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# Intraguild interactions between an oligophagous predator, *Delphastus catalinae* (Coleoptera: Coccinellidae), and a parasitoid, *Encarsia sophia* (Hymenoptera: Aphelinidae), of *Bemisia tabaci* (Homoptera: Aleyrodidae)

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**Abstract**

The intraguild interactions between two natural enemies of *Bemisia tabaci* (Gennadius), an oligophagous predator, *Delphastus catalinae* (Horn), and a parasitoid, *Encarsia sophia* (Girault & Dodd), associated with predation, parasitization, host feeding, and suppression of *B. tabaci* populations were determined on cabbage under laboratory and greenhouse conditions. We conducted two laboratory experiments: a no-choice test of prey consumption by three larval instars and adult *D. catalinae* foraging for either whitefly fourth instar nymphs or whitefly nymphs containing second or third larval instar or pupal parasitoids of *E. sophia*; and a choice test, in which three larval instars or adult *D. catalinae* were allowed to forage for the above prey, presented simultaneously. We also conducted a mesocosm experiment under greenhouse conditions in which a low (20 females) or high (40 females) release of *E. sophia* adults, a low (6) or high (12) release of *D. catalinae* adults, a combined release with both predators and parasitoids at the low rate (20 parasitoids and 6 predators), and the experiments were performed on caged plants infested experimentally with whiteflies. In no-choice and choice experiments, predation was generally lower on the whitefly nymphs containing *E. sophia* pupae than on larval stages or on unparasitized whitefly nymphs. In choice tests, adult *D. catalinae* did not discriminate between prey types. In both choice and no-choice tests, second instar *D. catalinae* larvae tended to discriminate against whitefly nymphs containing parasitoid larvae, and the third and fourth instar predator larvae tended to attack less the whitefly nymphs containing parasitoid pupae than larvae. In the mesocosm experiment, the results indicate that *D. catalinae* did not avoid feeding on *B. tabaci* nymphs with larval stages of *E. sophia* and numbers of whitefly nymphs killed by *E. sophia* were lower in the presence of *D. catalinae*. However, whitefly immatures on cabbage leaves were significantly less abundant in each of the three treatments with the presence of *D. catalinae* as compared with treatments that did not include the predators.


*Keywords:* *Delphastus catalinae*; *Encarsia sophia*; *Bemisia tabaci*; Intraguild predation; Biological control

## 1. Introduction

The sweetpotato whitefly, *Bemisia tabaci* (Gennadius) biotype 'B' (also reported as *B. argentifolii* Bellows and Perring), is a worldwide problem in agricultural crops. The rapid rise to key pest status has been partly attributed to insecticide resistance and decimation of natural enemies in response to broad spectrum insecticides. Therefore, biological control could be an attractive management alternative for whiteflies (Liu and Stansly, 1996a).

Many attempts at controlling *B. tabaci* using parasitoids (especially for the genera *Encarsia* and *Eretmocerus*) or predators have achieved great success (Gerling et al., 2001). With greatly increased choices of biological control agents for application in greenhouse crops, it is now possible to release several different beneficial species in order to control

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one or more pest species simultaneously (Meyling et al., 2004). However, when beneficial species share a pest species as their common prey, intraguild interactions between them may take place. Intraguild predation is a common interaction in many insect communities and has been defined as "the killing and eating of species that use similar resources and thus are potential competitors" (Polis and Holt, 1992). Generalist predators have relatively long generation time and do not feed only a target pest (Chang and Kareiva, 1999; Riechert and Lockley, 1984). Thereby, generalist predators usually act as intraguild predators. In recent years, many studies on intraguild predation by generalist predators on the specialist parasitoids have been conducted (Snyder and Ives, 2001; Snyder et al., 2004; Meyling et al., 2004; Shiojiri and Takabayashi, 2005; McGregor and Gillespie, 2005), and most of these studies indicate that predators do not discriminate between unparasitized and parasitized hosts. However, there are only limited published researches on intraguild predation between oligophagous predators and parasitoids. Understanding the differences between the intraguild interactions of generalist and oligophagous predators with parasitoids is needed and would be useful to manipulate both generalist or oligophagous predators and parasitoids in biological control of insect pests.

*Encarsia sophia* (Girault & Dodd), formerly also known as *E. transvena* (Timberlake), is an important parasitoid species parasitizing many species of whiteflies, including *B. tabaci* and *Trialeurodes vaporariorum* (Westwood) (Gerling et al., 1998; Huang and Polaszek, 1998; Hunter and Kelly, 1998). It is a solitary, arrhenotokous, heteronomous, autoparasitoid, whose female eggs are laid internally in whitefly nymphs and develop as primary parasitoids, whereas males develop as hyperparasitoids, either on females of their own species or on other primary aphelinid parasitoids. It was originally imported into the US and released in several southern states to control *B. tabaci*, and it has become field established in California, Texas and Florida (Goolsby et al., 2005).

*Delphastus catalinae* (reported previously as *D. pusillus*), an oligophagous predator of whiteflies, purple scale and twospotted spider mite (Hoelmer et al., 1993; Liu and Stansly, 1996b), has exhibited great potential to control *B. tabaci* (Heinz and Parrella, 1994a,b; Heinz et al., 1994; Hoelmer et al., 1994; Liu and Stansly, 1999, 2004; Liu, 2005), and gradually has become one of the most common predacious natural enemies used for controlling whiteflies under greenhouse conditions (Hunter, 1998).

