Effect of Potassium Bicarbonate (MilStop®) and Insecticides on the Citrus Mealybug, *Planococcus citri* (Risso), and the Natural Enemies *Leptomastix dactylopii* (Howard) and *Cryptolaemus montrouzieri* (Mulsant)

Brian K. Hogendorp

Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL 61801

Raymond A. Cloyd¹

Department of Entomology, Kansas State University, 123 Waters Hall, Manhattan, KS 66506-4004

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Abstract. Both laboratory and greenhouse experiments were conducted to determine if the fungicide, MilStop® (BioWorks, Victor, NY), which contains the active ingredient, potassium bicarbonate, has direct activity on the citrus mealybug, *Planococcus citri* Risso. Spray applications of four different rates (4.5, 5.9, 7.4, and 14.9 g·L⁻¹) were applied to green coleus, *Solenostemon scutellarioides* (L.) Codd., plants infested with citrus mealybugs. In addition, experiments were conducted to assess both the direct and indirect effects of MilStop® on two natural enemies of the citrus mealybug: the parasitoid, *Leptomastix dactylopii* (Howard), and the coccinellid beetle, *Cryptolaemus montrouzieri* (Mulsant). MilStop® provided between 56% and 86% mortality of citrus mealybug; however, the highest rate (14.9 g·L⁻¹) was phytotoxic to coleus plants. Percent mortality associated with the second highest rate (7.4 g·L⁻¹) was 82%, which was comparable to acetamiprid (84%) applied at 0.05 g·L⁻¹. For the natural enemies, MilStop® treatment rates of 1.5 and 3.5 g·L⁻¹ resulted in 16% mortality, whereas the 5.5- and 9.0-g·L⁻¹ rates resulted in 33% mortality of *L. dactylopii* adults. MilStop® treatment rates of 3.5, 5.5, 9.0, and 12.0 g·L⁻¹ resulted in 30%, 60%, 40%, and 90% mortality, respectively, of *C. montrouzieri* adults. Therefore, depending on the application rate, this fungicide may inadvertently kill citrus mealybugs when used to control fungal plant pathogens. It should not disrupt biological control programs targeting citrus mealybug in greenhouses that involve releases of *L. dactylopii* when used at low application rates, whereas MilStop® applications should be properly timed when using *C. montrouzieri*.

Pesticides are used to manage arthropod (insect and mite) pest populations and diseases in greenhouses (Bethke and Cloyd, 2009; Tauber and Helgesen, 1978). Fungicides are applied to control plant pathogenic fungi, although certain fungicides have been shown to directly affect populations of arthropod pests including spider mites (Biggs

and Hagley, 1988; Bower et al., 1995). However, no efficacy data are available for other arthropod pests including the citrus mealybug, *Planococcus citri* Risso, a major insect pest of greenhouses and other interior plantscapes throughout the United States (Kole and Hennekam, 1990; Kosztarab, 1996; McKenzie, 1967). If fungicides are efficacious against both plant pathogens and insect pests such as citrus mealybugs, the number of pesticide applications required during a cropping cycle could be reduced. Furthermore, because greenhouse producers may use biological control to regulate arthropod pest populations including the citrus mealybug (Bartlett, 1978; Douth, 1952; Pilkington et al., 2010), it is important to determine if fungicides could potentially disrupt biological control programs. In general, specific fungicides are considered to be less harmful to natural enemies than insecticides and miticides (Wright and Verkerk, 1995). However, fungicides used

in greenhouse production systems may negatively affect pest-natural enemy interactions, thus compromising the success of biological control programs (Cloyd, 2012; Echegaray and Cloyd, 2012).

