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Short Communication

Behavioral Mechanism for the Starved *Encarsia sophia* (Girault and Dodd) (Hymenoptera: Aphelinidae) Parasitizing and Feeding on more Whitefly Nymphs

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Abstract

Some host-feeding whitefly parasitoids by starving for a certain period of time before release may kill more hosts. Here, we compared the host-feeding and parasitic behaviors on third-instar nymphs of *Bemisia tabaci* (Gennadius) between starved and un-starved (newly-emerged) *Encarsia sophia* (Girault and Dodd). The results showed that the time from release to finding the first host used for host feeding and parasitism by un-starved females was 5.7 and 2.8 times longer than by starved females, respectively. The un-starved females had a significantly longer handling time (1151.9 s) to kill one host through parasitism than starved females (271.9 s). The results suggest that starved parasitoids are more effective biological control agents: they locate and kill their hosts more quickly than do un-starved parasitoids, and kill more hosts using the saved time.

Keywords: *Encarsia sophia*; Host feeding; Food deprivation; Biological control

Introduction

Many hymenopteran species not only parasitize and deposit eggs in their hosts but also feed on their hosts (host feeding), which in some species results in host mortality (Jervis and Kidd, 1986). The foraging decisions of a female parasitoid are influenced by intrinsic and extrinsic factors (Heimpel and Rosenheim, 1995; Hansen and Jensen, 2002; Sule *et al*., 2014). Hunger is likely the most important physiological influence on the foraging decisions of female parasitoids, especially for destructively host-feeding parasitoids that need to decide whether to oviposit or host feed (Jervis and Kidd, 1986). Many studies have indicated that starvation affects foraging behavior of parasitic wasps searching for host and non-host foods (Uefune *et al*., 2013).

The autoparasitoid *Encarsia sophia* (Girault and Dodd) (Hymenoptera: Aphelinidae) is a typical non-concurrent destructive host feeder that uses different host individuals for oviposition and host feeding (Zang and Liu, 2008). Recent research has demonstrated that *E. sophia* is a potentially superior biological control agent for *B. tabaci* than other commonly used species because it enhances the suppression of whitefly nymphs through host feeding and parasitism (Zang and Liu, 2008). Meanwhile, the capacity of *E. sophia* for host feeding and parasitism can be manipulated by altering the duration of starvation (Zang and Liu, 2009), the mating status of individuals before release (Zang *et al*., 2011b), the secondary host species used for the production of males (Zang *et al*., 2011a) and the primary host species used for the production of both sexes (Dai *et al*., 2013).

In previous studies, we have found that the starved *E. sophia* females can more effectively kill hosts through host feeding and parasitism than can newly-emerged (un-starved) parasitoids (Zang and Liu, 2009). In this study, we investigated the host-feeding and parasitism behaviors of starved and un-starved *E. sophia* females. Our goal was to elucidate the underlying behavioral mechanisms and to provide empirical evidence for the efficacy of *E. sophia* as agents of biological pest control by starving host-feeding parasitoids for a certain period of time before releasing them.

Materials and Methods

Insects and Host Plants

Laboratory colonies of *E. sophia* have been kept continuously in an air-conditioned insectary (26±1°C, 60±5% RH, and 14 L/10 D photoperiod) on *B. tabaci* 'Q' hosts that were maintained on potted tomato plants in a

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screened cage since 2008. The tomato plant (*Solanum lycopersicum* L.) was used as the host plant for the whitefly species. The plants with six fully extended leaves were used in the experiments.

Observations on Host-feeding and Parasitism Behavior between Starved and Un-starved Parasitoids

Preparation of hosts and parasitoids: (1) Whitefly hosts: Twenty unsexed adults of *B. tabaci* 'Q' were introduced onto the lower surface of the leaf of a potted tomato plant in a clip cage (3.0 cm in diameter) for oviposition for 12 h. The nymphs were then monitored daily until they developed into third instars. Twenty third-instar nymphs were used on the leaf, and extra whitefly nymphs were removed under a binocular stereoscopic microscope with an insect pin. (2) Parasitoids: The newly emerged females and males of *E. sophia* were obtained as described by Zang and Liu (2008). Newly emerged parasitoids were placed in male-female pairs in a clear glass tube (8.0 cm in length, 1.2 cm in diameter) and were starved for 6 h (an optimal duration of starvation) (Zang and Liu, 2009) before the parasitoids were introduced for observations. Meanwhile, one pair of newly emerged female and male was immediately introduced as a control in the experiment.

