DEVELOPMENT AND EVALUATION OF BIORATIONAL DIPS FOR ORNAMENTAL CUTTINGS INFESTED WITH THE MADEIRA MEALYBUG, *PHENACOCCUS MADEIRENSIS* GREEN

By

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To my loving family and friends. Your unconditional love and support will always guide me.

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DEVELOPMENT AND EVALUATION OF BIORATIONAL DIPS FOR ORNAMENTAL CUTTINGS INFESTED WITH THE MADEIRA MEALYBUG, *PHENACOCCUS MADEIRENSIS* GREEN

By

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In order to prevent the spread of cryptic invasive pests, a model on-site biorational dip protocol was developed by evaluating the phytotoxicity and efficacy of Natur'l Oil (soybean oil), Wetcit™(alcohol ethoxylate), Publix Soap (nonylphenol ethoxylate), and Vapor Gard®(di-1-p-menthene) at varying concentrations on coleus cuttings infested with *Phenacoccus madeirensis* Green. Efficacy was achieved with 1.0% Natur'l Oil (76.09%) and 0.1% Wetcit™ (74.99%) by Day 3 and reached highest mortality by Day 14 with 1.0% Natur'l Oil (90.97%) and 0.1% Wetcit™ (90.47%). Six of the key foliage phytotoxicity ratings for 0.1% Wetcit™ were also higher than 1.0% Natur'l Oil: chlorosis, chlorotic flecking, necrotic flecking, holes, tip chlorosis, and tip necrosis. Subsequently, 1.0% Natur'l Oil was selected as the model dip treatment and compared to other Natur'l Oil concentrations for determining exposure time and host plant efficacy. Exposure time efficacy for 1.0% was attained by Day 7 with the 30 (71.81%), 60 (72.54%), and 120 (80.24%) second dip and reached highest mortality with the 30 (87.82%), 60 (88.21%), and 120 (92.00%) second dip by Day 14.Verbena efficacy was achieved by Day 7 for 1.0% (80.74%) and 1.5% (85.85%) and attained highest mortality by Day 14 with 1.0%

(80.74%) and 1.5% (85.85%). Mint efficacy for 1.0% (82.71%) and 1.5% (96.89%) was also reached by Day 7 but 1.5% (96.89%) had the highest mortality by Day 14. Overall, 1.0% Natur'l Oil as a 30 second dip was determined as the model on-site dip protocol for treating infested ornamental cuttings.

CHAPTER 1
LITERATURE REVIEW OF THE MADEIRA MEALYBUG (*PHENACOCCUS MADEIRENSIS* GREEN)

Ornamental Industry Overview

Nursery and greenhouse ornamental crops are integral to United States agriculture. The total value of sales generated from 50,784 farms devoted to floriculture, propagation, and sod production exceeds $16 billion (United States Department of Agriculture National Agricultural Statistics Service 2007). Plant production from propagation operations and floriculture crops are one of the most important components of the ornamental industry. Floriculture crops include bedding plants, garden plants, cut flowers, cut florist greens, foliage plants, and potted flowering plants whereas propagation operations refer to the production of cuttings, seedlings, liners, and plugs. The total value of United States sales for floriculture crops is approximately $6.5 billion while propagation operations generate $440 million (United States Department of Agriculture National Agricultural Statistics Service 2007). Among 47 states surveyed in the 2007 Census of Agriculture, the five leading floriculture crop states were California ($1.2 billion), Florida ($909 million), Michigan ($439 million), Texas ($326 million), and North Carolina ($260 million) while the top five propagation operation states were Florida ($91 million), California ($84 million), Washington ($29 million), Michigan ($28 million) and Colorado ($28 million).

Florida's warm weather and humid climate provides an ideal environment for ornamental crop production and sale. Although the ornamental industry is ranked fourth in Florida cash receipts, foliage and floriculture still create a sizeable share amounting $695 million in comparison to vegetables and melons ($1.7 billion) and citrus ($1.5 billion) (Florida Department of Agriculture and Consumer Services 2013). Approximately 1,750 farms; 9,958 open acres of production area; and 264 million square feet of greenhouse or shaded production area are

devoted to Florida propagation operations and floriculture crops (United States Department of Agriculture National Agricultural Statistics Service 2007). For floriculture sales, Florida generates 21% of United States sales estimated at $3.94 billion (Florida Department of Agriculture and Consumer Services 2013). Additionally, Florida also creates 23% of the United States propagation sales valued at $355 million (Florida Department of Agriculture and Consumer Services 2013). Overall, Florida produces 72% of United States foliage plant production sales worth $433 million and is recognized as the most profitable foliage plant production state in the United States (Florida Department of Agriculture and Consumer Services 2013).

Internal, inter-regional, and international trade of all nursery products contribute to the total whole value of ornamental sales in Florida. Results from Hodges (2011) indicate that 67% of customer sales occurred within the state. Inter-regional sales to states such as North Carolina (11.5%), Connecticut (4.8%), Georgia (2.3%), and Texas (2.1%) also contribute towards Florida's nursery product sales while international trade to Canada (0.2%) and Europe (0.1%) provide the smallest contribution. Nursery products commonly produced or traded in Florida include tropical foliage (31%), deciduous and flowering trees (31%), miscellaneous plant types (10%), flowering potted plants (8%), and propagated liners, cuttings, and plugs (7%) (Hodges 2011). Results from Hodges (2011) which surveyed 556 Florida growers in 2008 showed that the purchasing of propagation materials, such as cuttings, seedlings, whips, grafts, and liners mostly occurred within the state of Florida (75%); however substantial purchases were made from California (10%), Oregon (3.5%), Washington (1.2%), Georgia (1.1%), and Costa Rica (2.7%) and brought to Florida. Other international purchases and shipments to Florida nursery growers involved vendors from the Bahamas, Dominican Republic, Brazil, Belize, Mexico, Canada,

Belgium, Germany, Netherlands, China, Australia, and New Zealand. Additionally, the Florida Department of Agriculture and Consumer Services (2013) reported nursery and greenhouse product import and export shipping routes to Japan, Netherlands, and Sweden.

Impact of Invasive Species on Ornamental Plants

The National Invasive Species Council (2001) defines an invasive species as "a species that is not native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health". However, another definition described by Hodges and Stocks (2010) defines an invasive species as "any species that competes with humans by consuming or damaging food, fiber, or other materials intended for human consumption or use". Nevertheless, the introduction of invasive species threatens the United States ornamental industry. Although further research is needed to determine invasive pest damage costs to growers within Florida and the United States, Oetting et al. (2006) indicated that Georgia suffered major ornamental pest damage costs from scales and mealybugs ($20 million), mites ($22.3 million), thrips ($7.5 million), whiteflies ($4.2 million), aphids ($2 million), and caterpillars ($1.3 million). Hodges et al. (1998) also reported that Florida growers also target mites, aphids, whiteflies, scales and mealybugs, and caterpillars. Overall, the most detrimental Florida ornamental pests include hemipterans, thrips, and mites (Table 1-1) (Buss 1993, Frank and Thomas 2004).

Source regions for non-native species traveling to Florida include the Caribbean, Central America, and South America and as much as 24% of arthropods entered Florida as plant cargo contaminants (Frank and Thomas 2004, Jenkins et al. 2014). In Florida, up to two new non-native arthropods have been reported every month (Thomas 2004, Dr. Amanda Hodges, personal communication). Increased movement of plant material heightened by the relaxation of trade barriers contribute to the increasing immigration rate of non-native arthropods from the Old

World to the New World (Pimentel et al. 2000, Dr. Amy Roda, personal communication). Additional contributing factors that may also influence the rate of invasive pest immigration include an increasing human population, rapid movement of people and materials, alteration of the environment, and climate change (Pimentel et al. 2000, Frank and Thomas 2004, Devitt et al. 2012).

On a national scale, Pimentel et al. (2005) estimated 4,500 arthropod species and nearly 100 aquatic invertebrate species were introduced to the United States. Approximately 95% of these introductions were accidental and facilitated by contaminated plants, soil, or water ballast from ships and other human- mediated transport vectors, such as airplanes, trains, and cars (Pimentel et al. 2000). Exact national or state figures on the number of non-native species or invasive pests immigrating as plant cargo contaminants are unknown since the United States Department of Agriculture, Animal and Plant Health Inspection Services inspect only 2% of imported plant stock (Brasier 2008). However, at United States ports of entry and border crossings, the Port Information Network (PIN) database records invasive pest interceptions on plant stocks during inspections. McCullough et al. (2006) evaluated PIN from 1984-2000 and found 73% to 84% of interceptions were insects from the orders Hemiptera, Lepidoptera, and Diptera. Most invasive pest interceptions were made while inspecting baggage (62%), cargo (30%) and plant propagated material (7%) and occurred at airports (73%), United States-Mexico land border crossings (13%), and marine ports (9%). Similarly, Jenkins et al. (2014) reported 77% of intercepted arthropods entering Puerto Rico and the United States Virgin Islands by freight or luggage originating within the Caribbean. The following orders were commonly intercepted during inspection: Hemiptera (52%), Diptera (16%), Coleoptera (10%), Lepidoptera (8%), Thysanoptera (5%), Acari (4%), and Hymenoptera (2%).

Inspections for invasive species are long and tedious as invasive species are difficult to detect due to their appearance, biology, and behavior (Jenkins et al. 2014, McCullough et al. 2006). Adult and immature specimen screenings take additional time since primary or secondary screening characteristics may be missing or difficult to interpret. Genetalia dissection under a dissecting microscope may be necessary for making a final identification on adult or immature specimens. Extensive dissecting microscope use may also be required for egg or small immature final identification.

Model Invasive Pest of Ornamental Plants

Phenacoccus madeirensis is an invasive cosmopolitan pest that is cryptic, polyphagous in nature, and one of the most difficult to manage with synthetic insecticides (Chong 2005, Ludwig 2009). *Phenacoccus madeirensis* is considered a major plant pest particularly throughout the southeastern United States (Miller et al. 2002, Chong 2005). More than 60 plant families include known hosts for *P. madeirensis,* including several important agricultural and ornamental commodities like tomatoes (*Solanum lycopersicum*), soybeans (*Glycine max*), citrus (*Citrus* sp.), hibiscus (*Hibiscus* sp.), chrysanthemums (*Chrysanthemum* sp.) and coleus (*Solenostemon* sp.) (Table 1-2).

