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Evaluation of Bioinsecticides for Management of *Bemisia tabaci* (Hemiptera: Aleyrodidae) and the Effect on the Whitefly Predator *Delphastus catalinae* (Coleoptera: Coccinellidae) in Organic Squash

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Abstract

Organic zucchini squash is a high-value vegetable crop in Florida and potential exists to expand its production throughout the state. A lack of knowledge on the effectiveness of organic products and their integration with natural enemies is an important constraint to the regulation of pest populations in organic squash production in Florida. The objectives of this study were to evaluate the effect of insecticides labeled for organic production that can be used for management of *Bemisia tabaci* (Gennadius) biotype B, on organically grown squash; and to determine the effects of the most efficient insecticides on a key natural enemy, *Delphastus catalinae* (Horn). Experiments were conducted in the greenhouse in exclusion cages. The first experiment compared the effects of four bioinsecticides on whitefly densities. Insecticides include 1) AzaSol (azadirachtin), 2) PyGanic EC 1.4 (pyrethrin), 3) M-Pede (insecticidal soap), and 4) Entrust (spinosad). The second experiment investigated the effects of bioinsecticides on *D. catalinae*. Treatment effectiveness was evaluated 1, 3, and 5 d posttreatment. PyGanic and M-Pede were highly effective in controlling whitefly populations on organic squash, while moderate control was provided by AzaSol and there was no control provided by Entrust. PyGanic and M-Pede treatments reduced *D. catalinae* populations when adults were released 1 d post pesticide application. However, when adults were released 5 d post application, there was no reduction. The importance of using bioinsecticides in combination with natural enemies to regulate pest populations in organic cropping systems is discussed.

Key words: *Bemisia tabaci* biotype B, zucchini squash, organic insecticide, organic farming, biological control

Zucchini squash, *Cucurbita pepo* L., is a high-value vegetable crop in Florida (Nyoike and Liburd 2010). During 2013, 8,700 acres of squash were harvested and the crop had a market value of 78 million USD (National Agricultural Statistical Service [NASS] 2014). Although ~75% of the squash produced in Florida are grown conventionally, about 20–25% of squash production is managed in accordance with USDA organic standards (Liburd 2012).

Crop-plant physiological disorders and insect-transmitted diseases are major problems for many squash growers around the state. A significant pest of zucchini squash in Florida is *Bemisia tabaci* (Gennadius) biotype B (Nyoike and Liburd 2010). This whitefly pest is largely responsible for transmitting viruses, including *Cucurbit leaf crumple virus*, which can result in stunted plants, deformed fruit, and significantly reduced yields (Nyoike et al. 2008). *Bemisia tabaci* is also responsible for causing physiological disorders in squash, primarily squash silverleaf disorder (SSL) associated with the feeding of immature whiteflies (Yokomi et al. 1990). SSL can reduce the photosynthetic ability of leaves (Cardoza et al. 2000, McAuslane et al. 2004) and in severe cases with heavy infestations, the plant may be stunted, reducing fruit production and causing severe economic damage to growers (Costa et al. 1994, Liburd et al. 2008).

Conventional cucurbit growers use soil applications of the neonicotinoid insecticide imidacloprid [AdmirePro (Bayer Cropscience, Research Triangle Park, NC)] to manage whitefly populations (Seal 2008). However, the use of neonicotinoid insecticides can be problematic for several reasons. Whiteflies have become resistant to a number of insecticides (Nauen et al. 2002, Liang et al. 2012), and many insecticides can have detrimental effects on pollinators (Desneux et al. 2007, Blacquière et al. 2012), which are essential for the production of squash (Canto-Aguilar and Parra-Tabla 2000). For organic growers, insecticides are used as a last resort after

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preventative and cultural tactics have been explored (USDA 2000). These insecticides must meet USDA organic standards and are normally listed on the Organic Materials Review Institute (OMRI) database. Insecticides approved for control of whiteflies in organic squash production include insecticidal soaps (e.g., M-Pede, Dow AgroSciences LLC, Indianapolis, IN), pyrethrin (e.g., PyGanic, McLaughlin Gormley King Company, Minneapolis, MN), and azadirachtin (e.g., AzaSol, Aza-Direct, Arborjet Inc., Woburn, MA; Dayan et al. 2009). Spinosad (e.g., Entrust, Dow AgroSciences LLC) is also commonly used in organic vegetable production; however, it is not specifically recommended for control of whiteflies (Dayan et al. 2009).