Hoelmer et al. (1994) and Heinz et al. (1994) reported that larvae and adults of *D. catalinae* exhibited a marked tendency to avoid feeding on third instar parasitoids (*E. sophia* and *E. pergandiella* Howard), especially for pupae. They also showed that younger instars of parasitoids, especially for those $\leqslant 7$ days old, suffered from a high risk predation in confrontations with *D. catalinae*. Their results indicate that intraguild predation by *D. catalinae* on parasitized whiteflies occurred. Understanding the role of intraguild interactions may contribute to an effective pest management strategy when multiple natural enemies may be necessary to control a given pest. Therefore, it is necessary to determine whether the potential negative impact on the parasitoid populations from *D. catalinae* reduces the chance of achieving successful biological control.

With an overall objective to determine whether two biological control agents, a predator and a parasitoid, could be better than either alone for biological control of *B. tabaci*, we performed no-choice and choice experiments to assess the intraguild interactions between the oligophagous predator *D. catalinae* and the parasitoid *E. sophia* of *B. tabaci* in the laboratory. In addition, we performed an experiment to determine whether the presence of the predator in combination with the parasitoid interferes with the performance (host feeding and parasitization) of the parasitoid for suppression of *B. tabaci* population under greenhouse conditions.

## 2. Materials and methods

### 2.1. Insects and plants

*Delphastus catalinae* were originally supplied by Applied Bio-Nomics Ltd. (Sidney, BC, Canada) in January 2006, and were maintained in an air-conditioned greenhouse (25–35 °C, and 60–90% RH) using *B. tabaci* maintained on cabbage (*Brassica oleracea* L. var. *capitata*, 'Golden Acre') as prey. The parasitoid *E. sophia*, naturally occurred in our greenhouses on *B. tabaci* biotype B, was reared in a separate air-conditioned greenhouse (25–35 °C, and 60–90% RH) on *B. tabaci* maintained on potted cabbage in two big cages ($110 \times 80 \times 80$ cm) which were screened with 52-mesh polyethylene screen on the sides and top.

The cabbage plants were grown in 15-cm plastic pots filled with Metro-Mix 360 growing medium (Sun Gro, Horticulture Distribution Inc., USA) and enclosed in whitefly proof screen cages. Plants grown to the stage with 3 fully extended true leaves were used for experiments. All laboratory experiments were conducted in an air conditioned insectary at $28 \pm 2$ °C, $70 \pm 5$% RH, and a photoperiod of 14:10 (L:D) h. Voucher specimens of *D. catalinae*, *E. sophia* and *B. tabaci* were deposited in the Insect Collection, Vegetable IPM Laboratory, Texas Agricultural Experiment Station at Weslaco.

### 2.2. Intraguild predation on E. sophia in the laboratory

#### 2.2.1. No-choice test

Only one kind of parasitoid instar (second or third instar larva or black pupa) was exposed to *D. catalinae* at a time. Thirty female and male whitefly adults were introduced onto the lower leaf surface of a cabbage leaf on a potted plant with a clip cage (4.0 cm in diameter) for oviposition for 12 h. The nymphs were monitored daily until they developed to early fourth instars. Twenty mated female parasitoids were introduced into each clip-cage for oviposition for 6 h. The development of the parasitoid larvae was

monitored daily until they developed to the desired stage (second or third instar, or black pupa) in the whitefly nymphs as described by Antony et al. (2003). The leaf disk with parasitized nymphs was cut out along the clip-cage bottom edge after parasitization occurred. Twenty whitefly nymphs containing desired larval or pupal stage of *E. sophia* were used on each disk, and extra whitefly nymphs were removed under a binocular stereoscopic microscope using an insect pin. Unparasitized fourth instar whitefly nymphs were used as controls. The whitefly nymphs with desired stages of *E. sophia* were placed in the experimental arena. To assure the parasitoid pupae were alive, the black pupae were observed under a stereomicroscope, and the ones seen moving from side to side were used. The leaf disks bearing only parasitized whitefly nymphs were individually placed on the bottom of a Petri dish (5 cm in diameter and 2.0 cm in depth) covered with a thin layer (≈0.3–0.5 cm) of 1.5% agar gel. Newly molted larvae (second, third, or fourth instar) or an adult (starved for 6 h) of *D. catalinae* were individually placed on each leaf disk inside the Petri dish. The dishes were inverted to simulate the up-side-down natural conditions. After a 24-h exposure time, the larvae or adults were removed, and numbers of parasitized whitefly nymphs consumed or attacked by the larvae or adults were quantified by counting undamaged individuals. Some parasitoid pupae that apparently were not damaged, but did not move after being observed under a stereomicroscope for 2 min were also considered killed by the *D. catalinae* larvae or adults. Each treatment was replicated 20 times.

