Alternatives to a Pyrethroid for Controlling Madeira Mealybug (Hemiptera: Pseudococcidae) on Coleus Cuttings

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Alternatives to a pyrethroid for controlling Madeira mealybug (Hemiptera: Pseudococcidae) on coleus cuttings

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Abstract

Mealybugs (Hemiptera: Pseudococcidae) are soft-bodied insects that infest a variety of ornamental plants, and early instars are almost undetectable to the human eye. Because the cryptic mealybugs can cause significant damage quickly, plant cuttings often are preventively dipped into pyrethroid-based insecticides. Dips differ widely, however, in their phytotoxicity, effectiveness in killing mealybugs, and operational efficiency and cost. Therefore, to assess the efficacy of alternative dips, tests were conducted on biorational products for controlling the Madeira mealybug, *Phenacoccus madeirensis* Green, on coleus plants, *Plectranthus scutellarioides*, var. 'Big Red Judy' L. (Lamiaceae). Initially, phytotoxicity was evaluated using different concentrations and exposure times for dips containing Natur'l oil, dish detergent, Wetcit®, or Vapor Gard®. The highest concentrations of these products for which phytotoxicity could be tolerated were 1%, 1%, 0.1%, and 0.1%, respectively, in 30 s dips. Based on the results, these concentrations were used in dips to evaluate their effectiveness in eliminating mealybugs. The most effective biorational product, Natur'l oil, then was compared with the commercial standard synthetic pyrethroid, Mavrik Aquaflow® (22.3% tau-fluvalinate). Both products killed > 90% of the nymphs within 14 d when applied as a 1% aqueous mixture for 60 s. Thus, Natur'l oil could be used instead of the pyrethroid as a dip to remove Madeira mealybugs from coleus cuttings.

Key Words: insecticide dips; nursery; Mavrik Aquaflow®; biorational products

Resumen

Las cochinillas son insectos de cuerpo blando que infestan una gran variedad de plantas ornamentales, los estadios tempranos de estos insectos son casi imperceptibles para el ojo humano. Las inmersiones de plantas en insecticidas que contienen piretroides sintéticos son utiliadas a menudo en un intento de matar cochinillas crípticas y prevenir daños las plantas. Las inmersiones difieren ampliamente en su fitotoxicidad, efectividad en eliminar cochinillas, eficiencia operacional y costo. Por lo tanto, para evaluar la eficacia de las inmersiones alternativas, se realizaron pruebas en productos bioracionales para controlar el piojo harinoso, *Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae), en plantas de coleo, *Plectranthus scutellarioides*, var. 'Big Red Judy' L. (Lamiaceae). Inicialmente, se evaluó la fitotoxicidad utilizando diferentes concentraciones y tiempos de inmersión en soluciones o emulsiones con aceite natural "Natur'l oil", detergente para platos, Wetcit® o Vapor Gard®. Las concentraciones más altas de estos productos en las cuales se tolera fitotoxicidad fueron 1%, 1%, 0.1%, y 0.1%, respectivamente, a un tiempo de inmersión de 30 s. Basados en estos resultados, estas concentraciones fueron utilizadas en inmersiones para evaluar la efectividad eliminando piojos harinosos El producto bioracional más eficaz, fue el aceite natural Natur'l oil que se comparó con el piretroide sintético comercial, Mavrik Aquaflow® (22,3% tau-fluvalinato), y ambos mataron a más del 90% de las ninfas cuando se aplicaron como mezcla acuosa al 1% por 60 s. Por lo tanto, el aceite natural "Natur'l oil" puede ser utilizado en lugar del piretroide sintético en inmersión para eliminar las cochinillas en los esquejes de coleo.

