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Effect of host plants on the development, survivorship and reproduction of *Encarsia bimaculata* (Hymenoptera: Aphelinidae), a parasitoid of *Bemisia tabaci* (Homoptera: Aleyrodidae)

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Abstract: *Encarsia bimaculata* Heraty & Polaszek, a parasitoid of *Bemisia tabaci* (Gennadius) biotype B, was recently discovered in South China. The development, survivorship, longevity and reproductive biology of *E. bimaculata* parasitizing *B. tabaci* on eggplant and hibiscus at 26 ± 0.5℃ were studied in the laboratory. The developmental time of *E. bimaculata* from egg to adult was longer on hibiscus (13.6 d) than on eggplant (12.1 d), and its survival rates from 2nd instar to adult emergence were 93.2% and 91.1% on hibiscus and eggplant, respectively. The mean longevities of *E. bimaculata* female adults ranged from 6.6 d on eggplant to 8.0 d on hibiscus, and the mean lifetime fecundities on the two plants were 27.6 and 35.8 eggs, respectively. The intrinsic rate of increase (r_m) of *E. bimaculata* population at the tested temperature was higher on hibiscus (0.2081) than on eggplant (0.1892). The results indicated that *E. bimaculata* performed better in development, survival and reproduction on hibiscus, a glabrous plant, than on eggplants, a hirsute plant.

Key words: *Encarsia bimaculata*; host plants; *Bemisia tabaci*; development; survivorship; reproduction

Sweetpotato whitefly, *Bemisia tabaci* (Gennadius), has become a serious pest of agriculture and horticulture around the world since the last decade. It causes damage through phloem feeding, plants physical disorders, transmission of plant viral diseases and fouling with honeydew and sooty mould (De Barro, 1995). Recent studies suggest that *B. tabaci* is a complex species or biotypes (Perring, 2001). To date, 24 biotypes have been identified, and the B biotype is one biotype distributed worldwide and also in China. The B biotype has high ability to develop resistance to insecticides, and therefore alternate strategies, including biological control with parasitoids and other natural enemies, have been extensively studied worldwide (Liu and Stansly, 1996; McAuslane and Nguyen, 1996; Gerling *et al.*, 2001).

Encarsia bimaculata Heraty & Polaszek was a recently described parasitoid of *B. tabaci*, and reported to be distributed in India, Philippines, Thailand, USA, Mexico, Sudan and Israel (Heraty and Polaszek, 2000). *Encarsia bimaculata* was first reported in China in 2004, and it was one of the dominant parasitoid species among the aphelinids parasitizing *B. tabaci* (Qiu *et al.*, 2004). Efficient mass-rearing and parasitoid releases depend on extensive knowledge of the relationships between the host and the parasitoid (Antony *et al.*, 2004). However, the biology of *E. bimaculata* has not been fully studied. Host plant morphology usually has significant effects on the searching efficiency, survivorship, development and fecundity of aphelinid parasitoids including *Encarsia* spp. (De Barro *et al.*, 2000). In this study, the biological parameters of *E. bimaculata* on eggplant, representing the hirsute plants, and hibiscus, representing a glabrous plant, were studied to determine the effects of host plant on the longevity, fecundity, fertility and survivorship of the parasitoid.

1 MATERIALS AND METHODS

1.1 Host plant and insect cultures

Eggplant, *Solanum melongena* L., 'Yuefengzihong', and hibiscus, *Hibiscus rosa-sinensis* L. (var. "Yanyangsan", a glabrous variety) were selected as host plants. The plants were individually planted in 12-cm diameter plastic pots. The eggplants were used when they were at 6 - 8 leaf stage. The hibiscus's 4th to 6th leaves from top were used when the plants were about 40 - 50 cm high.

To determine the hair density of eggplant leaves, the 2nd, 4th and 6th fully expanded leaves from the main terminal from each plant were selected, and

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numbers of hairs on the lower surface were counted on each of five randomly selected squares (1 cm^2 leaf area). A total of leaves from each position were selected for hair-density measurement.