#### 2.2.2. Choice test

Twenty mated whitefly female adults were introduced onto the lower surface of a cabbage leaf confined in a clip-cage for oviposition, and the whitefly adults were removed in 24 h. These developed nymphs were used for parasitization by *E. sophia*. To obtain desired stages of healthy and parasitized whitefly nymphs simultaneously on the same leaf disk, the area was re-confined by the clip-cage, and 10 whitefly females were introduced four days later for 12 h (based on our preliminary result that unparasitized whitefly nymphs developed 3–4 days quicker to early fourth instar than those parasitized). When some nymphs in the first whitefly cohort developed to third instars, five mated *E. sophia* females were introduced into each clip-cage for oviposition for 12 h, and 2 days later another five mated female parasitoids were introduced to the clip-cage for oviposition for 12 h. The parasitized whitefly nymphs were monitored daily for parasitoid development until six or more individuals of black pupae of *E. sophia* were visually found. Then, the leaf disks were cut off from the leaf, and six individuals for each of the second and third instars, and black pupae of *E. sophia* and six healthy early fourth instars of *B. tabaci* were identified under a stereoscopic microscope, and all extra unparasitized or parasitized whitefly nymphs were removed using an insect pin. All individuals of each *E. sophia* instar and unparasitized whitefly nymphs were marked using an insect pin. The three stages of *E. sophia* (second and third larval instars, and black pupae) and unparasitized early fourth-instar whitefly nymphs were offered simultaneously to *D. catalinae* in the same experimental arena. Larvae and adults of *D. catalinae* were individually introduced onto each leaf disk and whitefly nymphs with or without *E. sophia* killed by the beetles were assessed as described in the no-choice test above. Each treatment was replicated 20 times.

### 2.3. Intraguild predation on E. sophia and whitefly suppression under greenhouse conditions

Newly emerged *D. catalinae* and *E. sophia* adults from the stock culture were used in this study. A total of 18 rectangular cages (80 × 45 × 55 cm) with a glass top and covered with 52-mesh polyethylene screen on the four sides were placed in a greenhouse. In each cage, six potted cabbage plants having 3 fully expanded leaves were planted in sterilized soil. The plants were placed in two rows, three in each row. Thirty newly emerged *B. tabaci* adults (1:1 sex ratio) were released into each cage on 8 March, 2006. The development of these whiteflies was monitored, and the experiment was initiated on March 23, 2006 when fourth instars were found on the plants. All *E. sophia* females were mated before they were used. Six treatments were used in this experiment: (1) 20 *E. sophia* female adults, (2) 40 *E. sophia* female adults, (3) 6 *D. catalinae* adults (3 males and 3 females), (4) 12 *D. catalinae* adults (6 males and 6 females), (5) 20 *E. sophia* female adults + 6 *D. catalinae* adults (3 males and 3 females, which were released on 2 April, 10 days after parasitoids release), and (6) no *D. catalinae* or *E. sophia*. Each treatment had three replicates. Whitefly suppression on cabbage leaves in each treatment was assessed on 17 April, 1 May, and 16 May 2006. When assessing whitefly population suppression, one cabbage leaf, the 6th to 9th from the plant bottom, was detached from each plant (or six leaves from each cage). Numbers of healthy whiteflies (eggs, nymphs and exuviae), dead eggs and nymphs caused by *D. catalinae* predation, dead nymphs caused by *E. sophia* host-feeding, and parasitized whitefly nymphs (various larval instars, black pupae and exuviae of *E. sophia*) on each cabbage leaf, including both leaf surfaces, were counted under a stereo microscope. Death of a whitefly nymph caused by *D. catalinae* predation can be easily distinguished from those caused by parasitization or host feeding by a parasitoid (*Encarsia*) just as described by Gerling (1990) and Heinz and Parrella (1994b). *D. catalinae* (especially adults) prefers to feed on whitefly eggs (Gerling and Stern, 1993; Hoelmer et al., 1993). However, empty whitefly eggs fed by *D. catalinae* could not be easily distinguished from the eclosed empty eggs. Therefore, the number of dead eggs caused by *D. catalinae* feeding was estimated by subtracting the numbers of healthy whitefly nymphs, all dead nymphs caused by beetles and parasitoids from total empty egg shells. Whitefly assessment was made on half of each cabbage leaf on the later two sampling dates (1st and 16th May) because over

several thousands of whiteflies were found on each leaf, and the counts were converted to numbers per leaf for analyses.

### 2.4. Data analysis

For the data in the no-choice experiment, numbers of parasitized and unparasitized whitefly nymphs consumed by various stages of *D. catalinae* were analyzed using one-way analysis of variance (ANOVA), and means were separated using Tukey's HSD (Honestly Significantly Different) test at $P > 0.05$ (SAS Institute, 2006). For the data of the choice test, the log-likelihood ratio test ($G$ test) was used to test our null hypothesis that *D. catalinae* did not have preference among the *B. tabaci* nymphs with different developmental stages of the parasitoid and the unparasitized nymphs. Numbers of whitefly nymphs killed (parasitized and host-feeding) by *E. sophia* between two treatments (*E. sophia* alone and *E. sophia* plus *D. catalinae*) in the greenhouse experiment were analyzed using the paired $t$-tests. A repeated measure analysis (Proc Mixed; SAS Institute, 2006) was used to analyze the data for the mesocosm experiment of whitefly suppression by different release rates of *E. sophia* and/or *D. catalinae* sampled at three different dates. Numbers of whiteflies in each treatment were first log-transformed to stabilize error variances before analysis (Gomez and Gomez, 1984). Percentage of whiteflies killed by *D. catalinae* and/or *E. sophia* were transformed to the arcsine square root [arcsine (percent mortality/100)$^2$] to stabilize error variances before being subjected to a one-way ANOVA, and means were separated using Tukey's HSD test at $P > 0.05$ (SAS Institute, 2006).