Palabras Clave: insecticidas por inmersión; esquejes; Mavrik Aquaflow®; productos biorationales

The Madeira mealybug, *Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae), is a cosmopolitan polyphagous insect that has been detected on plants in > 60 taxonomic families, including some important agricultural and ornamental species. This pest is particularly difficult to manage due to its cryptic nature (Chong 2005). Historically, *P. madeirensis* has been controlled by insecticides such as profenophos, chlorpyriphos, buprofezin, dimethoate, imidacloprid, dinotefuran, thiamethoxam, and tau-fluvalinate, among others (Willmott & Cloyd 2013). These compounds affect different metabolic pathways, e.g., disrupting the insect nervous system or chitin biosynthesis (Cloyd & Benthke 2011). However, the frequent and often indiscriminate use of some broad spectrum insecticides has induced insecticide resistance in similar target species, such as *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) (Saddiq et al. 2014). Several of

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these insecticides also can affect human health negatively (Vijverberg & vanden Bercken 1990; Wendt-Rasch et al. 2003; Desneux et al. 2007; WHO 2009; Saillenfait et al. 2015). Consequently, alternatives to broad spectrum insecticides are needed for controlling *P. madeirensis* on ornamental plants (Guerrero 2014). Biorational insecticides are available (Horowitz et al. 2009; Fishel 2016), but they must be effective and minimize phytotoxicity (Osborne 1986 & Bethke 2011).

The objective of this study was to develop an acceptable biorational insecticide dip for coleus cuttings, *Plectranthus scutellarioides* L. (Lamiaceae), infested with *P. madeirensis*, and to compare its efficacy with the ornamental plant industry standard insecticide dip, Mavrik Aquaflow® (22.3% tau-fluvalinate; Wellmark International, Schaumburg, Illinois, USA). Dip treatments are used to eliminate mealybugs from coleus cuttings before they are planted in an effort to minimize the level of infestation and damage on full-grown plants.

Materials and Methods

MADEIRA MEALYBUG COLONY ESTABLISHMENT AND MAINTENANCE

About 100 *P. madeirensis* were transferred onto coleus plants on 16 Jan 2013 from a greenhouse colony that had been reared for about 3 generations on basil plants at the University of Florida, Mid-Florida Research and Education Center, Apopka, Florida, USA. The species identification was verified and a sample deposited at the Florida State Collection of Arthropods, maintained by the Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville, Florida, USA. Our *P. madeirensis* colony was maintained on coleus plants under standard greenhouse conditions at Mid-Florida Research and Education Center (25–27 °C and 14:10 h [L:D] photoperiod). Mealybugs were transferred to new coleus plants monthly by placing the new plants adjacent to heavily infested ones.

The coleus plants used in this study, variety 'Big Red Judy,' were obtained from a local nursery in North Central Florida. Cuttings were removed from plants by selecting healthy 10 to 15 cm long branches, cutting each at the base, removing lower leaves, and planting them in 10 cm diam plastic pots filled with Fafard Growing Mix 2/C-2 (Sungro Horticulture, Agawam, Massachusetts, USA) containing Canadian sphagnum peat moss, perlite, vermiculite, dolomitic limestone, and wetting agent. Plants were maintained for 2 wk in the greenhouse using a mist system that was activated every 10 min for 10 s from 8:00 AM to 8:00 PM. Plants were moved to another greenhouse table for regular maintenance using the methods of Croxton & Kessler (2007). Cuttings from 3-mo-old coleus plants were used for all tests.