B. tabaci was originally maintained on collard, *Brassica oleracea* var. *acephala* L. (var. "Chunzao") in a large greenhouse, and a subcolony was maintained in rearing cages (60 cm × 60 cm × 60 cm) in the laboratory for 10 generations on collard at 26.0 ± 0.5℃, 50% – 70% R.H. and photoperiod of 14:10 (L:D) h. *B. tabaci* was identified to be "B" biotype using RAPD-PCR (De Barro & Driver, 1997) and mt COI (Frohlich *et al*., 1999).

Encarsia bimaculata was primarily collected from the Experiment Farm of South China Agricultural University, and was identified by J. Huang (College of Plant Protection, Fujian Agricultural University). The voucher specimens are deposited in the Laboratory of Biological Control, South China Agricultural University. *Encarsia bimaculata* was reared on collard in rearing cages in the laboratory condition for more than 10 generations before they were used.

1.2 Developmental period and survivorship of *E. bimaculata* immatures

To infest plants for the experiments, about 40 pairs of *B. tabaci* adults were introduced into a leaf-clip cage (3 cm in diameter, 1.5 cm in height) on the lower leaf surface. The adults were allowed to lay eggs for 12 h. The more preferred 3rd and 4th instars of *E. bimaculata* were used based on data from our preliminary study.

Mated female parasitoids were obtained by confining a newly emerged female and a male in a Petri dish (5 cm in diameter) for 4 – 6 h. The females were then introduced to the leaf-cages covering 3rd or early 4th instar *B. tabaci* nymphs (averaged 4.12 nymphs/cm^2) to lay eggs for 12 h. From the 4th d of parasitization, nymphs of *B. tabaci* were examined daily under a Leica M10 stereomicroscope. Number of parasitoid larvae visible inside the *B. tabaci* nymphal cuticle (usually the early second instar larva) and the developmental period from the day the female parasitoid laying eggs to the day the progeny emergence were monitored. The survivorship of the immatures during the same period was also noted. The experiments were conducted in incubators (PXY-300Q-A, Shaoguan Keli Experimental Instrument Co., Ltd., Shaoguan, China) at 26.0 ± 0.5℃, 70% – 80% R.H. and photoperiod was 14:10 h (L:D). Eighty and 92 female adults (divided into 4 replicates) were studied on hibiscus and eggplant, respectively.

1.3 Longevity and reproduction of *E. bimaculata* adults

In this experiment, the mated females, obtained as described above, were individually introduced into clip cages to lay eggs on the 3rd and early 4th instar *B. tabaci* nymphs. Parasitoids were moved to a new clip cages daily and the old leaf were examined daily until the parasitoid larvae were visible inside the *B. tabaci* nymphal cuticle. The longevity of a female adult and the number of progeny reproduced by the females were recorded. The experiments were conducted under the same conditioned as above. Eighty and 86 female adults (divided into 4 replicates) were studied on hibiscus and eggplant, respectively.

1.4 Data analysis

Differences in developmental times and survivorship of the immatures, longevity and reproduction of the adults at different host plants were compared using analysis of variance (PROC ANOVA or PROC GLM, SAS Institute, 1988). Means were separated using the Student-New-Kuel Multiple range test at a significant level of $P = 0.05$ (SAS Institute, 1988).

The life table parameters were computed according to Birch (1948) using a statistical jackknife technique (Maia *et al*., 2000):

$$R_0 = \sum l_s m_x,\ T = \sum x m_x l_x / \sum l_x m_x,$$
$$r_m = \ln R_0 / T,\ \lambda = \exp(r_m) \text{ and } DT = (\ln 2)/r$$

where x is the age (days) of *E. bimaculata*, l_x is the survival rates at the corresponding time, m_x is the number of female offspring produced per surviving female adult during per day. The life table parameters were compared using analysis of variance (PROC ANOVA or PROC GLM, SAS Institute, 1988). Means were separated using the Student-New-Kuel Multiple range test at a significant level of $P = 0.05$ (SAS Institute, 1988).

