, where $V = (1/K) \times T - C/K$, within the temperature range in which the relationship is linear (15–32.5°C). The model was fitted using the analytical program Linear Fit (OriginPro 9.0, OriginLab, Northampton, MA). V is the developmental rate in days at temperature T (°C), K is the required heat units in degree-days (DD) in effective accumulation, and C is the minimum developmental thresholds (DTs; Arbab et al. 2008, Qiu et al. 2012).

Life table parameters were estimated by TWO-SEX-MSChart program (Chi 2012) based on the age-stage, two-sex life table theory (Chi 1988). The age-stage-specific survival rate (S_{xj}) ($x =$ age, $j =$ stage), the age-stage-specific fecundity (f_{xj}), the age-specific survival rate (l_x), the age-specific fecundity (m_x), and the population parameters (r, the intrinsic rate of increase; λ, the finite rate of increase; R_0, the net reproductive rate; *T*, the mean generation time; *D*, the doubling time) were calculated as:

$$l_x = \sum_{j=1}^{m} s_{xj} \tag{1}$$

$$m_x = \frac{\sum_{j=1}^{m} s_{xj} f_{xj}}{\sum_{j=1}^{m} s_{xj}} \tag{2}$$

$$\sum_{x=0}^{\infty} \exp[-r(x+1)] l_x m_x = 1 \tag{3}$$

$$\lambda = \exp(r) \tag{4}$$

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \tag{5}$$

$$T = \frac{\ln R_0}{r} \tag{6}$$

$$D = \frac{\ln 2}{r} \tag{7}$$

Results

Survival Rate. Except for the first-instar nymphs and entire immature stage ($P < 0.05$), humidity did not affect the survival of second- and third-instar nymphs of *P. solenopsis* ($P > 0.05$). The survival rates of first- to third-instar nymphs and entire immature stage of *P. solenopsis* were significantly affected by temperature ($P < 0.05$) and humidity–temperature interactions ($P < 0.05$; Table 1). The survival rates of first-instar nymphs, second-instar nymphs, and entire immature stage were all the highest at 27.5°C and 45% RH, but the lowest were observed at 15°C and 60% RH, 15°C and 45% RH, and 15°C and 45% RH, respectively. The survival rates of third-instar nymphs were all 100.0% at 25°C and 60% or 75% RH, and 20°C and 75% RH. The lowest survival rate of third-instar nymphs was 63.7% at 35°C and 75% RH (Table 2).

Table 1. Two-way ANOVA of the effects of temperature, relative humidity, and their interactions on survival rate of *P. solenopsis*

Developmental stage	Source[a]	df	Mean square	*F*	*P*
First instar	Temp	6,84	3205.41	60.83	<0.0001
	RH	2,84	454.59	8.63	0.0004
	Temp × RH	12,84	2515.49	47.74	<0.0001
Second instar	Temp	6,84	351.27	4.45	0.0005
	RH	2,84	20.91	0.27	0.7677
	Temp × RH	12,84	268.63	3.41	0.0018
Third instar	Temp	6,84	1665.53	23.22	<0.0001
	RH	2,84	29.70	0.41	0.6621
	Temp × RH	12,84	1257.36	17.53	<0.0001
Immature[b]	Temp	6,84	5449.52	115.71	<0.0001
	RH	2,84	624.89	13.27	<0.0001
	Temp × RH	12,84	4236.81	89.96	<0.0001

[a] Temperature regimes are 15, 20, 25, 27.5, 30, 32.5, and 35°C; the RH regimes are 45, 60, and 75%.

[b] Immature refers to the developmental period of *P. solenopsis* from first instar to adult emergence.

Developmental Period. With the exception of the second- and third-instar nymphs ($P > 0.05$), humidity significantly affected the developmental periods of first-instar nymphs and entire immature stage of *P. solenopsis* ($P < 0.05$). Developmental periods of first- to third-instar nymphs and entire immature stage of *P. solenopsis* were also significantly affected by temperature ($P < 0.05$) and humidity–temperature interactions ($P < 0.05$; Table 3). The developmental period of first-instar nymphs was the longest at 15°C and 75% RH, and the shortest was observed at 35°C and 75% RH. Developmental periods of second- and third-instar nymphs and entire immature stage of *P. solenopsis* were all the longest at 15°C and 45% RH, but the shortest were observed at 32.5°C and 45% RH, 32.5°C and 45% RH, and 30°C and 45% RH (Table 4).

Minimum Developmental Thresholds and Effective Accumulative Temperature. As shown by the high coefficient of determination (adjusted $R^2 > 0.90$), at 45% RH the linear model adequately described the relationship between the developmental rate of *P. solenopsis* and temperature. The minimum threshold temperature of the second-instar nymph stage was the lowest (10.7°C), whereas that of the third-instar nymph stage was the highest (13.5°C). The effective accumulative temperature for *P. solenopsis* to develop from first-instar nymph to adult and complete one generation was 238.1 DD and 393.7 DD, respectively (Table 5).

Female Adult Percentage and Longevity. Female adult percentages and longevities were significantly affected by temperature, humidity, and humidity–temperature interactions ($P < 0.05$; Table 6). Female adult percentage was the highest at 35°C and 45% RH, and the lowest was noticed at 20°C and 60% RH. Female adult longevity was the longest at 20°C and 75% RH, but the shortest was observed at 30°C and 60% RH (Table 7).