Insecticides can be important in preventing pest population build-up on the host, hindering the proliferation of viruses and transmission among plants (Nyoike and Liburd 2010). However, these insecticides must be used in integrated pest management (IPM) programs to delay the development of resistance in pest populations, reduce the spread of disease among and between fields, and conserve natural enemies. Current efforts in experimenting sustainable methods to control whiteflies include intercropping (Hooks et al. 1998, Frank and Liburd 2005, Nyoike and Liburd 2010), trap cropping (Castle 2006, Lin et al. 2015), plant resistance (Baldin and Beneduzzi 2010), botanical insecticides (Marques et al. 2014, Baldin et al. 2015), and biocontrol (Simmons and Abd-Rabou 2011, Moreno-Ripoll et al. 2014).

The coccinellid beetle, *Delphastus catalinae* (Horn) (Coleoptera: Coccinellidae) is an obligate predator of *B. tabaci* biotype B and has been cited as a good biological control candidate for whiteflies as a result of high prey consumption rates, long adult lives, and high fecundity rates (Heinz et al. 1999). Heinz et al. (1999) reported that *D. catalinae* reduced whitefly densities by a minimum of 55% to a maximum of 67% in exclusion cage experiments. Further reduction in whitefly densities could be achieved by incorporating *D. catalinae* with organically approved insecticides that pose minimal risks to biological control organisms; however, it is important to consider that not all organic insecticides are safer for biological control agents (Biondi et al. 2012a).

Management of *B. tabaci* is extremely difficult irrespective of the production system (organic or conventional) that is adopted by growers. However, organic growers face an even more daunting task because the majority of pest management practices are developed for conventional growers and often are not permitted in organic production (i.e., synthetic pesticides and fertilizers). Therefore, a lack of knowledge on the effectiveness of organic products is one of the constraints to organic squash production in Florida and other regions in the United States. Research on the effectiveness of organic insecticides for managing whitefly populations in squash as well as their effects on natural enemies will provide additional information on how these insecticides can be integrated into IPM programs and used to regulate pest populations. The objectives of this study were: 1) to assess the effectiveness of insecticides labeled for organic production on whitefly populations in zucchini squash and 2) to determine the effects of these insecticides on mortality and predatory activity of *D. catalinae*.

Materials and Methods

Research was conducted 1 April 2013 to 21 May 2013 and repeated the following spring 13 March 2014 to 5 May 2014 at 25 ± 6°C with 62 ± 20% RH in the Small Fruit and Vegetable IPM (SFVIPM) greenhouse at the University of Florida in Gainesville, FL. The greenhouse construction included fiberglass siding with a double-layer clear polyfilm roof, a swamp cooler in the back of the house, and gas heater with horizontal air flow cooling fans controlled by a temperature control system. One-liter pots were sown with the zucchini squash variety 'Cashflow' (Johnny's Selected Seeds, Winslow, ME). Plants were grown from seeds in Miracle-Gro Organic garden soil (Miracle-Gro, Marysville, OH) and squash plants were fertilized with organic fertilizer (Scotts Organic Fertilizer, Marysville, OH). Potted squash plants were manually watered three to four times per week.

Adult whiteflies and *D. catalinae* used in the trials were obtained from a colony reared in 30- by 30-cm wire mesh cages on collards, *Brassica oleracea* in the SFVIPM laboratory. Adult *B. tabaci* biotype B were originally obtained from a colony reared on collards and cotton, *Gossypium hirsutum* L., maintained by a colleague in the Department of Entomology and Nematology, University of Florida, Gainesville, FL. Whiteflies from this colony were observed to induce SSL in infested squash and, therefore, were considered to be *B. tabaci* biotype B. The whitefly colony had not been previously exposed to insecticides. *Delphastus catalinae* adults were originally purchased from Biocontrol Network, LLC (Brentwood, TN) and maintained on a colony of whiteflies for ~5 mo before they were used in experiments. Cages were kept in an environmental chamber at 25°C with 60% RH and a photoperiod of 14:10 (L:D) h in the Department of Entomology and Nematology, University of Florida, Gainesville, FL. *Brassica oleraceae* were watered two to three times per week to maintain turgidity and new plants were put into the cage once every 2 wk.

