Survival and Predation of *Delphastus catalinae* (Coleoptera: Coccinellidae), a Predator of Whiteflies (Homoptera: Aleyrodidae), After Exposure to a Range of Constant Temperatures

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ABSTRACT *Delphastus catalinae* (Horn) is a predator of whiteflies that has shown promise as a tool in pest management strategies. Exposure to short-term temperature extremes can affect the survival of predators in a greenhouse or field environment. The B-biotype sweetpotato whitefly, *Bemisia tabaci* (Gennadius), survives the winters of mild climates (where temperatures are commonly above 0°C), but it is not known if *D. catalinae* can survive such winters. The influence of constant temperature on the survival of *D. catalinae* was determined in the laboratory using eggs and nymphs of the B-biotype *B. tabaci*. Over 90% of the adult beetles exposed to temperature regimens of 5, 10, 15, 20, 25, 30, and 35°C for 24 h survived when confined with hosts. The lower and upper thresholds for survival over that duration were around 0 and 40°C, respectively; ~1% of the insects survived temperatures beyond these extremes. Survival of *D. catalinae* pupae was similar to that of adults. Adult *D. catalinae* survived up to 5.8 mo when confined on a plant infested with whitefly eggs and nymphs and held at 25°C; 50% of the cohort survived for 3.4 mo. Those held in a similar test at 35°C lived up to 0.6 mo. The number of immature whiteflies consumed during 24 h by adult *D. catalinae* generally increased with temperatures of 14–30°C. This study provides information on temperatures that may affect the survival of *D. catalinae* during commercial shipment and after release for biological control in the field or greenhouse, and it may help in the understanding of their ability to survive mild winters.

KEY WORDS *Bemisia tabaci*, *Delphastus catalinae*, biological control, vegetable, whitefly

THE SWEETPOTATO WHITEFLY B-BIOTYPE, *Bemisia tabaci* (Gennadius) (also reported as *Bemisia argentifolii* Bellows and Perring), attacks a wide range of plant species and is a serious pest worldwide. It attacks crops in temperate and tropical climates as well as crops in fields and greenhouses. Although application of insecticides is currently the main method of control, there is a pronounced interest within the agricultural community for alternative approaches in whitefly management, such as the use of beneficial organisms.

Delphastus catalinae (Horn) (Coleoptera: Coccinellidae) is a member of the coccinellid tribe *Serangiini*, members of which are obligate whitefly predators (Gordon 1994). This tropical beetle is native to Colombia, South America, and is now found in Central America, South America, Trinidad, Canary Islands, Hawaii, Southern California, and Southern Florida (Gordon 1994, Pickett et al. 1997). Its distribution to these locations may have occurred primarily through the spread of plant materials (Gordon 1994). However, intentional releases were made in the desert southwest of the United States and in Hawaii (Pickett et al. 1997). Additional dissemination of this species to many international locations has occurred over the past several years for research and biological control purposes (Hoelmer and Pickett 2003). *D. catalinae* [previously reported as *Delphastus pusillus* (LeConte)] has not been vigorously investigated, and research conducted on this insect has primarily been in relation to other whitefly species. However, several studies have shown its potential for the control of *B. tabaci* (Hoelmer et al. 1993a, b, Heinz and Parrella 1994, Liu and Stansly 1999). *D. pusillus* is a species that lives only in the eastern United States, but its similar appearance had previously led researchers to report it as *D. catalinae* (Gordon 1994). Although *D. catalinae* is now marketed for whitefly control, there is confusion on the taxonomy of the species of *Delphastus* in commercial colonies. Hoelmer and Pickett (2003) recently concluded that the species held in commercial insectary cultures is probably *D. catalinae* rather than *D. pusillus.* Little is known about the overwintering range and the impact of climate on the population dynamics of *D. catalinae* in the United States. Climate is a factor that can dramatically affect its *Bemisia* host (Gerling 1984, Simmons and Elsey 1995, Simmons

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1998). In field and greenhouse environments, insects are subjected to extreme temperatures. Coastal South Carolina is the northernmost area of eastern North America where the B-biotype of *B. tabaci* survives the winter (Simmons and Elsey 1995). However, it is not known if *D. catalinae* can survive even mild winters (where temperatures are commonly above 0°C).