Adult female mealybugs are traditionally used to identify mealybugs (Williams and Granara de Willink 1992). The adult *P. madeirensis* female is wingless, oval, elongate, flattened dorsoventrally, and 2-3.5mm (0.08-0.14in) in length (Green 1923). When squashed, the body exudes green fluid. Thick white mealy wax covers the gray body and red legs. Females have bare intersegmental areas on the thorax that form a pair of dark longitudinal lines on the dorsum. Additionally, females have eighteen pairs of lateral wax filaments that encompass the body with the posterior pair of wax filaments projecting furthest from the body but less than the entire length of its body. Eleven days after mating, gravid females can oviposit up to 530 eggs (Chong

et al. 2003). Female longevity typically decreases as temperature increases which accounts for ovipositing females living up to 19 days and virgin females surviving for 38 days in controlled, moderate temperatures (Longo et al. 1995, Chong et al. 2003).

Plant damage caused by *P. madeirensis* is similar to other mealybug species and can be severe during high infestation. Crawlers appear to collectively feed on the host plant with piercing-sucking mouthparts and cause dimpling and yellowing. Feeding leads to serious direct damage on ornamental crops such as premature leaf drop, curling, deformation, and stem and growth shoot infestation resulting in retarded plant growth. However, honeydew excretion inflicts the most aesthetic damage on host plants as black sooty mold develops from honeydew droplets left on the host plant. Honeydew production also attracts nearby ants which provide predator protection in exchange for honeydew as a food source (Bethke 2009).

Biology

Sexual dimorphism and behavioral differences are apparent during the life cycle *of P. madeirensis*. Newly emerged first instars or crawlers appear yellow, lack a white mealy wax on the body, and are 0.5 to 0.75mm (0.02in-0.03in) in length (Green 1923, Townsend et al. 2000). Crawlers undergo a wandering stage where they disperse from the ovisac either by crawling or catching the wind. Crawlers roam around the host plant trunk, twigs, leaves, and fruit in search for an ideal feeding site. Crawlers feed on the host plant using their piercing-sucking mouthparts and are commonly found feeding on the undersides of leaves or tender shoots. Honeydew production begins shortly after feeding. Through each successive instar, honeydew excretion increases as nymph mobility decreases (Sinacori 1995).

Second instar body color and behavior are used to determine gender (Townsend 2000). Both male and female nymphs continue to feed and exude honeydew on the host plant while developing a thin white mealy wax on the body which varies in length from 1.0-1.5mm (0.04-

0.06in). Males turn pale to bright pink and construct a white narrow filamentous cocoon on the undersides of leaves in which they encase themselves and molt three times before becoming an adult male (Sinacori 1995, Williams 1985, Townsend et al. 2000). Females remain yellow, feed collectively, and become sessile on the host plant. In addition to crawlers, male and female second instars also overwinter (Sinacori 1995).

Gender is also distinguished by third and fourth instar appearance and behavior. Third instar males remain pale to bright pink in body color and are fully enclosed within their cocoon as they enter the pre-pupal stage. In contrast, the third instar female body color turns gray and develops a thicker layer of white mealy wax. Female body length also expands and ranges between 1.75-2mm (0.07-0.08in). Additionally, females become increasingly sessile and start feeding alone along leaf midribs. In the fourth instar, females reach reproductive maturity as wingless adults while males enter the pupal stage within their cocoons (Townsend et al. 2000). Adult females release the sex pheromone trans-1R, 3R-chrysanthemyl R-2 methylbutanoate to eventually mate with newly emerged adult males (Ho et al. 2011).

Males in the fifth instar emerge from their cocoons as reproductive, winged adults and search to mate with an adult female. Males appear gnat-like with a single pair of wings and have vestigial mouthparts; stout, truncate genital capsules; a thin white mealy wax covering their red-brown body; and a pair of white posterior waxy filaments protruding from the body but less than its entire length. Adult males immediately search and mate with adult females as they only live for 3-6 days due to their vestigial mouthparts (Sinacori 1995, Ho et al. 2011, Chong et al. 2003).

Gravid females oviposit up to 530 eggs within a white filamentous ovisac and die immediately afterwards (Chong et al. 2003). Ovisacs contain a cluster of yellow eggs that turn darker over time (Longo et al. 1995). All eggs are oval in shape and less than 0.5mm (0.02in) in

length. Fecundity generally decreases as temperature increases which accounts for females ovipositing as few as 67 eggs and up to 530 eggs depending on the temperature (Yeh et al. 2006, Chong et al. 2003).

Taxonomy

Most scientific literature references *P. madeirensis* as indigenous to the neotropics (Williams and Granara de Willink 1992). However, Williams (1987) suggests that *P. madeirensis* is native to the Nearctic area of northern Mexico due to his work on the taxonomic revision of *Phenacoccus*. Until the late 1980s, *P. madeirensis* was frequently mistaken for *P. gossypii*, since taxonomic descriptions of *Phenacoccus* species previously relied on Myers (1928), Ferris (1950) and McKenzie (1967) (Chong 2005) . The revised taxonomic description of *P. madeirensis* and *P. gossypii* by Williams (1987) ultimately clarified the distribution of both species within the United States. As a result, *P. madeirensis* became a commonly recognized and encountered pest in the southern United States, whereas *P. gossypii* became a rare and localized pest within Mexico, California, Texas and Florida.

At the field identification level, *P. madeirensis* cannot be differentiated from the native Mexican mealybug, *Phenacoccus gossypii* Townsend and Cockerell, and the franseria mealybug, *Phenacoccus franseriae* Ferris. Both mealybugs are commonly intercepted at U.S. ports of entry from Mexico (Williams 1987, Williams and Watson 1988). Several identification characteristics viewed by slide mounting are used for final identification. On the thorax, *P. madeirensis* lacks multilocular disk pores from the mediolateral areas while *P. gossypii* has dorsal mediolateral multilocular disk pores. *Phenacoccus franseriae* only has dorsomedial cerarrii on abdominal segments VI and VII. *Phenacoccus madeirensis* also can be distinguished by its lanceolate, tiny cerarian setae and dorsal setae (Williams 1987, Williams & Watson 1988).

Distribution

Although native to the New World, the first record of *P. madeirensis* was from the coast of Africa in Madeira Island (Green 1923). Williams and Granara de Willink (1992) inferred that *P. madeirensis* was introduced to Africa through the sale and distribution of infested host plants on Atlantic triangular slave trade. Crawler infestation on host plants has been difficult to detect since crawlers are small, pale, and evade detection by hiding on the undersides of leaves or burrowing within plant crevices or nodes. Additionally, crawlers do not readily attract ants or induce the growth of black sooty mold since they exude minimal honeydew.

During the late 1980s to early 1990s, the distribution of *P. madeirensis* included temperate to tropical regions within North America, South America, the Caribbean and Africa. However, *P. madeirensis* spread to the Mediterranean, Southeast Asia, Oceania, and Pacific Islands as the international trade and transportation of infested host plants expanded from more tropical to temperate regions around the world (Table 1-3). *Phenacoccus madeirensis* eventually became recognized as a cosmopolitan pest. The most current publications cite the spread of *P. madeirensis* in Europe. Muniappan (2011) and Papadopoulou and Chryssohoides (2012) reported new *P. madeirensis* populations from Thailand and Greece.

Chemical Control Methods

Florida greenhouse and nursery growers undergo immense pressure to produce high quality nursery products in a warm, humid climate under high invasive pest pressure due to international trade and transportation. As a result, the most prevalent control method is the use of synthetic pesticides (Hodges 2011). Nearly 98% of Florida growers use at least one pesticide (Hodges et al. 1998) (Table 1-5). The Florida statewide average number of pesticides used per nursery was 5.8 with no indication of using different modes of action. South Florida scored higher than the statewide average with regard to treating bedding plants, floriculture crops, and

all crops for larger firms. The high pesticide use may be influenced by the zero tolerance of any mealybug species on shipped nursery stock to California and other southern states (Dr. Amy Roda, personal communication).

Mealybug biology and behavior impact the efficacy, type, and application of current synthetic insecticides. Crawlers generally lack a waxy or filamentous covering which makes them the most susceptible life stage to contact-based synthetic insecticides (Buss and Turner 1993). However, crawlers can hide in crevices which may be an issue with low residual pesticides and foliage spray applications (Dr. Amy Roda, personal communication). Nymphs gradually increase their protective covering through successive instars and become subsequently harder to control with contact-based synthetic insecticides as their protective covering grows thicker. Adults are naturally protected since they are well covered with smooth or filamentous wax. Ovipositing mealybug species such as *P. madeirensis* protect their eggs in a waxy, filamentous ovisac which prevents direct contact with synthetic insecticides. Overall, each life stage moves to, feeds on, or hides in parts of the plant that may be difficult for contact-based synthetic pesticides to reach such as the undersides of leaves, notches created by plant nodes or buds on the stems, or crevices on the leaves, fruit, or stems (Hollingsworth and Hamnett 2009).

Insecticidal dip treatments are considered a viable option for treating infested foliage cuttings. A foliage cutting is an excised stem and leaf that can be transplanted into a suitable growing medium for producing new roots, stems, and leaves independent from the parent plant. Conover and Poole (1970) and Osborne (1986) described why foliage cuttings cannot be reliably treated with current synthetic insecticide application practices: (1) root application of systemic insecticides is relatively ineffective since cuttings are rootless; (2) when cuttings are placed under mist for root stimulation and moisture, low volume spray application does not ensure

adequate coverage; and (3) high-volume spray application can uproot the cuttings from the pot (Osborne 1986).

A limited number of studies evaluated dipping as an effective control for pests on ornamental cuttings. Only three studies directly assessed synthetic dip treatment efficacy on mealybugs and scales infesting propagation commodities (Osborne 1986, Hata et al. 1992 and Hansen et al. 1992). Synthetic dip treatments include the use of insecticides in the following classes: organophosphates, carbamates, and pyrethroids. The most commonly tested synthetic insecticide dip treatment for ornamental cuttings or flowers infested with mealybugs or scales is a type of pyrethroid called fluvalinate.

Osborne (1986) was the first to use fluvalinate as a dip treatment for ornamental pests. The solanum mealybug, *Phenacoccus solani*, was one of several pest species tested on *Hoya carnosa* (L. f.) and *Gynura procumbens* (Lour.) cuttings. The first dip treatment test for *P. solani* had two replicates. Approximately 22 cuttings of *Hoya carnosa* infested with a density of 19 *P. solani* per cutting were assigned at random to either a control (water dip for 1 minute) or one minute dip in the recommended rate of fluvalinate (1.68g per 100 liters of water). Mortality was assessed 3, 7, and 14 days after treatment. Results from the first dip treatment test showed at least 70% *P. solani* mortality 14 days after treatment.