## 3. Results

### 3.1. Intraguild predation on E. sophia in the laboratory

#### 3.1.1. No-choice test

Predation by three larval instars and adults of *D. catalinae* on unparasitized and parasitized *B. tabaci* nymphs by *E. sophia* varied (Fig. 1). The second instar *D. catalinae* most preferred unparasitized fourth-instar *B. tabaci*, followed by the whitefly nymphs with second and third instars of *E. sophia*, while the nymphs with *E. sophia* pupae were the most non-preferred prey ($F = 68.08$; df = 3, 76; $P < 0.0001$). The third and fourth instars and adults of *D. catalinae* exhibited similar predation on the unparasitized

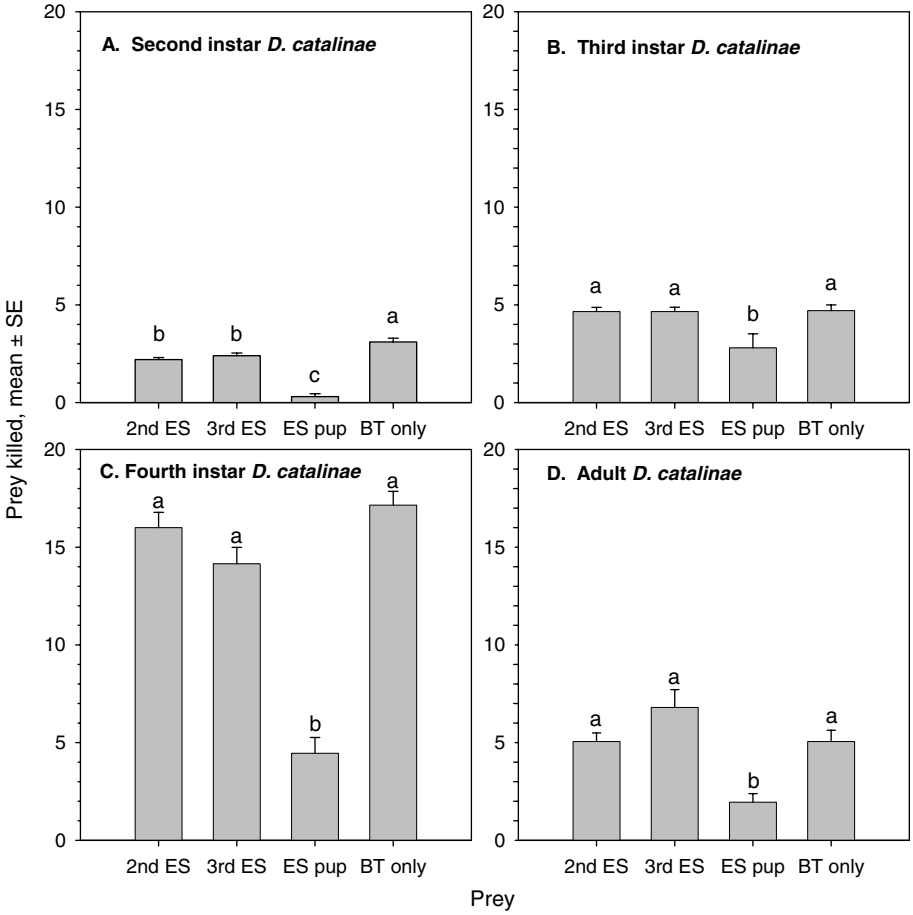


Fig. 1. Predation by various stages of *D. catalinae* on parasitized *B. tabaci* fourth-instar nymphs with different developmental stage and unparasitized nymphs during 24-h exposure under no-choice conditions. The same letters above bars in each figure indicate that means do not differ significantly ($P > 0.05$, Tukey's HSD test). Prey stages: 2nd ES – second instar *E. sophia* larva; 3rd ES – third instar *E. sophia* larva; ES pup – Black pupa of *E. sophia*; and BT only – *B. tabaci* fourth instar.

and parasitized whitefly nymphs. They attacked fewer whitefly nymphs with *E. sophia* pupae than other parasitized and unparasitized whitefly nymphs, and did not distinguish between the parasitized whitefly nymphs with second or third instars and the unparasitized nymphs ($F = 4.86$–$60.035$; df = 3, 76; $P < 0.01$).

### 3.1.2. Choice test

Predation differed among the stages of *D. catalinae* when they were offered a choice of four different whitefly nymphs unparasitized or parasitized by *E. sophia* (Fig. 2). The second instar *D. catalinae* attacked more unparasitized whitefly nymphs and the nymphs with second instar *E. sophia* than the nymphs with third instar and pupae of *E. sophia* ($G = 21.4769$; df = 3; $P < 0.0001$). The third and fourth instar *D. catalinae* attacked fewer whitefly nymphs with *E. sophia* pupae than other parasitized and unparasitized nymphs (third instar larvae: $G = 28.4591$; df = 3; $P < 0.001$; fourth instar larvae: $G = 15.2081$; df = 3; $P < 0.001$). However, *D. catalinae* adults did not differentiate between unparasitized whitefly nymphs and the whitefly nymphs with second and third instar larvae or pupae of *E. sophia* ($G = 1.9922$; df = 3; $P = 0.5740$).

### 3.2. Effect of D. catalinae on E. sophia in the greenhouse

The presence of *D. catalinae* significantly affected the performance of *E. sophia*, including numbers of whitefly killed by host feeding and parasitization at the three different sampling dates ($t = 5.82$–$7.10$, df = 4; $P = 0.0043$–$0.0021$) (Fig. 3). Mean whitefly nymphs killed by *E. sophia* was 1.2-fold less in the treatment with the presence of *D. catalinae* than *E. sophia* alone 25 days after initial release on 17 April, and the reduction of whitefly nymphs killed increased to 3.0- and 5.5-fold in another 15 days (1st May) and 30 days (16th May), respectively.

