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# Adult Survival of *Delphastus catalinae* (Coleoptera: Coccinellidae), a Predator of Whiteflies (Hemiptera: Aleyrodidae), on Diets of Whiteflies, Honeydew, and Honey

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**ABSTRACT** *Delphastus catalinae* (Horn) is a coccinellid predator that is commercially sold for the management of whiteflies. A study was conducted to assay the effect of selected diets on the survival of adult *D. catalinae*. Treatments of water (as a control), 10% honey, honeydew, and whiteflies [*Bemisia tabaci* (Gennadius)] were provided to the beetles in laboratory assays. Newly emerged, unfed adult insects were used at the start of a survival experiment with trials lasting 50 d. Another survival experiment used mixed-aged adults from a greenhouse colony, and the trials lasted 21 d. Survival was poor on a diet of solely water;  $\approx 1\%$  survived beyond a week at 26°C. Survival using the newly emerged insects was similar between those fed honeydew and honey diets, but those on the whitefly diet had the greatest survival ( $\approx 60\%$  on day 50). However, in the experiment with mixed-aged beetles, adults on honey, and whitefly diets performed the same over a 21-d experiment. Excluding those on the water diet, survival of beetles on the various diets ranged from  $\approx 50\text{--}80\%$  after 21 d. In an open choice assay across 7 h, *D. catalinae* adults were found on the whitefly diet in a much greater incidence than on the other diets, and the number of beetles found on the whitefly diet increased over time. The data supports that when *D. catalinae* are employed in greenhouses or fields for whitefly management, during low prey populations, honeydew from the whitefly can help sustain the population of this predator. Moreover, a supplemental food such as a honey solution can help sustain the population of *D. catalinae* when the prey is decreased to low numbers. These results may help in the development of strategies to enhance the utility of predators for the management of whiteflies.

**KEY WORDS** *Bemisia tabaci*, *Delphastus catalinae*, biological control, predator, diet

Whiteflies are important worldwide insect pests. The B-biotype sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (also reported as *B. argentifolii* Bellows & Perring), and other members of the *Bemisia* complex cause serious problems in crop production (Stansly and Naranjo 2010). They attack an extensive number of plant species in greenhouse and field production systems (Department of Agriculture and Food, Government of Western Australia 2008; Simmons et al. 2008a; Abd-Rabou and Simmons 2010) and cause damage by feeding and by transmitting >100 plant viruses (Jones 2003). There is interest by the agricultural community and general public for growers to produce crops with as little pesticides as possible. Hence, the use of alternatives to the chemical approach, such as the use of natural enemies, is an attractive strategy for the management of whiteflies and other pests.

Parasitoids and predators are often used in greenhouses to help manage whiteflies. Several species of predators are associated with whiteflies, including *Delphastus catalinae* (Horn) (Coleoptera: Coccinellidae) (Muma 1955, Hoelmer et al. 1993a, Nordlund and Legaspi 1996, Arnó et al. 2010). *D. catalinae* is a small sized (1.4 mm long and 1.2 mm wide, male) obligate whitefly predator in the tribe *Serangiini* (Gordon 1994). Some aspects of its potential for the control of *B. tabaci* have been demonstrated (Hoelmer et al. 1993b, Heinz and Parrella 1994, Liu and Stansly 1999, Lucas et al. 2004).

Whiteflies in the *B. tabaci* complex are active in various climates. We reported on critical temperature limits for the survival of *D. catalinae* (Simmons and Legaspi 2004, Legaspi et al. 2008) and its overwintering capacity in mild winters of coastal South Carolina and northern Florida (Simmons and Legaspi 2007). Depressed populations of *D. catalinae* can survive mild winters where the low temperatures are commonly above 0°C (Simmons and Legaspi 2007). Likewise, feral population of its whitefly prey survives mild winters (Simmons and Elsey 1995).