The second dip treatment test for *P. solani* also had two replicates. Ten cuttings of *Gynura procumbens* infested with a density of 30 *P. solani* per cutting were randomly assigned to four different treatments: 1) control (twelve minute dip in water and placed in water filled vials to root), 2) one minute dip in the recommended rate of fluvalinate and placed in water-filled vials, 3) two minute dip in the recommended rate of fluvalinate and placed in water filled vials, and 4) one minute dip in the recommended rate of fluvalinate, potted in soil, and placed under

mist that actuated every 30 minutes for 15 seconds from 0800 to 2000 hours. Mortality was assessed 3, 7, and 14 days after treatment. Fluvalinate-treated cuttings had significantly fewer mealybugs, averaging 8.3 *P. solani* in comparison to 58.8 on the control cuttings. No significant difference was found between the different dipping times for fluvalinate treated cuttings and no phytotoxicity was reported with fluvalinate. However, fluvalinate treated cuttings showed longer root development than the water control.

Hata et al. (1986) went a step further and investigated the potential synergistic effect of fluvalinate with insecticidal soap (0.1g per liter of water + 9.6mLper liter of water by volume) as a postharvest dip treatment for harvest sprayed and non-harvest sprayed red ginger flowers. Harvest sprayed red ginger flowers were treated with the recommended rate for chlorpyrifos and a spreader-thicker, Triton B-1956, mixed together and applied until runoff. At foliage harvest, the plants were sprayed at 347 liters per hectare at two week intervals totaling six applications.

All red ginger flowers in the Hata et al. (1986) study were infested with several different ornamental mealybug pests, including the citrus mealybug, longtailed mealybug, and the obscure mealybug, *Pseudococcus affinis* (Maskell). All sprayed and non-sprayed flowers harvested from the field were divided into two groups. Half were treated with water (control) and half were dipped in the postharvest dip treatment. Mortality was assessed 24 and 48 hours post-treatment for flowers that were harvest sprayed and dipped and flowers that were only dipped. Results showed 0% mean percentage of flowers infested with mealybugs for sprayed and dipped flowers while only dipped flowers showed 3% to 17% mealybugs present.

Hansen et al. (1992) tested and compared the synergistic effect of fluvalinate and cyfluthrin mixed with insecticidal soap. The maximum label concentrations for fluvalinate (0.5mL per 100 liters of water), cyfluthrin (0.3mL per 100 liters of water), and insecticidal soap

(20mL solution) were used both separately and in combination with soap as postharvest dip treatments for controlling the coconut mealybug, *Nipaecoccus nipae* (Maskell). Two cuttings of red ginger flowers were infested with either nymphs or adults and randomly assigned to a dip treatment. After counting the number of mealybugs present on each cutting, the infested two flowers were submerged in each dip treatment for 0, 1, 5, and 15 minutes.

Adult and nymph mortality were assessed a day after treatment and varied greatly. Flowers dipped for 0 minutes in all treatments showed less than 14% adult mortality and 20% nymph mortality. Flowers treated with fluvalinate for 1 minute showed the highest nymph mortality (63.4%) compared to all other test times for fluvalinate. For the other treatments, highest nymph mortality was more than 97% as a 15 minute dip. Highest adult mortality for fluvalinate (94.2%) and fluvalinate with insecticidal soap (94.5%) occurred during the 1 minute dip. Cyfluthrin with insecticidal soap achieved the overall highest adult mortality as a 15 minute dip (98.4%) compared to all other treatments at the same dip time.

Overall, Osborne (1986), Hata et al. (1992) and Hansen et al. (1992) indicated fluvalinate as an effective mealybug dip treatment. However, the current use of fluvalinate is limited due to environmental and worker health issues. The United States Environmental Protection Agency classifies fluvalinate as a moderately toxic compound in EPA toxicity class II (Extension Toxicology Network 1996). Fluvalinate is a broad spectrum insecticide known to be highly toxic to fish, aquatic invertebrates, and non-target insects, such as beneficial arthropods used in IPM programs (United States Environmental Protection Agency 1986). Additionally, workers have reported coughing, sneezing, throat irritation, itching, or burning sensations on the arms or face with or without a rash, headache or nausea (United States Environmental Protection Agency 1986). As a result, fluvalinate has been and continues to be a Restricted Use Pesticide that only

certified applicators are legally allowed to purchase and apply. The alternative synthetic insecticide approved for use as an ornamental dip for cuttings is tau-fluvalinate, also known as (2R) fluvalinate. Tau-fluvalinate is also a broad-spectrum insecticide with restricted use (United States Environmental Protection Agency 2005).

Biorational Control Methods

Biorational insecticides, such as oils, surfactants, and anti-transpirants, may be viable dip treatment alternatives for controlling mealybugs and scales on ornamental cuttings. Stansly et al. (1996) defined biorational insecticides as "any type of insecticide active against target pest populations, relatively innocuous to non-target organisms, and therefore non-disruptive to biological control methods". A wide variety of insecticides with different modes of action can fit this definition and therefore are considered biorational insecticides. Schuster and Stansly (2003) listed the following as biorational insecticides: chemical controls, such as oils, surfactants, neem, *Bacillus thuringiensis* products, and new chemical classes, such as insect growth regulators (pyriproxyfen, buprofezin, tebufenozide, novaluron) and miscellaneous insecticides (pymetrozine, spinosad, indoxacarb, emamectin, benzoate, rynaxypyr, metaflumizone, spinetoram, flubendiamide, pyridalyl). In particular, oils and surfactants are known to be efficacious against ornamental and agricultural pests. Anti-transpirants currently are being explored for potential insecticidal activity.

Oils

Oils were one of the first types of chemicals used to control agricultural pests (Liu and Stansly 2000). For over 100 years, resistance to oils has never been recorded and this may be due in part to several different modes of action. Capinera (2008) lists the following modes of action for oils: mortality by starvation when oils prevent plant pests from using their piercing-sucking mouthparts, death by suffocation or desiccation when oils halt respiration via spiracle blockage,

or toxicity from muscle or nerve damage caused by oils penetrating and degrading the tracheae. Overall, oils have very short residual activity which is ideal when used in conjunction with biological controls. The most important types of oil used for insecticides today include narrow range horticultural oil, essential oil, and vegetable oil.

Both narrow range horticultural oil and essential oils are efficacious, cost-effective controls for a variety of plant pests but easily can cause phytotoxicity on agricultural and ornamental products, thus reducing their marketability. Narrow range horticultural oils are made of highly refined petroleum oil, while essential oils are composed of hydrophobic liquids containing volatile aromatic compounds from plants that are typically extracted by distillation (Capinera 2008, Hollingsworth and Hamnet 2009). Use of narrow range horticultural oil requires vigilant care and a delicate balance between application rate and plant management, since phytotoxicity has been reported on plants that were weakened or under moisture stress (Liu and Stansly 2000, Miller 1989, Capinera 2008). Phytotoxicity damage also has been documented on herbaceous and foliage plant material sprayed with limonene or other essential oils known to be effective against mealybugs and scales (Isman 1999, Isman 2000, Ibrahim et al 2001, Hollingsworth 2005, Cloyd et al. 2009).

In comparison to narrow range horticultural oils and essential oils, vegetable oils consist of extracted triglycerides from plants (Sharma and Mudhoo 2011). Vegetable oils, such as soybean oil and cotton seed oil, differ from narrow range horticultural oil and essential oils since they tend to show only slight phytotoxicity. Soybean oil and cotton seed oil inflict minimal phytotoxicity on collards and tomatoes infested with whiteflies, and are known to perform as well if not better than horticultural oils (Liu and Stansly 2000). Several studies reported only slight phytotoxicity caused by cotton seed oil or soybean oil on agricultural or ornamental plants

(Rock and Crabtree 1987, Lancaster et al. 1999). Additionally, Pless et al. (1995) recommended soybean oil as an effective dip and spray treatment for controlling plant feeding pests like San Jose scale, terrapin scale, and European red mite. Overall, vegetable oils tend to provide good control on agricultural pests with minimal phytotoxicity, thus showing further promise as dip treatments for ornamental cuttings infested with plant feeding pests like *P. madeirensis*.

Soaps and Surfactants

Surfactants and soaps are a type of chemical adjuvant meant to reduce the surface tension of water, thereby enhancing the biological activity of pesticides by modifying pesticide spray droplet size, retention, and spreading on leaf surfaces (Katagi 2008). Various types of surfactants are derived from plants and petroleum oils which can be further modified into different molecular weights or ionic character.

The chemical structures of typical surfactants used during a pesticide application include anionic, cationic, and non-ionic surfactants. Non-ionic surfactants with a polyethoxy chain as a hydrophilic part are the most popular for pesticide use to date. Examples of non-ionic surfactants also commonly found in household cleaning products include: alcohol ethoxylate, octylphenoxy ethoxylate, alkylphenoxy ethoxylate, sorbitan alkylate, and novel silicone derivatives (Katagi 2008).

Historically, surfactants have been used as wetting, spreading, emulsifying, or sticking agents to improve the effectiveness and coverage of many pesticides (Liu and Stansly 2000). As such, further research is needed to determine the surfactant mode of action on insects. Only Coret and Chamel (1995) reported the non-ionic surfactant mode of action on plant cuticles.

Nevertheless, non-ionic surfactant insecticidal activity has been observed. Several decades of research report insecticidal effects of surfactants on ornamental and agricultural pests (Liu and Stansly 2000, Imail et al. 1994, Davidson et al. 1991, Hesler and Plapp 1986,

Tattersfield and Gimingham 1927, Wolfenbarger et al. 1967, Imail and Tsuchiya 1995, Cory and Langford 1935). Select growers near Apopka, FL have recently used dish detergents as cheap cost-effective insecticides for controlling ornamental pests (Dr. Lance Osborne, personal communication).

Antitranspirants

Antitranspirants are chemicals which create a physical or physiological barrier capable of reducing transpiration and therefore water loss when applied to plant foliage (Davenport et al. 1969). Chemicals used to create a physical barrier include spray emulsions of latex, wax, or acrylic which form a film over the leaf surface and reduce water loss (Davenport et al. 1969). Physiological barriers involve chemicals that act as plant growth regulators by closing the stomata and inhibiting plant growth (Davenport et al. 1969).

Plant growth inhibition has been extensively reported after antitranspirant application for preventing water loss (Gale and Hagan 1966, Rowan 1988, Davenport et al. 1969, McConnel 1985, Mmbaga and Sheng 2002). Insecticidal effects of antitranspirants also have been observed, although the mode of action for insecticidal antitranspirants has not been described in the scientific literature (French 1988). Additional efficacy studies on ornamental pests are needed to evaluate antitranspirants as viable biorational insecticides.

