

Fitness evaluation of *Encarsia sophia* parasitizing *Aleurocybotus indicus* on two rice cultivars

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ABSTRACT

Banker plant system has been widely used to control vegetable pests through the use of different combinations of host plant-alternative host natural enemy. In order to control the destructive pest *Bemisia tabaci* (Gennadius, 1889) (Hemiptera: Aleyrodidae) with banker plant system, estimating the reproductive potential of parasitoid *Encarsia sophia* (Girault & Dodd, 1915) (Hymenoptera: Aphelinidae) parasitizing and feeding on alternate host rice whitefly *Aleurocybotus indicus* (Hymenoptera: Aphelinidae) is critically necessary. Two rice cultivars ('Changyou' and 'Jinjing') were used as banker plant. Our research showed that the longevity of *E. sophia* female adult in 'Changyou' treatment was significantly longer than that in 'Jinjing' treatment. The intrinsic rate of increase (r) and net reproductive rate (R_0) of *E. sophia* parasitizing *A. indicus* on 'Changyou' rice plant were 0.2295 d⁻¹ and 34.6 eggs, respectively, and significantly greater than those on 'Jinjing' (0.0.2001 d⁻¹ and 26.4 eggs) rice plant. Additionally, the net host feeding rate (q_x) of *E. sophia* feeding on *A. indicus* in 'Changyou' (36.6 rice whitefly) treatment was significantly greater than that (23.7) in 'Jinjing' treatment. In conclusion, between two rice cultivars that were tested in this study, 'Changyou' rice plant could serve as a suitable banker plant for rearing *E. sophia* in biological control programs. The established banker plant system might provide growers with a new option for long-term control of *B. tabacci* in vegetable production.

Key words: Biological control, banker plant, Encarsia sophia, life table, rice whitefly, silver leaf whitefly.

INTRODUCTION

Banker plant system, i.e. open-rearing systems, takes the attention gradually due to gather the advantages of augmentative and conservation biological control (Frank, 2010). The typical banker plant system consists of three parts, including a non-crop banker plant, a non-pest herbivore, and natural enemies (Zheng et al., 2017). In this biological control strategy, the non-pest herbivore was used as an alternative host or prey for breeding parasitoid and predator (Xiao et al., 2011). Because the parasitoid at egg, larva, and pupa stage was in the body of alternate host, the effect of alternate host on the population fitness and control efficiency of parasitoid was great (Huang et al., 2011). Selecting a suitable alternate host was the critical step for establishing an efficient banker plant system.

Previous studies have shown that host plant species or cultivars affect the development time of parasitoids (Kalule and Wright, 2005; Lampert and Bowers, 2010). However, the effects of host plants on parasitoid development are probably not simply due to the differences in host plant resistance to their host. For example, *Aphidius colemani* (Viereck) developed significantly faster on the cabbage aphid, *Brevicorvne brassicae* (L.), reared on cabbage 'Ruby Ball' than on 'Minicole', although both cultivars are partially resistant to *B. brassicae* (Kalule and Wright, 2005). In contrast, development time of a polyphagous tachinid parasitoid of a lepidopteran, *Compsilura concinnata* Meigen, was shorter on the cabbage looper, *Trichoplusia ni* Hübner, fed on cucumber (a suitable host) than those fed on tomato (a less suitable host) (Caron et al., 2008). In the study of Pan et al. (2014), *Aphidius gifuensis* developed faster on aphids reared on the two susceptible

cultivars, AK58 and Xinong979, than on the relatively resistant 'Xiaoyan22'. Some herbivore insects can sequester defensive compounds from the host plant and reduce their quality as parasitoid's hosts, and then negatively influence host acceptance and parasitoid development (Ode et al., 2004; Moreau et al., 2009; Ode and Crompton, 2012).

The silver leaf whitefly, *Bemisia tabaci* (Gennadius, 1889) (Hemiptera: Aleyrodidae) is one of the most devastating pests and plant virus vectors throughout the world (Rakha et al., 2017; Kaur et al., 2017). Its host range is wide, including vegetable, ornamental, and greenhouse crops (Roditakis et al., 2017). The application of insecticides is the primary whitefly control strategy on these crops (Basij et al., 2017; Rakha et al., 2017). Due to the critical concern about the abuse of pesticides, the interest in the biological control strategies increased gradually (Chen and Liu, 2011). *Encarsia sophia* (Girault & Dodd, 1915) (Hymenoptera: Aphelinidae) has been used to control *B. tabaci*. However, the cost and control efficiency of augmentative biological control strategy with *E. sophia* were unfavorable (Xiao et al., 2011). To establish an efficient banker plant system consisting of *E. sophia*, it is necessary to evaluate the reproductive potential of *E. sophia* parasitizing alternate host.