ASSESSMENT OF COLEUS CUTTING PHYTOTOXICITY CAUSED BY BIORATIONAL PRODUCT DIPS

Beginning in Mar 2013, the following biorational products were tested: Natur'l oil (93% soybean oil, 7% emulsifiers; StollerUSA, Houston, Texas, USA); Publix® Dish Detergent, Ultra, Mild & Gentle (Publix Supermarket, Lakeland, Florida, USA); Wetcit® (8.15% alcohol ethoxylate surfactant; Oro Agri Internationa, Fresno, California, USA); and Vapor Gard® (96% di-1-p-menthene; Miller Chemical and Fertilizer, Hanover, Pennsylvania, USA). Products were mixed in distilled water at concentrations of 0.1%, 0.5%, 1%, and 1.5%. Distilled water alone also was used as a treatment. For each dip, 5 uninfested 10-cm-long coleus cuttings with 2 fully develop leaves were submerged simultaneously to a depth of about 10 cm and lightly agitated for 30 s. This is a typical procedure used by nurseries to treat plant cuttings. Each treatment was repeated twice and cuttings were planted in individual 10 cm diam plastic pots filled with Fafard® growing mix. Plants were maintained under the mist system for 4 wk and watered 12 h per d at intervals of 30 s every 10 min. Phytotoxicity was ranked weekly for 4 wk using the following categories: chlorosis, chlorotic flecking, necrotic flecking, holes, tip chlorosis, and tip necrosis. Each phytotoxcity symptom was subjectively assigned a numerical value ranging from 0 for no damage to 5 for highly damaged plants. This approach to scoring plant damage was adapted from assessments of other ornamental plants treated with insecticides for controlling aphids, scale insects, and mealybugs (see Hansen et al. 1992).

EFFICACY OF THE BIORATIONAL PRODUCT DIPS FOR CONTROLLING MADEIRA MEALYBUGS ONVV COLEUS CUTTINGS

Based on initial phytotoxicity evaluations in 2013 (Table 1), the following concentrations were assessed for efficacy in controlling *P. madeirensis*: 1% Natur'l oil, 1% Publix® dish detergent, 0.1% Wetcit®, and 0.1% Vapor Gard®. Submergence in distilled water only also was evaluated. Individual biorational product dips were used to treat twenty-five 10-cm-long coleus cuttings, each with 2 fully developed leaves. At 24 h before dipping, cuttings were infested with 15 *P. madeirensis* ranging from crawlers to adult females. Evaluations were completed immediately after the 30 s dipping and on the subsequent 3rd, 7th, and 14th days. Mealybugs were observed using a head-mounted magnifier (Donegan Optical, Lenexa, Kansas, USA) and considered dead if they exhibited no movement after being gently touched 3 times with a small moistened paint brush or had a shriveled, hollow, and blackened appearance (Hata et al. 1992). The threshold for an effective biorational treatment was 70% mortality. Tests were conducted for each post-dip d as a 4 × 5 randomized complete block design with 5 replicates.

Because the 1% Natur'l oil dip was the most effective biorational treatment with an acceptable level of phytotoxicity in the coleus cuttings, it was evaluated at 5 dipping durations: 1, 15, 30, 60, and 120 s. For each duration, thirty 10-cm-long coleus cuttings, each with 2 fully developed leaves were infested 24 h before testing with 15 *P. madeirensis* ranging from nymphs to adult females. Mealybug mortality was assessed as indicated previously. Evaluations followed a 2 × 5 randomized complete block design with 3 replicates.

EVALUATION OF NATUR'L OIL VERSUS MAVRIK AQUAFLOW® DIPS FOR CONTROLLING MADEIRA MEALYBUG NYMPHS ON COLEUS CUTTINGS

The evaluation of Natur'l oil versus Mavrik Aquaflow® occurred in 2015 under standard greenhouse conditions (25–27 °C and 14:10 h [L:D] photoperiod) at the University of Florida Entomology and Nematology Department. We sourced the *P. madeirensis* colony from the Mid-Florida Research and Education Center and maintained it primarily on coleus plants in a greenhouse under standard growing conditions. However, to periodically increase colony size, mealybug nymphs were reared on potato for at least 1 generation and then transferred to coleus plants. Dips consisted of 1% Natur'l oil, or the commercial standard 1.68 g (AI) per 100 L Mavrik Aquaflow® (22.3% tau-fluvalinate in water), and were compared for controlling mealybugs on coleus cuttings. Mavrik Aquaflow® was not tested for phytotoxicity because it is used routinely in the ornamental plant industry. At 24 h before testing, 15 first, second, or third instar *P. madeirensis* nymphs were transferred to 2 fully developed leaves on each 10-cm-long coleus cutting (Daane et al. 2012). Infested cuttings were agitated for 60 s in a 3 L plastic container filled with either Natur'l oil, Mavrik Aquaflow®, or distilled water. After treatment, individual cut-

Table 1. Phytotoxicity ratings for coleus cuttings agitated for 30 s in biorational product dips[1].