Female Adult Prelarviposition Period and Fecundity. Because the mealybug failed to produce their offspring at 15 and 35°C, the data from the two temperature treatments were excluded in the analysis. Female adult prelarviposition periods and fecundities were significantly affected by temperature, humidity, and humidity–temperature interactions ($P < 0.05$; Table 8). Female adult prelarviposition period was the longest at 20°C and 60% RH; the shortest was observed at 32.5°C and 45% RH. The maximum female fecundity was observed at 27.5°C and 45% RH, but the minimum was observed at 20°C and 45% RH (Table 9).

Life Table Parameters. On the whole, the mean generation time, net reproductive rate, intrinsic increase rate, finite increase rate, and doubling time of *P. solenopsis* were significantly different among different treatments ($P < 0.05$; Table 10). The mean generation time significantly decreased with the increasing temperature; the longest was 64.2 d at 20°C and 45% RH, and the shortest was 20.9 d at 32.5°C and 45% RH. The net reproductive rate reached the maximum value (244.6 hatched eggs) at 27.5°C and 45% RH, and

Table 2. Combined effects of temperature and relative humidity on survival rate of *P. solenopsis* reared on *H. rosa-sinensis*

Developmental stage	Temp (°C)	Survival rate (%)[a]				
		45% RH	60% RH	75% RH	$F_{2,12}$	P
First instar	15	55.0 ± 2.2Ea	40.0 ± 2.2Db	60.8 ± 1.5Ea	28.24	<0.0001
	20	82.2 ± 2.6Ba	84.0 ± 4.3Ba	85.0 ± 1.6ABa	0.22	0.8087
	25	88.7 ± 1.5Aa	85.0 ± 2.1Ba	90.0 ± 3.2Aa	1.21	0.3327
	27.5	94.8 ± 0.9Aa	93.6 ± 0.5Aab	92.4 ± 0.8Ab	2.60	0.1151
	30	68.0 ± 2.5Ca	70.0 ± 4.5Ca	66.3 ± 2.9DEa	0.29	0.7539
	32.5	62.2 ± 1.6CDb	65.8 ± 2.5Cab	72.8 ± 2.7CDa	5.44	0.0208
	35	57.5 ± 3.2DEb	62.2 ± 1.6Cb	81.0 ± 5.1Aa	14.08	0.0007
	$F_{6,28}$	54.29	39.63	17.76	–	–
	P	<0.0001	<0.0001	<0.0001	–	–
Second instar	15	63.1 ± 1.3Dc	92.8 ± 3.1Aa	82.9 ± 2.2Bb	42.53	<0.0001
	20	79.6 ± 1.9Cb	88.0 ± 1.8ABa	82.0 ± 2.8Bab	3.88	0.0501
	25	91.0 ± 2.3ABa	89.8 ± 4.3ABa	94.2 ± 3.2Aab	0.45	0.6477
	27.5	95.0 ± 1.7Aa	90.8 ± 1.7ABa	92.0 ± 2.0Aab	1.46	0.2715
	30	84.8 ± 3.7BCb	87.4 ± 2.3ABb	74.0 ± 3.3Ca	5.03	0.0259
	32.5	90.4 ± 1.6ABa	84.6 ± 1.6Bb	82.4 ± 1.5Bb	6.76	0.0108
	35	93.8 ± 6.3Aa	73.0 ± 2.7Cb	91.2 ± 3.3Aa	8.14	0.0068
	$F_{6,28}$	15.37	6.22	7.16	–	–
	P	<0.0001	0.0003	0.0001	–	–
Third instar	15	63.9 ± 1.9Db	69.6 ± 1.8Db	86.7 ± 3.7Ba	21.16	0.0001
	20	82.8 ± 2.4Cb	86.2 ± 3.5Bb	100.0 ± 0.0Aa	13.66	0.0008
	25	92.5 ± 3.2ABb	100.0 ± 0.0Aa	100.0 ± 0.0Aa	5.35	0.0219
	27.5	97.8 ± 0.9Aa	98.0 ± 1.4Aa	97.2 ± 0.9Aa	0.15	0.8591
	30	94.3 ± 3.9ABa	86.1 ± 1.8Ba	86.8 ± 5.2Ba	1.42	0.2796
	32.5	89.6 ± 2.3BCa	78.6 ± 2.2Cb	69.6 ± 3.6Cc	13.21	0.0009
	35	82.1 ± 2.8Ca	73.5 ± 1.5CDb	63.7 ± 2.1Cc	18.34	0.0003
	$F_{6,28}$	18.98	34.10	30.43	–	–
	P	<0.0001	<0.0001	<0.0001	–	–
Immature[b]	15	23.0 ± 1.2Fc	28.0 ± 1.2Fb	48.0 ± 1.4DEa	105.00	<0.0001
	20	57.4 ± 2.4Cb	69.0 ± 1.9Ca	69.0 ± 1.9Ba	10.73	0.0021
	25	65.6 ± 1.7Bc	76.1 ± 2.8Bb	84.0 ± 2.9Aa	13.36	0.0009
	27.5	88.4 ± 1.7Aa	83.5 ± 1.2Ab	82.5 ± 1.4Ab	4.73	0.0306
	30	47.0 ± 2.5DEc	50.0 ± 3.5Dbc	58.3 ± 2.0Ca	3.82	0.0549
	32.5	50.9 ± 1.6Da	43.8 ± 1.3Eb	41.8 ± 1.5Fb	10.32	0.0025
	35	41.3 ± 2.4Ea	33.3 ± 1.3Fb	46.0 ± 1.9EFa	13.14	0.0012
	$F_{6,28}$	109.03	108.95	85.25	–	–
	P	<0.0001	<0.0001	<0.0001	–	–

[a] Mean ± SE. Means followed by the same letter(s) within a column (upper case letter) and within a row (lower case letter) are not significantly different (one-way ANOVA, LSD, $P = 0.05$).
[b] Immature refers to the developmental period of *P. solenopsis* from first instar to adult emergence.