Rice (*Oryza sativa* L.) is the host of the relatively host specific whitefly *Aleurocybotus indicus* (David & Subramaniam, 1976) (Homoptera: Aleyrodidae), which could be parasitized by the parasitoid *E. sophia*. Furthermore, *E. sophia* proved strong capability of parasitism and feeding compared to other parasitoids. Therefore, the objective of this study was evaluating the reproductive potential of *E. sophia* parasitizing and feeding on alternate host *A. indicus* on rice plants for developing a successful banker plant system for controlling *B. tabaci*.

MATERIALS AND METHODS

Insects and plants

In 2018, the parasitoid *Encarsia sophia* was supplied by the college of Agricultural and Food Science, Zhejiang A&F University, Lin'an City. This parasitoid was reared on rice (*Oryza sativa* L.) plants with alternate host *Aleurocybotus indicus*. The rice plants 'Changyou' and 'Jinjing' grown in plastic pots (12 cm-diameter) filled with a peat moss:perlite soil mix (3:1 ratio) were watered and fertilized as needed (Xu et al., 2019). Both parasitoids and its host *A. indicus* were enclosed in nylon net (40 mesh) cages (dimensions: $60 \times 60 \times 60$ cm) and maintained in air-conditioned insectaries at 25 ± 2 °C and $70 \pm 10\%$ RH with a photoperiod of 14:10 h.

Life tables

Approximately 20 d old rice plants (n = 10) grown in plastic pots (12 cm-diameter) were used as the host plants for *A. indicus. Aleurocybotus indicus* adults (n = 30) came from 'Changyou' and 'Jinjing' wheat (*Triticum aestivum* L.) plants and were reared on the homologous rice plants. *Aleurocybotus indicus* and rice plants were enclosed in nylon net cages to allow for feeding and reproduction. Adults of *A. indicus* were removed 24 h later and the eggs were maintained on the rice plant until developing to fourth instar. The fourth instar nymph was used in the life table experiments.

Before the life table study, the parasitoids *E. sophia* were reared with *A. indicus* on 'Changyou' and 'Jinjing' rice plants, both of which served as the host plants for five generations. Ten mated *E. sophia* female adults emerged from *A. indicus* were introduced into the nylon net cages using an aspirator. After reproducing for 24 h, the parasitoid adults were removed. The rice plants ('Changyou' and 'Jinjing') in the nylon net cages with parasitized and unparasitized *A. indicus* were maintained in an incubator at 25 ± 0.5 °C, $70 \pm 10\%$ RH and a photoperiod of 14:10 h. A week later, the parasitized *A. indicus* were removed with a hairbrush. Fifty mummies were randomly selected from each nylon net cage for use in the next step.

All mummies were inspected daily until the parasitoids emerged as adults or died. Emerged female and male *E. sophia* adults were paired. When the number of female adults was greater than males, other males were used to pair with the females. Each pair was supplied with 20 fourth instar *A. indicus* nymphs in a nylon net cage for 24 h of oviposition and feeding. The parasitoids were transferred daily to a new nylon net cage with 20 fourth instar *A. indicus* nymphs reared on the 'Changyou' and 'Jinjing' plants. This process was repeated until the *E. sophia* female died. A new male was provided if the male died before the female. After removing all parasitoids, rice plants with *A. indicus* were placed in growth separate chambers and checked daily. The development time, survival rate, longevity, parasitizing rate and host feeding rate of parasitoid were recorded on a daily basis.

Life table and host feeding analysis

The raw data of development, survival rate, longevity, and female daily fecundity of *E. sophia* individuals were analyzed according to an age-stage, two-sex life table using the computer program TWOSEX-MSChart (Chi, 2019a). The age-stage specific survival rate (s_{xj}) , age-specific survival rate (l_x) , age-stage specific fecundity (f_{xj}) , age-specific fecundity (m_x) , age-specific net fecundity (l_xm_x) , net reproductive rate (R_0) , intrinsic rate of increase (r), finite rate of increase (λ) , mean generation time (T), age-stage life expectancy (e_{xj}) , and age-stage reproductive value (v_{xj}) were calculated based on Chi (2019a). In this study, *x* is age and *j* is stage.