Elucidation of the factors that affect the efficacy of predators facilitates their use as a potential management component for whiteflies. To our knowledge, the effect of short-term temperature extremes on the survival of this insect has not been reported. Such information would be useful not only for commercial rearing and shipping of this insect but also for determining climatic conditions affecting its efficacy as a biological control tool against whiteflies. The primary objective of this study was to determine the influence of short-term temperatures on the survival of adult and pupal *D. catalinae.* The secondary objective was to determine survival time of adult *D. catalinae* on immature *B. tabaci* under a moderate and a warm temperature. In addition, the predation rate of *D. catalinae* on *B. tabaci* immatures was evaluated under several constant temperature regimens.

Materials and Methods

Survival of Beetles After Short-Term Exposure to Different Temperatures. Insects used in this experiment were from a greenhouse colony maintained at the USDA–ARS, U.S. Vegetable Laboratory, in Charleston, SC. The whiteflies (B-biotype *B. tabaci*) have been reared (Simmons 1994) on assorted vegetable crops since 1992, but feral adults from sweetpotato, *Ipomea batatas* L., were added to the colony annually to maintain genetic diversity. The beetles (*D. catalinae*) were purchased commercially in 1999 and released for greenhouse pest control, and they have persisted since the original release. The greenhouse colony of *D. catalinae* was held under temperatures that ranged from ~18 to 36°C. Voucher specimens of the beetles were deposited at the Division of Plant Institute, Gainesville, FL. Adult *D. catalinae* of unknown ages were collected and confined in cages at constant temperature in environmental chambers with a 16:8 (L:D) h photoperiod. Relative humidity (RH) was maintained at 80 ± 15% for the temperature treatments by providing open trays of water as needed. The adult beetles were confined in a cage made from a 480-ml cylindrical paper carton (8.5 cm diameter). The top of the carton was removed and replaced with fine mesh screening; it was held in place by the ring for the original top of the carton. An excised leaf (~20-cm^2 area) of collard, *Brassica oleracea* variety *acephala* de Condolle, which was infested with *B. tabaci* eggs and nymphs, was placed in each cage for the 25 ± 1°C and lower temperature treatments. A preliminary test indicated that excised collard leaves held at test temperatures above 25°C exhibited some wilting after 24 h, but survival of *D. catalinae* was not affected; at 35°C, survival did not differ on intact or detached collard leaves. Nevertheless, to minimize leaf moisture as a potential factor on survival, a fresh leaf was provided for all tests. For tests at temperatures above 25°C, an intact collard leaf was used. A collard seedling, grown to the three to five leaf stage in a Jiffy starter pellet (Jiffy Products of America, Batavia, IL) and infested with *B. tabaci* eggs and nymphs, was set in a 5-cm-diameter plastic dish placed on top of the cage. All leaves were detached from the plant except one of a size similar to that used in tests for the other temperature treatments. The stem of the plant with the remaining leaf was turned downward into the cage through a slit cut along one side of the screening. The cut screen was overlapped and cotton fiber surrounded the stem at the entrance to prevent insect escape.

Twenty insects were tested per cage. There were one to three cages tested per trial. A total of 40 replicates (cages) were tested for 25°C, and 5 replicates were tested for 50°C. The number of replicates for the other temperature treatments was a minimum of 14 and a maximum of 27. Hence, a minimum of 100 and a maximum of 800 insects were tested per treatment. The beetles were exposed to a given test temperature for 24 h, and the percentage of beetle survival was determined. Including 25°C, the insects were tested at temperatures in 5°C increments above and below 25°C until no insect survived the tested temperature. After exposure at each temperature, the insects were held at room temperature (~24°C) for ~1 h, and the number of live and dead beetles was recorded. Insects were not tested at all temperatures simultaneously. Trials for a given temperature were randomized across time. As a control, one to three cages of beetles were tested at 25°C along with each test at the other temperatures. Surviving beetles were not used in subsequent tests.