Table 3. Two-way ANOVA of the effects of temperature, relative humidity, and their interactions on developmental period of *P. solenopsis*

Developmental stage	Source[a]	df	Mean square	F	P
First instar	Temp	6,84	1244.65	961.34	<0.0001
	RH	2,84	13.41	10.36	<0.0001
	Temp × RH	12,84	936.84	723.59	<0.0001
Second instar	Temp	6,84	436.54	373.64	<0.0001
	RH	2,84	1.70	0.25	0.2377
	Temp × RH	12,84	327.83	280.60	<0.0001
Third instar	Temp	6,84	1822.35	190.68	<0.0001
	RH	2,84	27.82	2.91	0.0593
	Temp × RH	12,84	1373.72	143.74	<0.0001
Immature[b]	Temp	6,84	9652.07	702.18	<0.0001
	RH	2,84	62.87	4.57	0.0127
	Temp × RH	12,84	7254.77	527.78	<0.0001

[a] Temperature regimes are 15, 20, 25, 27.5, 30, 32.5, and 35°C; the RH regimes are 45, 60, and 75%.
[b] Immature refers to the developmental period of *P. solenopsis* from first instar to adult emergence.

the minimum value (16.4 hatched eggs) was observed at 32.5°C and 75% RH. Both the intrinsic increase rate and finite increase rate reached the maximum values ($0.22\,d^{-1}$ and $1.25\,d^{-1}$) at 27.5°C and 45% RH, while the minimum values ($0.05\,d^{-1}$ and $1.05\,d^{-1}$) were observed at 20°C and 45% RH. The longest doubling time was 13.4 d at 20°C and 45% RH, and the shortest was 3.1 d at 27.5°C and 45% RH (Table 10).

Discussion

Survival and Developmental Period. Generally, there is a parabolic relationship between survival rate/developmental period and temperature/humidity in an insect (Broufas et al. 2009; Gautam et al. 2010; Zhou et al. 2010a,b; Pappas et al. 2013).

In the present study, the first-instar nymphs were highly sensitive to extreme temperatures; their survival rates were the lowest among the three instar nymphs at 15 or 35°C and the three RHs (except for third-instar nymphs at 35°C and 75% RH); later instars had a higher survival rate at all temperatures. This has supported the findings of previous studies (Prasad et al. 2012, Sreedevi et al. 2013, Fand et al. 2014). In contrast, Vennila et al. (2010) has reported that the second-instar nymphs were most sensitive to extreme temperatures among all instar nymphs. At 15–35°C

Table 4. Combined effects of temperature and relative humidity on developmental period of *P. solenopsis* reared on *H. rosa-sinensis*

Developmental stage	Temp (°C)	Developmental period (d)[a]				
		45% RH	60% RH	75% RH	$F_{2,12}$	P
First instar	15	28.8 ± 0.1Ab	26.2 ± 0.8Ac	32.2 ± 1.2Aa	13.71	0.0008
	20	10.2 ± 0.2Ba	9.4 ± 0.1Bb	9.6 ± 0.2Bb	5.96	0.0159
	25	5.7 ± 0.1Ca	4.5 ± 0.1Cb	5.6 ± 0.2Ca	31.16	<0.0001
	27.5	4.6 ± 0.1Da	4.8 ± 0.1Ca	4.9 ± 0.1CEa	1.21	0.3318
	30	4.2 ± 0.1Eb	4.2 ± 0.1Cb	5.2 ± 0.1CEa	24.05	<0.0001
	32.5	4.2 ± 0.1Ea	4.2 ± 0.1Ca	4.6 ± 0.2CEa	2.69	0.1082
	35	4.7 ± 0.1Da	4.4 ± 0.1Cab	4.1 ± 0.1Eb	6.25	0.0138
	$F_{6,28}$	5005.00	656.65	476.79	–	–
	P	<0.0001	<0.0001	<0.0001	–	–
Second instar	15	19.8 ± 0.2Aa	18.4 ± 0.2Aa	19.8 ± 1.1Aa	1.73	0.2195
	20	11.5 ± 0.2Ba	9.3 ± 0.2Bb	7.5 ± 0.2Bc	120.89	<0.0001
	25	5.3 ± 0.2CDa	5.3 ± 0.2Ca	5.1 ± 0.2Ca	0.44	0.6548
	27.5	4.9 ± 0.2DEa	4.7 ± 0.2Da	4.7 ± 0.2Ca	0.22	0.8022
	30	4.4 ± 0.2EFa	4.5 ± 0.2Da	4.5 ± 0.2Ca	0.10	0.9055
	32.5	4.3 ± 0.1Fa	4.4 ± 0.2Da	4.4 ± 0.2Ca	0.11	0.9001
	35	5.5 ± 0.1Cc	9.2 ± 0.2Ba	7.0 ± 0.1Bb	117.96	<0.0001
	$F_{6,28}$	1366.60	726.36	164.96	–	–
	P	<0.0001	<0.0001	<0.0001	–	–
Third instar	15	44.2 ± 0.3Aa	29.8 ± 0.6Ac	32.0 ± 0.5Ab	235.75	<0.0001
	20	10.7 ± 0.3Ba	11.2 ± 0.2Ba	8.5 ± 0.3Cb	29.72	<0.0001
	25	6.2 ± 0.2Ca	6.6 ± 0.2Ca	5.4 ± 0.2Db	10.57	0.0023
	27.5	5.5 ± 0.2Da	5.5 ± 0.2Da	5.3 ± 0.3Da	0.19	0.8272
	30	3.9 ± 0.2Eb	4.1 ± 0.2Eb	4.9 ± 0.1Da	10.53	0.0023
	32.5	3.8 ± 0.1Ec	3.9 ± 0.1Eb	4.6 ± 0.2Da	6.95	0.0099
	35	6.0 ± 0.1CDc	7.4 ± 0.2Cb	15.2 ± 0.4Ba	356.88	<0.0001
	$F_{6,28}$	4457.21	1016.86	1018.44	–	–
	P	<0.0001	<0.0001	<0.0001	–	–
Immature[b]	15	92.8 ± 1.0Aa	74.3 ± 0.4Ac	84.1 ± 1.1Ab	106.46	<0.0001
	20	32.4 ± 0.9Ba	29.8 ± 0.5Bb	25.6 ± 0.4Bc	26.11	<0.0001
	25	17.2 ± 0.5Ca	16.3 ± 0.5Da	16.1 ± 0.4Da	1.31	0.3062
	27.5	13.3 ± 0.3Da	13.4 ± 0.4Fa	14.2 ± 0.3Ea	2.35	0.1380
	30	12.5 ± 0.2Db	12.9 ± 0.3Fb	14.6 ± 0.3DEa	15.70	0.0004
	32.5	13.3 ± 0.4Dc	14.7 ± 0.2Eb	18.6 ± 0.5Ca	44.80	<0.0001
	35	16.1 ± 0.5Cc	21.0 ± 0.2Cb	26.3 ± 0.4Ba	163.17	<0.0001
	$F_{6,28}$	2214.90	3115.86	1944.50	–	–
	P	<0.0001	<0.0001	<0.0001	–	–