Dip %	Chlorosis	Chlorotic Flecking	Necrotic Flecking	Holes	Tip Chlorosis	Tip Necrosis	Total
			Natur'l oil				
0.1%	1.43 i	1.43 j	1.16 hi	1.11 ghi	1.02 f	1.04 fg	7.19
0.5%	1.52 ghi	1.51 ij	1.16 hi	1.09 hi	1.03 f	1.02 g	7.33
1.0%	1.54 ghi	1.54 jhi	1.21 fghi	1.08 i	1.02 f	1.21 bcd	7.59
1.5%	1.92 d	1.88 de	1.50 bc	1.18 fgh	1.06 cdef	1.09 efg	8.63
Water	1.49 i	1.49 j	1.17 hi	1.15 ghi	1.08 cde	1.04 g	7.40
						Mean	7.63
			Detergent				
0.1%	1.54 ghi	1.53 jhi	1.20 fghi	1.21 efg	1.06 cdef	1.16 cde	7.70
0.5%	1.65 fg	1.65 gh	1.41 cde	1.25 def	1.07 cdef	1.20 bcd	8.23
1.0%	1.89 de	1.85 de	1.61 ab	1.31 cde	1.14 ab	1.00 g	8.80
1.5%	1.90 d	1.86 de	1.65 a	1.36 bc	1.16 a	1.20 bcd	9.13
Water	1.50 hi	1.50 j	1.17 hi	1.19 fgh	1.03 ef	1.05 fg	7.44
						Mean	8.26
			Wetcit®				
0.1%	1.76 ef	1.71 fg	1.29 efg	1.41 bc	1.04 def	1.29 ab	8.49
0.5%	2.07 c	1.96 cd	1.43 cd	1.40 bc	1.07 cdef	1.25 bc	9.16
1.0%	2.29 b	2.13 b	1.61 ab	1.65 a	1.06 cdef	1.26 bc	10.00
1.5%	2.26 b	2.09 b	1.67 a	1.56 a	1.03 ef	1.30 ab	9.91
Water	1.84 de	1.82 ef	1.25 fgh	1.43 b	1.03 f	1.23 bc	8.60
						Mean	9.23
			Vapor Gard®				
0.1%	1.62 fgh	1.62 ghi	1.12 i	1.16 fghi	1.07 cdef	1.03 g	7.60
0.5%	1.81 de	1.79 ef	1.31 def	1.20 fgh	1.10 bc	1.03 fg	8.23
1.0%	2.19 bc	2.02 bc	1.52 bc	1.33 cd	1.09 bcd	1.13 def	9.28
1.5%	2.58 a	2.31 a	1.52 bc	1.31 cde	1.07 cdef	1.37 a	10.15
Water	1.53 ghi	1.53 ij	1.20 fgi	1.12 ghi	1.02 f	1.05 fg	7.45
						Mean	8.54
F	33	20.08	25.72	8.92	11.58	12.25	
df	12, 948	12, 948	12, 948	12, 948	12, 948	12, 948	
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	

[1]Means followed by the same letter within a treatment column are not significantly different ($P > 0.05$, Tukey-Kramer)

tings were inserted into a moist 5 × 5 × 3.8 cm rockwool block inside a separate 3 L plastic container. Individual containers for each dip were placed randomly on a greenhouse bench and maintained under the mist system for 2 wk using the same irrigation schedule as used for plant propagation. Two experienced observers independently counted the number of live mealybugs on each cutting after 1, 7, and 14 d. To avoid contaminating the newly emerged crawlers, viable ovisacs were removed from cuttings. Observations were obtained on 5 cuttings per treatment for each of the 3 treatments arranged in a randomized complete block design with 5 replicates.