Potassium bicarbonate (MilStop®; BioWorks, Victor, NY) is a fungicide registered for use in agricultural and greenhouse cropping systems for the control of various foliar plant pathogens (Abd-El-Kareem, 2007; Cushman et al., 2007; Ziv and Hagiladi, 1993; Ziv and Zitter, 1992). The effects of potassium bicarbonate have not been extensively evaluated against arthropod pests and there is minimal information on any direct or indirect effects on natural enemies. Gradish et al. (2011) showed that potassium bicarbonate and other pesticides evaluated were not directly harmful to the natural enemies, *Orius insidiosus* (Say), *Amblyseius swirskii* (Athias-Henriot), and *Eretmocerus eremicus* Rose & Zolnerowich, under laboratory and greenhouse conditions. Therefore, the objectives of this study were to 1) determine the efficacy of MilStop® and other pesticides against the citrus mealybug; and 2) assess any direct and/or indirect effects on the natural enemies of the citrus mealybug, *Leptomastix dactylopii* (Howard) and *Cryptolaemus montrouzieri* (Mulsant), also known as the “mealybug destroyer,” under both greenhouse and laboratory conditions.

Materials and Methods

Experiments were conducted to determine the direct effects of MilStop® (active ingredient = potassium bicarbonate) on the citrus mealybug, *Planococcus citri* (Expt. 1) and the direct and indirect effects on two natural enemies of the citrus mealybug, *Leptomastix dactylopii* and *Cryptolaemus montrouzieri* (Expts. 2 through 4).

Expt. 1: Effects of potassium bicarbonate (MilStop®) on the citrus mealybug. Sixty plants of green coleus, *Solenostemon scutellarioides* (L.) Codd., were started from cuttings taken from stock plants and transplanted into 15.2-cm containers (Kord Products, Toronto, Canada) in a growing medium (Universal SB 300 Mix; Strong-Lite Horticulture Products, Pine Bluff, AR) consisting of 50% composted pine bark, 20% Canadian sphagnum peatmoss, 20% medium coarse vermiculite, 10% perlite, a starter nutrient charge, and a wetting agent. Plants were fertilized with 20N–8.3P–8.8K at 250 ppm nitrogen in a constant liquid feed program and grown in a glass greenhouse on 12 × 3-m wire-mesh raised benches and arranged in a completely randomized design. There were a total of 10 treatments, which included four rates of potassium bicarbonate and six other compounds including sesame oil, pyrethrins, polyetherpolymethylsiloxane, acetamiprid, alkyl aryl polyoxyethylene, and azadirachtin (Table 1). There were five replications per treatment. In addition, a water control and an untreated control (no water applied) were included. Effects of treatments on the citrus mealybug were evaluated 7 d post-application.

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Table 1. Pesticide treatments [common name (active ingredient) and trade name] and rates on the citrus mealybug, *Planococcus citri*.

Common name ^a	Trade name	Rate used
Potassium bicarbonate	MilStop®	0.60 oz/1 gallon (4.5 g·L ⁻¹)
Potassium bicarbonate	MilStop®	0.80 oz/1 gallon (5.9 g·L ⁻¹)
Potassium bicarbonate	MilStop®	1.0 oz/1 gallon (7.4 g·L ⁻¹)
Potassium bicarbonate	MilStop®	2.0 oz/1 gallon (14.9 g·L ⁻¹)
Sesame oil	Organocide™	2.0 fl oz/1 gallon (14.7 mL·L ⁻¹)
Pyrethrins	Schultz Expert Gardener® ^{by}	RTU at 34 mL per plant
Polyether-polymethylsiloxane ^c	Capsil®	0.46 mL·L ⁻¹
Acetamiprid	TriStar®	0.05 g·L ⁻¹
Alkyl aryl polyoxyethylene	Spreader Sticker	0.11 mL·L ⁻¹
Azadirachtin	Ornazin®	8.0 fl oz/100 gallons (0.60 mL·L ⁻¹)

^aPesticide treatments: potassium bicarbonate (MilStop®; BioWorks, Victor, NY), sesame oil (Organocide™; Organic Laboratories, Inc., Stuart, FL), pyrethrins (Schultz Expert Gardener®; Schultz Comp., Bridgeton, MO), polyether-polymethylsiloxane-copolymer (Capsil®; Aquatrols, Paulsboro, NJ), acetamiprid (TriStar®; Cleary Chemicals, LLC, Dayton, NJ), alkyl aryl polyoxyethylene (Spreader Sticker; PBI/Gordon Corp., Kansas City, MO), and azadirachtin (Ornazin®; SePRO Corp., Carmel, IN).