Assessing the Effectiveness of Bioinsecticides on Whitefly Populations

A total of five treatments were evaluated for their effectiveness in reducing whitefly densities. The experiment was a completely randomized design that was replicated by year. One squash plant was a sampling unit, and each treatment was applied to a 1-m^3 exclusion cage that contained five squash plants. Treatments included four insecticides approved for organic production and an untreated control. Organic insecticide treatments were applied thoroughly to the plant, such that both sides of the leaves were sprayed for full coverage but not dripping, with a backpack sprayer (model 425, SOLO, Newport News, VA) at the manufacturer's maximum labeled rates and included: 1) AzaSol at 1.32 g $liter^{-1}$ (Arborjet Inc.), 2) PyGanic EC 1.4 at 15.63 ml $liter^{-1}$ (McLaughlin Gormley King Company), 3) M-Pede at 20.05 ml $liter^{-1}$ (Dow AgroSciences LLC), 4) Entrust SC at 0.10 ml $liter^{-1}$ (Dow AgroSciences LLC), and 5) an untreated control that did not receive any treatment. Twelve mating pairs of adult whiteflies were collected from the whitefly colony and released into each cage. Whiteflies were given 2 wk to establish, mate, and lay eggs on the squash plants before the insecticide applications. At the start of sampling, there were approximately six to eight leaves per squash plant. Sampling was conducted every 2 d for 3 wk, and the underside of all leaves were examined using the leaf-turn method and a 10× hand lens to quantify the number of immature and adult whiteflies over time (Nyoike and Liburd 2010).

Effects of Bioinsecticides on *Delphastus catalinae*

The insecticides that provided the greatest suppression of whiteflies in experiment 1 were used in a second experiment to determine their effects on *D. catalinae*. Experimental design was a 3×4 factorial, with factors A (insecticides) and B (predator release time), which

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was replicated by year. One squash plant was a sampling unit, and each treatment combination was applied to a 1-m^3 exclusion cage that contained four squash plants. Insecticides were applied at labeled rates (as described above) and treatments included: 1) PyGanic EC 1.4, 2) M-Pede, and 3) an untreated control that did not receive any treatment. Predator treatments included 1) releasing *D. catalinae* 1 d post insecticide treatment; 2) releasing *D. catalinae* 3 d post insecticide treatment; 3) releasing *D. catalinae* 5 d post insecticide treatment, and 4) no release of *D. catalinae* (control). Twelve mating pairs of adult whiteflies were collected from the whitefly colony and released into each cage to infest squash plants and provide food for the predators. Whiteflies were given 2 wk to establish, mate, and lay eggs on the squash plants before insecticides were applied. At the start of sampling, there were approximately six to eight leaves per squash plant. In treatments containing *D. catalinae*, five *D. catalinae* adults of undetermined sex and age were released into each cage to achieve a predator to prey ratio of 1:5 based on the number of whitefly adults added at the beginning of the experiment.

Sampling was conducted every 2 d for 2 wk to monitor *D. catalinae* and whitefly populations. Squash plants were visually inspected for the presence of *D. catalinae* adults and counts were recorded. In addition, the underside of all leaves were examined using the leaf-turn method and a 10 × hand lens to quantify the number of immature and adult whiteflies over time (Nyoike and Liburd 2010).

Data Analysis

Whitefly data were obtained by calculating the mean of adult and immature whitefly counts recorded from each squash plant per treatment. The data were replicated by year and analyzed using repeated measures analysis of variance procedure (ANOVA; PROC GLM, SAS Institute 2009) with treatment, time, and treatment × time as the fixed effects. Sample date was the repeated measure. *Delphastus catalinae* data were obtained by calculating the mean number of *D. catalinae* on each squash plant per treatment at the end of the sampling period. The data were replicated by year and analyzed using analysis of variance procedure (ANOVA; PROC GLM, SAS Institute 2009) with pesticide, release time, and pesticide × release time as the fixed effects. Treatment means were separated by least significant differences (LSD) test (SAS Institute 2009) where ANOVA indicated a significant effect on the model by factor. Differences among treatments were considered significant if $P \leq 0.05$.