2 RESULTS

2.1 Leaf hair density

The hair densities on the lower surface of the 2nd, 4th and 6th leaves of the eggplant were 148.4 ± 20.5, 114.4 ± 16.4 and 102.0 ± 14.3 hairs/cm^2, respectively, with an overall average density of 121.6 ± 15.4 hairs/cm^2.

2.2 Development and survivorship of *E. bimaculata* immatures

E. bimaculata developed faster on eggplant (12.1 ± 0.2 d) than on hibiscus (13.6 ± 0.4 d) from egg to adult ($F = 39.16$, $df = 1, 164$, $P = 0.0001$) (Table 1). However, the survival rate of *E. bimaculata* immatures from the 2nd instar to adult on eggplant was significantly lower on eggplant (91.1%) than on hibiscus (93.2%) ($F = 92.03$, $df = 1, 6$, $P = 0.0004$) (Table 1).

Table 1 Developmental period and survivorship of immatures of *E. bimaculata* on eggplant and hibiscus

Host plants	n	Developmental period (days)[a]	Survivorship (%)[b]
		Egg to adult	Second instar to adult
Eggplant	92	12.1 ± 0.2 b	91.1 ± 1.8 b
Hibiscus	80	13.6 ± 0.4 a	93.2 ± 2.6 a

Data in the table are mean ± *SE*. Within the same column, the values with different letters are significantly different at $P < 0.05$. [a] ANOVA statistics were: $F = 39.16$, $df = 1,164$, $P = 0.0001$; [b] ANOVA statistics were: $F = 92.03$, $df = 1,6$, $P = 0.0004$.

2.3 Longevity and reproduction of *E. bimaculata* adults

Host plant had significant effects on the longevity and reproduction of *E. bimaculata* (Table 2). The longevities of *E. bimaculata* female adults on eggplant ranged from 4 to 10 d with an average of 6.6 d, whereas those on hibiscus ranged from 4 to 12 d with an average of 8.0 d. The longevities of *E. bimaculata* on eggplant and on hibiscus were significant ($F = 59.65$, $df = 1,158$, $P = 0.0001$).

An individual *E. bimaculata* female deposited fewer eggs in the whitefly nymphs on eggplant (an average of 27.6 eggs, range: 14 – 36) than on hibiscus (an average of 35.9 eggs, range: 12 – 37) ($F = 147.82$; $df = 1,158$; $P = 0.0001$). The average daily offspring deposited per female were 4.2 eggs on eggplant and 4.5 eggs on hibiscus. The daily offspring reproduced and the daily survivorships of the females on different plants are shown in Fig. 1.

Table 2 Longevity and reproduction of *E. bimaculata* adults on eggplant and hibiscus

Host plants	n	Longevity of female adults (days)[a]		Progeny per female[b]		
		Mean ± *SE*	Range	Mean ± *SE*	Range	Daily reproduction
Eggplant	86	6.6 ± 0.4 b	4 – 10	27.6 ± 2.1 b	14 – 36	4.2
Hibiscus	80	8.0 ± 0.6 a	4 – 12	35.9 ± 4.3 a	12 – 37	4.5

Within the same column, the values with different letters are significantly different at $P < 0.05$. [a] ANOVA statistics were: $F = 59.65$, $df = 1,158$, $P = 0.0001$; [b] ANOVA statistics were: $F = 147.82$, $df = 1,158$, $P = 0.0001$.