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Feeding on nonprey such as nectars, pollen, sugars, and honeydew have been demonstrated to have a positive effect on the survivorship of many natural enemies (e.g., Cottrell and Yeargan 1998, Gouridine et al. 2003, Gouridine et al. 2005, Lundgren 2009, Seagraves 2009). Whiteflies and aphids are well known for their excretion of honeydew, a sticky carbohydrate, during their feeding on plants. Studies on honeydew feeding have primarily been focused on Hymenoptera (e.g., Hardin et al. 2008, Dulaurent et al. 2010, Koch et al. 2011). Yet, feeding on honeydew by other insects is common (Schutz and Gaugler 1989, Heimpel and Jervis 2005, Wäckers 2005, Lundgren 2009). Moreover, some coccinellids have been observed to feed on honeydew produced by their prey (Hagen 1962). The amount and quality of honeydew produced by *B. tabaci* can vary based on instar and temperature (Henneberry et al. 2001). When biological organisms are successfully used to manage populations of whiteflies, the whitefly population can resurge from new infestations, from low populations, or both, which escaped attack. After the prey population is decimated, the natural enemy may also die because of little or no food. When whiteflies are no longer present, it is not known if remaining honeydew may help sustain the natural enemy or not. Moreover, when the whitefly population is scarce or depleted, an alternative food may help sustain the natural enemy and extend its effectiveness.

Although small size coccinellids are often overlooked, they are important in regulating many homopterous pests (Hagen 1962). Knowledge of the ecology of whitefly predators will facilitate their role as a pest management component. The purpose of this study was to determine any influence of selected non-whitefly diets on survival of adult *D. catalinae* as compared with its standard whitefly prey. In addition, research was conducted to determine any preference by *D. catalinae* for one or more of the diets in the experiment.

### Materials and Methods

**Survival Assays.** Laboratory experiments were set up to test for any influence of selected diets on adult survival of *D. catalinae*. Insects used in all experiments herein were from greenhouse colonies maintained at the USDA-ARS, U.S. Vegetable Laboratory, Charleston, SC. The whiteflies, B-biotype *B. tabaci*, were reared on assorted vegetable crops according to Simmons (1994). Adult coccinellids (*D. catalinae*) were purchased commercially (Rincon-Vitova Insectaries Inc., Ventura, CA) in 2010 and were released into a greenhouse with *B. tabaci* feeding on numerous vegetable crops.

An experiment was set up consisting of four diet treatments: water, 10% honey solution, honeydew, and whitefly. Collard seedlings were grown in Jiffy starter pellets (Jiffy Products of America, Batavia, IL). One collard seedling, 4–5 leaf stage, was placed in each cage arena. The cage consisted of an 18-cm depth by 20-cm-diameter clear plastic cylinder. The starter pellet and base of each plant were placed in an inter-

locking seal plastic bag. The bag was zip sealed and cotton fiber was placed around the stem of the plant to complete the seal of the bag so that beetles could not crawl into the bag. For the water treatment, a dental wick ( $\approx 2$  cm long) was saturated with deionized water and was placed in a 3-cm-diameter dish. Water was used as a check, and a single water station was provided to cages of all treatments. For the whitefly diet treatment, 3–4 young collard leaves ( $\approx 30$ – $60$  cm<sup>2</sup> per leaf) infested with all stages (but mostly eggs and nymphs) of *B. tabaci* were placed on the floor of each cage. For the honey treatment, 10% honey by volume in deionized water was used to saturate a cotton dental wick ( $\approx 2$  cm long) in a 3-cm-diameter dish. Three stations of honey-solution-cotton wicks were provided for the honey treatment cage. For the honeydew treatment, an 8.3-cm-diameter petri dish top was placed on a greenhouse bench below a *B. tabaci*-infested 'Early Prolific' squash (*Cucurbita pepo* L.) plant (flowering stage) for 2–3 d to catch honeydew. Subsequently, two of the petri dishes with honeydew were provided for the honeydew treatment cage. The tops of all cages were covered with fine mesh screen and secured with a pair of rubber bands around each cage after 20 adult *D. catalinae* were released in each cage within 24 h after emergence. To obtain a known age of adult beetles, pupae were collected from the colony and held in cages in the laboratory at 26°C, and were monitored for emergence. A cage for each treatment was then held in an environmental chamber (model I-36VL, Percival, Perry, IA) for 50 d at 26°C and 80–85% RH. Lighting in the chamber was by fluorescent bulbs oriented vertically along two opposite walls; the photoperiod regime was 16:8 (L:D) h. Daily observations were made on survival of the beetles for each treatment. Dead beetles were removed daily. Sex was not determined. Diet treatments were replaced daily, except the whitefly treatment was replaced every 1–2 d. Leaves of collard seedlings in the cages were checked weekly and any found *D. catalinae* larvae were removed to prevent them from reaching the adult stage and getting mixed with the test beetles. The experiment was repeated six times.