Data on daily host feeding rates were analyzed using the CONSUME-MSChart program (Chi, 2019b). The host feeding rate was defined as the number of *A. indicus* killed by the parasitoids to obtain nutrition. The age-specific host feeding rate (k_x), age-specific net host feeding rate (q_x), cumulative host feeding rate (C_x), finite host feeding rate (ψ), and stable host feeding rate (ω) were calculated using Chi (2019) and Wang et al. (2016) methods. The net host feeding rate (C_0) was the total number of *A. indicus* killed by an average individual during its life span.

Bootstrap method was used to estimate the variance and standard error of the population parameters and host feeding rates (Polat-Akköprü et al., 2015). To reduce the variability of the estimates, we used 100 000 bootstrap iterations according to Polat-Akköprü et al. (2015). The paired bootstrap test was used to detect significant differences between treatments.

RESULTS

Development and fecundity

Due to the variable developmental rate of *E. sophia* individuals, there was overlap among egg, larva+pupa and adult stages (Figure 1). The development duration of *E. sophia* is shown in Table 1. There was nonsignificant difference in the egg and Larva+pupa stages of *E. sophia* between 'Changyou' and 'Jinjing' treatments. The longevity of *E. sophia* parasitizing *A. indicus* on 'Changyou' (14.4 d) was significantly longer than that on 'Jinjing' (12.3 d).





Table 1. Development and fecundity of *Encarsia sophia* parasitizing and feeding on *Aleurocybotus indicus* on 'Changyou' and 'Jinjing' rice plants.

Stage	Changyou		Jinjing	
	n	Mean ± SE	n	Mean ± SE
Egg, d	80	1.1 ± 0.3a	80	1.1 ± 0.3a
Larva+Pupa, d	80	$9.7 \pm 0.4a$	80	$10.3 \pm 0.4a$
Female adult, d	53	$14.4 \pm 0.5a$	50	$12.3 \pm 0.5b$
Male adult, d	21	$11.3 \pm 0.5a$	23	$10.5 \pm 0.7a$
Oviposition, d	53	$13.4 \pm 0.5a$	50	$11.6 \pm 0.5b$
Fecundity, egg	53	$48.1 \pm 1.7 \mathrm{a}$	50	$36.7 \pm 2.3a$

Different letters in the same row mean significant difference (paired bootstrap test, P < 0.05).

Fecundity

The oviposition time of *E. sophia* in 'Changyou' (13.4 d) treatment was also significantly longer than that on 'Jinjing' (11.6 d) treatment. The mean number of egg produced by *E. sophia* female adult parasitizing *A. indicus* on 'Changyou' was 48.1 eggs, and significantly more than that on 'Jinjing' (36.7 eggs) (Table 1).

The number of eggs produced by *E. sophia* individuals at age x and stage j is shown in Figure 2. The curve f_{x3} showed age-stage specific fecundity and represented females in the third life stage. The peak age-stage specific fecundity (f_{x3}), age-specific fecundity (m_x), and age-specific fecundity (l_xm_x) of *E. sophia* parasitizing *A. indicus* on 'Changyou' rice plant were 5.4, 4.0, and 3.5 eggs at 13th day, respectively, and were the maximum values of f_{x3} , m_x , and l_xm_x in 'Jinjing' treatment was 3.9, 3.2 and 2.8 eggs at 16th d, respectively.





Life expectancy (e_{xj}) and reproductive values (v_{xj})

The value of age-stage life expectancy (e_{xj}) was the remaining longevity that individual at age x and stage j could live (Figure 3). For example, the e_{xj} of a newborn egg in 'Changyou' and 'Jinjing' treatments were 22.4, and 21.3 d, respectively. The peak value of e_{xj} for *E. sophia* females parasitizing *A. indicus* on 'Changyou' rice plant (17.3 d) was longer than that on 'Jinjing' rice plant (14.9 d). For male adult, the peak values of e_{xj} in 'Changyou' and 'Jinjing' treatments were 12.5, and 11.5 d, respectively.