From a nursery manager standpoint, there are several advantages to using biorational insecticides, such as soaps, surfactants, oils, and anti-transpirants: (1) safety to human and environmental health, (2) apparent lack of resistance mechanisms among insects and mites, (3) reliable efficacy on other important plant feeding ornamental pests such as the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring (4) relatively low cost with no applicator certification required (5) compatibility with using biological controls within an integrated pest management program, and (6) inexpensive to purchase (Butler et al. 1993, Stansly et al. 2006,

Chapman 1967, Davidson et al. 1991, Liu and Stansly 1995, Liu and Stansly 2000, Agnello et al. 1994, Pless et al. 1995).

Research Objectives

Propagative horticultural products such as cuttings are highly profitable for the Florida ornamental industry. Ornamental cuttings are constantly being imported and exported among the southeastern states and throughout the world. The likelihood of invasive pests evading detection on plant cargo or being resistant to postharvest pesticides is high but oftentimes mitigated since many countries and states have a zero tolerance for mealybugs and will refuse entry of shipments and commodities if a single pest is found (Dr. Amy Roda, personal communication). As a result, nursery growers need a safe, effective, easy to implement, and low cost application method and treatment to prevent invasive species from entering their greenhouses and nurseries.

Using insecticides as a dip treatment is an effective application method in comparison to spraying and systemic insecticide use for cuttings. However, further research is needed on utilizing dips as a treatment method for infested ornamental cuttings. From the late 1980s to mid-1990s, fluvalinate was the most commonly tested dip treatment until the Environmental Protection Agency labeled fluvalinate as a restricted use pesticide. Subsequently biorational dip treatments such as oils, surfactants, and anti-transpirants, show promising potential as a cost effective, safe, and efficacious treatment for ornamental pests infesting imported cuttings.

Overall, infested host plant sale and distribution between states or across continents on airplanes, ships, and trucks successfully contribute to the dispersal and establishment of invasive species outside of greenhouse conditions. Further research on this invasive pathway requires the use of a model ornamental invasive pest to assess overall efficacy of biorationals as viable dip treatment for controlling infested cuttings. In this study, the Madeira mealybug, *Phenacoccus madeirensis* Green (Hemiptera: Pseudococcidae), was used as the model ornamental plant pest as

it is already established in Florida but has traveled worldwide as an invasive cryptic species. Additionally, *P. madeirensis* is an extensively studied invasive ornamental pest that is difficult to treat with synthetic insecticides and can easily evade detection during plant inspection. For the purposes of this study, *P. madeirensis* was used to accomplish the following research objectives:

1. Develop a model biorational dip treatment by assessing phytotoxicity and subsequent biorational dip treatment efficacy on coleus cuttings infested with *P. madeirensis*.
2. Evaluate the model biorational dip treatment at different exposure times, rates, and on three ornamental cuttings infested with *P. madeirensis*.

Table 1-1. Invasive ornamental pests encountered in Florida (Frank and Thomas 2004).

Pest Group	Scientific Name	Common Name	Origin
Aphids	*Aphis gossypii* Glover	Melon aphid	Eurasia
	Myzus persicae (Sulzer)	Green peach aphid	Asia
Hard and Soft Scales	*Aulacaspis yasumatsui* Takagi	Cycad aulacaspis scale	Asia
	Bemisia tabaci Gennadius	Sweetpotato whitefly	Asia
	Coccus hesperidum L.	Brown soft scale	Asia
	Pseudaulacaspis cockerelli (Cooley)	False oleander scale	Asia
Mealybugs	*Maconellicoccus hirsutus* (Green)	Pink hibiscus mealybug	Asia
	Planococcus citri (Risso)	Citrus mealybug	Asia
Mites	*Tetranychus urticae* Koch	Two spotted spider mite	Europe
Thrips	*Frankliniella occidentalis* (Pergande)	Western flower thrips	Western United States
	Scirtothrips dorsalis (Hood)	Chilli thrips	Asia
	Thrips palmi Karny	Melon thrips	Asia
Whiteflies	*Aleurodicus dugesii* Cockerell	Giant whitefly	Mexico
	Bemisia argentifolii Bellow & Perring	Silverleaf whitefly	Middle East
	Dialeurodes citri (Ashmead)	Citrus whitefly	Asia
	Singhiella simplex (Singh)	Fig or ficus whitefly	Asia

Table 1-2. Reported host plants of *Phenacoccus madeirensis*.

Family	Scientific Name	Common Name	Reference
Acanthaceae	*Acanthus mollis*	Bear's Breech (Oyster Plant)	Ben-Dov 2004; Sinacori 1995
	Aphelandra	Aphelandra	Stocks 2012
	Crossandra infundibuliformis	Crossandra (Firecraker Flower, Kanakambara)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Dicliptera sexangularis	Sixangle Foldwing	Stocks 2012
	Eranthemum pulchellum	Blue Sage	Stocks 2012
	Hemigraphis alternata	Redivy (Red Ivy, Red Flame Ivy)	Stocks 2012
	Hemigraphis repanda	Dragon flame	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Hypoestes phyllostachya	Polka Dot Plant	Stocks 2012
	Justicia pectoralis	Freshcut (Chapantye, Zeb Chapantye, Carpintero, Te Criollo, Curia, Death-Angel, Masha-Hari)	Stocks 2012
	Justicia spicigera	Mexican Honeysuckle	Stocks 2012
	Odontonema strictum	Firespike (Cardinal Guard, Scarlet Flame)	Stocks 2012
	Pachystachys coccinea (=Jacobinia coccinea)	Cardinal's Guard	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Pachystachys lutea	Lollipop Plant (Golden Shrimp Plant)	Stocks 2012
	Peristrophe hyssopifolia	Marble Leaf Peristrophe	Stocks 2012
	Pseuderanthemum fasciculatum	Falseface	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Acanthaceae	*Pseuderanthemum laxiflorum*	Shooting Star (Star Flower, Purple Flase Erantheum, Dazzler)	Stocks 2012
	Ruellia brittoniana	Britton's Wild Petunia (Mexican Petunia, Common Ruellia, Wild Petunia)	Stocks 2012
	Ruellia elegans	Ragin' Cajun False Petunia	Stocks 2012
	Thunbergia battiscombei	Scrambling Sky Flower	Stocks 2012
	Thunbergia erecta	Bush Clockvine (King's Mantle)	Stocks 2012
	Thunbergia grandiflora	Bengal Trumpet (Bengal Clock Vine, Clock Vine, Sky Flower)	Stocks 2012
	Verbesina virginica	Frostweed (White crownbeard, Iceplant, Iceweed, Virginia Crownbeard, Indian Tobacco, Richweed, Squawweed)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Amaranthaceae	*Amaranthus*	Amaranth	Ben-Dov 1994 ; Ben-Dov 2004; Williams 1987
	Iresine	Bloodleaf	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Amaryliidoideae	*Narcissus*	Daffodil	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Anacardiaceae	*Mangifera indica*	Mango	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Williams 1987
Annonaceae	*Annona muricata*	Soursop	Ben-Dov 2004; Kondo et al. 2001
	Annona Montana	-	Kondo et al. 2001
Apiaceae	*Eryngium foetidum*	Spiritweed	Stocks 2012
	Petroselinum hortense	Parsley	Ben-Dov 2004; Mazzeo et al. 1994
Apocynaceae	*Allamanda cathartica*	Golden Trumpet	Stocks 2012
	Mandevilla amabilis	Thai Rose	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Apocynaceae	*Mandevilla laxa*	Chilean Jasmine	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Mandevilla splendens (=Dipladenia splendens)	'Alice Dupont' Allamanda	Ben-Dov 1994 ; Ben-Dov 2004; Stocks 2012; Williams 1987
	Plumeria	Plumeria (Frangipani)	Stocks 2012
	Trachelospermum difforme	Climbing Dogbane	Stocks 2012
	Trachelospermum jasminoides	Confederate Jasmine (Star Jasmine, Trader's Compass)	Stocks 2012
Aquifoliaceae	*Ilex vomitoria*	Yaupon (Yaupon Holly, Cassina)	Stocks 2012
Araceae	*Dieffenbachia maculata*	Dumbcane	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Schismatoglottis calyptrata (=Schismatoglottis neoguineensis)	-	Stocks 2012
Araliaceae	*Aralia Fatsia japonica*	Spikenard Paperplant (Fatsi, Japanese Aralia)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012
	Hedera helix	English Ivy (Common Ivy)	Stocks 2012
	Polyscias	-	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Schefflera actinophylla	Octopus Tree (Umbrella Tree, Amate)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Araliaceae	*Schefflera arboricola*	Dwarf Umbrella Tree	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Arecaceae	*Dypsis lutescens*	Yellow Butterfly Palm (Golden Cane Palm, Areca Palm)	Stocks 2012
	Wodyetia	Wodyetia	Stocks 2012
Asclepiadaceae	*Hoya carnosa*	Porcelain Flower (Wax Plant)	Ben-Dov 2004; Mazzeo et al. 1994; Mazzeo et al. 2008; Stocks 2012
	Hoya purpurea-fusca	Silver Pink Wax Plant	Stocks 2012
Asparagaceae	*Agave*	Agave (Century plant)	Ben-Dov 2004; Mazzeo et al. 1994; Mazzeo et al. 2008
	Liriope muscari	Big Blue Lilyturf (Lilyturf, Border Grass, Monkey Grass)	Stocks 2012
Asteraceae	*Ageratina adenophora (=Eupatorium adenophorum)*	Eupatory (Sticky snakeroot, Crofton Weed, Mexican Devil)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams and Granara de Willink 1992
	Ageratum houstonianum	Bluemink (Flossflower, Garden Ageratum, Blueweed, Pussy Foot)	Ben-Dov 2004; Granara de Willink 2003
	Ambrosia	Ragweeds (Bitterweeds, Bloodweeds)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012
	Artemisia californica	California sagebush	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Aster	Aster	Ben-Dov 1994; Ben-Dov 2004
	Bidens alba	Romerillo	Stocks 2012
	Bidens pilosa	Spanish Needles	Kondo et al. 2001; Stocks 2012
	Borrichia	Seaside Tansies	Stocks 2012
	Calendula	Pot Marigold	Ben-Dov 1994; Ben-Dov 2004; Williams 1987