^bFull designation: Schultz Expert Gardener® Insect Spray RTU. RTU = ready-to-use formulation.

^cFull designation: polyether-polymethylsiloxane-copolymer and nonionic surfactant.

Plants were 15.2 to 25.4 cm in height when each plant was artificially infested with 15 second- and early third-instar citrus mealybugs. Citrus mealybugs were reared on butternut squash, *Cucurbita maxima* L., in a growth chamber located in the National Soybean Research Laboratory at the University of Illinois (Urbana, IL). The chamber was maintained at 24 ± 5 °C, 50% to 60% relative humidity (RH), and a 24-h light:0-h dark photoperiod. After 24 h, all plants were treated with the appropriate treatments. Spray applications were performed using a 946-mL plastic spray bottle (The Home Depot, Manhattan, KS). Individual plants were sprayed to runoff with 34 mL of spray solution, which was sufficient to cover all plant parts including stems and both sides of the leaves. Deionized water was used for all treatment applications. Greenhouse temperatures during the experiment ranged from 21 to 29 °C with a RH between 50% and 60%. Test plants received natural lighting for the duration of the experiment, which was conducted in September. Plants were irrigated as needed by hand using a water breaker attached to a hose; no overhead irrigation was done. Coleus plants were harvested 7 d post-application, and the number of live, dead, and total number of citrus mealybugs was counted for each plant (= replicate). Any phytotoxicity associated with the designated treatments was recorded at that time.

Statistical analysis. Data were analyzed using a one-way analysis of variance (ANOVA). Percent citrus mealybug mortality for each treatment was calculated by dividing the number of dead mealybugs by the total number of mealybugs found per plant, which met the assumptions for the ANOVA. Significant treatment means associated with live, dead, and total number of citrus mealybugs was separated using a Fisher's protected least significant difference (LSD) test at $P \leq 0.05$ (SAS Institute, 2002). Percent mortality values were normalized by arcsine square root transformation and subjected to a one-way ANOVA with treatment as the main effect. Significant treatment means were separated using a Fisher's protected LSD

test at $P \leq 0.05$ (SAS Institute, 2002). All data presented are non-transformed.

Expts. 2 through 4: Effects of potassium bicarbonate (MilStop®) on the natural enemies *Leptomastix dactylopii* and *Cryptolaemus montrouzieri*

The next series of experiments were conducted to determine the direct effects of MilStop® on the parasitoid, *Leptomastix dactylopii*, and the predatory coccinellid beetle, *Cryptolaemus montrouzieri*. Expt. 4 was performed to assess the indirect effects of MilStop® on *L. dactylopii*.

Expt. 2: Direct effects of potassium bicarbonate (MilStop®) on *Leptomastix dactylopii*. Filter paper (Whatman® No. 1; Whatman®, Maidstone, U.K.) was placed in the bottom of an inverted petri dish measuring 100 × 20 mm. A total of 42 petri dishes was used in the experiment. A small quantity (0.1 mL) of a 50:50 (v/v) honey:water solution (honey mixed with deionized water) was applied to the inside of the lid of each petri dish. The petri dish and filter paper were sprayed once with 0.8 mL of the treatment solution using a 946-mL spray bottle calibrated so that the full-spray trajectory thoroughly moistened the entire petri dish and filter paper. Deionized water was used as the solvent for all treatment applications.