An additional experiment was conducted using adults randomly collected from the colony. These were classified as "mixed-aged" in contrast to the experiment with newly emerged adults. This experiment was set up and data were collected as described above, except survival data were collected daily for 21 d. The experiment was repeated six times.

**Nonpreference Assay.** An open choice experiment was set up for the determination of nonpreference of adults among the aforementioned diets. The same cage arena as noted above was used in this experiment. Mixed-aged *D. catalinae* adults from the colony were collected and starved for one day before the assay, except they were provided a water wick. Each of the four diet treatments were placed in a 3 cm diameter dish. A leaf section of collard infested with *B. tabaci* eggs and nymphs were cut to fit within the dish. For the honeydew treatment, dishes were first left below

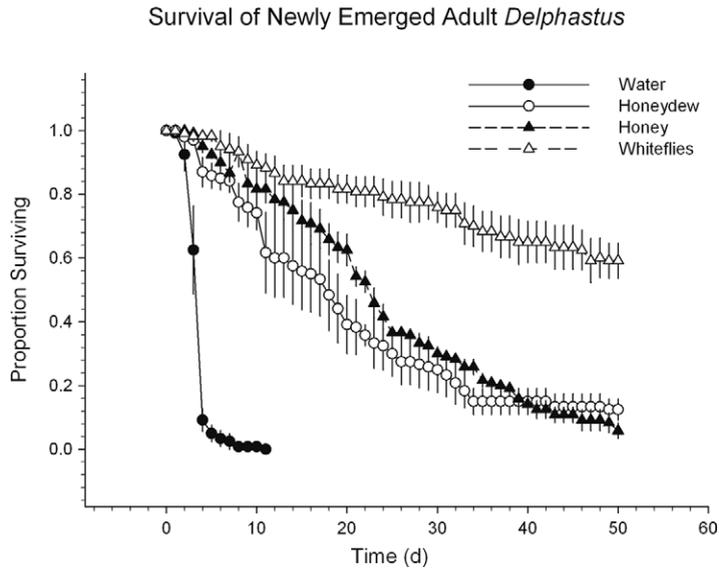


Fig. 1. Mean  $\pm$  SEM survival rates for populations of *D. catalinae* adults on four diet treatments when held in the laboratory from the time of emergence until 50 d (26°C).

whitefly-infested squash plants to obtain honeydew as described above. Two dishes of the same treatment were set up adjacent to each other. Two dishes of the whitefly-infested leaf disks were needed to ensure the prey would not be limited during the experiment, and two were used for the other diets for consistency. The four diet treatments were placed in a circle with 3.5 cm between treatments. A vial of 20 adult *D. catalinae* was placed in the center of the cage and the top of the vial was removed to allow the insects to disperse at their convenience. Four cages were set up for the experiment on a bench in the laboratory (25–26°C). The number of beetles on dishes of each treatment was recorded 1, 3, 5 and 7 h after exposure. The experiment was repeated 20 times.

**Data Analyses.** Diet preference through time, in the open choice assay, was analyzed using a repeated measures Analysis of Variance where the treatment factor was diet and the dependent variables were the insect counts recorded over four time periods. Post hoc treatment effects of diet were tested using Hotelling's T-square test ( $\alpha = 0.05$ ). All statistical analyses were performed using SYSTAT 12 Statistics\_I\_II\_III\_IV (Systat Software Inc. 2007).

## Results

**Survival Assays.** The only observed *D. catalinae* eggs deposited on leaves of the collard seedlings in the experiment using newly emerged beetles were from the whitefly diet treatment. Actual egg counts were not taken. The whiteflies deposited eggs on the collard seedlings in the experiment and some live nymphs were observed. As expected, beetle survival was poor on a diet of water only; few ( $\approx 1\%$ ) survived beyond 1 wk (Fig. 1). Survival of beetles in the experiment with newly emerged insects was similar between those

fed honeydew and honey diets, but those on the whitefly diet had the greatest survival (Fig. 1). However, in the experiment with mixed-aged beetles, adults on honey and whitefly diets performed the same over a 21-d experiment (Fig. 2). Excluding those on the water diet, survival of beetles on the various diets ranged from  $\approx 50$ –80% after 21 d in both survival experiments. By day 50, survival was  $\approx 60\%$  on the whitefly diet and  $\approx 15\%$  on the honey and honeydew diets.