### 3.3. Whitefly population suppression in the greenhouse

Repeated measure analysis indicates that numbers of healthy whiteflies among the three sampling dates ($F = 111.28$; df = 2, 24; $P < 0.0001$) and the interaction of sampling dates and treatments were significantly different ($F = 21.67$; df = 10, 24; $P < 0.0001$). Numbers of whitefly immatures on 17 April were not significantly different among the six treatments ($F = 2.42$; df = 5, 12; $P = 0.0972$) (Fig. 4). Without the presence of *D. catalinae* or *E. sophia*,

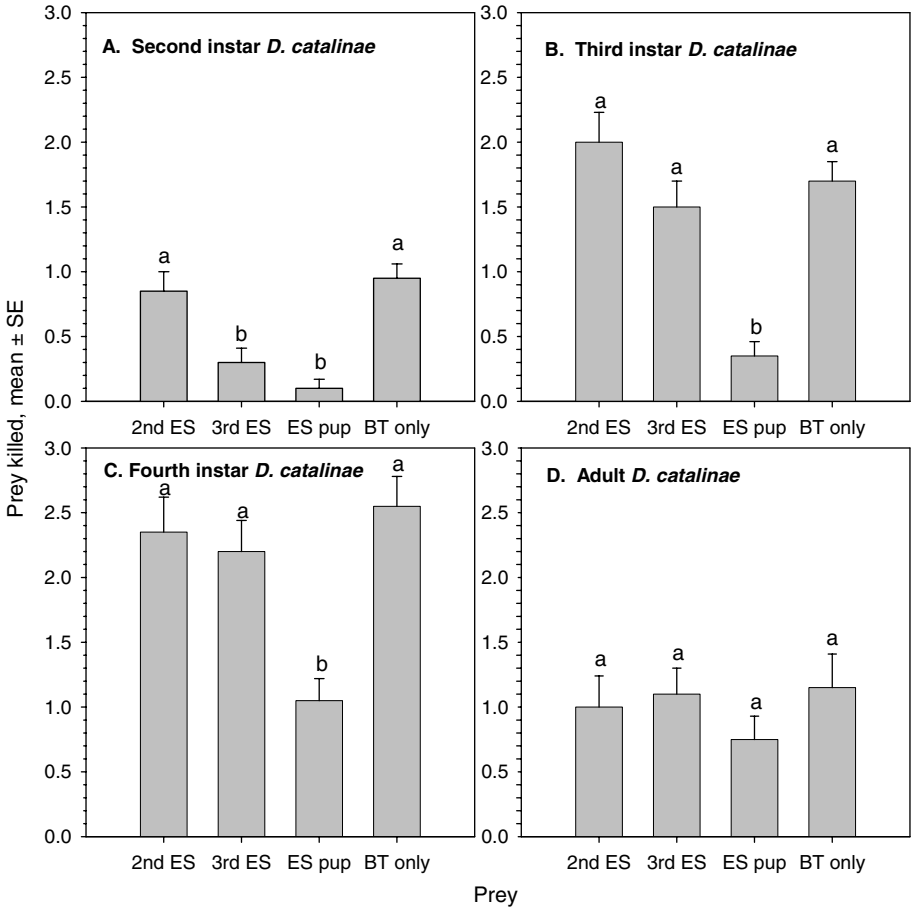


Fig. 2. Predation by various stages of *D. catalinae* on parasitized *B. tabaci* fourth-instar nymphs with different developmental stage and unparasitized nymphs during 24-h exposure under choice conditions. The same letters above bars in each figure indicate that means do not differ significantly ($P > 0.05$, *G* test). Prey stages: 2nd ES – second instar *E. sophia* larva; 3rd ES – third instar *E. sophia* larva; ES pup – Black pupa of *E. sophia*; and BT only – *B. tabaci* fourth instar.

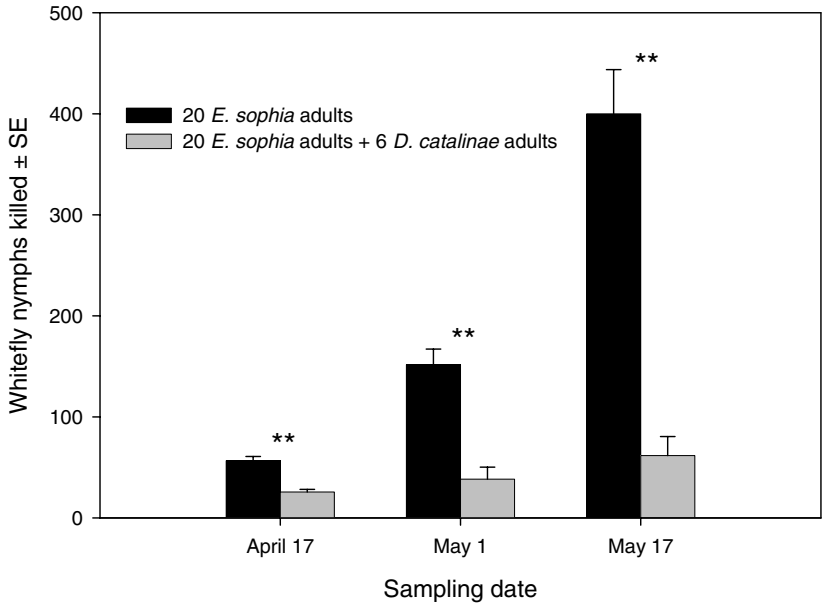


Fig. 3. Comparison of *B. tabaci* nymphs killed (parasitized and damaged by host feeding) by *E. sophia* between the treatment of 20 *E. sophia* adults only and the treatment of 20 *E. sophia* adults and 6 *D. catalinae* adults. The paired bars with an '**' indicate that the means differ significantly ($P < 0.05$, paired *t*-test).