Newly emerged (24 h old or less) female and male *L. dactylopii* were collected using an aspirator and allowed to mate for 24 h in 9-dram plastic vials with a drop (0.05 mL) of 50:50 (v/v) honey:water solution applied to the inside portion of the lid. A single female parasitoid was then placed into each petri dish immediately after the treatments had been applied. After 48 h, a laboratory syringe was used to apply 0.8 mL of deionized water to the filter paper of each petri dish to ensure that the filter paper was constantly moist. Each female parasitoid was checked after 24, 48, 72, and 96 h to assess whether it was alive or dead. The number of live and dead female parasitoids per assessment period per petri dish was recorded and used to determine percent mortality. The experiment was conducted as a completely randomized design

with six MilStop® treatments (0.5, 1.5, 3.5, 5.5, 9.0, and 12.0 g·L⁻¹) along with a water control. These rates were selected for evaluation based on recommendations from the company representative (Randy Martin, Director of Product Development, BioWorks). There were six replications per treatment.

Expt. 3: Direct effects of potassium bicarbonate (MilStop®) on *Cryptolaemus montrouzieri*. Adult *Cryptolaemus montrouzieri* were obtained from a commercial supplier of biological control agents (IPM Laboratories, Inc., Locke, NY). On arrival, the adult beetles were processed immediately for the experiment. Approximately 20 citrus mealybugs of varying ages, from second- to early fourth-instar, were placed into each inverted glass petri dish (100 × 200 mm) containing a green coleus, *S. scutellarioides*, leaf. Moistened filter paper was located underneath the leaf. A total of 70 petri dishes was used in the experiment. One adult beetle was applied to each petri dish using a moistened camel hair paintbrush. The adult beetles were allowed to acclimate for 24 h and were provided with a continuous food source. After 24 h, the designated treatments were applied using a 946-mL plastic spray bottle, which was calibrated to disperse 8.0 mL of solution. Each petri dish received 4.0 mL. This volume was sufficient to thoroughly moisten the adult *C. montrouzieri*, citrus mealybugs, and coleus leaf. The experiment was designed to simulate greenhouse conditions in regard to simultaneous exposure of both the predator and citrus mealybugs. Deionized water was used as the solvent for all treatment applications. Adult beetle mortality was assessed 24, 48, 72, and 96 h after application of the designated treatments. The experiment was conducted as a completely randomized design with six MilStop® treatments and a deionized water control. There were 10 replications per treatment. The MilStop® treatments and rates were the same as in the previous experiment described.

Expt. 4: Indirect effects of potassium bicarbonate (MilStop®) on *Leptomastix dactylopii*. Approximately 84 newly emerged (24 h old or less) female and male *L. dactylopii* were collected using an aspirator and placed into 9-dram plastic vials with a drop (0.05 mL) of 50:50 (v/v) honey:water solution placed on the inside portion of the lid as a food source (one female and male per vial). The parasitoids were allowed to mate for 24 h. Forty-two glass petri dishes (100 × 20 mm) were inverted, lined with filter paper, and a small volume (0.1 mL) of 50:50 (v/v) honey:water solution was placed on the inside portion of the lid as a food source. The filter paper was initially moistened with ≈2.0 mL of deionized water using a laboratory syringe, and a green coleus leaf was positioned so that the leaf margins draped over the exterior of the petri dish. This prevented any parasitoids and citrus mealybugs from escaping.

Twenty late-second and early-third instar citrus mealybug nymphs were transferred onto the leaf surface of each petri dish with a moistened camel hair paintbrush. Each petri