[a] Mean ± SE. Means followed by the same letter(s) within a column (upper case letter) and within a row (lower case letter) are not significantly different (one-way ANOVA, LSD, $P = 0.05$).
[b] Immature refers to the developmental period of *P. solenopsis* from first instar to adult emergence.

Table 5. Linear regression analyses of the development of *P. solenopsis* reared on *H. rosa-sinensis* at constant temperatures and relative humidities

RH(%)	Life stage	Regression equation[a]	Adjusted R^2	$F_{1,4}$	P	C[b]	K[c]
45	First instar	V=0.0127T-0.1500	0.97	145.75	0.0003	78.7	11.8
	Second instar	V=0.0115T-0.1231	0.93	69.71	0.0011	86.7	10.7
	Third instar	V=0.0143T-0.1925	0.97	190.93	0.0002	70.1	13.5
	Immature[d]	V=0.0042T-0.0498	0.92	58.49	0.0016	238.1	11.9
	One generation[e]	V=0.0025T-0.0337	0.93	54.88	0.0051	393.7	13.2
60	First instar	V=0.0122T-0.1291	0.88	38.03	0.0035	82.0	10.6
	Second instar	V=0.0108T-0.0999	0.97	83.57	0.0008	92.8	9.3
	Third instar	V=0.0132T-0.1709	0.98	309.25	<0.0001	75.5	12.9
	Immature[d]	V=0.0037T-0.0374	0.84	27.68	0.0063	271.0	10.1
	One generation[e]	V=0.0019T-0.0203	0.89	34.66	0.0098	515.5	10.5
75	First instar	V=0.0108T-0.1144	0.91	52.89	0.0019	92.8	10.6
	Second instar	V=0.0102T-0.0809	0.90	46.75	0.0024	98.1	7.9
	Third instar	V=0.0106T-0.1061	0.91	54.60	0.0018	94.4	10.0
	Immature[d]	V=0.0029T+0.0207	0.63	9.35	0.0377	348.4	7.2
	One generation[e]	V=0.0012T+0.0033	0.63	7.87	0.0676	806.5	2.7

[a] V is the developmental rate (1/developmental period) and T is the temp (°C).
[b] C is the minimum thermal threshold for development (°C).
[c] K is the effective accumulative temperature with the unit of degree-days.
[d] Immature refers to the developmental period of *P. solenopsis* from first instar to adult emergence.
[e] One generation refers to the developmental period of *P. solenopsis* from first instar to next first instar emergence.

and 45–75% RH, the survival rates of first-instar nymphs of *P. solenopsis* ranged between 40.0 and 94.8%; a similar range was observed by Sreedevi et al. (2013). There were also previous studies that differed from our results (Prasad et al. 2012, Fand et al. 2014). The survival rates of the second-instar nymphs of *P. solenopsis* ranged between 63.1 and 95.0%. This was consistent with the findings in the studies of Fand et al. (2014) and Sreedevi et al. (2013), but was lower than the findings in the study of Prasad et al. (2012). The survival rates of the third-instar nymphs of *P. solenopsis* ranged between 63.7 and 100.0% in our study, which differed from previous studies (Prasad et al. 2012, Sreedevi et al. 2013, Fand et al. 2014). The survival rates of entire immature stage of *P. solenopsis* ranged between 23.0 and 88.4%; a similar range at 20–36°C and 65% RH was observed by Prasad et al. (2012), but differed from the result in the study of Sreedevi et al. (2013).