The reproductive value (v_{xj}) showed the contribution of individuals at age x and stage j to the future population. The maximum v_{xj} of *E. sophia* in 'Changyou' and 'Jinjing' treatments were 20.8 and 17.0 eggs at 8th and 11th d, respectively (Figure 4).

Figure 3. Age-stage life expectancy (e_{xj}) of *Encarsia sophia* parasitizing *Aleurocybotus indicus* on 'Changyou' (A) and 'Jinjing' (B) rice plants.



Population parameters

The population parameters of *E. sophia* are shown in Table 2. The intrinsic rate of increase (r) of *E. sophia* parasitizing *A. indicus* on 'Changyou' (0.2295 d⁻¹) was significantly greater than that on 'Jinjing' (0.2001 d⁻¹). The finite rate of increase (λ) showed the similar phenomenon. The net reproductive rate (R_0) of *E. sophia* parasitizing *A. indicus* on 'Changyou' and 'Jinjing' were 34.6 and 26.4 eggs, respectively, and the R_0 in 'Changyou' treatment was significantly greater than that in 'Jinjing' treatment.

Figure 4. Age-stage reproductive value (v_{xj}) of *Encarsia sophia* parasitizing *Aleurocybotus indicus* on 'Changyou' (A) and 'Jinjing' (B) rice plants.



Table 2. Population parameters of *Encarsia sophia* parasitizing *Aleurocybotus indicus* on 'Changyou' and 'Jinjing' rice plants.

Parameters	Changyou	Jinjing
Intrinsic rate of increase (r), d^{-1} Finite rate of increase (λ), d^{-1} Net reproductive rate (R_0), egg Mean generation time (T), d	$\begin{array}{c} 0.2295 \pm 0.0115a \\ 1.2581 \pm 0.0145a \\ 34.6 \pm 4.5a \\ 15.4 \pm 0.5a \end{array}$	$\begin{array}{c} 0.2001 \pm 0.0102b\\ 1.2223 \pm 0.0124b\\ 26.4 \pm 3.7b\\ 16.3 \pm 0.5a \end{array}$
Net host feeding rate (C ₀) Stable host feeding rate (ω) Finite host feeding rate (ψ)	$36.6 \pm 4.8a$ $0.2660 \pm 0.0407a$ $0.3346 \pm 0.0549a$	$23.7 \pm 3.3b$ $0.2035 \pm 0.0276a$ $0.2487 \pm 0.0360a$

Different letters in the same row mean significant difference (paired bootstrap test, P < 0.05).

Host feeding

The host feeding rates of *E. sophia* are plotted in Figure 5. Because *E. sophia* could not feed on *A. indicus* at egg and larva+pupa stages, these stages formed gaps in the host feeding rate from egg to adult emergence. Both the age-specific host feeding rate (k_x) and the age-specific net host feeding rate (q_x) of *E. sophia* feeding on *A. indicus* on 'Changyou' and 'Jinjing' rice plants showed roughly periodic peaks during all adult stage. The peak value of k_x in 'Changyou' treatment (3.7 eggs at 16th day) was higher than that in 'Jinjing' (2.8 eggs at 15th day) treatment. In addition, the maximum value of q_x in 'Changyou' and 'Jinjing' treatments were 3.2 and 2.4 eggs, respectively, and the former is greater than the latter.

Figure 5. Age-specific host feeding rate (k_x) , age-specific net host feeding rate (q_x) , and cumulative host feeding rate (C_x) of *Encarsia sophia* feeding on *Aleurocybotus indicus* on 'Changyou' (A) and 'Jinjing' (B) rice plants.



The cumulative net host feeding rates are shown in Table 2 (C_x) and Figure 3 (C_0). The cumulative host feeding rate (C_x) of *E. sophia* from birthday (0 d) was defined as the net host feeding rate (C_0). The C_0 of *E. sophia* in 'Changyou' treatment was 36.6 eggs, and was significantly greater than that in 'Jinjing' (23.7 eggs) treatment. The stable host feeding rate (ω) and finite host feeding rate (ψ) of *E. sophia* feeding on *A. indicus* on 'Changyou' (0.2660 and 0.3346) were greater than on 'Jinjing' (0.2035 and 0.2487), respectively.