dish containing the citrus mealybugs was sprayed using a 946-mL plastic spray bottle with ≈ 8.0 mL of the treatment solution, which was sufficient to thoroughly moisten the citrus mealybugs and coleus leaf. Deionized water was used as a solvent for all treatment applications. The potassium bicarbonate rates used were 0.5, 1.5, 3.5, 5.5, 9.0, and 12.0 g·L⁻¹. The petri dish lid was then inserted into the base and a weight was placed on the top to prevent any parasitoids and citrus mealybugs from escaping. In addition, the petri dish was positioned such that citrus mealybugs could not migrate to the underside of the coleus leaf, which prevented any mealybugs from escaping attack by the parasitoid. The experiment was conducted as a completely randomized design with six potassium bicarbonate treatments, a water control, and an untreated control. There were five replications per treatment per release time (n = 2) for a total of 70 experimental units. In 35 of the experimental units, a mated female *L. dactylopii* was placed into the petri dish containing citrus mealybugs immediately after the treatments had been applied. In the remaining 35 experimental units, newly mated *L. dactylopii* were released into the petri dish containing citrus mealybugs 24 h post-application. The female parasitoids were allowed to remain in the petri dishes containing the citrus mealybugs for 24 h, after which time they were removed. The filter paper underneath the coleus leaf was moistened as needed with ≈ 2.0 mL of deionized water using a laboratory syringe to keep the leaves hydrated (turgid) during the course of the experiment. Petri dishes were monitored daily for 2 weeks after mealybugs were parasitized (mummified) to assess adult parasitoid emergence. Parasitization rate denotes those parasitoids that survived to the “mummy” stage. Once emergence was initiated, the petri dishes were monitored daily and any parasitoids were collected and sexed using antennae morphology (Malais and Ravensberg, 2003). The experiment ended 2 d after no more adult parasitoids had emerged from the parasitized mealybugs.

Results

Expt. 1: Effects of potassium bicarbonate (MilStop®) on the citrus mealybug. Treatment was significant for the number of live ($F = 6.20$; $df = 11, 59$; $P \leq 0.0001$) and dead ($F = 6.74$; $df = 11, 59$; $P \leq 0.0001$) citrus mealybugs (Table 2). The total number of citrus mealybugs recovered from the treated plants was significant ($F = 2.04$; $df = 11, 59$; $P = 0.047$) as was percent mortality ($F = 9.74$; $df = 11, 59$; $P \leq 0.0001$) (Table 2). Most of the treatments were significantly different from the water control and/or the untreated control based on percent mortality of the citrus mealybugs with the exception of sesame oil, azadirachtin, and alkyl aryl polyoxyethylene (Table 2). The 5.9-, 7.4-, and 14.9-g·L⁻¹ rates of MilStop® provided mortality values of 76%, 82%, and 86% of citrus mealybugs, respectively. These rates were comparable

Table 2. Mean ($\pm$ SEM) number of live, dead, and total number of citrus mealybug (CMB), *Planococcus citri*, and percent mortality associated with all treatments 7 d after application to coleus, *Solenostemon scutellarioides* plants.^z

Treatment (active ingredient)	Rate (per L)	Live CMB	Dead CMB	Total CMB	Percent mortality
Potassium bicarbonate	4.5 g	5.8 $\pm$ 1.2 bc ^y	8.2 $\pm$ 2.0 abc	14.0 $\pm$ 2.2 ab	56 cde
Potassium bicarbonate	5.9 g	3.6 $\pm$ 1.7 cd	9.8 $\pm$ 1.3 a	13.4 $\pm$ 2.0 ab	76 abc
Potassium bicarbonate	7.4 g	1.6 $\pm$ 0.5 d	9.4 $\pm$ 1.9 ab	11.0 $\pm$ 1.6 abcd	82 ab
Potassium bicarbonate	14.9 g	1.4 $\pm$ 0.6 d	8.0 $\pm$ 1.1 abc	9.4 $\pm$ 1.3 bcd	86 ab
Sesame oil	14.7 mL	9.2 $\pm$ 1.4 ab	5.5 $\pm$ 0.3 cd	15.0 $\pm$ 1.4 a	40 ef
Pyrethrins	—	3.6 $\pm$ 0.5 cd	8.8 $\pm$ 1.3 abc	12.4 $\pm$ 1.3 abc	69 bcd
Polyether-polymethylsiloxane ^x	0.46 mL	7.0 $\pm$ 2.7 bc	6.2 $\pm$ 1.3 bc	13.2 $\pm$ 2.0 ab	53 cd
Acetamiprid	0.05 g	1.6 $\pm$ 0.8 d	6.6 $\pm$ 0.7 abc	8.2 $\pm$ 1.1 cd	84 a
Alkyl aryl polyoxyethylene	0.11 mL	9.8 $\pm$ 1.5 ab	2.6 $\pm$ 0.8 de	12.4 $\pm$ 0.9 abc	23 fg
Azadirachtin	0.60 mL	7.0 $\pm$ 1.8 bc	5.4 $\pm$ 1.4 dc	12.4 $\pm$ 1.8 abc	44 def
Untreated control	—	6.2 $\pm$ 1.3 bc	1.0 $\pm$ 0.3 e	7.2 $\pm$ 1.5 d	15 fg
Water control	—	12.2 $\pm$ 1.4 a	0.2 $\pm$ 0.2 e	12.4 $\pm$ 1.3 abc	2 g