The durations of the first- to third-instar nymphs and entire immature stage of *P. solenopsis* at 15°C and the three RHs were significantly longer than those at other temperatures and the three RHs, and were also longer than the results in the studies of Sreedevi et al. (2013) and Fand et al. (2014). When temperatures were no lower than 20°C, the developmental periods of different instar nymphs mostly ranged between 4 and 10 d; this was in agreement with the reports by Hameed at al. (2012), Prasad et al. (2012), Kumar et al. (2013), Sreedevi et al. (2013), and Fand et al. (2014). We found that developmental periods of different instar nymphs were very similar, which has also been described by Hameed et al. (2012). However, the changing developmental durations for all the three nymphal instars were also observed in more previous studies (Nikam et al. 2010, Vennila et al. 2010, Prasad et al. 2012, Fand et al. 2014).

Minimum Developmental Thresholds and Effective Accumulative Temperature. The minimum developmental threshold and effective accumulative temperature of *P. solenopsis* can provide useful information for predicting the potential occurrence and geographical distribution of this pest (Wang et al. 2010). Linear model is widely used to describe the linear relationship between developmental rates and temperatures in a medium range and calculate lowest threshold and effective accumulative temperature required to complete development of life stages (Kontodimas et al. 2004, Sreedevi et al. 2013). In our study, the linear relationship between developmental rates and temperatures in the range of 15–32.5°C for immature stage and one generation of female *P. solenopsis*, and their minimum threshold and effective accumulative temperature were well explained by the linear models at 45% RH. The similar trends for a temperature range of 18–32°C and 18–33°C have also been reported by Prasad et al. (2012) and Lu et al. (2011). In our study, the minimum threshold temperature of first-instar nymphs of *P. solenopsis* was very similar to the Zhejiang population on *H. rosa-sinensis* (Lu et al. 2011), the Warangal population on cotton (Prasad et al. 2012), and the Pune population on potato (*Solanum tuberosum* L., Solanaceae) (Fand et al. 2014), but was lower than the New Delhi population on *H. rosa-sinensis* (Sreedevi et al. 2013). The effective accumulative temperature of first-instar nymphs in our study was very similar to the Zhejiang and New Delhi populations on *H. rosa-sinensis* in the studies from Lu et al. (2011) and Sreedevi et al. (2013), but was lower than the Warangal population on cotton in the study from Prasad et al. (2012). The minimum threshold temperature of second-instar nymphs was lower than the Zhejiang (Lu et al. 2011) and New Delhi (Sreedevi et al. 2013) populations on *H. rosa-sinensis*, and the Warangal population on cotton (Prasad et al. 2012), but was higher than

Table 6. Two-way ANOVA of the effects of temperature, relative humidity, and their interactions on female adult percentage and longevity of *P. solenopsis*

	Source[a]	df	Mean square	F	P
Female adult percentage	Temp	6,84	211.65	2.94	0.0113
	RH	2,84	3299.33	45.83	<0.0001
	Temp × RH	12,84	988.80	13.74	<0.0001
Female adult longevity	Temp	6,84	4855.14	96.61	<0.0001
	RH	2,84	522.96	10.41	<0.0001
	Temp × RH	12,84	3769.64	75.01	<0.0001

[a] Temperature regimes are 15, 20, 25, 27.5, 30, 32.5, and 35°C; the RH regimes are 45, 60, and 75%.

Table 7. Combined effects of temperature and relative humidity on female adult percentage and longevity of *P. solenopsis* reared on *H. rosa-sinensis*

Temp (°C)	Female adult percentage (%)[a]					Female adult longevity (d)[a]				
	45% RH	60% RH	75% RH	$F_{2,12}$	P	45% RH	60% RH	75% RH	$F_{2,12}$	P
15	70.7 ± 2.3Ba	72.0 ± 2.6Aa	46.5 ± 1.5Cb	43.01	<0.0001	45.0 ± 0.8Bb	53.0 ± 1.1Ba	33.9 ± 1.3Ec	80.56	<0.0001
20	67.9 ± 2.7BCa	35.8 ± 1.3Dc	58.0 ± 1.2Ab	78.82	<0.0001	74.0 ± 1.3Ac	89.9 ± 2.1Ab	102.0 ± 3.0Aa	38.97	<0.0001
25	65.9 ± 2.2BCa	50.6 ± 3.1Cb	48.5 ± 1.0Cb	17.71	0.0003	42.3 ± 1.2Bb	49.7 ± 2.1BCa	52.5 ± 1.6BCa	9.77	0.0030
27.5	70.0 ± 1.4Ba	60.4 ± 2.0Bb	54.8 ± 2.1ABb	17.05	0.0003	42.8 ± 1.6Bb	51.6 ± 1.3Ba	50.6 ± 1.0CDa	13.48	0.0009
30	62.4 ± 1.8Ca	52.9 ± 1.4Cb	51.0 ± 2.7BCb	10.85	0.0020	42.0 ± 1.1Bc	31.3 ± 1.0Db	46.0 ± 1.3Da	48.24	<0.0001
32.5	63.6 ± 1.3Ca	51.4 ± 1.6Cb	49.4 ± 1.9Cb	22.49	<0.0001	35.2 ± 1.8Ca	33.1 ± 1.4Dab	30.4 ± 1.3Eb	2.41	0.1317
35	80.6 ± 3.4Aa	37.0 ± 3.7Dc	49.7 ± 1.7Cb	51.14	<0.0001	37.6 ± 0.8Cc	46.2 ± 1.2Cb	56.3 ± 0.6Ba	110.14	<0.0001
$F_{6,28}$	6.93	27.92	5.30	–	–	201.21	164.38	213.89	–	–
P	0.0002	<0.0001	0.0010	–	–	<0.0001	<0.0001	<0.0001	–	–