Results

Effectiveness of Bioinsecticides on Whiteflies in Organic Squash

Adult whitefly densities were different by treatment ($F = 19.97$; df = 4, 29; $P \leq 0.0001$) and over time ($F = 9.06$; df = 5, 29; $P \leq 0.0001$), but there was no interaction effect ($F = 1.24$; df = 20, 29; $P = 0.2934$). Adult whitefly densities were less in PyGanic, M-Pede, and AzaSol treatments compared with Entrust and the untreated control (Fig. 1a). There were also fewer adult whiteflies in the PyGanic and M-Pede treatments compared with the AzaSol treatment (Fig. 1a).

Immature whitefly densities were different by treatment ($F = 4.20$; df = 4, 29; $P = 0.0084$) and over time ($F = 28.95$; df = 5, 29; $P \leq 0.0001$), but there was no interaction effect ($F = 0.43$; df = 20, 29; $P = 0.9719$). There were fewer immature whiteflies in the PyGanic, M-Pede, and AzaSol treatments compared with the untreated control (Fig. 1b). There were also fewer immature whiteflies in the M-Pede treatment compared with the Entrust treatment (Fig. 1b).

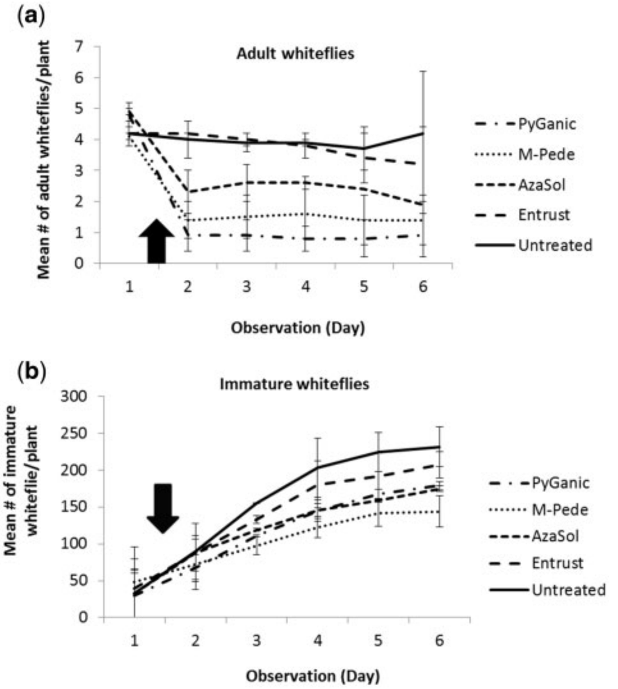

Fig. 1. Mean (±SE) number of (**a**) adult whiteflies and (**b**) immature whiteflies observed per squash plant over the sampling period to determine the effectiveness of five insecticide treatments: PyGanic, M-Pede, AzaSol, Entrust, and an untreated control. The arrow indicates the date when the insecticides were applied to the squash plants.

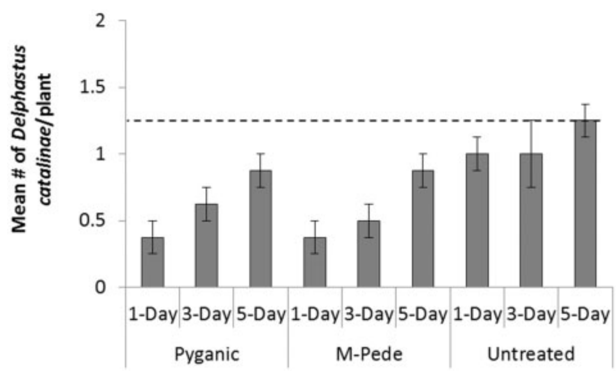

Fig. 2. Mean (±SE) number of *D. catalinae* adults observed per squash plant at the end of the sampling period for the organic insecticide efficacy study evaluating the release of *D. catalinae* to determine the impact of three insecticide treatments (PyGanic, M-Pede, and an untreated control) when *D. catalinae* is released 1, 3, and 5 d post insecticide application. The dotted line represents the density at which *D. catalinae* adults were released per plant.

Effects of Selected Bioinsecticides on *Delphastus catalinae*

Delphastus catalinae densities were different by insecticide treatment ($F = 19.00$; df = 2, 8; $P = 0.0009$) and release time ($F = 11.29$; df = 2, 8; $P = 0.0047$), but there was no interaction effect ($F = 0.57$; df = 4, 8; $P = 0.6912$). *Delphastus catalinae* populations were reduced in both PyGanic and M-Pede treatments compared with the

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untreated control (Fig. 2). *Delphastus catalinae* adults were also reduced when released 1 d and 3 d after insecticide application compared with *D. catalinae* adults released 5 d after insecticide application (Fig. 2).