^zThere were five replications per treatment with 15 citrus mealybugs per replicate.

^yMeans not followed by a common letter are significantly different ($P \leq 0.05$) as determined by Fisher's protected least significant difference test.

^xFull designation: polyether-polymethylsiloxane-copolymer and nonionic surfactant.

to acetamiprid with 84% percent mortality of citrus mealybugs (Table 2). The remaining treatments provided less than 70% mortality of citrus mealybugs (Table 2). Despite the level of control provided by the high rate (14.9 g·L⁻¹) of MilStop®, this rate was phytotoxic to the coleus plants with symptoms such as necrosis of leaf edges, curled leaves, and brown spotting on leaves. At this point, it is difficult to explain why we recovered low numbers (7.2 of 15) of citrus mealybugs in the untreated control.

Expt. 2: Direct effects of potassium bicarbonate (MilStop®) on Leptomastix dactylopii. The MilStop® rates tested resulted in 33% or less mortality of adult *L. dactylopii* after 96 h posttreatment (Table 3) with the higher application rates, in general, more harmful than the water control. The mortality among all the designated treatments across the four assessment periods (24, 48, 72, and 96 h) was 11% (five dead parasitoids out of a total of 42 parasitoids).

Expt. 3: Direct effects of potassium bicarbonate (MilStop®) on Cryptolaemus montrouzieri. MilStop® rates of 3.5 g·L⁻¹ and higher were toxic to *C. montrouzieri* adults with mortality ranging between 30% and 90% after 96 h posttreatment (Table 4). The highest rate (12.0 g·L⁻¹) of MilStop® was extremely harmful to the coccinellid adults with mortality values between 70% and 80% after 48 h and 90% after 96 h posttreatment. The water control resulted in 0% adult mortality after 96 h posttreatment (Table 4).

Expt. 4: Indirect effects of potassium bicarbonate (MilStop®) on Leptomastix dactylopii. *Leptomastix dactylopii* females did not consistently parasitize citrus mealybugs in the water control or untreated control despite using appropriate instars (mid- to late-third or early fourth) that are most preferred by *L. dactylopii* (de Jong and van Alphen, 1989). Therefore, we only evaluated *L. dactylopii* survival associated with immediate release after the treatment had been applied. The survival rate of female *L. dactylopii* after 24 h was between 81% and 90%, respectively, so

Table 3. Percent mortality of the parasitoid, *Leptomastix dactylopii*, 24, 48, 72, and 96 h after exposure to potassium bicarbonate (MilStop®).^z

Potassium bicarbonate treatment (rate per L)	Percent mortality			
	24 h	48 h	72 h	96 h
0.5 g	0	0	0	0
1.5 g	0	0	0	16
3.5 g	0	0	0	16
5.5 g	0	16	16	33
9.0 g	16	16	16	33
12.0 g	0	0	0	0
Water control	0	0	0	0

^zThere were six replications per treatment with each replication consisting of a single adult parasitoid.