An experiment was conducted using the pupal stage similar to that for adult *D. catalinae* survivorship. Collard leaf disks with *D. catalinae* pupae were cut from greenhouse plants and placed on the bottom of cages with the pupae turned upward. Each leaf disk was slightly greater than the area of the leaf occupied by the pupa. Pupae that appeared to be near emergence of the adult, based on dark color, were not included in the experiment. After holding the pupae at the various test temperatures for 24 h, they were held at 25°C to allow emergence over 12 d. Survival of the pupae was based on their ability to successfully emerge to the adult stage and exit the pupal cuticle. A minimum of 5 and a maximum of 15 replicates were conducted per treatment. Surviving beetles were not used again in subsequent experiments.

Survival of Adult Beetles at Two Constant Temperatures. An experiment was designed to determine longevity of *D. catalinae* from adult emergence to death. The test was conducted at two constant temperatures in environmental chambers maintained at 25 ± 1 and 35 ± 1°C, 16:8 (L:D) h photoperiod, and 85 ± 5% RH. Leaf disks containing *D. catalinae* pupae were obtained from a colony as described above and held at 25°C. Within 24 h of emergence, 30 adult beetles were placed in a cage. The cage consisted of an 18 cm deep by 20 cm diameter clear plastic crisper. Two ventila-

tion holes of 10 cm diameter were cut on opposite sides of the cage and covered with fine mesh screening. To further secure the beetles in the cage, the cover of the container was placed on screening laid across the top of the cage. A cowpea plant, *Vigna unguiculata* L. Walpers, at the cotyledon to first true leaf stage was established in Jiffy starter pellet and infested with *B. tabaci* eggs and early-instar nymphs. The base of the plant with the starter pellet was placed in an interlocking-seal plastic bag. The bag was sealed and cotton fiber was placed around the stem of the plant to prevent beetles from crawling into the bag and obtaining an additional source of moisture. The plant was then placed in the cage. To help provide a continuous diverse immature host supply for the beetles, a detached collard leaf infested with *B. tabaci* eggs and nymphs was placed on the bottom of the cage. The whitefly-infested cowpea plant was replaced every 3–4 d, and the whitefly-infested collard leaf was replaced every 1–2 d. Three cages were set up for each temperature. Each day, the numbers of dead and live beetles in each cage were recorded until all beetles died. The gender of the beetles was not determined. The experiment was repeated three times for a total of 270 beetles at each temperature regimen. Additional data were collected on newly emerged adult beetles for the 25 and 35°C temperature regimens to determine the effect of diet on survival. Adult *D. catalinae* were set up at both temperatures as described above with a cowpea plant but were not provided food. Data were collected as described above. Water was not provided in the tests with or without food.

Predation at Different Constant Temperature Regimens. A test was conducted on the influence of several constant temperatures on the consumption of immature *B. tabaci* by adult *D. catalinae.* Each test was conducted over 24 h under temperature regimens of 14, 18, 22, 26, 30, and 35°C using environmental chambers with a 14:10 (L:D) h photoperiod. Adult *D. catalinae* of unknown ages were starved for 24 h before each test in a 150-mm covered petri dish, but they were provided a wet cotton ball in a 35 by 10-mm dish as a source of water. Arenas for the predation tests consisted of covered 100 by 15-mm plastic petri dishes provided with disks of "Burbank" tomato (*Lycopersicon esculentum* Miller) plant leaflets that were previously infested with *B. tabaci* nymphs. One to two leaf disks were included as needed to provide a total of ~200 whitefly eggs and nymphs per dish. No water was provided during the predation tests. For each test, the egg and nymphal stages of *B. tabaci* on the disks were counted and recorded before introduction of the beetles. One adult *D. catalinae* was placed in the predation dish that was put in chambers at each temperature for 24 h. After the predation period, the beetle was removed from the dish, and the number of eggs and nymphs was counted and recorded. First-instar whiteflies of the "crawler" stage at the end of the predation period were recorded as eggs from the pretest count. The total number of living whiteflies after 24 h was subtracted from the total count recorded before predation to obtain the number of eggs and nymphs preyed on. The test was repeated 10 times for each of the above-mentioned temperatures.