[a] Mean ± SE. Means followed by the same letter(s) within a column (upper case letter) and within a row (lower case letter) are not significantly different (one-way ANOVA, LSD, $P = 0.05$).

the Pune population on potato (Fand et al. 2014). The effective accumulative temperature of second-instar nymphs was higher than the Zhejiang (Lu et al. 2011) and New Delhi (Sreedevi et al. 2013) populations on *H. rosa-sinensis*, but was lower than the Warangal population on cotton (Prasad et al. 2012). The minimum threshold temperature of third-instar nymphs was similar to the Zhejiang (Lu et al. 2011) and New Delhi (Sreedevi et al. 2013) populations on *H. rosa-sinensis*, the Warangal population on cotton (Prasad et al. 2012), and the Pune population on potato (Fand et al. 2014). The effective accumulative temperature of third-instar nymphs was similar to the Zhejiang population on *H. rosa-sinensis* (Lu et al. 2011), but was lower than the Warangal population on cotton (Prasad et al. 2012) and the New Delhi population on *H. rosa-sinensis* (Sreedevi et al. 2013). The minimum threshold temperature of immature stage was very similar to the Warangal population on cotton (Prasad et al. 2012), the Zhejiang (Lu et al. 2011) and New Delhi (Sreedevi et al. 2013) populations on *H. rosa-sinensis*. The effective accumulative temperature of immature stage was very similar to the Zhejiang (Lu et al. 2011) and New Delhi (Sreedevi et al. 2013) populations on *H. rosa-sinensis*, but was lower than the Warangal population on cotton (Prasad et al. 2012). The minimum threshold temperature (13.2°C) and effective accumulated temperature (393.7 DD) for *P. solenopsis* to complete a generation were very similar to the Zhejiang population on *H. rosa-sinensis* (Lu et al. 2011). The results revealed that winter and spring in temperate and subtropical regions may be unsuitable for the development of *P. solenopsis*. Previous studies have reported that tropical and subtropical regions were highly suitable for *P. solenopsis* (Wang et al. 2010, Lu et al. 2011, Fand et al. 2014). Based on our results, current meteorological data and climate warming, we conclude that *P. solenopsis* can complete 8–10 generations per year currently and

Table 8. Two-way ANOVA of the effects of temperature, relative humidity, and their interactions on female adult prelarviposition period and fecundity of *P. solenopsis*

	Source[a]	df	Mean square	*F*	*P*
Prelarviposition period	Temp	4,60	4141.38	1170.02	<0.0001
	RH	2,60	22.69	6.41	0.0019
	Temp × RH	8,60	2814.44	795.14	<0.0001
Fecundity	Temp	4,60	391424.37	95.79	<0.0001
	RH	2,60	156730.27	38.35	<0.0001
	Temp × RH	8,60	299234.38	73.23	<0.0001

[a] Temperature regimes are 20, 25, 27.5, 30, and 32.5°C; the RH regimes are 45, 60, and 75%.

Table 9. Combined effects of temperature and relative humidity on female adult prelarviposition period and fecundity of *P. solenopsis* reared on *H. rosa-sinensis*

Temp (°C)	Prelarviposition period (d)[a]					Fecundity (no. of first-instar nymphs laid per female)[a]				
	45% RH	60% RH	75% RH	$F_{2,12}$	*P*	45% RH	60% RH	75% RH	$F_{2,12}$	*P*
20	32.4 ± 0.3Aa	33.0 ± 0.6Aa	29.3 ± 0.4Ab	11.92	<0.0001	152.1 ± 4.1Db	268.6 ± 5.8Ba	244.2 ± 7.3Ca	156.20	<0.0001
25	15.9 ± 0.1Bb	16.1 ± 0.4Bab	16.6 ± 0.3Ba	2.14	0.1236	384.3 ± 5.2Bb	424.2 ± 10.2Aa	299.3 ± 6.6Bc	77.93	<0.0001
27.5	11.3 ± 0.6Cb	13.4 ± 0.6Ca	14.0 ± 0.6Ca	5.22	0.0105	468.8 ± 10.7Aa	424.2 ± 11.3Ab	347.6 ± 12.6Ac	27.29	<0.0001
30	9.6 ± 0.4Db	11.5 ± 0.3Da	11.3 ± 0.5Da	5.35	0.0076	464.0 ± 11.1Aa	215.5 ± 4.4Cb	230.2 ± 6.4Cb	289.63	<0.0001
32.5	7.7 ± 0.4Eb	8.8 ± 0.4Eab	9.7 ± 0.6Ea	4.38	0.0189	290.3 ± 12.6Ca	197.2 ± 9.6Cb	173.5 ± 10.8Db	31.38	<0.0001
$F_{4,20}$	1134.08	379.87	165.80	–	–	328.54	140.32	52.76	–	–
P	<0.0001	<0.0001	<0.0001	–	–	<0.0001	<0.0001	<0.0001	–	–

[a] Mean ± SE. Means followed by the same letter(s) within a column (upper case letter) and within a row (lower case letter) are not significantly different (one-way ANOVA, LSD, $P = 0.05$).