Table 4. Percent mortality of the predatory coccinellid beetle, *Cryptolaemus montrouzieri* adults, 24, 48, 72, and 96 h after exposure to the potassium bicarbonate (MilStop®).^z

Potassium bicarbonate treatment (rate per L)	Percent mortality			
	24 h	48 h	72 h	96 h
0.5 g	0	10	10	10
1.5 g	10	10	10	10
3.5 g	20	30	30	30
5.5 g	50	50	60	60
9.0 g	30	40	40	40
12.0 g	70	80	90	90
Water control	0	0	0	0

^zThere were 10 replications per treatment with each replication consisting of a single adult predator.

parasitoid survival was not responsible for the lack of parasitization. Although *L. dactylopii* females did not parasitize a sufficient number of citrus mealybugs in the experiment as has been observed in previous studies (Cloyd and Sadof, 2000), they did parasitize some citrus mealybugs and adults did emerge. Parasitized (mummified) citrus mealybugs and emerged adults were observed in the untreated control [four citrus mealybugs parasitized (three females and one male emerged)], water control [one citrus mealybug parasitized (one male emerged)], 1.5-g·L⁻¹ rate [five citrus

mealybugs parasitized (four females and one male emerged)], 3.5-g-L⁻¹ rate [two citrus mealybugs parasitized (two males emerged)], and 9.0-g-L⁻¹ rate [one citrus mealybug parasitized (one male emerged)] of potassium bicarbonate.

Discussion

This study shows that MilStop® has contact activity against the citrus mealybug. The label rate of MilStop® is 2.5 to 5.0 lbs/100 gallons of water, which would be equivalent to the 4.5- and 5.9-g-L⁻¹ rates used in our study that resulted in 56% and 76% mortality of citrus mealybugs. Higher rates (7.4 and 14.9 g-L⁻¹) provided 82% and 86% mortality, respectively. Most of the other compounds evaluated in our study provided less than 70% mortality of citrus mealybugs although the pyrethrins treatment resulted in 69% citrus mealybug mortality. Two of the compounds, polyether-polymethylsiloxane and alkyl aryl polyoxyethylene, are surfactants or spreader stickers. We tested these compounds because it has been shown that certain surfactants have insecticidal and miticidal activity (Cowles et al., 2000; Liu and Stansly, 2000). However, in our study, these compounds and the others evaluated including sesame oil, pyrethrins, and azadirachtin did not appear to negatively affect citrus mealybugs. For example, the product containing sesame oil provided 40% mortality of citrus mealybugs. This is similar to a previous study in which Organocide™ (Organic Laboratories, Inc., Stuart, FL), the product evaluated in our study that contains 5% sesame oil, resulted in less than 50% mortality of citrus mealybugs (Cloyd et al., 2009). Products such as Garden Safe Houseplant & Garden Insect Spray® (Schultz Comp., Bridgeton, MO), which contains 0.01% pyrethrins, and Pyola® (Gardens Alive, Inc., Lawrenceburg, IN) containing 0.5% pyrethrins resulted in 75% and 50% mortality of citrus mealybug, respectively (Cloyd et al., 2009). In the current study, pyrethrins provided 69% mortality of the citrus mealybug.

One reason for the lack of efficacy is that these active ingredients are strictly contact in activity and the hydrophobic waxy covering that surrounds the body of the citrus mealybug in later instars (third to fourth) may have prohibited the sprays from penetrating and making direct contact with the body (Copeland et al., 1985; Franco et al., 2009). Azadirachtin, which is an insect growth regulator, derived from the neem tree, *Azadirachta indica* A. Juss. (Simon Ascher, 1993; Ware and Whitacre, 2004), may not have been effective because the older instars used in our study are less susceptible to the insecticide than earlier instars (Copeland et al., 1985). Furthermore, Quarles (2005) indicated that neem extracts are not effective against mealybugs. Acetamiprid is a neonicotinoid insecticide (Matsuda et al., 2001; Tomizawa and Casida, 2003) that has proven to be effective against citrus mealybug with activity against the later instars (R.A. Cloyd, unpublished data). In our

study, the highest rates of MilStop® used (7.4 and 14.9 g-L⁻¹) provided similar levels of citrus mealybug mortality (82% and 86%) as acetamiprid (84%).