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Asteraceae	*Chrysanthemum frutescens*	Marguerite	Stocks 2012
	Chrysanthemum morifolium	Florist's Daisy	Stocks 2012
	Chrysopsis	Golden Aster	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Chromolaena odorata	Christmas Bush (Common Floss Flower, Siam Weed)	Stocks 2012
	Cineraria	Cineraria	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Cynara scolymus	Globe Artichoke (Alcachofra, Alcachofera, Artichaut, Tyosen-Azami)	Stocks 2012
	Dahlia	Dahlia	Stocks 2012
	Eclipta prostrata	False Daisy	Stocks 2012
	Emilia fosbergii	Florida Tasselflower	Stocks 2012
	Erigeron philadelphicus	Philadelphia Daisy (Skevish, Skervish, Philadelpha Fleabane, Poor Robin's Plantain)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Euryops chrysanthemoides (=Gamolepis chrysanthemoides)	Bull's Eye (African Bush Daisy)	Stocks 2012
	Eupatorium capillifolium	Dogfennel	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Eupatorium odoratum	Jack in the Bush	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Eupatorium serotinum	Lateflowering Thoroughwort (Late Boneset)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Gaillaria pulchella	Firewheel (Indian Blanket, Indian Blanket Flower, Sundance)	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Asteraceae	*Gazania*	African daisy	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Gerbera jamesonii	Barberton Daisy (African Daisy)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Gynura aurantiaca	Velvetplant (Purple Passion Plant, Purple Passion Vine)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Haplopappus	Haplopappus	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Helianthus annuus	Sunflower	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Helianthus tephrodes	Algodones Sunflower	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Helichrysum	Helichrysum	Ben-Dov 2004; Stocks 2012; Williams 2004
	Leucanthemum vulgare (= Chrysanthemum leucanthemum)	Oxeye Daisy (Common Daisy, Common Daisy, Dog Daisy, Margarite, Moon Daisy, and Ox-eye Daisy)	Ben-Dov 2004; Granara de Willink 2003
	Mikania micrantha	Climbing Hempweed (Mile-a-minute, Chinese creeper, Bittervine)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Mikania scandens	Climbing Hempvine (Climbing Hempweed, Climbing Boneset, Guaco)	Stocks 2012
	Osteospermum	South African Daisy (African Daisy, Cape Daisy, Blue-Eyed Daisy)	Stocks 2012
	Parthenium hysterophorus	Santa Maria Feverfew (Whitetop Weed)	Ben-Dov 1994; Ben-Dov 2004
	Pluchea camphorata	Camphor Pluchea	Stocks 2012
	Pluchea odorata	Sweetscent (Salt Marsh Fleabane, Shrubby Camphorweed)	Ben-Dov 1994; Ben-Dov 2004

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Asteraceae	*Rudbeckia fulgida*	Orange Coneflower	Stocks 2012
	Rudbeckia hirta	Black Eyed Susan (Brown Eyed Susan, Brown Betty, Brown Daisy, Gloriosa Daisy, Golden Jerusalem, Poorland Daisy, Yellow Daisy, Yellow Ox- Eye Daisy)	Stocks 2012
	Senecio hybridus	Cineraria	Stocks 2012
	Solidago	Goldenrods	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Sphagneticola trilobata	Bay Biscayne Creeping-Oxeye	Stocks 2012
	Stevia rebaudiana	Candyleaf (Sweetleaf, Sugarleaf)	Stocks 2012
	Stokesia	Cornflower Aster (Stokes' Aster)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Tagetes	Marigold	Stocks 2012
	Tanacetum parthenium	Feverfew	Stocks 2012
	Taraxacum officinale	Dandelion (Common Dandelion)	Ben-Dov 2004; Mazzeo et al. 1994
	Tithonia diversifolia	Tree Marigold (Mexican Tournesol, Mexican Sunflower, Nitobe Chrysanthemum)	Stocks 2012
	Vernonia	Vernonia	Stocks 2012
	Wedelia trilobata	Bay Biscane Creeping-oxeye	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Blechnaceae	*Blechnum*	Blechnum (Hard fern)	Stocks 2012
Begoniaceae	*Begonia*	Begonia	Ben-Dov 1994; Ben-Dov 2004; Mazzeo et al. 1994; Williams 1987

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Bignoniaceae	*Jacaranda*	Jacaranda	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
Borginaceae	*Cordia curassavica*	Black Sage (Wild Sage)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Symphytum officinale	Boneset (Common Comfrey, Quaker Comfrey, Cultivated Comfrey, Knitbone, Consound, Slippery-root)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Brassicaeae	*Brassica oleraceae*	-	Kondo et al. 2001
	Brassica campestris	-	Kondo et al. 2001
Bromeliaceae	*Ananas comosus*	Pineapple	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Tillandsia	Tillandsia	Ben-Dov 2004
Burseraceae	*Bursera simaruba*	Gumbo Limbo	Stocks 2012
Cactaceae	*Hatiora salicornioides*	Dancing Bones (Cactus, Drunkard's Dream, Spice Cactus)	Stocks 2012
	Opuntia	Nopales (Paddle Cactus)	Stocks 2012
Cactaceae	*Hylocereus undatus*	Dragonfruit (Pitaya, Red Pitaya)	Ben-Dov 2004; Mazzeo et al. 1994; Mazzeo et al. 2008
Campanulaceae	*Lobelia cardinalis*	Cardinalflower	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
Caprifoliaceae	*Viburnum odoratissimum*	Sweet Viburnum	Stocks 2012
	Viburnum suspensum	Viburnum (Snadanqua Viburnum, Sandandwa Viburnum)	Stocks 2012
Celtidaeae	*Trema micrantha*	Jamaican Nettletree (Florida Trema, Guacimilla)	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Commenlinaceae	*Commelina diffusa*	Climbing Dayflower (Spreading Dayflower)	Stocks 2012
Compositae	*Ligularia tussilaginea*	Leopard Plant (Aureo Maculata)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Convovulaceae	*Ipomea setifera*	Morning Glory	Ben-Dov 2004; Matile-Ferrero and Germain 2004
	Jacquemontia blanchetti		Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
Crassulaceae	*Adromischus cristatus*	Crinkle leaf plant	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Kalanchoe beharensis	Elephant's Ear (Kalanchoe)	Stocks 2012
Cucurbitaceae	*Cucurbita peop*	Pumpkin (Field Pumpkin)	Stocks 2012
Cupressaceae	*Juniperus chinensis*	Chinese juniper	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Dioscoreaceae	*Tacca*	Bat Flower (Arrowroot)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Ebanaceae	*Diospyros duclouxii*	-	Beltra and Soto 2011; Ben-Dov 2004
Ericaceae	*Arbutus unedo*	Cane Apple (Strawberry Tree, Apple of Cain)	Ben-Dov 2004; Mazzeo et al. 1994
Euphorbiaceae	*Acalypha godseffiana*	Beefsteak Plant (Copperleaf, Fire Dragon, Jacobs Coat, Match-Me-If-You-Can, Three-Seeded Mercury)	Stocks 2012
	Acalypha hispida	Fox Tail (Philippines Medusa, Red Hot Cat's Tail, Chenille Plant)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Acalypha wilkesiana	Wilkes' Acalypha (Copperleaf, Joseph's Coat, Fire Dragon)	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Stocks 2012;

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Euphorbiaceae	*Chamaesyce*	Sandmat	Stocks 2012
	Cnidoscolus	-	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Codiaeum variegatum	Croton (Garden Croton, Varigated Croton)	Stocks 2012
	Croton glandulosus	Vente Conmigo	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Croton punctatus	Gulf Croton	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Euphorbia pulcherrima	Poinsettia (Noche Buena)	Ben-Dov 1994; Ben-Dov 2004; De Lotto 1977
	Jatropha curcas	Barbados Nut (Purging Nut, Physic Nut, JCL)	Stocks 2012
	Jatropha diversifolia (=Manihot diversifolia)	-	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Jatropha integerrima	Peregrina (Spicy Jatropha)	Stocks 2012
	Manihot aesculifolia	-	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Manihot esculenta	Cassava (Yuca, mogo, manioc, mandioca, kamoting kahoy)	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Stocks 2012; Williams 1987; Williams and Granara de Willink 1992
	Manihot glaziovii	Ceara Rubbertree	Ben-Dov 1994; Ben-Dov 2004; Couturier et al. 1985
	Manihot michaelis	-	Ben-Dov 1994; Ben-Dov 2004

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Euphorbiaceae	*Manihot rhomboidea*	-	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Phyllanthus amarus	Carry Me Seed (Sanskrit, Bahupatra)	Stocks 2012
	Phyllanthus debilis	-	Kondo et al. 2001
	Ricinus communis	Castor oil plant	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
Fabaceae	*Acacia flexuosa*	Acacia (Thorntrees, Whistling Thorns, Wattles, Yellow-Fever Acacia, Umbrella Acacia)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Arachis hypogaea	Peanut (Groundnut)	Stocks 2012
	Cajanus cajan	Pigeonpea (Tropical Garden Pea, Kadios, Congo Pea, Gungo Pea, Gunga Pea, No-Eye Pea)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Calliandra haematocephala	Calliandra	Stocks 2012
	Cassia imperialis	Cassias (Cassia)	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Coronilla	Coronilla	Beltra and Soto 2011; Ben-Dov 2004
	Desmodium tortuosum	Dixie Ticktrefoil (Florida Beggarweed)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Erythrina bogotensis	-	Beltra and Soto 2011; Ben-Dov 2004

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Fabaceae	*Erythrina caffra*	Coast Coral Tree	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Erythrina viarum	Bucayo	Ben-Dov 2004; Sinacori 1995
	Glycine max	Soybean (Soya Bean)	Ben-Dov 2004; Kondo et al. 2001
	Mimosa pudica	Shameplant (Sensitive Plant, Touch-me-not)	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willlink 1992
	Phaseolus aureus	-	Kondo et al. 2001
	Sophora secundiflora	Mescal Bean (Texas Mountain Laurel)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Sophora tomentosa	Yellow Necklacepod (Silver-Bush, Necklace Pod)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams and Granara de Willink 1992
	Trifolium	Clover (Trefoil)	Stocks 2012
	Vigna radiata	Mung Bean (Mungbean, Mung, Mungo, Green Gram, Golden Gram)	Ben-Dov 2004; Kondo et al. 2001
Garryaceae	*Aucuba*	Aucuba	Stocks 2012
Geraniaceae	*Geranium*	Cranesbills	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Pelargonium hortorum	Zonal Geranium (Garden Geranium, Malva, Malvon)	Ben-Dov 2004; Granara de Willink 2003; Stocks 2012
	Pelargonium pelatum	Ivyleaf Geranium (Ivyleaf Pelargonium, Cascading Gernamium, Kolsuring)	Stocks 2012
	Pelagaonium zonale	-	Kondo et a. 2001