Table 10. Life table parameters of *P. solenopsis* reared on *H. rosa-sinensis* at different temperatures and relative humidities

Temp (°C)	RH (%)	Mean generation time (d)[a]	Net reproductive rate[a]	Intrinsic increase rate[a]	Finite increase rate[a]	Doubling time (d)[a]
20	45	64.2 ± 1.6 a	34.6 ± 5.8efg	0.05 ± 0.00 g	1.05 ± 0.00 g	13.4 ± 0.5a
	60	62.6 ± 0.5a	41.8 ± 4.7ef	0.06 ± 0.00g	1.06 ± 0.00 g	12.0 ± 0.5b
	75	55.6 ± 0.9b	28.2 ± 3.1efg	0.06 ± 0.00g	1.06 ± 0.00 g	11.6 ± 0.0b
25	45	33.1 ± 0.5c	146.7 ± 17.5b	0.15 ± 0.00d	1.16 ± 0.00 d	4.7 ± 0.1ef
	60	32.5 ± 1.3c	121.0 ± 11.4c	0.15 ± 0.00d	1.16 ± 0.00d	4.8 ± 0.1def
	75	32.7 ± 0.5c	101.7 ± 8.8c	0.14 ± 0.00de	1.15 ± 0.00de	5.0 ± 0.0de
27.5	45	24.6 ± 0.6efg	244.6 ± 8.7a	0.22 ± 0.01a	1.25 ± 0.01a	3.1 ± 0.1 h
	60	26.8 ± 1.3de	157.6 ± 5.9b	0.19 ± 0.01b	1.21 ± 0.01b	3.7 ± 0.1gh
	75	28.2 ± 1.3d	110.9 ± 0.5c	0.17 ± 0.01c	1.18 ± 0.01c	4.2 ± 0.2fg
30	45	22.2 ± 0.6gh	74.8 ± 7.9d	0.19 ± 0.00b	1.21 ± 0.00b	3.6 ± 0.1gh
	60	24.4 ± 0.2efg	31.2 ± 4.3efg	0.14 ± 0.01de	1.15 ± 0.01de	5.1 ± 0.2de
	75	25.9 ± 0.9def	44.2 ± 5.4e	0.15 ± 0.00 d	1.16 ± 0.00de	4.8 ± 0.1def
32.5	45	20.9 ± 0.9 h	47.9 ± 1.3e	0.19 ± 0.01b	1.21 ± 0.01b	3.8 ± 0.1gh
	60	23.5 ± 0.9fgh	20.6 ± 0.6fg	0.13 ± 0.01e	1.14 ± 0.01e	5.5 ± 0.3 d
	75	28.3 ± 1.4 d	16.4 ± 0.8 g	0.10 ± 0.00f	1.11 ± 0.01f	7.0 ± 0.3c
$F_{14,60}$		233.20	78.61	113.61	116.53	219.08
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Mean ± SE. Means followed by the same letter(s) within a column (upper case letter) and within a row (lower case letter) are not significantly different (one-way ANOVA, LSD, $P = 0.05$).

more generations per year in the future in Guangxi, China. It is reported that the economic losses are likely to occur in the areas where more than eight generations of *P. solenopsis* may develop in a year (Fand et al. 2014), so it may be an important invasive pest in Guangxi.

Female Adult Percentage, Longevity, Prelarviposition Period, and Fecundity. Many previous studies showed that female percentage, longevity, prelarviposition period, and fecundity of *P. solenopsis* were significantly affected by temperatures (Prasad et al. 2012, Sreedevi et al. 2013) and temperature–RH interactions (Ali et al. 2012, Hameed et al. 2012, Kumar et al. 2013). Our results have been in agreement with the previous studies. Vennila et al. (2010) reported that female *P. solenopsis* accounted for >95% of the population under 23.3–30.2°C and 40.5–92.5% RH. Prasad et al. (2012) suggested that the lowest percentage of females was still up to 89.5% at 20–36°C and 65% RH, and Sreedevi et al. (2013) reported that female percentage ranged between 70.2 and 94.5% at 18–35°C and 65% RH. In our study, the highest percentage of females was observed at 35°C and 45% RH, with a value of 80.6%. However, a lower female percentage (even below 50%) was observed at other temperatures and RHs. This significantly differed from the previous studies (Vennila et al. 2010, Prasad et al. 2012, Sreedevi et al. 2013).

An upward parabola between mean senescence rates of females and temperature in *P. solenopsis* has been described by Fand et al. (2014), and our study supported the results of the previous study. At all RHs, female longevity of *P. solenopsis* was the longest at 20°C, and this trend has been described by Prasad et al. (2012), Kumar et al. (2013), and Ali et al. (2012). However, in the present study, female longevities were significantly longer than those in the previous studies at the same temperatures (Ali et al. 2012, Prasad et al. 2012, Kumar et al. 2013).