STATISTICAL ANALYSIS

Mean coleus phytotoxicity levels and mealybug mortality were analyzed using the GLIMMIX procedure (SAS/STAT Version 9.3, SAS Institute, Inc., Cary, North Carolina, USA). This procedure fits binary outcomes and accounted for non-normality and non-homogeneous variances. Data for the symptomatic phytotoxicity ratings were totaled for each concentration of the biorational insecticides and distilled water to generate an overall rating. Differences between cumulative *P. madeirensis* percent mortality for the 4 most promising treatments and water were analyzed using Tukey-Kramer Least Squares Means for multiple comparisons (JMP® Pro 11, SAS Institute, Inc., Cary, North Carolina, USA). Mealybug mean survival over time after the 1% Natur'l oil, 1% Mavrik Aquaflow®, or water dip was compared using the same multiple comparison test. Differences in all analyses were considered significant at $P < 0.05$.

Results

The total level of phytotoxicity in the coleus cuttings was the sum of the ratings for each of the categories of damage (Table 1). Numerically lower total phytotoxicity occurred with the 0.1% Natur'l oil (7.19) and 0.1% Vapor Gard (7.60) dips, and the damage rating was similar for distilled water at 7.40 to 7.44. The 0.1% dish detergent dip had a rating of 7.70, and the rating for 0.1% Wetcit® dip was 8.49. Mealybug mortality was highest for 1% Natur'l oil and 0.1% Wetcit®, exceeding 90% within 14 d after a 30 s dip (Fig. 1). The 1% dish detergent and 0.1% Vapor Gard® dips were less effective. The distilled water dip also induced > 60% cumulative mortality of mealybugs. Because the 0.1% Wetcit® dip caused unacceptable phytotoxicity and 0.1% Natur'l oil dip had the lowest phytotoxicity rating, the 0.1% Natur'l oil dip was selected for further testing to control *P. madeirensis* life stages on coleus cuttings.

The 30, 60, and 120 s dipping of 1% Natur'l oil caused significantly higher cumulative mealybug mortality than 1 and 15 s dipping (Fig. 2). The 3 longer durations also killed the mealybugs sooner. Distilled water was a much less effective dip. Peak mealybug mortality at 14 d following the 30 s treatment was about 90% as in the previous test.