In addition to evaluating the effect of bioinsecticides on *D. catalinae*, whitefly populations were also monitored to observe the effect of bioinsecticides and *D. catalinae* on both adult and immature whitefly densities. Adult whitefly densities were different by insecticide treatment ($F = 189.11$; df $= 2, 71$; $P \leq 0.0001$), but not by *D. catalinae* release time ($F = 2.24$; df $= 3, 71$; $P = 0.0914$), and there was no insecticide treatment × predator release time interaction effect ($F = 0.49$; df $= 6, 71$; $P = 0.8111$). Adult whitefly densities were reduced in the PyGanic and M-Pede treatments compared with the untreated control (Fig. 3a). However, there was no significant difference in adult whitefly populations based on *D. catalinae* releases (Fig. 3a). Adult whitefly densities were also different over sample dates (time) ($F = 107.01$; df $= 4, 71$; $P \leq 0.0001$) and there was an insecticide treatment × time interaction ($F = 11.75$; df $= 8, 71$; $P \leq 0.0001$), such that treatment differences were observed after insecticide application. However, there was no predator release time × time interaction effect ($F = 0.21$; df $= 12, 71$; $P = 0.9974$).

Immature whitefly densities were different by insecticide treatment ($F = 25.90$; df $= 2, 71$; $P \leq 0.0001$), *D. catalinae* release time ($F = 9.58$; df $= 3, 71$; $P \leq 0.0001$), and there was an insecticide treatment × predator release time interaction effect ($F = 7.03$; df $= 6, 71$; $P \leq 0.0001$). There were fewer immature whiteflies in the PyGanic treatment compared with the M-Pede treatment and the untreated control (Fig. 3b). There were also fewer immature whiteflies when *D. catalinae* was released 1, 3, and 5 d after insecticide application (or no insecticide application) compared with when *D. catalinae* was not released (Fig. 3b). Furthermore, immature whitefly populations were not different between insecticide treatments when *D. catalinae* was released 1 d after insecticide application; however, immature whitefly populations were different between insecticide treatments when *D. catalinae* was released 3 and 5 d after insecticide application and when *D. catalinae* was not released (Fig. 3b). Immature whitefly densities were also different over time ($F = 31.97$; df $= 4, 71$; $P \leq 0.0001$), and there was an insecticide treatment × time interaction effect ($F = 3.00$; df $= 8, 71$; $P = 0.0059$), such that treatment differences were observed after insecticide application. There was also a predator release time × time interaction effect ($F = 3.73$; df $= 12, 71$; $P = 0.0002$), such that treatment differences were observed after all *D. catalinae* releases had been made.

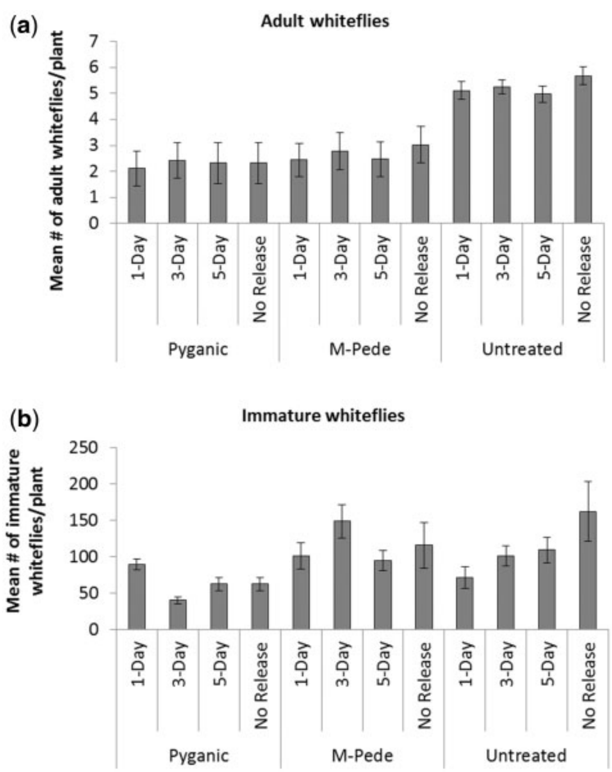

Fig. 3. Mean (±SE) number of (**a**) adult whiteflies and (**b**) immature whiteflies observed per squash plant and averaged over the sampling period for the organic insecticide efficacy study evaluating the release of *D. catalinae* to determine the impact of three insecticide treatments 1) PyGanic, 2) M-Pede, and 3) an untreated control when *D. catalinae* is released 1, 3, and 5 d post insecticide application.