Observations: All observations and recordings of foraging behavior of the parasitoids were conducted using the video recording system described by Ruan *et al.* (2007). The movement and behavior of the parasitoids on the leaf undersurface inside the cage were observed and recorded using a video camera (Sony DCR-HC43E, Shanghai, China) for 24 h in an air-conditioned insectary as described above. After recording, the paired parasitoids were removed immediately, and tomato plants with *B. tabaci* nymphs enclosed in clip leaf-cages were moved to another air-conditioned insectary. Host mortality induced by host feeding and parasitism was evaluated under a stereoscopic microscope 7 days after the removal of parasitoids. Each treatment was replicated 20 times. After each recording, the video was replayed using a television set and viewed continuously. To compare the effects of starvation on host-feeding and parasitic foraging behaviors, the time interval from release to finding the first host, external inspection time, handling (feeding or oviposition) time and rest time were recorded respectively. Finally, total numbers of feeding and parasitism events over 24 h were counted respectively for each recording.

Data analysis: To determine whether starvation affected host-feeding or parasitic behavior that parasitoids exhibited, Student's *t*-test was used to analyze host mortality, foraging behavior (times) and total number of foraging events between starved and un-starved females. All of the statistical analyses were performed using the DPS (Data Processing System) software.

Results

Effects of Starvation on the Capacity of Host Feeding and Parasitism

The starved females of *E. sophia* fed significantly more on whitefly nymphs than unstarved females (t=3.5432; df=37; P=0.0011). The parasitism of starved females did not significantly differ from un-starved females (t=1.9516; df=37; P=0.0586). Generally, the starved *E. sophia* killed significantly more whiteflies through host feeding and parasitism than did un-starved parasitoids (t=3.9490, df=37; P=0.0003) (Fig. 1).

Effects of Starvation on Host-feeding Behavior

The time spent finding the first host used for host feeding in un-starved females was approximately 5.7 times longer than the time spent by starved females. As soon as the first host was found, starved females exhibited similar external inspection times to un-starved females. However, starved females took significantly more time to feed on the host than did un-starved females. Specifically, starved females took two times longer than un-starved females for feeding on a host. There was no difference in rest time between both treatments after host feeding was completed. Generally, there was no difference in handling time spent killing one host through host feeding between starved parasitoids (1428.6 s) and un-starved ones (1635.9 s) (t=0.5918; df=37; P=0.5576). However, total number of feeding events by starved females in 24 h was significantly more than that by un-starved ones (Table 1).

Effects of Starvation on Parasitism Behavior

The time that un-starved females spent finding hosts for parasitism was approximately 2.8 times longer than the time spent by starved females. After finding hosts, starved parasitoids took a similar time to complete external inspection to un-starved parasitoids. There was no difference in oviposition time between both treatments. However, un-starved parasitoids had, on average, longer rest times than starved parasitoids after oviposition. Generally, un-starved parasitoids exhibited significantly longer handling times (1151.9 s) to kill a single host through parasitism than starved parasitoids (271.9 s) (t=2.6974; df=33; P=0.0109). In addition, there was no difference in total number of parasitism events over 24 h between starved parasitoids and un-starved ones (Table 2).

Discussion

We compared in detail the host-feeding and parasitism behavior of the autoparasitoid *E. sophia* that were starved for 6 h after emergence and newly emerged without starvation. With observations recorded using a video recording system, we found that starved females fed more on

Table 1: Time spent (s, mean±SE) for different feeding activities on the first host encountered (*Bemisia tabaci*) by *Encarsia sophia* without starvation and starved for 6 h before release

Treatment	Interval from release to finding first host (s)	External inspection time (s)	Feeding time (s)	Rest time (s)	Total number of feeding events/24 h
Starved for 6 h	1800.6±238.2	459.42±39.37	766.11±139.43	203.11±106.57	7.8±0.6
Without starvation	10318.2±1444.8	571.80±44.43	380.00±57.25	684.05±279.30	5.4±0.4
	t=5.6723; df=37; *P*<0.0001	*t*=1.8857; df=37; *P*=0.0672	*t*=2.6092; df=37; *P*=0.0130	*t*=1.5771; df=37; *P*=0.1233	*t*=3.5432; df=37; *P*=0.0011