**Nonpreference Assay.** In the open choice assay among diets, *D. catalinae* adults displayed significant feeding preferences through time ( $F = 465.1$ ,  $df = 3, 316$ ;  $P < 0.001$ ). All pairs of comparison of diet effects showed that the whitefly diet was the most highly preferred. Across an exposure period of 7 h, *D. catalinae* adults were found on the whitefly diet in much greater numbers than on the other diets, and the number of beetles found on the whitefly diet increased over time (Fig. 3). The next preferred treatments were honey and honeydew, respectively, while the least preferred treatment was the water control diet (Hotelling T-square;  $P < 0.05$ ).

## Discussion

Because of movement of infested plant materials and because of its protection within greenhouses in cool climates, *B. tabaci* is known from every continent around the globe (De Barro et al. 2000a, 2000b). Greenhouses commonly have elevated moisture levels compared with open environments. Moderately high ambient moisture can be more beneficial for the populations of both *D. catalinae* (Simmons et al. 2008b) and its whitefly prey (Simmons and Mahroof 2011). Moreover, honeydew may be more accessible at the higher than lower moisture environment. The com-

Survival of Mixed-Aged Adult *Delphastus*

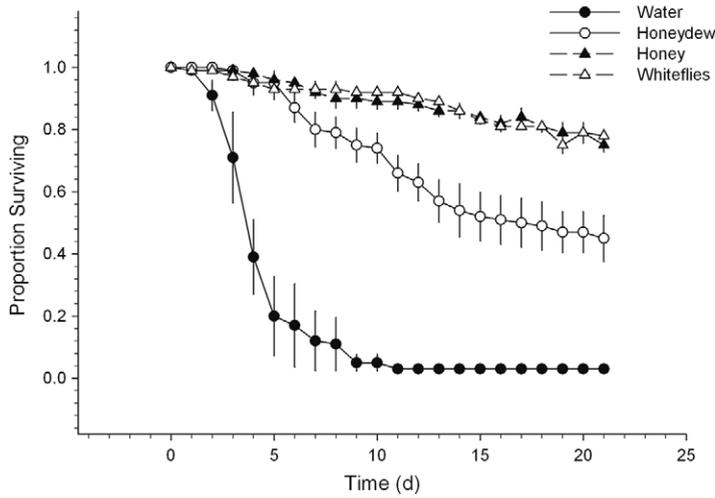


Fig. 2. Mean  $\pm$  SEM survival rates for populations of *D. catalinae* adults (mixed ages) randomly taken from a greenhouse colony and provided four diet treatments when held in the laboratory for 21 d (26°C).

position of carbohydrates and amino acids in honeydew can vary based on the host plant of *B. tabaci* and on the biotype of this whitefly (Byrne and Miller 1990). Although the host plant (squash) for the whitefly was constant in our study, the quality of honeydew was not determined. Insects can produce components in honeydew that do not occur in the host plant. For example, *B. tabaci* is the only known insect that produces trehalulose as a major component of its honeydew (Byrne and Miller 1990, Byrne et al. 2003, Hardin et al. 2008). Although diet can influence egg production in many coccinellid species (Hagen 1962),

the study herein was not focused on reproductive output. Instead, the study was focused on the ability of the adult predator to be sustained after, when employed for biological control of whiteflies, the prey population is depleted or scarce. The effectiveness of a predator could be enhanced if it could not only control the pest when management is initially needed, but also if it can be held until it is later needed for subsequent whitefly infestations. The greater the amount of time that the predator can be sustained without the prey offers a greater benefit from the natural enemy.

*Delphastus* Diet Feeding Preference

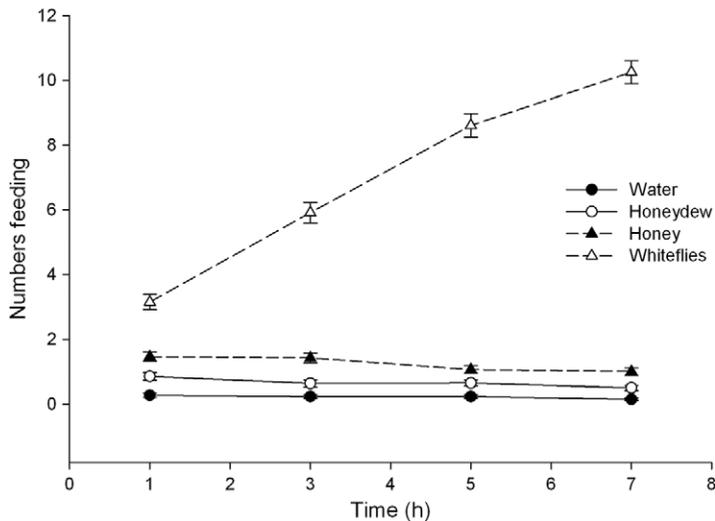


Fig. 3. Open choice test with *D. catalinae* adults on four diet treatments when held in the laboratory for 7 h.