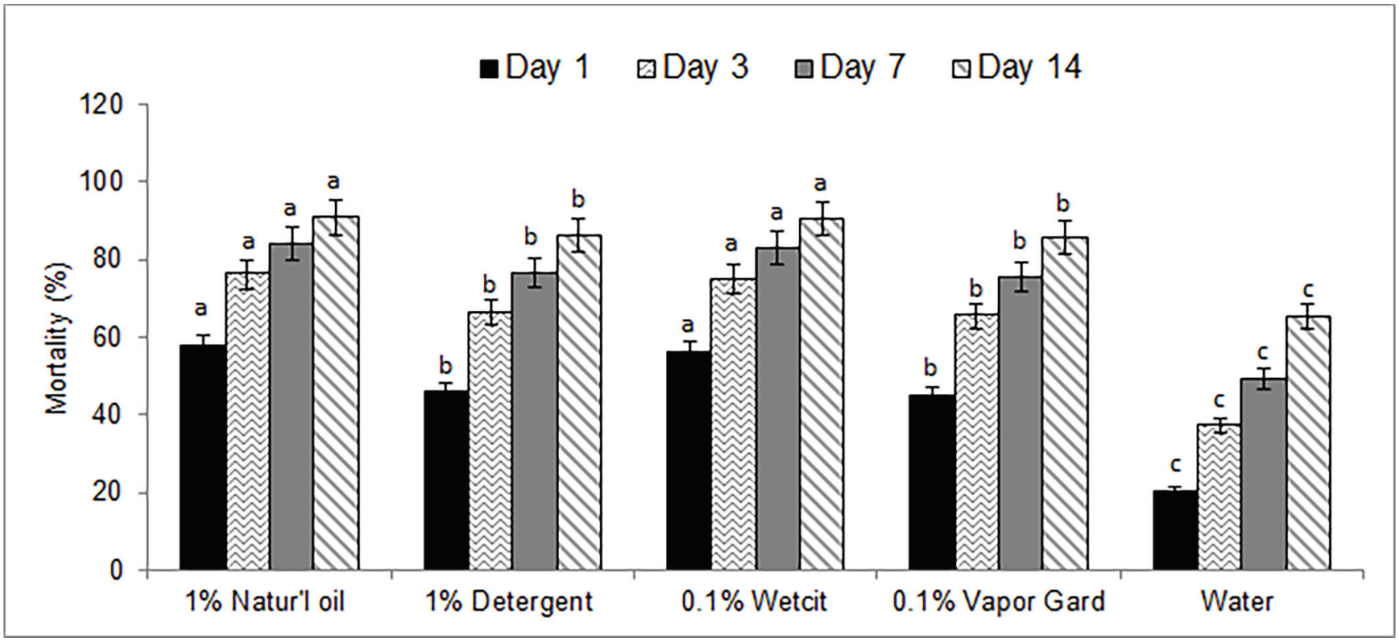

Fig 1. Cumulative mean (± SE) percent mortality of *Phenacoccus madeirensis* on d 1, 3, 7, and 14 resulting from 30 s biorational product dips and distilled water. Different letters indicate significant differences between treatments on the successive days (Tukey-Kramer least squares means for multiple comparisons, $P < 0.05$).

Comparing mealybug mortality caused by 60 s dipping of 1% Natur'l oil or 1% Mavrik Aquaflow®, statistically both products reduced the same number of nymphs per cutting to 4 in 1 d and virtually eliminated them within 14 d (Fig. 3). Additionally, the distilled water dip reduced the number of mealybugs by about 40% in 14 d.

Discussion

A 60 s dipping of 1% Natur'l oil was effective in virtually eliminating *P. madeirensis* nymphs from coleus cuttings within 14 d post-treatment without causing unacceptable phytotoxicity. Natur'l oil is a vegetable oil obtained from soybeans commonly used as a non-ionic surfactant