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Gesneriaceae	*Chrysothemis pulchella (=Tussacia pulchella)*	Squarestem (Sunset bells, Copper Leaf, Black Flamingo, Chrysothemis)	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Episcia decurrens	-	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Nematanthus wettsteinii	Goldfish Plant (Candy Corn Plant)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Saintpaulia	African Violet	Stocks 2012
Hamamelidaceae	*Loropetalum chinense*	Chinese Fringe Flower (Chinese Witchhazel, Loropetalum)	Stocks 2012
Lamiaceae	*Anisomeles indica (=Epimeredi indicus)*	Indian catmint	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001;Williams 1987; Williams and Granara de Willink 1992
	Coleus	Coleus	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987; Williams and Granara de Willink 1992
	Melissa officinalis	Common Balm (Lemon Balm)	Stocks 2012
	Mentha	Mint	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Ocimum basilicum	Basil (Sweet basil)	Ben-Dov 2004; Kondo et al. 2001; Mazzeo et al. 1994; Stocks 2012
	Orthosiphon aristatus	Cat's Whiskers (Java Tea, Kumis Kucing, Misai Kucing)	Stocks 2012
	Plectranthus australis	Little Spurflower (Swedish Ivy, Swedish Begonia, Creeping Charlie)	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Lamiaceae	*Plectranthus scutellarioides*	Coleus	Stocks 2012
	Plectranthus nummularius	Whorled Plectranthus	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Salvia coccinea	Blood Sage (Texas Sage, Scarlet Sage, Tropical Sage)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Salvia guaranitica	Anise-Scented Sage (Hummingbird Sage)	Stocks 2012
	Salvia officinalis	Kitchen Sage (Garden Sage, Common Sage)	Stocks 2012
	Salvia splendens	Scarlet Sage (Tropical Sage)	Kondo et al. 2001; Stocks 2012
Loasaceae	*Petalonyx thurberi*	Thurber's Sandpaper Plant	Ben-Dov 1994; Ben-Dov 2004; Peterson 1965, Williams 1987
Lythraceae	*Cuphea llavea (=Cuphea speciosa)*	Cuphea	Stocks 2012
	Cuphea ignea	Cigar Flower (Cigar Plant, Firecracker Plant, Mexican Cigar)	Stocks 2012
Malvaceae	*Abutilon*	Abutilon (Chinese Bell Flower, Chinese Lantern, Mallow, Indian Mallow, and Flowering Maple)	Stocks 2012
	Althaea	Althaea (Mashmallow plant)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Gossypium	-	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987; Williams and Granara de Willink 1992
	Hibiscus acetosella	False Roselle	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Malvaceae	*Hibiscus cannabinus*	Kenaf	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Hibiscus esculentus	Okra	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Hibiscus mutabilis	Confederate Rose (Cotton Rosemallow)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Hibiscus rosa-sinensis	Chinese Hibiscus (China Rose, Shoe Flower)	Ben-Dov 1994; Ben-Dov 2004; Matile-Ferrero and Germain 2004; Jansen et al. 2010; Stocks 2012;
	Hibiscus tiliaceus	Coast Hibiscus (Sea Hibiscus, Beach Hibiscus, Coast Cottonwood, Green Cottonwood, Native Hibiscus, Native Rosella, Cottonwood Hibisicus, Kurrajong, Sea Rosemallow, Norfolk Hiiscus, Hau, Purau)	Stocks 2012
	Jute	Jute	Ben-Dov 2004; Kondo et al. 2001
	Malva	Malva	Ben-Dov 2004; Mazzeo et al. 1994; Stocks 2012
	Malvaviscus arboreus	Wax Mallow (Turkcap, Turk's Turban, Ladies Teardrop, Scotchman's Purse)	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Williams 1987
	Sida	Sida	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987; Williams and Granara de Willink 1992
	Taliparitti tiliaceum	Sea Hibsicus (Beach Hibiscus, Cottontree, Mahoe)	Stocks 2012
	Theobroma cacao	Cacao Tree (Cocoa Tree)	Ben-Dov 2004; Donald 1956

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Malvaceae	*Urena lobata*	Ceasarweed	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Menispermaceae	*Clyclea insularis*	-	Kondo et al. 2001
Moraceae	*Artocarpus communis*	Breadfruit	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Ficus benghalensis	Banyan (Banian)	Ben-Dov 2004; Williams 2004
	Ficus pumila	Climbing fig (Creeping Fig)	Stocks 2012
Myrtaceae	*Eugenia uniflora*	Brazilian Cherry (Surinam Cherry, Cayenne Cherry)	Stocks 2012
Oleaceae	*Ligustrum japonicum*	Japanese Privet (Wax-Leaf Privet)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Onagraceae	*Ludwigia octovalvis*	Mexican Primrose-Willow (Narrow-Leaf Water Primrose, Seedbox)	Stocks 2012
Passifloraceae	*Passiflora edulis*	Passion Fruit (Purple Grandilla, Passionfruit, Maracuja)	Ben-Dov 2004; Kondo et al. 2001
	Passiflora incarnata	Purple Passionflower (Maypop, True Passionflower, Wild Apricot, Wild Passion Vine)	Stocks 2012
Primulaceae	*Primula*	Primula	Ben-Dov 1994; Ben-Dov 2004; Marotta and Tranfaglia 1990
Poaceae	*Aventa sativa*	Oats	Ben-Dov 2004
Polygonaceae	*Rumex*	Sorrel (Dock)	Ben-Dov 2004; Williams 2004
Portulacaceae	*Portulaca oleracea*	Little Hogweed (Verdolaga, Pigweed, Common Purslane, Pusley)	Stocks 2012
Ranunculaceae	*Clematis tashiroi*	-	Kondo et al. 2001
Rubiaceae	*Gardenia jasminoides*	Cape Jasmine (Common Gardenia, Cape Jessamine)	Ben-Dov 2004; Granara de Willink 2003; Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Rubiaceae	*Ixora*	West Indian Jasmine (Rangan, Kheme, Ponna, Chann Tanea, Techi, pan, Santan, Jarum-Jarum, Jungle Flame, Jungle Geranium)	Stocks 2012
	Pentas lanceolata	Egyptian Starcluster	Stocks 2012
Rutaceae	*Citrus*	Citrus	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams and Granara de Willink 1992
	Citrus limonium	Lemon	Ben-Dov 2004; Mazzeo et al. 1994; Stocks 2012
	Ruta graveolens	Common Rue (Herb of Grace)	Stocks 2012
	Zanthoxylum fagara	Lime Pricklyash (Wild Lime, Colima, Una de Gato, Corriosa)	Stocks 2012
Rosaceae	*Malus domestica*	Apple	Ben-Dov 2004; Mazzeo et al. 1994
	Malus sylvestris	European Wild Apple	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Rosa	Rose	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Rubus	Rubus	Stocks 2012
Sapindaceae	*Cupaniopsis anacardioides*	Carrotwood (Tuckeroo, Beach Tamarind, Green-Leaved Tamarind)	Ben-Dov 2004; Stocks 2012
	Dodonaea viscosa	Florida hopbush	Stocks 2012
	Nephelium lappaceum	Rambutan	Ben-Dov 2004; Williams 2004
Scrophulariaceae	*Capraria biflora*	Goatweed	Stocks 2012
	Leucophyllum frutescens	Texas Barometer Bush (Texas Sage, Texas Ranger, Silverleaf, Cenizo)	Stocks 2012
Smilacaeae	*Smilax*	Catbriers (Greenbriers, Prickly-Ivys, Smilaxes)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Solanaceae	*Brunfelsia*	Brunfelsia	Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Solanaceae	*Capsicum annuum*	Cayenne Pepper (Chili pepper)	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Mazzeo et al. 1994; Stocks 2012; Williams 1987; Williams and Granra de Willink 1992
	Cestrum diurnum	Day-Blooming Cestrum (Day-Blooming Jessamine)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
	Cestrum nocturnum	Night-Blooming Cestrum (Night-Blooming Jessamine, Lady of the Night, Raat ki Rani)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987, Williams and Granara de Willink 1992
	Datura metel	Angel's Trumpet (Devil's Trumpet, Metel)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
Solanaceae	*Physalis viscosa*	Starhair Groundcherry (Grape Groundcherry, Arrebenta-Cavalo, Balaozinho, Camambu)	Stocks 2012
	Solanum diphyllum	Twoleaf Nightshade	Stocks 2012
	Solanum integrifolium	-	Kondo et al. 2001
	Solanum lycopersicum (=Lycopersicon esculentum)	Tomato (Garden Tomato)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Solanum melongena	Eggplant (Aubergine, Melongene, Brinjal, Guinea Squash)	Ben-Dov 1994; Ben-Dov 2004; Mazzeo et al. 1994; Williams 1987, Williams 2004; Williams and Granara de Willink 1992
	Solanum nigrum	-	Kondo et al. 2001
	Solanum pseudocapsicum	Jerusalem Cherry (Madeira Winter Berry, Winter Cherry)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Solanaceae	*Solanum torvum*	Turkey Berry (Devil's Fig, Prickly Nightshade, Shoo-shoo Bush, Wild Eggplant, Pea Eggplant, Pea Aubergine)	Stocks 2012
	Solanum tuberosum	Potato	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Solanum wendlandii	Giant Potato Creeper (Costa Rica Nightshade)	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Solanum wrightii	Giant Potato Tree (Brazilian Potato Tree)	Stocks 2012
Tillaceae	*Corchorus olitorius*	-	Kondo et al. 2001
	Triumfetta semitriloba	Sacramento burbark	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams and Granara de Willink 1992
Urticaceae	*Boehmeria*	Smallspike False Nettle	Stocks 2012
	Parietaria floridana	Florida pellitory	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Pilea	Pilea	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
	Pouzolzia zeylanica	Graceful Pouzolzsbush	Stocks 2012
	Urera	Urera	Ben-Dov 1994; Ben-Dov 2004; Williams and Granara de Willink 1992
	Urtica	Nettle	Ben-Dov 1994; Ben-Dov 2004; Williams 1987
Verbenaceae	*Callicarpa americana*	American Beautyberry	Stocks 2012
	Citharexylum spinosum	Florida Fiddlewood (Spiny Fiddlewood)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012