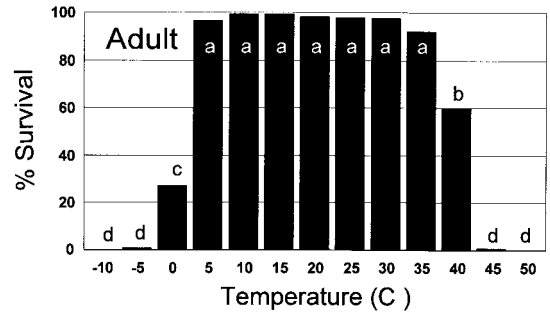

Fig. 1. Survivorship of adult *D. catalinae* of unknown ages after exposure to different constant temperatures for 24 h. Percentage bars with different letters are significantly different (analysis of variance [ANOVA], $P < 0.05$) according to Tukey's test (SAS Institute 1999); SEM ranges from ±1.8 to ±3.1 for the different bars.

Data Analysis. All data analyses were conducted using SAS software (SAS Institute 1999). For both beetle stages tested, comparisons among temperature treatments were made on the proportions of survival using Tukey's studentized range test after a arcsine square-root transformation to normalize the data. Back-transformed means are presented. A similar comparison was done across trials of the check treatment to test for any change in survival over the duration of the experiment. A comparison among temperature treatments was made for mean rates of beetle predation using Tukey's studentized range test. The relationship between number of prey consumed and temperature was analyzed by regression. Unless stated otherwise, significant differences were determined at $\alpha = 0.05$.

Results and Discussion

Survival of Beetles After Short-Term Exposure to Different Temperatures. Adult *D. catalinae* held for 24 h at −10 or 50°C did not survive (Fig. 1). Survival was very low ($P < 0.05$): ~1% for those held at −5°C and those held at 45°C for 24 h (Fig. 1). At 5–35°C, over 90% of the beetles survived. For beetles held at temperatures of 10°C and below, the adults were not active when they were first removed from the chamber, but they became active within 1 h at room temperature. Beetles held at 15°C were not in a chill stupor at the immediate end of the exposure period, but movement was considerably less than at warmer temperatures. The performance of the pupae at the different temperatures was similar to that of the adults (Fig. 2). Several physiological factors can affect the upper and lower lethal temperatures of insects (Chapman 1969). Survival of starved beetles was high when held at 25°C for 48 h (Fig. 3A); therefore, any lack of feeding in a heat or cold stupor may not have been a factor in this study. Also, factors such as gender or age apparently had no effect on the results, because survival was stable over time based on the 25°C check.

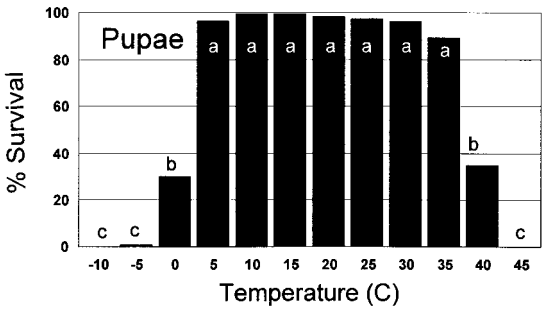

Fig. 2. Survivorship of *D. catalinae* pupae after exposure to different constant temperatures for 24 h; survival was based on successful emergence to the adult stage. Percentage bars with different letters are significantly different (ANOVA, $P < 0.05$) according to Tukey's test (SAS Institute 1999); SEM ranges from ±2.9 to ±5.0 for the different bars.