In our study, MilStop® had minimal direct effect on adults of the parasitoid, *L. dactylopii*, but was directly harmful to adults of the coccinellid predator, *C. montrouzieri*. Gradish et al. (2011) demonstrated that under laboratory and greenhouse (semifield) conditions, exposure to potassium bicarbonate at 476 mg-L⁻¹ (0.476 g-L⁻¹), which was substantially lower than the label rate, did not directly affect (based on mortality) the natural enemies *O. insidiosus*, *A. swirskii*, and *E. eremicus*. High mortality associated with *C. montrouzieri* adults may be related to their general susceptibility to potassium bicarbonate or by consumption of contaminated prey (sprayed citrus mealybugs), which has been demonstrated with insecticides (Cloyd and Bethke, 2011). The limited results obtained in Expt. 4 make it difficult to assess the actual indirect effect of MilStop® on the ability of *L. dactylopii* to parasitize citrus mealybugs. However, it is possible that MilStop® applications either directly killed citrus mealybugs or reduced the quality of citrus mealybugs such that they were not acceptable as a host for egg-laying by *L. dactylopii* females, which has been shown in a previous study (Rothwangl et al., 2004). Further research is warranted to quantitatively determine this relationship.

In greenhouse situations, the crop canopy may provide refugia for natural enemies so they can avoid direct contact from insecticide residues (Liburd et al., 2007). Also, it may not be the active ingredient that is responsible for negative effects on natural enemies, but the inert ingredients (which are confidential in the case of MilStop®) in the formulation (Cowles et al., 2000; Imai et al., 1995; Willmott et al., 2013). The high rate (14.9 g-L⁻¹) of MilStop® was phytotoxic to coleus plants, which may be related to the solution concentration because phytotoxicity may occur more frequently at higher concentrations (1.25% to 5%) and when applied as coarse spray droplets. Therefore, it is recommended that the lowest concentration, based on the label, be used especially under greenhouse conditions (Ziv and Zitter, 1992).

Fungicides have been evaluated to determine any harmful effects against natural enemies; however, most of these studies have been associated with predatory mites (Alston and Thomson, 2004; Bernard et al., 2004; Ioriatti et al., 1992). Although studies have demonstrated that certain fungicide active ingredients including maneb are toxic to the parasitoid, *Microplitis croceipes* Cresson (Felton and Dahlman, 1984), others have shown that the active ingredient mancozeb was not harmful to two leafminer parasitoids, *Hemiptarsemus varicornis* Girault and *Diglyphus isaea* Walker (Bjorksten and Robinson, 2005). Despite these studies, there is still limited information on the effects of fungicides on parasitoids and predatory beetles. Therefore, it is difficult to compare the effects of MilStop® on *L. dactylopii* and *C. montrouzieri*

with other fungicides, although Gradish et al. (2011) found that both potassium bicarbonate and myclobutanil (Nova®; Dow AgroSciences, Calgary, Alberta, Canada) were not harmful to the parasitoid, *E. eremicus*; however, as stated previously, the rate of potassium carbonate used (0.476 g-L⁻¹) was much lower than the recommended label rate.

In conclusion, MilStop® does have insecticidal activity against citrus mealybugs at the rates evaluated. Although we are aware of the limitations associated with the study in regard to the effects of MilStop® on natural enemies, which were a function of the availability of the parasitoid and predator, MilStop® was less harmful to adult female *L. dactylopii* than adults of the coccinellid beetle, *C. montrouzieri*, particularly at the higher rates tested. It should be noted that the highest rate used (14.9 g-L⁻¹) is an off-label use and as such there may be issues affiliated with potential violations of pesticide regulations. Nevertheless, as a result of the efficacy against citrus mealybugs, it may behoove the manufacturer to consider revising the label to include mealybugs. This may expand the use of the product against both insect pests and foliar plant pathogens. Although the indirect effects of MilStop® on *L. dactylopii* are still uncertain, it is possible that this pesticide, depending on the application rate, may inadvertently kill citrus mealybugs when used to control foliar fungal plant pathogens and not disrupt biological control programs in greenhouses that involve releases of *L. dactylopii* targeting citrus mealybug. However, MilStop® applications should be properly timed when using *C. montrouzieri* to avoid unintentionally killing them.

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