Table 1-2. Continued

Family	Scientific Name	Common Name	Reference
Verbenaceae	*Clerodendrum bungei*	Rose Glorybower (Bagflower, Bleeding-Heart)	Stocks 2012
	Clerodendrum paniculatum	Pagoda Flower (Bagflower, Bleeding-Heart)	Stocks 2012
	Duranta erecta	Golden Dewdrop (Pigeon Berry, Skyflower, Xcambococh e)	Stocks 2012
	Lantana camara	Lantana (Spanish Flag, West Indian Lantana, Red Wild Sage, Red Yellow Sage)	Ben-Dov 1994; Ben-Dov 2004; Kondo et al. 2001; Stocks 2012; Williams 1987; Williams and Granara de Willink 1992
	Lantana montevidensis	Trailing Shrubverbena (Weeping Lantana, Creeping Lantana, Small Lantana, Purple Lantana, Trailing Verbena)	Ben-Dov 1994; Ben-Dov 2004; Williams 1987; Williams and Granara de Willink 1992
	Stachytarpheta jamaicensis	Light-Blue Snakeweed (Blue Porterweed, Jamaica Vervain, Indian Snakeweed, Nettle-Leaved Vervain)	Stocks 2012
Verbenaceae	*Verbena canadensis*	Rose Mock Vervain (Purple Verbena)	Stocks 2012
	Verbena hybrida	Verbenas (Vervains)	Ben-Dov 1994; Ben-Dov 2004; Stocks 2012; Williams 1987
Vitaceae	*Vitis vinifera*	Common Grapevine (Wine Grape)	Ben-Dov 2004; Mazzeo et al. 1994
Zingiberaceae	*Curcuma longa*	-	Kondo et al. 2001
	Zingiber mioga	Japanese Ginger (Myoga Ginger)	Ben-Dov 2004; Kondo et al. 2001

Table 1-3. Reported distribution of *Phenacoccus madeirensis*.

Region	Country	State	Reference
North America	Mexico	-	CABI 2000; Williams and Granara de Willink 1992
	United States	Alabama	Ben-Dov 1994; CABI 2000
		California	Ben-Dov 1994; CABI 2000; Williams 1987
		Florida	Ben-Dov 1994; CABI 2000; Williams 1987
		Georgia	Chong 2005; Townsend et al. 2000
		Illinois	Ben-Dov 1994; CABI 2000
		Louisiana	Ben-Dov 1994; CABI 2000
		Maryland	Ben-Dov 1994; CABI 2000
		Minnesota	Ben-Dov 1994; CABI 2000
		Mississippi	Ben-Dov 1994; CABI 2000
		New York	Ben-Dov 1994; CABI 2000
		North Carolina	Ben-Dov 1994; CABI 2000
		Texas	Ben-Dov 1994; CABI 2000; Williams 1987
		Virginia	Ben-Dov 1994; CABI 2000
		Wisconsin	Ben-Dov 1994; CABI 2000
Caribbean	Antigua and Barbuda	-	Ben-Dov 1994; CABI 2000
	Bahamas	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Barbados	-	CABI 2000; Williams 1992
	Bermuda	-	CABI 2000; Williams 1987
	British Virgin Islands	-	CABI 2000; Williams and Granara de Willink 1992
	Cayman Islands	-	CABI 2000; Williams 1987; Williams and Granara de WIllink 1992
	Costa Rica	-	CABI 2000; Williams and Granara de Willink 1992
	Cuba	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Dominican Republic	-	CABI 2000; Williams and Granara de Willink 1992
	Grenada	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Guadeloupe	-	CABI 2000; Williams and Granara de Willink 1992
	Guatemala	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Haiti	-	CABI 2000; Williams and Granara de Willink 1992
	Jamaica	-	CABI 2000; Williams and Granara de Willink 1992
	Montserrat	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Panama	-	CABI 2000; Williams and Granara de Willink 1992
	Puerto Rico	-	CABI 2000; Williams and Granara de Willink 1992
	St. Kitts-Nevis	-	Ben-Dov 1994; CABI 2000; Williams and Granara de Willink 1992
	St. Lucia	-	CABI 2000; Williams and Granara de Willink 1992

Table 1-3. Continued

Region	Country	State	Reference
Caribbean	Trinidad and Tobago	-	Ben-Dov 1994; CABI 2000; Williams 1987; Williams and Granara de Willink 1992
South America	Bolivia	-	CABI 2000; Williams and Granara de Willink 1992
	Brazil	-	CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Colombia	-	CABI 2000; Williams and Granara de Willink 1992
	Ecuador	-	CABI 2000; Williams and Granara de Willink 1992
	Guyana	-	CABI 2000; Williams and Granara de Willink 1992
	Paraguay	-	CABI 2000; Williams and Granara de Willink 1992
	Peru	-	CABI 2000; Williams and Granara de Willink 1992
	Venezuela	-	CABI 2000; Williams and Granara de Willink 1992
Africa	Angola	-	Ben-Dov 1994; CABI 2000
	Benin	-	CABI 2000
	Cameroon	-	Ben-Dov 1994; CABI 2000; Williams 1987
	Cape Verde	-	Ben-Dov 1994; Williams 1987; Williams 1987
	Congo	-	CABI 2000
	Dominican Republic		
	Ivory Coast	-	Ben-Dov 1994; CABI 2000
	Gabon	-	CABI 2000
	Gambia	-	Ben-Dov 1994; CAB 2000; Williams 1987
	Ghana	-	CABI 2000
	Liberia	-	Ben-Dov 1994; CABI 2000
	Mozambique	-	Ben-Dov 1994; CABI 2000; Williams 1987
	Nigeria	-	Ben-Dov 1994; CABI 2000; Williams 1987
	Sao Tome and Principe	-	CABI 2000
	Senegal	-	Ben-Dov 1994; CABI 2000
	Sierra Leone	-	Ben-Dov 1994; CABI 2000; Williams 1987
	Togo	-	CABI 2000; Williams 1987
	Zaire	-	Williams 1987
	Zimbabwe	-	Ben-Dov 1994; CABI 2000; Williams 1987
Mediterranean	Crete	-	Ben-Dov 2004; Jansen 2010
	France	-	Ben-Dov 2004; Matile-Ferrero and Germain 2004
	Greece	-	Papadopoulou and Chryssohoides 2012
	Italy	-	Ben-Dov 1994; CABI 2000; Longo et al. 1995; Mazzeo et al. 1994; Sinacori et al. 1995; Sinacori and Tsolakis 1994
	Pakistan	-	Ben-Dov 2004; Williams 2004
	Portugal	-	Ben-Dov 1994; CABI 2000; Williams 1987; Williams and Granara de Willink 1992
	Spain	-	Ben-Dov 2004; Beltra 2011
Southeast Asia, Oceania, and Pacific Islands	Guam	-	CABI 2000
	Japan	-	Kondo 2001
	Miconesia	-	CABI 2000

Table 1-3. Continued

Region	Country	State	Reference
Southeast Asia, Oceania, and Pacific Islands	Taiwan	-	Yeh et al. 2006
	Thailand	-	Muniappan et al. 2011
	Philippines	-	Williams 2004
	Vietnam	-	Williams 2004

Table 1-4. Natural predators and parasitoids of *Phenacoccus gossypii* and *Phenacoccus madeirensis* (Chong 2005).

Order	Family	Species	Prey/Host Species	References
Diptera	Syrphidae	*Toxomerus marginata* Macquart	*P. gossypii*	Heming 1936
Coleoptera	Coccinellidae	*Cryptolaemus montrouzieri* Mulsant	Many	Chong 2005
	Coccinellidae	*Diomus austrinus* Gordon	*P. madeirensis*	Chong 2005
Neuroptera	Chrysopidae	*Chrysopa oculata* Say	*P. gossypii*	Heming 1936
	Chrysopidae	*'Chrysopa'* sp.	*P. gossypii*	Aguilar and Lamas 1980
	Chrysopidae	*Dichochrysa* sp.	*P. madeirensis*	Sinacori and Tsolakis 1994; Miller et al. 2004
	Hemerobiidae	*Sympherobius californicus* Banks	*P. gossypii*	Aguilar and Lamas 1980
	Hemerobiidae	*Sympherobius fallax* Navás	*P. madeirensis*	Sinacori and Tsolakis 1994; Miller et al. 2004
	Hemerobiidae	*Sympherobius pygmaeus* (Rambur)	*P. madeirensis*	Sinacori and Tsolakis 1994; Miller et al. 2004
Hymenoptera	Aphelinidae	*Coccophagus gurneyi* Compere	*P. gossypii*	Gordh 1979; Peck 1963; Thompson 1953
	Encrytidae	*Acerophagus coccois* Smith	*P. gossypii*	Ashmead 1900; Van Driesche et al. 1986, 1987; Noyes and Hayat 1994; Noyes 2003
		Acerophagus coccois Smith	*P. madeirensis*	Castillo and Bellotti 1990; Noyes 2003; Löhr; Rosen 1969; Beardsley 1976; Van Driesche et al. 1987
		Acerophagus pallidus Timberlake	*P. gossypii*	Flanders 1935; Thompson 1953; Simmonds 1957; Peck 1963; Herting 1972; De Santis 1989; Noyes and Hayat 1994
		Acerophagus pallidus Timberlake	*P. madeirensis*	Herting 1972; Noyes and Hayat 1994;
		Aenasius flandersi Kerrich (= *Aenasius phenacocci* Bennet)	*P. gossypii*	Herting 1972; De Santis 1979; Noyes and Hayat 1994; Noyes 2003
		A. flandersi	*P. gossypii*	Bennett 1957
		A. flandersi	*P. madeirensis*	Noyes 2000
		Aenasius masii Domenichini	*P. gossypii*	De Santis 1979; Noyes and Hayat 1994; Coquis and Salazar 1976
		Anagyrus sp.	*P. gossypii*	Herting 1972; Noyes and Hayat 1994; Noyes 2003; Salazar 1972