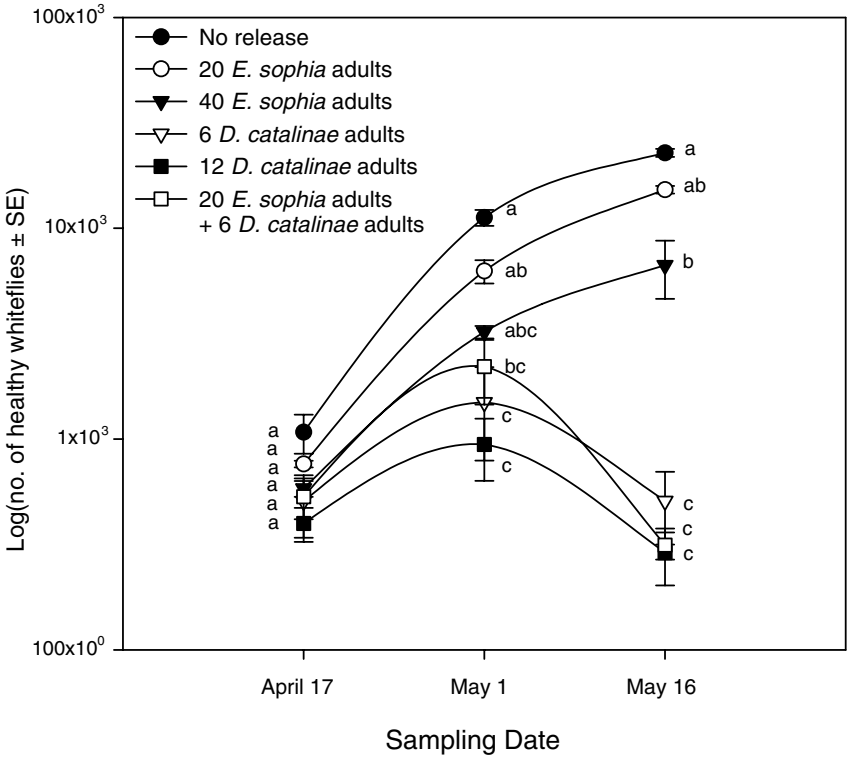


Fig. 4. *Bemisia tabaci* suppressions as expressed as log number of healthy immatures (eggs + nymphs + exuviae) in the six treatments: (1) no natural enemy releases, (2) 20 *E. sophia* adult releases, (3) 40 *E. sophia* adult releases, (4) 6 *D. catalinae* adult releases, (5) 12 *D. catalinae* adult releases, and (6) 20 *E. sophia* and 6 *D. catalinae* adult releases. Mean whiteflies (log-transformed) among treatments on each date followed by the same letters do not differ significantly ($P > 0.05$, Tukey's HSD test).

total number of *B. tabaci* immatures per cabbage leaf increased to 1078 in 25 days (17 April), and increased 10.4 times in another 15 days (1st May) and 21.2 times in another 30 days (16th May). Similar trends were found in the treatments of 20 and 40 *E. sophia* adults, although the population increases in these two treatments were at a relatively lower pace. Compared with the data in the first sampling date, numbers of whitefly immatures on cabbage leaves among the treatments with natural enemies differed significantly on the two later sampling dates. On 1 May,