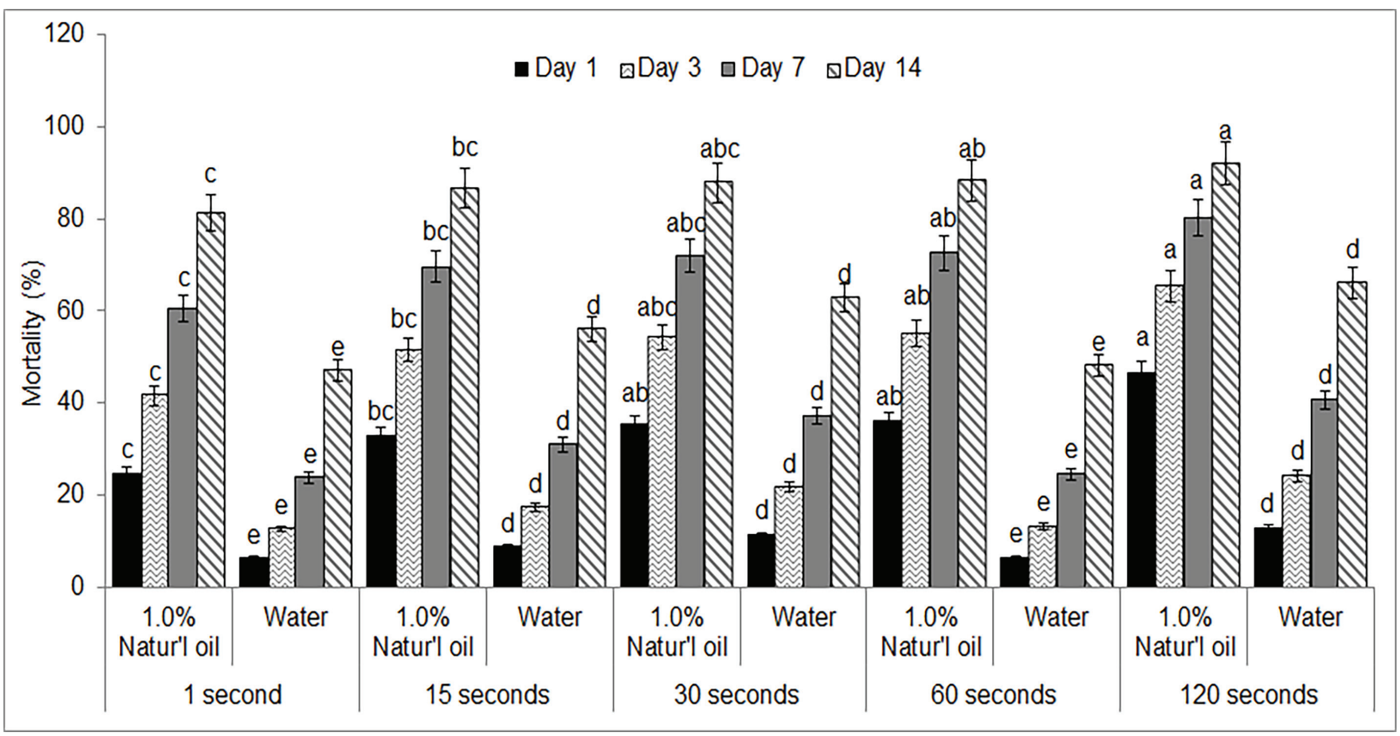

Fig 2. Cumulative mean (± SE) percent mortality of *Phenacoccus madeirensis* on d 1, 3, 7, and 14 resulting from a 1% Natur'l oil dip of 1, 15, 30, 60, or 120 s duration. Different letters indicate significant differences between treatment durations on the successive days (Tukey-Kramer least squares means for multiple comparisons, $P < 0.05$).