Discussion

Effectiveness of Bioinsecticides on Whiteflies in Organic Squash

PyGanic, M-Pede, and AzaSol were effective in reducing adult whitefly populations on squash. Pyrethrins (PyGanic) and insecticidal soaps (M-Pede) act to kill insects through direct contact and azadirachtin-based products (AzaSol, Aza-Direct) are botanical insecticides that act as insect feeding deterrents (Dayan et al. 2009). These products are recommended for control of whiteflies in organic squash, and this is supported by our findings of reduced adult whitefly densities on squash. Adult whitefly populations were significantly lower in PyGanic and M-Pede treatments compared with the AzaSol treatment. In addition to AzaSol acting as an insect feeding deterrent, the azadirachtin-based product can also act as an insect growth regulator by blocking the synthesis and release of molting hormones leading to incomplete ecdysis in immature insects (Dayan et al. 2009). Von Elling et al. (2002) reported that the strongest effects of a neem-based insecticide were recorded after treatment of whitefly larval instars, such that the proportion of pupae and subsequent emerging adults were significantly reduced. Therefore, AzaSol may have greater efficacy on whitefly populations through multiple generations, by affecting ecdysis in immature insects and reducing the total number of adults in the next generation. Furthermore, the efficacy of neem active ingredients such as AzaSol on whiteflies may be variable as a result of their sensitivity to UV radiation and temperature (Johnson et al. 2003).

M-Pede, PyGanic, and AzaSol significantly reduced immature whitefly populations on squash. This finding has significant implications since immature whiteflies have been implicated in the induction of squash silverleaf disorder. Schuster et al. (2009) reported significantly fewer whitefly immatures on tomatoes in a field study treated with a combination of Aza-Direct and PyGanic compared to the control. Liu and Stansly (2000) also found M-Pede to be effective at reducing immature populations of *B. tabaci* on tomatoes; however, they determined that a greater concentration is necessary (i.e., 20 ml/liter) to achieve the same level of reduction in immature whitefly populations when compared to other products used in conventional systems.

Entrust did not reduce adult or immature whitefly populations. Organic growers regularly use Entrust for whitefly control due to limited organic tools for whitefly management. However, Entrust

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was completely ineffective against whiteflies in this study. Entrust is a naturalyte insecticide from the Spinosad group and is formulated from the fermentation of the natural bacterium, *Saccharopolyspora spinosa* (Dow Chemical Company 2001). Entrust has been shown to be effective against other pests including several chrysomelid beetles and lepidopteran pests (Barčić et al. 2006, Maxwell and Fadamiro 2006, Padilla-Cubas et al. 2006) and can also have lethal and sublethal side effects on nontarget organisms (Biondi et al. 2012b). The mode of action is by contact and ingestion, which induces excitation of neurons in the central nervous system and produces involuntary muscle contractions and tremors (Dayan et al. 2009). The piercing–sucking feeding behavior of whiteflies means that minimal leaf tissue is ingested; therefore, Entrust has little effect on sucking hemipteran insects such as the whitefly, which resulted in its ineffectiveness to suppress whiteflies.

Effects of Selected Bioinsecticides on *Delphastus catalinae*

The findings from this experiment suggest that *D. catalinae* adult densities were reduced in PyGanic and M-Pede treatments. *D. catalinae* adult densities were reduced 1 and 3 d post insecticide application compared with 5 d post application. The findings suggest there may be a need to delay (~5 d) the release of *D. catalinae* when used in conjunction with PyGanic or M-Pede for efficient pest management.

Adult whiteflies were not affected by the presence of *D. catalinae*, which is consistent with observations that the predatory beetle does not feed on the adult stages of *B. tabaci* biotype B. However, adult populations were reduced by PyGanic and M-Pede applications, which is consistent with the findings from the first study.