The duration of the exposure to a temperature is apparently important to beetle survival. In a preliminary test ($n = 12$; one replication), survival of adult *D. catalinae* after a 48-h exposure period was high (>80%) at constant temperatures of 5, 10, 15, 20, and 25°C, was low (17–50%) at 30 and 35°C, and none survived at 40°C. However, for the 24-h exposure test, 60% of the adult beetles survived at 40°C (Fig. 1). The greater the duration of exposure to extreme temperatures, the more likely that an effect on feeding may be a confounding factor. Nevertheless, this study was focused on the effects of relatively short-term temperature exposures on survival of *D. catalinae.* When insects are shipped commercially for biological control purposes, exposure to an extreme low or high temperature may exist for only a relatively short period. The impact of the exposure on adult beetle survival would depend on both its duration and magnitude. Similarly, in a field environment where moderate winters produce temperatures that are moderately low for a brief time, survival might be possible. Nevertheless, our experiments on the performance of *D. catalinae* suggest that temperatures at or below freezing may have a profound impact on survival if those temperatures are sustained for several hours. Conversely, *B. tabaci* can tolerate much lower temperatures (Simmons and Elsey 1995) than this predator.

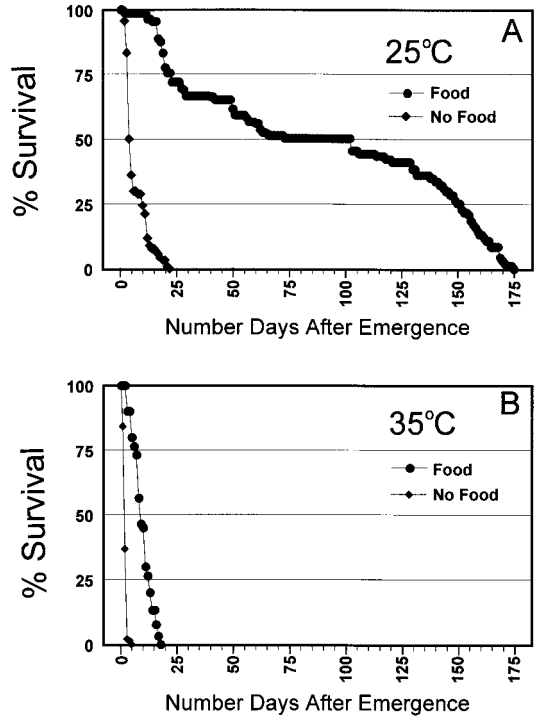

Fig. 3. Percentages of survival of populations of adult *D. catalinae* after emergence when held at 25 (A) or 35°C (B), with or without food (*B. tabaci* eggs and nymphs). Water was not provided in either test. A total of 270 beetles were used per treatment per temperature.

Survival of Adult Beetles at Two Constant Temperatures. In the absence of food and water, newly emerged adult *D. catalinae* survived up to 21 d at 25°C and 4 d at 35°C (Fig. 3A and B). Over 50% of the beetles survived for 7 d when starved at 25°C, whereas <50% were alive 2 d after being held without food at 35°C. When the adult beetles were held at 35°C and provided food, they lived up to 16 d, with 56% living for 7d (Fig. 3B). Conversely, when food was provided to adult beetles held at 25°C, survival ranged from 2 to 174 d; 50% were alive from 73 to 102 d after emergence (Fig. 3A). During the experiment, a few adult *B. tabaci* emerged from pupae on the collards, but we suspect that they were, at most, only a fraction of the diet of the beetles. Hoelmer et al. (1993b) reported on the longevity of *D. catalinae* (*D. pusillus* in report) when fed *B. tabaci* eggs at 28°C. In that study, in a petri dish arena, the females lived an average of 61 d and males lived an average of 45 d. The females were only allowed to mate for 1 d after emergence. Although we did not determine gender, the primary reason the beetles lived longer in our study at 25 than at 28°C in the Hoelmer et al. (1993b) study may be because of the different effect of the two temperatures. However, we do not know what effects a diet of both eggs and nymphs, or the availability of mating partners for a long period of time may have had in our study. Mating pairs were observed in copula in our experiment up to 150 d after emergence, and random checks of leaves from the cages indicated that eggs continued to be deposited at least up to that time. Legaspi et al. (1996) reported that temperature can affect the survival of another coccinellid predator, *Serangium parcesetosum* Sicard; the adults survived longer at 20°C than at higher temperatures. In that study, mean longevity was 79 d for beetles maintained at 20°C, although the insects were not provided a constant whitefly diet.