Hoelmer et al. (1993a) reported that *D. catalinae* does not oviposit when it feeds only on whitefly nymphs. Although *D. catalinae* can mate and lay eggs into old age (over 5 mo after emergence) (Simmons and Legaspi 2004), it is not known for how long after feeding on prey eggs that the predator can continue to oviposit. Larvae of small coccinellids have an internal duct within the mandibles where they extract and digest extraoral liquid food (Savoiskaya 1960). Observations from a video-camera indicate that *D. catalinae* feeds after it bites through the whitefly integument to extract the contents (Hoelmer et al. 1993a). Even though honeydew was available with the presence of whiteflies, we do not know if *D. catalinae* commonly feeds on honeydew while the whitefly is available. However, the data from our nonpreference experiment suggest that they feed little on honeydew while the prey is available. No attempt was made to assess the ability of the beetles to consume dried versus fresh honeydew. On the one hand, in an environment with live whiteflies, fresh honeydew is available. However, if a whitefly population were depleted for any reason, less moist honeydew is what is left behind. In our experiment on survival, honeydew that generally appeared dried was observed on the petri dish after 1 d. The honey and water diets were presumably convenient for the beetle to consume. In a related study with three parasitoids of *B. tabaci*, survival for each natural enemy was the same when fed sucrose or trehalulose solutions, whereas the survival of each was decreased on a diet of water (Hardin et al. 2008). In a study with another coccinellid, *Coleomegilla maculata* (DeGeer), the population of the predator increased in the field when it had pollen and prey available as compared with when it only had prey available (Cottrell and Yeagan 1998).

Feeding on eggs of *B. tabaci* is preferred by *D. catalinae* compared with small and large nymphs (Legaspi et al. 2006). Large nymphs produce more honeydew than smaller nymphs (Henneberry et al. 2001). Temperatures in the mid-20s°C are moderate for the survival of *D. catalinae* (Simmons and Legaspi 2004, 2007; Legaspi et al. 2008). Honeydew production by *B. tabaci* is elevated at temperatures from 27 to 32°C versus a lower temperature (22°C) (Henneberry et al. 2001). We previously reported that at 25°C, 50% of the cohort of *D. catalinae* adults feeding on *B. tabaci* survived up to 3.4 mo and over 50% survived for 7 d when held without food (Simmons and Legaspi 2004). Those data coupled with data in the study herein illustrate the combined role of diet and climate on survival of *D. catalinae*.

In contrast to the open field, a confined environment such as a greenhouse is often the setting where employed biological control agents are more effective against whiteflies. In the field, dispersal of parasitoids or predators from the target crop is a possibility. Yet, strategies that facilitate natural enemies to stay in or near the field are desired (Gourdine et al. 2003, Arnó et al. 2010). Our data supports that when *D. catalinae* are employed in greenhouses or fields for whitefly management, during low prey populations, honeydew

from the whitefly prey can help sustain the population of this predator. Yet, it is not known how long after deposition will honeydew be accessible by the predator. We suspect that the initial quantity, temperature, rainfall, and overhead irrigation are among the factors that may dictate the duration that honeydew may be used by predators. Moreover, in the field, Hoelmer and Pickett (2003) suggested a high degree of dispersal by *D. catalinae*. In coccinellids, immigration into a habitat can be influenced by both visual and olfactory cues (Seagraves 2009). The mixed-aged beetles represented a case where a population of *D. catalinae* could feed on whiteflies until the whiteflies population becomes depleted. Thereafter, the beetles would need an additional food source to sustain their population. The data herein indicate that both honeydew and honey are food sources that can help sustain the beetles, but these diets may have a greater impact if the beetles have some whitefly prey earlier in their adult life. These results may help in the development of strategies to enhance the utility of predators for the management of whiteflies in a greenhouse or field environment.

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