Immature whiteflies were reduced when *D. catalinae* was released 1, 3, and 5 d post insecticide application compared to when *D. catalinae* was not released. This finding supports our hypothesis that the presence of *D. catalinae* can aide in the suppression of immature whiteflies. Razze et al. (2015) also reported a significant reduction in immature whitefly populations when *D. catalinae* adults were released on squash compared with squash plants where *D. catalinae* was not released in a greenhouse experiment.

Immature whitefly densities were also significantly reduced in PyGanic treatments compared with M-Pede and the untreated control. In the PyGanic treatment, immature whiteflies were reduced when *D. catalinae* releases were delayed (3–5 d). These observations suggest that, in addition to PyGanic effectively reducing immature whitefly populations, delaying *D. catalinae* adult releases after application of PyGanic results in the most efficient control of whiteflies by allowing pesticide toxicity to degrade over time.

In the untreated control with no insecticide application, a reduction in immature whitefly densities was observed when *D. catalinae* was released 1 d after treatment. This finding suggests that *D. catalinae* was effective at reducing immature whitefly densities, and is likely to be most effective at reducing whitefly populations early in the season if insecticides are not used.

In the M-Pede treatment, reductions in immature whitefly densities were recorded when *D. catalinae* was released 1 and 5 d after application of M-Pede; however, immature whitefly densities were not different from treatments where *D. catalinae* was not released. The observation of similar immature whitefly densities between treatments where *D. catalinae* was released 1 and 5 d after application of M-Pede and the treatment where *D. catalinae* was not released was unexpected. The presence of *D. catalinae* adults is hypothesized to reduce immature whitefly densities, as was observed in the PyGanic and untreated control treatments.

Several *D. catalinae* adults were also observed in the flowers (data not shown) of the squash treated with M-Pede, suggesting that adults were seeking out other food sources despite the availability of immature whitefly populations. One hypothesis is that there may be a property of M-Pede (i.e., insecticidal soap) that may disrupt *D. catalinae* feeding activity and could explain the variation in feeding behavior. Liu and Stansly (1999) observed that some *D. catalinae* larvae fed on honeydew and dew drops. Therefore, it is possible that *D. catalinae* could utilize alternate food sources in unfavorable conditions.

In addition to the possibility that M-Pede may inhibit *D. catalinae* feeding, another factor that could be contributing to variability in immature whitefly populations in some M-Pede treatments is the effect of insecticides on whitefly eggs, which is a life stage that was not considered in this study. Liu and Stansly (1995) reported that M-Pede was not effective at reducing whitefly eggs in tomatoes compared with other insecticides used in the study, including mineral oil and a pyrethroid, bifenthrin. Therefore, if eclosion of nymphs from the egg stage was delayed until after the insecticide was applied, a greater density of nymphs may have survived. Furthermore, future greenhouse studies should consider how sex and age of adult *D. catalinae* may effect *D. catalinae* predation on whitefly populations.

In conclusion, M-Pede and PyGanic were effective in reducing adult whitefly populations. M-Pede and PyGanic were also effective at reducing immature whitefly populations, but it is hypothesized that M-Pede may have a property in the insecticidal soap that is interfering with the feeding of *D. catalinae*. *Delphastus catalinae* populations were reduced when released 1 and 3 d post insecticide application. Therefore, it is recommended that *D. catalinae* should not be released within 1–3 d of spraying M-Pede and PyGanic insecticides for maximum whitefly control. Based on these findings, the application of PyGanic with a delayed release (~5 d) of *D. catalinae* to reduce both adult and immature whitefly populations is recommended. Further studies on sublethal and transgenerational effects of organic pesticides on both the pest and natural enemies need to be carefully considered before incorporating pesticides into an IPM program (Desneux et al. 2007, Biondi et al. 2013). Additionally, a cost–benefit analysis should be considered when comparing the use of different organically approved insecticides (i.e., cost of the product, residual activity, number of applications, effect on biological controls).

The findings from this research on the effectiveness of insecticides approved for organic production for managing *B. tabaci* biotype B on organic squash will provide additional tools for managing whitefly populations as well as other emerging pests. Furthermore, the compatibility of these insecticides with natural enemies including *D. catalinae* will provide information on how these insecticides can be used in combination with natural enemies to regulate pest populations in organic cropping systems.

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