Table 2: Time spent (s, mean±SE) for different parasitic activities on the first host (*Bemisia tabaci*) by *Encarsia sophia* without starvation and starved for 6 h

Treatment	Interval from release to finding first host (s)	External inspection time (s)	Oviposition time (s)	Rest time (s)	Total number of parasitism events/24 h
Starved for 6 h	6537.6±1068.6	41.35±9.56	162.88±10.99	67.71±34.19	3.6±0.4
Without starvation	18510.0±2058.0	30.50±6.86	164.06±11.69	957.33±314.21	2.8±0.3
	t=5.0737; df=33; *P*<0.0001	*t*=0.9303; df=33; *P*=0.3590	*t*=0.0729; df=33; *P*=0.9423	*t*=2.7349; df=33; *P*=0.0100	*t*=1.8604; df=33; *P*=0.0718

whitefly nymphs and killed more whiteflies through host feeding and parasitism than did un-starved females.

In previous studies, we found that some whitefly parasitoid species exhibited a stronger capacity for host feeding on native hosts (Zang and Liu, 2008) and that the responses of parasitoids differed significantly with the duration of starvation before being exposed to their hosts (Zang and Liu, 2009; 2010). Especially for *E. sophia*, the females that were starved for 6 h not only killed more whiteflies through host feeding but also lived longer and parasitized more hosts than the females that were not starved throughout their lifetimes (Zang and Liu, 2009). The present results indicated that starvation before release significantly affected their host-feeding and parasitism behaviors. The un-starved females took much longer than starved females to find the first host used for host feeding. After finishing the external inspection, however, starved females spent more time feeding on a host than unstarved females. A recent study by Lessard and Boivin (2013) indicated that starved *Trichogramma euproctidis* females also took a longer time to feed on a host than water-fed and honey-fed females. The un-starved females took much longer than starved females to find the first host used for parasitism. Additionally, un-starved parasitoids had longer rest times, on average, than starved parasitoids following oviposition. Generally, the total time spent parasitizing a host by the starved females was significantly shorter than the time spent by un-starved females. Nevertheless, starved parasitoids appear to be more effective at finding and feeding on a larger number of hosts. The effectiveness of starved parasitoids likely reflects their ability to quickly locate hosts for both host feeding and parasitism.

It is important to find ways to manipulate parasitoids so that they can quickly destroy as many hosts as possible through practical means. It has been proposed that the effectiveness of non-host-feeding parasitoids in suppressing pest populations might depend on the availability of sugar-rich foods such as nectar and honeydew (Begum *et al*., 2006). However, to date, few biological control practitioners have embraced the idea. Parasitoids with host-feeding behavior, particularly synovigenic species, are promising biological control agents for pest insects (Jervis *et al*., 1996). We reported that the effectiveness of biological control on pests could be enhanced by starving the parasitoids for a certain period of time before they will be used (Zang and Liu, 2009; 2010). These results of behavioral observations, confirm that the starved parasitoids can use a shorter time to find and handle their hosts, thereby killing more pests using the saved time.

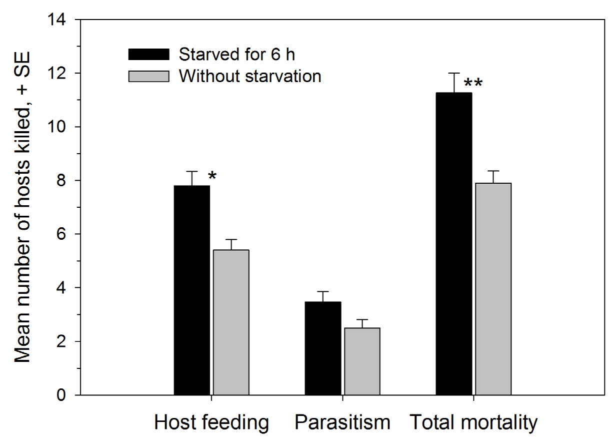

Fig. 1: Number of *Bemisia tabaci nymphs* killed by 6-h starved and unstarved *Encarsia sophia* through host feeding and parasitism over 24 h. The paired bars with '*' or '**' indicate that the means differ significantly at $P < 0.01$ or $P < 0.001$, respectively

Conclusion

The present study provided empirical evidence to support the release of starved host-feeding parasitoids in pest management. Certainly, their suppression efficacies should be determined under field environment conditions in future.

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