High and low temperatures are not suitable for the population growth of *P. solenopsis* (Wang et al. 2010, Prasad et al. 2012, Sreedevi et al. 2013). The mealybug failed to produce offspring at 15 and 35°C, which means that the pest cannot complete its life cycle at extreme temperatures (≤15°C, or ≥35°C). Previous study presumed that under unfavorable conditions the dying female *P. solenopsis* produce its crawler sac, and the first-instar nymphs was sheltered under its moribund body in the state of arrested growth and then became active when favorable conditions returned (Abbas et al. 2010a). In general, diapause is a survival strategy in insects to overcome harsh environmental conditions (Hao et al. 2012). The overwintering diapause of *P. solenopsis* is very universal in the field (Abbas et al. 2010a), but summer diapause has not been found or reported. Previous studies showed that *P. solenopsis* successfully completed its life cycle at 15°C (Sreedevi et al. 2013) and 35°C (Prasad et al. 2012, Kumar et al. 2013, Sreedevi et al. 2013), but female mealybug did not produce eggs (Hameed et al. 2012), or eggs did not hatch (Ali et al. 2012, Prasad et al. 2012, Sreedevi et al. 2013) at 40°C. In our study, female's prelarviposition period in *P. solenopsis* rapidly shorten with the increasing temperature, and it was close to each other at different RH. Female's prelarviposition periods at 25 or 30°C and 60% RH were close to the results reported by Prasad et al. (2012) at the similar conditions. But female's prelarviposition periods in our study were longer than the results raised by *H. rosa-sinensis* and cotton in the study of Sreedevi et al. (2013) and Vennila et al. (2010). The number of offspring produced by single female *P. solenopsis* ranged from 152.1 to 468.8 and was significantly higher than the results in other literatures at an approximate condition (Vennila et al. 2010, Ali et al. 2012, Hameed et al. 2012, Kumar et al. 2013). Our results may be more close to the maximum fecundity that was predicted by Fand et al. (2014) at 30°C. Prasad et al. (2012) found that unmated female *P. solenopsis* did not produce progenies in 1 mo after emergence at 20–35°C. However, other studies showed that male *P. solenopsis* has a negligible role in reproduction (Nikam et al. 2010, Vennila et al. 2010), and our results have supported this opinion.

Life Table Parameters. It is reported that temperature and humidity significantly influenced the life table parameters of *P. solenopsis* (Hameed et al. 2012, Prasad et al. 2012, Kumar et al. 2013, Fand et al. 2014). Present results showed that the range of 25–32.5°C and 45–75% RH is suitable for the developmental of *P. solenopsis*; the mean generation time and doubling time were very short, with the ranges from 20.9 to 33.1 d and 3.1 to 7.0 d, respectively. The intrinsic and finite increase rates were more than 0.10 and 1.11 d^{-1}, respectively, even though the net reproductive rates were less than 80 hatched eggs at 30 and 32.5°C due to the low immature stage survival rate and high growth rate. Fand et al. (2010) reported that the mean generation time, doubling time, net reproductive rate, the intrinsic and finite increase rates of this mealybug on potato were 28.34 d, 4.08 d, 123.41 hatched eggs, 0.1699 d^{-1}, and 1.185 d^{-1}, respectively at 27 ± 2°C and 65 ± 5% RH, which were in conformity with the results of our study. Although the mean generation time and net reproductive rate differed from our results, the doubling time, the intrinsic and finite increase rates of this mealybug on Bt cotton at 20–30°C and 65–75% RH (Kumar et al. 2013) and on potato at 20–30°C and 65 ± 5% RH (Fand et al. 2014) were similar to the results of our study. Kumar et al. (2013) found that nymphs of this mealybug failed to complete development at 85% RH and all treated temperatures. This implies that mild high temperature and lower RH conditions are helpful to the growth and development of *P. solenopsis*, and our study has further supported this conclusion. Previous studies have reported that the presence or field infestation of *P. solenopsis* was positively correlated with temperature and negatively correlated with humidity or rainfall (Dhawan et al. 2009, Kumar et al. 2014). Another study has demonstrated that rainfall also affected the population development of another serious mealybug (*Maconellicoccus hirsutus* Green, Pseudococcidae) on *H. rosa-sinensis* at some locations in the Mariana Islands

(Reddy et al. 2009). Wang et al. (2014) reported that *P. solenopsis* had a higher developmental rate, survival rate, and fecundity during the constant temperatures of 22–32°C, which agrees basically with our results. This implies there may be no significant difference in the optimum conditions among different geographical populations (Shi et al. 2012). Life table parameters indicated that *P. solenopsis*' population in Guangxi of China can be established in a short period in summer and autumn, which helps to explain the field abundance of *P. solenopsis* on *H. rosa-sinensis* in southern China.

Geographic environment, host plant species and quality may lead to variations in the biological characters of mealybugs (Serrano and Lapointe 2002, Oliveira et al. 2014). The differences of biological traits among geographical populations and on host plant of *P. solenopsis* have been reported by Sreedevi et al. (2013) and Huang et al. (2014). Generally, invasive pests often cause damage whenever they are introduced into a new area (Cudmore et al. 2010), such as the outbreak of *P. solenopsis* in India and Pakistan. Our study showed that the optimum conditions for the development of Guangxi population of *P. solenopsis* reared on *H. rosa-sinensis* were 25–32.5°C and 45–75% RH. Guangxi provides highly favorable conditions for this pest where it can occur 8–10 generations per year with obvious overlapping generations. Reasonable control measures for *P. solenopsis* should be established based on the population dynamics and the weather conditions in summer and autumn. This study will provide useful information for forecasting and effective control of *P. solenopsis*. However, except for temperature and humidity, other factors (such as host plant species, food quality, light intensity, and photoperiod) also influence the life traits of *P. solenopsis* in an agricultural region. Therefore, the effects of more environmental factors on the population development of this mealybug need to be investigated in further studies.

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