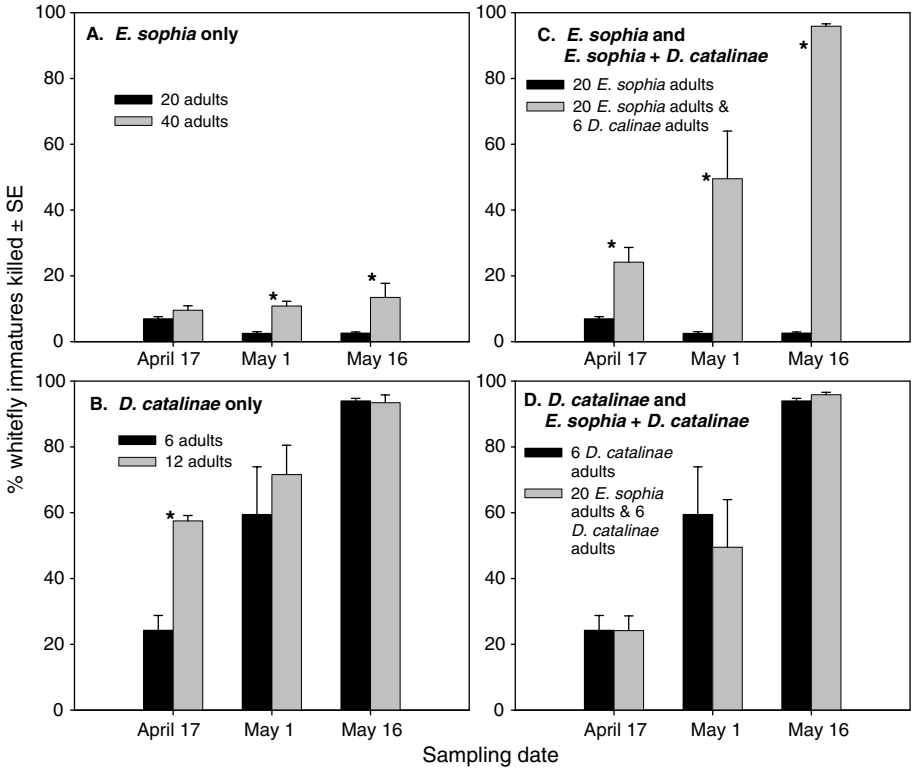


Fig. 5. Percentage of *B. tabaci* immatures (eggs + nymphs) killed by *E. sophia* and *D. catalinae* with different rates of release and combinations. The paired bars with an '*' indicate that the means differ significantly ($P < 0.05$, Tukey's HSD test).

whitefly immatures differed greatly among the six treatments ($F = 11.26$; df = 5,12; $P = 0.0003$). Numbers of the whitefly immatures in the two treatments with *E. sophia* alone were not significantly different from those in the treatment without natural enemies, and were not significantly different from the treatment of 6 *D. catalinae* plus 20 *E. sophia*. Whitefly immatures in the treatment with 40 *E. sophia* adults were also not significantly different from those with *D. catalinae*. On the last sampling date (16th May), whitefly immatures on cabbage leaves varied greatly among the six treatments ($F = 56.81$; df = 5,12; $P < 0.0001$). Numbers of whitefly immatures were significantly less abundant in the treatment with 40 *E. sophia* adults and in each of the three treatments with the presence of *D. catalinae* as compared with treatments that did not include the predators, although there were no significant difference between the treatments with 20 *E. sophia* and without natural enemies, and between the treatments with 20 and 40 *E. sophia* adults.

Of the treatments with natural enemies, different numbers of individual released and the combination between the two species resulted in different outcomes expressed as percentages of whitefly immatures killed by the natural enemies (Fig. 5). Percentages of whitefly immatures killed by *E. sophia* (parasitized and killed by host feeding) were not significantly different between the low and high rates of release on 17 April ($F = 3.05$; df = 1,4; $P = 0.1559$), but more were killed with the higher rate of *E. sophia* on the two later sampling dates ($F = 11.36$–$37.24$; df = 1,4; $P = 0.0036$–$0.0280$) (Fig. 5A). Percentages of whitefly immatures attacked (consumed and fatally damaged) by *D. catalinae* were significantly different between the low and high rates of release on 17 April ($F = 9.38$; df = 1,4; $P = 0.0376$), but were not significantly different between the two release rates on the two later sampling dates ($F = 0.01$–$0.07$; df = 1,4; $P = 0.4509$–$0.9543$) (Fig. 5B). The addition of 6 *D. catalinae* adults to the lower release rate of 20 *E. sophia* adults significantly increased the percentage of whitefly immatures killed on all three sampling dates as compared with those without *D. catalinae* ($F = 16.90$–$2810.52$; df = 1,4; $P = 0.0147$–$0.0001$) (Fig. 5C). In contrast, the addition of 20 *E. sophia* adults to the lower release rate of *D. catalinae* adults did not increase the percentages of whitefly immatures killed on all three sampling dates ($F = 0.01$–$1.62$; df = 1, 4; $P = 0.2716$–$0.9398$) (Fig. 5D).

## 4. Discussion

The compatibility between whitefly predators and parasitoids can be important. If both parasitoids and *D. catalinae* are compatible, growers can be more flexible and affordable to use both the parasitoids and the predators together for better biological control of whiteflies under protected conditions (Pickett et al., 1999). Hoelmer et al. (1994) found that *D. pusillus* (LeConte) (= *D. catalinae*) avoid feeding on fourth instar *B. tabaci* parasitized by *E. transvena* (Timberlake) (= *E. sophia*) and *Eretmocerus* sp. nr. *californicus* in favor of unparasitized whitefly

nymphs. Heinz et al. (1994) reported that *D. catalinae* became more discriminating as the parasitoid *E. pergandiella* developed. Their results indicate that *D. catalinae* could be compatible with those parasitoids, although they also pointed out that avoidance of parasitized whitefly nymphs by the beetles was not absolute. Our results in the no-choice and choice tests indicate that *D. catalinae* may not be compatible with *E. sophia* to control *B. tabaci*. The beetles readily feed on *E. sophia*-parasitized whitefly nymphs with either *E. sophia* larvae or pupae regardless of whether the larvae or adults of *D. catalinae* were offered a choice of unparasitized or parasitized whitefly nymphs with larvae or pupae of the parasitoid (Figs. 1 and 2). It appears that older larvae and adults of *D. catalinae* were less discriminating than younger larvae in selecting the whitefly nymphs unparasitized or parasitized by *E. sophia*, although in the no choice test, the adults fed less whitefly nymphs with *E. sophia* pupae. In both choice and no-choice tests, the third and fourth instar *D. catalinae* fed on fewer whitefly nymphs with *E. sophia* pupae, but did not distinguish the whitefly nymphs with second and third larval instars of *E. sophia*. In contrast, the second larval instar of *D. catalinae* apparently could in some degree differentiate unparasitized *B. tabaci* nymphs from *E. sophia* parasitized ones, although they also fed on the whitefly nymphs with *E. sophia* larvae. In addition, *E. sophia* parasitized whitefly nymphs normally take 3–4 days longer to reach fourth instar than unparasitized whitefly nymphs, they would be more vulnerable to predation.