Predation at Different Constant Temperature Regimens. The total number of prey consumed was enhanced by temperature in a linear relationship ($P < 0.004$; $r^2 = 0.17$; $y = 97.5 + 2.70x$) when tested from 14 to 35°C, but predation was similar at most of the temperatures (Table 1). In a study on *S. parcesetosum*, higher predation rates were reported at higher temperatures (30 and 40°C) than at 20°C (Legaspi et al.

Table 1. Mean predation rates ±SEM of a coccinellid predator, *D. catalinae*, under different constant temperatures for 24 h when provided immature whiteflies, B-biotype *B. tabaci*

Temperature (°C)	Mean number of whitefly immatures consumed (pretest number)				Percentage of prey items consumed
	Egg	First to third instars	Fourth instar	Total	
14	109.3 ± 16.0 (122.6)ab	16.5 ± 5.2 (76.7)c	0.0 ± 0.0 (0)a	125.8 ± 19.7 (199.3)b	60.4
18	74.3 ± 14.0 (89.8)b	70.0 ± 7.0 (118.4)ab	0.1 ± 0.1 (0.3)a	144.4 ± 8.7 (208.5)ab	69.9
22	121.1 ± 14.1 (149.6)ab	52.2 ± 7.6 (85.9)ab	0.6 ± 0.2 (1.1)a	173.9 ± 18.8 (236.6)ab	72.5
26	91.2 ± 24.7 (108.0)ab	70.0 ± 10.3 (105.0)ab	0.7 ± 0.3 (1.1)a	161.9 ± 17.1 (214.1)ab	75.5
30	150.7 ± 17.9 (165.4)a	37.6 ± 11.1 (45.4)b	0.8 ± 0.7 (1.1)a	189.1 ± 11.9 (211.9)a	88.9
35	92.1 ± 20.3 (107.3)ab	88.6 ± 7.2 (139.5)a	0.0 ± 0.0 (0)a	180.7 ± 18.7 (246.8)ab	72.3

Means followed by different letters within a column are significantly different ($P < 0.05$) according to Tukey's studentized range test (SAS Institute 1999); $n = 10$ observations per temperature; data in parenthesis are mean number of insects before introduction of the beetles.

1996). In our study, the adult beetles consumed 125–189 prey items and an average of 60–89% of the available prey items at the different temperatures. Excess prey remained at the end of each test (Table 1). Overall, ~50–80% of the prey consumed were eggs, which constituted the majority of the available prey items. Similarly, ~1% of the prey items consumed were fourth-instar whitefly nymphs, and only a very small percentage of the available prey were fourth instars. Under ambient temperature (~23°C), adult *D. catalinae* spend more time consuming *B. tabaci* as prey size increases from egg (0.3 min) to fourth instar (5 min) (Liu and Stansly 1999). Within the 18–35°C range, this predator has a high incidence of consumption in the presence of hosts, but it is not known how search time may be affected across these temperatures when prey is rare or absent.

Our experiments were designed to reflect multiple factors which may affect a population of *D. catalinae* when it is used for biological control in a greenhouse or field environment. No attempt was made to determine any sublethal effects. This study demonstrates short-term lethal temperatures for adult and pupal *D. catalinae* and duration of survival at moderate and warm temperatures. This information has implications for commercial rearing and shipping of these beetles as well as for their performance when used for the management of whiteflies.

Acknowledgments

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