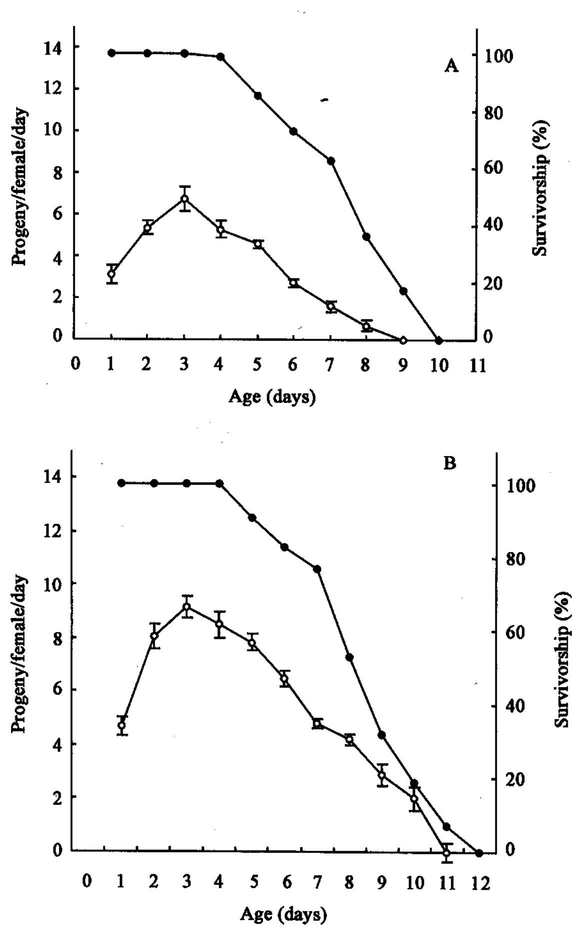

Fig. 1 Oviposition (circles) and observed age-specific survivorship (solid dots) of *E. bimaculata* on eggplant (A) and hibiscus (B)

2.4 Demographic parameters

The developmental time, daily fecundity, adult longevity and progeny sex ratio of *E. bimaculata* were used to calculate the life table parameters, including the intrinsic rate of increase (r_m), net reproductive rate (R_o), mean generation time (T), finite rate of increasing (λ) and doubling time (D_T). Of the 436 individuals of *E. bimaculata* collected from both the laboratory colony and the fields, 70.87% were females. *E. bimaculata* performed a relatively lower intrinsic rate of increase and net reproductive rate on eggplant compared with those on hibiscus (Table 3). The intrinsic rate of increase on eggplant ($r_m = 0.1892$) and hibiscus ($r_m = 0.2081$) were significantly different ($F = 34.53$, $df = 1,6$ $P = 0.0011$). Other parameters, including the mean generation time, doubling time and finite rate of increase of *E. bimaculata* on the two plants were similar.

3 DISCUSSION

E. bimaculata was first recorded as a potential parasitoid of *B. tabaci* in China in 2004 (Qiu *et al*., 2004). Among the 10 species of aphelinids found in two comprehensive surveys across Guangdong Province from May 2000 to December 2001 and from October 2002 to November 2002, 32.3% and 33.9% were *E. bimaculata*, indicating that it was a dominant species in all parasitoids of *B. tabaci* in Guangdong.

Table 3 Life table parameters for *E. bimaculata* on eggplant and hibiscus (95% CL)

Host plants	Generation time (T)(days)	Net reproduction rate (R_0)	Doubling time (DT) (days)	Finite rate of increase (λ)	Intrinsic rate of increase (r_m)[a]
Eggplant	15.31	18.21	3.52	1.208	0.1892 ± 0.020 b
Hibiscus	16.85	33.32	3.33	1.228	0.2081 ± 0.015 a

[a] Within the column of r_m, the values with different letters are significantly different at $P < 0.05$. ANOVA statistics were: $F = 34.53$, $df = 1,6$, $P = 0.0011$.

Antony *et al*. (2004) reported that the developmental time of immatures of an Indian population of *E. bimaculata* on cassava was averaged 13.6 d (females: 12.7 d; and males: 14.5 d). Our study indicates that the developmental time of *E. bimaculata* on eggplant was averaged 12.1 d, 2.5 d shorter than the average developmental time in the study of Antony *et al*. (2004), whereas the developmental period on hibiscus in our study (13.6 days) was identical to the results of Antony *et al*. (2004). De Barro *et al*. (2000) reported the developmental period of *E. bimaculata* (Bundaberg population) on five different host plants, rockmelon, cotton, tomato, soybean and hibiscus ("Mrs George Davis" or "Enid Lewis"). *Encarsia bimaculata* complete their development in 16 to 18 d on those plants at 22 to 30℃, which were numerically longer than the results in our study.

The longevity of *E. bimaculata* has not yet been reported in the literature. Compared with the longevities of *E. formosa* (15.2 d on poinsettia at 28℃, Enkegaard 1993), it appears that the longevities of *E. bimaculata* in our study (6.6 d on eggplant and 8.0 d on hibiscus) are significantly shorter than that of *E. formosa*.