It was found that *D. catalinae* adults and larvae prefer whitefly eggs to other stages (Hoelmer et al., 1993). However, they could attack a significant number of whitefly nymphs (Figs. 1 and 2). In the no-choice test, the fourth instar *D. catalinae* preyed 3–7-fold more on whitefly nymphs with second and third instar *E. sophia* larvae, and 2–15-fold more on whitefly nymphs with *E. sophia* pupae than did the second and third instar *D. catalinae*. The fourth larval instar *D. catalinae* also attacked 2–3-fold more whitefly nymphs that were unparasitized or parasitized by *E. sophia* than *D. catalinae* adults. In the choice test, the third and the fourth larval instar *D. catalinae* also did not distinguish the unparasitized whitefly nymphs and the nymphs with *E. sophia* larvae, but they did kill fewer whitefly nymphs with *E. sophia* pupae. *D. catalinae* adults did not exhibit any choice among the four types of prey. Overall, our results suggest that *D. catalinae* did not exhibit a marked tendency to avoid feeding on whitefly nymphs that had been parasitized by *E. sophia*.

Our results clearly show that the presence of *D. catalinae* significantly interfered with number of *B. tabaci* nymphs killed (parasitized and host feeding) by *E. sophia* (Fig. 3). It was clear that the longer the two natural enemies exist concomitantly, the more the impact of *D. catalinae* on the performance of *E. sophia*. For instance, *E. sophia* alone killed ≈2-, 4-, and 6-fold more whitefly nymphs than those in the treatment of *E. sophia* with *D. catalinae* on the first, second and third sampling dates (17th April, and 1st and 16th May), respectively. Our results also indicate that when *D. catalinae* was released on caged cabbages, the whitefly populations reduced sharply in a short period of time compared with the treatment where only *E. sophia* adults were released. Although releases of 20 and 40 *E. sophia* adults significantly reduced *B. tabaci* populations on the cabbage plants as compared with the treatment without release of any natural enemies, *B. tabaci* populations were still extremely high with >6000 healthy whitefly immatures on each leaf 55 days after parasitoids were released (Fig. 4). Releases of *D. catalinae* with or without *E. sophia* significantly suppressed *B. tabaci* populations. In contrast, *E. sophia* in both 20 and 40 adult treatments killed <15% of total whitefly populations, compared with those in the three treatments with *D. catalinae* that killed >90% of total whitefly populations on the last sampling date (Fig. 5).

The significant differences in suppression of whitefly populations are mainly associated with different preying characteristics between the parasitoid and the predator. *D. catalinae* attacks and consumes all stages of *B. tabaci*, especially eggs, while *E. sophia* only kills whitefly nymphs by parasitization and host-feeding. On the other hand, the parasitoid *E. sophia* reproduces by arrhenotoky, with males developing as secondary ectoparasitoids on females of their own or of other *Encarsia* and *Eretmocerus* species (Giorgini and Baldanza, 2004). Therefore, its impact on suppression of whitefly population may not be assessed in a short time.

Heinz and Nelson (1996) reported that releases of *D. catalinae* with other *Encarsia* species (*E. formosa* and *E. pergandiella*) significantly reduced whitefly populations to lower levels than any of a single enemy species. However, our results did not show that the addition of *E. sophia* with *D. catalinae* improved whitefly suppression. In addition, the impact of *D. catalinae* may also involve physical interference or disruption of the host feeding, foraging or parasitization by *E. sophia*.

In conclusion, *D. catalinae* readily feed on *E. sophia*-parasitized whitefly nymphs and did not show significant avoidance of parasitized or unparasitized whitefly nymphs except for the whitefly puparia with parasitoid pupae. In addition, the presence of *D. catalinae* significantly interfered with the performance of *E. sophia* by killing (parasitizing and host feeding) fewer whitefly nymphs. Analysis of the interactions between the two natural enemies, it clearly shows that *D. catalinae* could exhibit a devastating impact on *E. sophia*. Addition of *E. sophia* to the treatment of *D. catalinae* did not increase numbers of whitefly immatures killed in the mesocosm experiments under greenhouse. However, our microcosm experiments under laboratory conditions and mesocosm experiments under cage conditions may not reflect the real intraguild interactions between *D. catalinae* and *E. sophia*. For instance, Snyder et al. (2004) studied the interactions between an aphid parasitoid, *Aphelinus asychis* Walker, and a predatory ladybird beetle, *Harmonia axyridis* Pallas. They first found that in their microcosm feeding experiment, both larvae and adults of *H. axyridis* fed on aphids (*Macrosiphum euphorbiae* Thomas) and parasitized aphids (mummies), raising

the concern that intraguild predation of parasitoids by *H. axyridis* could disrupt aphid control. Later, they found that in their cage and greenhouse studies, ladybird beetles dampened peak aphid densities during an outbreak without altering densities of parasitoid pupae or the ratio of parasitoids to aphids, and they did not find evidence that *H. axyridis* disrupted aphid control by resident *A. asychis*. Therefore, more research is essentially needed to determine the biotic and abiotic factors that might affect the intraguild interactions between *D. catalinae* and *E. sophia* before using *D. catalinae* in conjunction with *E. sophia* or similar parasitoids for management *B. tabaci* and other whiteflies.

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