DISCUSSION

Results of this study indicated that the longevity and oviposition days of *E. sophia* parasitizing *A. indicus* on 'Changyou' rice plant were significantly longer than those on 'Jinjing' rice plant. In addition, the intrinsic rate of increase (r) of *E. sophia* in 'Changyou' treatment was significantly greater than that in 'Jinjing' treatment. The net reproductive rate (R_0) and net host feeding rate (C_0) also showed the similar phenomenon.

We found that *E. sophia* female adult lived longer when feeding on *A. indicus* on 'Changyou' rice plant, which suggested that the longevity of *E. sophia* female adult might be indirectly affected by host plant. In a previous study of Zhou et al. (2010), longevity of *E. sophia* female adult feeding on *B. tabaci* on tomato (*Lycopersicon esculentum* Mill., 'Pen Zhai Hong') was 12.8 d, which was different from our research. Both of those study suggested that the alternate host and host plant could affect the longevity of parasitoid, further affect the oviposition days. Different host plants have the potential to affect parasitoid development and performance by supplying hosts that differ in their nutritional value (Sarfraz et al., 2009; Lampert and Bowers, 2010). Besides, many insects have the ability to sequester defensive compounds from their host plants. These compounds can confer protection against attack by parasitoids and directly affect parasitoid survival and growth (Lampert and Bowers, 2010; Stoepler et al., 2011). The effect of the nutrition and defensive compounds of banker plant on the longevity of *E. sophia* should be researched in future.

The age-stage life expectancy (e_{xj}) and reproductive value (v_{xj}) could be used to estimate the population dynamics. With the help of age-stage life expectancy (e_{xj}) , we can truly infer the reminding longevity of *E. sophia* at any age, which was beneficial to arrange the production plan. The reproductive value (v_{xj}) showed the reproductive potential of *E. sophia* at age x, which could be used to evaluate the control potential of *E. sophia* individuals at any time.

The net reproductive rate (R_0) of *E. sophia* in 'Changyou' (34.6 eggs) treatment was significantly greater than that in 'Jinjing' (26.4 eggs) treatment, which was less than that in the research of Zhang et al. (2016). The intrinsic rate of increase (r) of *E. sophia* parasitizing *A. indicus* on 'Changyou' was also significantly greater than that on 'Jinjing', which suggested that the 'Changyou' rice plant might be a more suitable banker plant for reproducing *E. sophia* efficiently. In a similar report of Zhang et al. (2016), the intrinsic rate of increase (r) of *E. sophia* feeding on *B. tabaci* on tomato ('Rui Qi First') was 0.2544 d⁻¹, which was also different from the intrinsic rate of increase (r) of *E. sophia* in our study. In a previous study, a greater proportion of *B. tabaci* were parasitized by *E. transvena* Timberlake on tomato than on tobacco and eggplant. Rate of parasitism on tomato was 25.19 and on tobacco was 24.70 in greenhouse (Pillai et al., 2014). Both of these researches indicated that the effect of host plant on the parasitoid might be great. In addition, Giron et al. (2004) found that the increase in the fecundity of *Eupelmus vuilletti* is mainly determined by the amount of lipids obtained whereas the lifespan extension is mainly determined by carbohydrates. Therefore, the difference in the fecundity of *E. sophia* on two rice cultivars might be due to their nutrition. The amount of protein and carbohydrates in host and host plant should be study in future.

In the tritrophic interaction, the plant secondary metabolite was delivered from host plant to parasitoid along with nutrition. Many researches have indicated that host plants have direct or indirect effects on natural enemies of herbivore insects, especially for endoparasitoids (Sarfraz et al., 2009). The difference in plant secondary compound of 'Changyou' and 'Jinjing' might be the major reason influencing the suitability of *E. sophia*. In addition, in a successful parasitism behavior, there were four steps: (a) host habitat location, (b) host location, (c) host acceptance, and (d) host suitability, and the host plant is important for host location (Vinson, 1976). The physical characteristics of host plant might influence the efficiency of searching host for natural enemies, and further affect the population fitness of parasitoid. Therefore, the different performance of *E. sophia* in the fecundity may be affected by the host plants on which the host whitefly were reared.

CONCLUSIONS

The increasing population potential (intrinsic rate of increase and net reproductive rate) of *Encarsia sophia* parasitizing *Aleurocybotus indicus* on 'Changyou' rice plant was significantly greater than that on 'Jinjing' rice plant, which suggested that 'Changyou' might be the more suitable for establishing an efficiently banker plant system.

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