De Barro *et al*. (2000) reported that the mean daily numbers of progeny of *E. bimaculata* were 1.7 on soybean, 1.8 on tomato, 3.2 on cotton, 3.7 on rockmelon, and 3.9 on hibiscus with an average of 2.9; whereas the average daily fecundity in our study is relatively higher, 4.2 on eggplant and 4.5 on hibiscus. De Barro *et al*. (2000) also found that the peak of parasitization of *E. bimaculata* occurred on the 3rd d when parasitizing *B. tabaci*, which was coincided with our results.

De Barro *et al*. (2000) found that the total numbers of progeny per *E. bimaculata* female parasitizing *B. tabaci* nymphs were 11.3 on soybean, 16.3 on tomato, 26.0 on rockmelon, 27.8 on hibiscus and 29.5 on cotton with an average of 22.2. In comparison with De Barro's data above, the total numbers of progeny of *E. bimaculata* per female in our study were 27.6 on eggplant, which was higher than those on soybean and tomato, and was similar to those on rockmelon, hibiscus and cotton. The progeny of the parasitoid on hibiscus in our study was 35.9, which was much higher than those on all 5 plants in De Barro *et al*.'s study.

Of the life table parameters of *E. bimaculata*, we found that the r_m value of *E. bimaculata* on eggplant was significantly lower than that on hibiscus, indicating that *E. bimaculata* may be more adaptable on hibiscus than on eggplant.

Host plants play a significant role in performance of natural enemies of many pests (Price *et al*., 1980; Turlings *et al*., 1995). We have found that *E. bimaculata* on the glabrous leaves of hibiscus deposited more eggs than on the hirsute leaves of eggplant in our study. Leaf hair density and physical structure of plants have been reported to have major effects on the searching efficiency of parasitoids, and generally the hairy leaf surface reduce or inhibit the walking or searching ability of parasitoids on the surface, and, in turn, reduce parasitism by the parasitoids (van Lenteren *et al*. 1987, 1995; Headrick *et al*., 1996; McAuslane *et al*., 1996). Headrick *et al*. (1996) found that the walking speeds of *Eretmocerus eremicus* were relatively fast on glabrous leaves and slow on hirsute leaves. Similarly, van Lenteren *et al*. (1995) demonstrated that as hair density increased the ability of the parasitoid to find hosts decreased. Our study indicates that *E. bimaculata* has a higher potential to control *B. tabaci* on a hibiscus than on eggplant. More researches will be needed to utilize *E. bimaculata* as a biological control agent of *B. tabaci* under greenhouse and field conditions.

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（责任编辑：袁德成）

寄主植物对双斑恩蚜小蜂的发育、存活和繁殖的影响

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摘要：研究了茄子和扶桑两种不同寄主植物对烟粉虱寄生性天敌双斑恩蚜小蜂 *Encarsia bimaculata* 发育、存活和繁殖等特性的影响。在26±0.5℃的条件下，在扶桑上，双斑恩蚜小蜂卵至成虫的发育历期为13.6天，2龄幼虫至成虫的存活率为93.2%；而在茄子上双斑恩蚜小蜂卵至成虫的发育历期和2龄幼虫至成虫的存活率分别为12.1天和91.1%。扶桑上双斑恩蚜小蜂雌性成虫的平均寿命为8.0天，平均单雌产卵量为35.9粒；而在茄子上雌性成虫的平均寿命为6.6天，平均单雌产卵量为27.6粒。双斑恩蚜小蜂在扶桑和茄子植物上的种群内禀增长率分别为0.2081和0.1892。两种不同寄主植物对双斑恩蚜小蜂在若虫发育历期和存活率、成虫寿命和平均产卵量以及内禀增长率等方面均存在着显著差异。研究结果表明，寄主植物对双斑恩蚜小蜂的发育、存活和繁殖有较大的影响。

关键词：寄主植物；双斑恩蚜小蜂；烟粉虱；发育；存活；繁殖

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