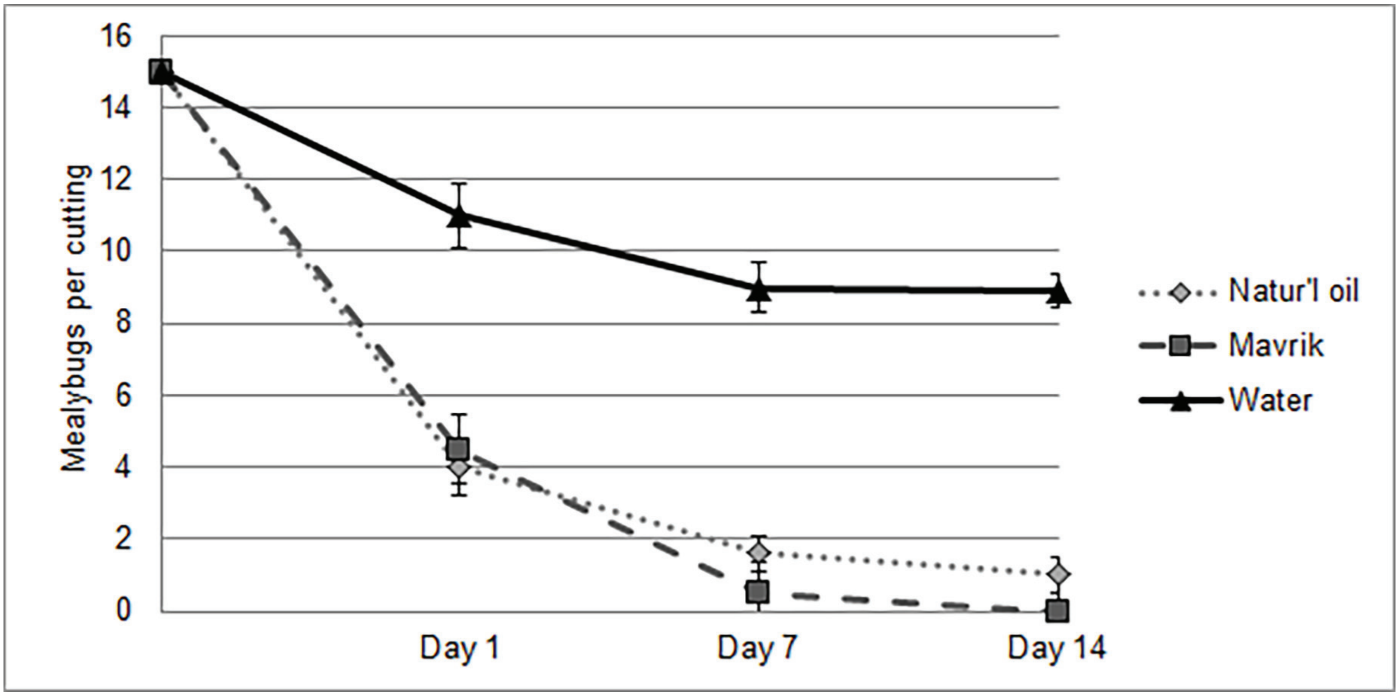

Fig 3. Mean number of *Phenacoccus madeirensis* on coleus cuttings at d 0, 1, 7, and 14 after cuttings were agitated for 60 s in a dip containing 1% Natur'l oil, 1%, Mavrik Aquaflow® (22.3% tau-fluvalinate in water), or distilled water.

for applying herbicides, fungicides, and insecticides. The insecticidal properties of Natur'l oil are well known, as it has been used effectively to control pests such as whiteflies and mites (Butler et al. 1993; Liu & Stansly 2000; Amer et al. 2001). Several vegetable oils, in addition to soybean oil, also are toxic to soft-bodied insects (Butler & Henneberry 1990; Pless et al. 1995).

Mavrik Aquaflow® (formulated at 1% in a 60 s dipping) similarly controlled *P. madeirensis* on coleus plants. Most mealybugs died within 7 d and none remained after 2 wk with this product. Osborne (1986) reported that a 60 s dipping of Mavrik Aquaflow® at the manufacturer's recommended rate consistently reduced *Phenacoccus solani* Ferris (Hemiptera: Pseudococcidae) populations by at least 80% on longevity spinach, *Gynura procumbens* (Lour.) Merrill (Asteraceae). This product contains a pyrethroid that has been used extensively in agriculture for many years even though it is highly toxic to parasitoids and predators (Ulber et al. 2010). Moreover, pyrethroids have induced resistance in various target insect pests, including mealybugs (Zalom et al. 2005).

Our study determined that Natur'l oil is as effective as Mavrik Aquaflow® for removing *P. madeirensis* nymphs from coleus cuttings and probably could be used in dips for controlling other insect pests on ornamental plants. Indeed, Natur'l oil could replace Mavrik Aquaflow® or be used in rotation to limit the development of insecticide resistance in *P. madeirensis* and related mealybug species. Although the ornamental plant industry has no standard methods for dipping coleus cuttings, we found that the effective concentration and duration of a Natur'l oil or Mavrik Aquaflow® dip needed to control *P. madeirensis* was similar, but Natur'l oil costs less ($35 per 3.8 L from Stoller USA, Houston, Texas, USA, versus $410 per 3.8 L from Forestry Distributing, Boulder, Colorado, USA) and is without risk to human health and the environment.

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