Table 1-4. Continued

Order	Family	Species	Prey/Host Species	References
Hymenoptera	Encrytidae	*Anagyrus* sp.	*P. madeirensis*	Löhr et al. 1990; Boussienguet and Neuenschwander 1989; Neuenschwander et al. 1987; Noyes and Hayat 1994
		Anagyrus diversicornis (Howard)	*P. gossypii*	Kerrich 1982; Van Driesche et al. 1987; De Santis 1989
		Anagyrus diversicornis (Howard)	*P. madeirensis*	Noyes 2000
		Anagyrus elgeri (Kerrich)	*P. madeirensis*	De Santis 1989; Kerrich 1982; Noyes and Hayat 1994
		Anagyrus fusviventris Girault	*P. gossypii*	Viggiani and Battaglia 1983; Noyes and Hayat 1994; Noyes 2000
		Anagyrus loecki Noyes & Menezes	*P. madeirensis*	Noyes 2000
		Anagyrus pseudococci (Girault)	*P. gossypii*	De Santis 1979; Noyes and Hayat 1994
		Anagyrus sinope Noyes & Monezes	*P. gossypii*	Noyes 2000
		Anagyrus sinope Noyes & Monezes	*P. madeirensis*	Noyes 2000
		Blepyrus insularis (Cameron)	*P. madeirensis*	Boussienguet and Neuenschwander 1989; Noyes and Hayat 1994; Noyes 2000
		Cheiloneurus carinatus Compere	*P. madeirensis*	Herting 1972
		Chrysoplatycerus ferrisi Timberlake	*P. gossypii*	Kerrich 1978; Noyes and Hayat 1994
		Coccidoxenoides perminutus Girault	*P. madeirensis*	Herting 1972
		Dicarnosis ripariensis Kerrich	*P. gossypii*	Kerrich 1978; Noyes and Hayat 1994; Noyes 2003
		Ericydnus lamasi (Domenichini)	*P. gossypii*	Salazar 1972; De Santis 1979; De Santis 1983; Noyes and Hayat 1994; Noyes 2000
		Gryranusoidea sp.	*P. madeirensis*	Boussienguet and Neuenschwander 1989; Noyes and Hayat 1994
		Gryranusoidea phenacocci (Beardsley)	*P. gossypii*	Beardsley 1969; Noyes and Hayat 1994

Table 1-4. Continued

Order	Family	Species	Prey/Host Species	References
Hymenoptera	Encrytidae	*Holcencyrtus* sp.	*P. gossypii*	Salazar 1972; Noyes and Haya 1994
		Holcencyrtus myrmicoides (Compere & Zinna)	*P. madeirensis*	Herting 1972
		Leptomastidea sp.	*P. gossypii*	Coquis and Salazar 1976; Noyes and Hayat 1994
		Leptomastidea abnormis (Girault)	*P. gossypii*	Dozier 1932; Heming 1936; Thompson 1954; Peck 1963; Gordh 1979; Trjapitzin 1989; Noyes and Hayat 1994; Noyes 2000
		Leptomastix sp.	*P. madeirensis*	Boussienguet and Neuenschwander 1989; Noyes and Hayat 1994
		Leptomastix dactylopii Howard	*P. gossypii*	Bess 1939; Fullaway 1946
		Leptomastix dactylopii Howard	*P. madeirensis*	Peck 1963; Gordh 1979; Noyes and Hayat 1994; Noyes 2000
		Metanotalia madeirensis (Walker)	*P. madeirensis*	Zuparko 1995
		Prochiloneurus sp.	*P. gossypii*	Coquis and Salazar 1976; Noyes and Hayat 1994
		Prochiloneurus bolivari Mercet	*P. madeirensis*	Boussienguet and Neuenschwander 1989; Noyes and Hayat 1994
		Prochiloneurus insolitus (Alam)	*P. madeirensis*	Neuenschwander et al. 1987
		Prochiloneurus seini (Dozier)	*P. gossypii*	Salazar 1972; Noyes and Hayat 1994
		Pseuaphycus angelicus (Howard)	*P. gossypii*	Flanders 1935; Thompson 1954; Peck 1963; Herting 1972; Gordh 1979
		Pseuaphycus angelicus (Howard)	*P. madeirensis*	Herting 1972
		Pseudaphycus mundus Gahan	*P. gossypii*	Gahan 1946; Peck 1963; Herting 1972; Gordh 1979; Noyes and Hayat 1994; Noyes 2003
		Zarhopalus zancles Noyes	*P. madeirensis*	Noyes 2000
	Pteromalidae	*Pachyneuron eros* Girault	*P. gossypii*	De Santis 1979
	Signiphoridae	*Chartocerus* sp.	*P. madeirensis*	Noyes 2000
	Signiphoridae	*Chartocerus dactylopii* (Ashmead)	*P. gossypii*	Gordh 1979; Noyes 2003
	Signiphoridae	*Chartocerus niger* (Ashmead)	*P. gossypii*	Herting 1972

Table 1-5. Reported insecticides used to control Phenacoccus madeirensis for homeowner and ornamental industry use.

Chemical Name Or Common Name	Registered Product Or Trade Name	Chemical Class	References
Acephate (C)	1300 Orthene TR (F,G)	Organophosphate	Osborne et al. 2006
	Acephate Pro 75 (WSP)	Organophosphate	Buss and Turner 2006; Osborne et al. 2006
	Acephate 97UP	Organophosphate	Bethke 2010
	Orthene 75 S	Organophosphate	Townsend et al. 2000
	Orthene TT&O Spray 97 (WSP)	Organophosphate	Buss and Turner 2006; Bethke 2010
	Orthene Turf (F,G)	Organophosphate	Osborne et al. 2006
	PT 1300 Orthene TR	Organophosphate	Bethke 2010
	Tree and Ornamental Spray 97 (F,G)	Organophosphate	Osborne et al. 2006
Acetamiprid (SY,C)	Tristar 30 SG (F,G)	Neonicotinoid	Price et al. 2001; Osborne et al. 2006
	TriStar 70 (F,G,WSP)	Neonicotinoid	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006; Bethke 2010; Ludwig 2009
Azadirachtin (SY)	Azatin XL Biological Insecticide (F,G)	Insect Growth Regulator	Price et al. 2001; Osborne et al. 2006; Bethke 2010
	Azatin XL Plus (EC)	Insect Growth Regulator	Buss and Turner 2006; Bethke 2010
	Azatin XL 0.26 (EC)	Insect Growth Regulator	Townsend et al. 2000; Bethke 2010
	Azatrol (EC)	Insect Growth Regulator	Price et al. 2008
	Ornazin 3% EC	Insect Growth Regulator	Price et al. 2001; Osborne et al. 2006; Bethke 2010
Beauveria bassiana ATCC 74040 (C)	Naturalis L	Biological	Price et al. 2008
Beauveria bassiana Strain GHA (C)	Botanigard 22 WP	Biological	Price et al. 2001; Bethke 2010
	Botanigard ES Mycoinsecticide	Biological	Price et al. 2001; Bethke 2010
	Mycotrol O	Biological	Price et al. 2001
Bendiocarb (SY,C)	Turcam 76 (WP)	Pyrethroid	Townsend et al. 2000
Bifenthrin (C)	Attain TR	Pyrethroid	Price et al. 2001; Bethke 2010
	Attain TR Micro (F,G)	Pyrethroid	Price et al. 2001; Osborne et al. 2006

Table 1-5. Continued

Chemical Name Or Common Name	Registered Product Or Trade Name	Chemical Class	References
Bifenthrin	Bifenthrin PRO Multi-Insecticide (EPA Reg. No. 51036-391)*	Pyrethroid	Price et al. 2001; Bethke 2010
	Talstar Flowable (F, G)	Pyrethroid	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006
	Talstar GC* (F,G)	Pyrethroid	Buss and Turner 2006
	Talstar Nursery Flowable* (F)	Pyrethroid	Price et al. 2001; Buss and Turner 2006
	TalstarOne Multi-Insecticide	Pyrethroid	Price et al. 2001
	Talstar T&O 10 (WP)	Pyrethroid	Townsend et al. 2000
Buprofezin (C)	Talus 40 (SC)	Insect Growth Regulator	Price et al. 2001
	Talus Insect Growth Regulator (F,G)	Insect Growth Regulator	Price et al. 2001; Osborne et al. 2006
Carbaryl (C,SY)	Sevin (SL)	Carbamate	Buss and Turner 2006
	Sevin 50W	Carbamate	Townsend et al. 2000
	Sevin 80 (WSP)	Carbamate	Buss and Turner 2006
Chlorpyrifos (C)	Chlorpyrifos Pro 2 (F)	Organophosphate	Osborne et al. 2006
	Chlorpyrifos Pro 4 (F)	Organophosphate	Osborne et al. 2006
	Duraguard ME* (F)	Organophosphate	Price et al. 2001; Osborne et al. 2006; Bethke 2010
	Dursban 50 (WP)	Organophosphate	Townsend et al. 2000; Osborne et al. 2006
Chlorpyrifos (C) & Cyfluthrin (C)	Duraplex TR* (G)	Organophosphate & Pyrethroid	Price et al. 2001; Osborne et al. 2006; Bethke 2010
Clothianidin (SY)	Celero 16 WSG (F)	Neonicotinoid	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006
Cyfluthrin (C)	Bayer Advanced Garden Power Force Multi-Insect Killer** (SL)	Pyrethroid	Buss and Turner 2006
	Decathlon 20 WP (F,G)	Pyrethroid	Price et al. 2001; Townsend et al. 2000; Osborne et al. 2006; Bethke 2010
	Tempo 20 WP GC* (WSP)	Pyrethroid	Buss et al. 2006
Cyfluthrin	Temp 20 Power Pak (WSP)	Pyrethroid	Buss et al. 2006

Table 1-5. Continued

Chemical Name Or Common Name	Registered Product Or Trade Name	Chemical Class	References
Cyfluthrin	Tempo Ultra (SC, WP, WSP)	Pyrethroid	Buss et al. 2006
	Tempo 2 (EC)	Pyrethroid	Buss et al. 2006
Cyfluthrin (C) & Imidacloprid (SY,C)	Discus (F)	Pyrethroid & Neonicotinoid	Osborne et al. 2006
Deltamethrin (C)	DeltaGard GC 5SC* (SC)	Pyrethroid	Buss and Turner 2006; Bethke 2010
	DeltaGard T&O 5SC (SC)	Pyrethroid	Buss and Turner 2006; Bethke 2010
Diazinon (C)	Diazinon 25 (EC)	Organophosphate	Townsend et al. 2000
Dimethoate (SY,C)	Dimethoate 400 (F)	Organophosphate	Osborne et al. 2006
Dinotefruan (SY, C)	Safari 20 SG	Neonicotinoid	Price et al. 2001; Bethke 2010; Ludwig 2009
	Safari 2G	Neonicotinoid	Price et al. 2001; Bethke 2010
Disulfoton (SY)	Bayer Advanced Garden 2-in-1 Systemic Azalea, Camellia & Rhododendon Care** (G)	Organophosphate	Buss and Turner 2006
Fenoxycarb (C)	Preclude TR	Insect Growth Regulator	Price et al. 2001
	Precision 25 (WP)	Insect Growth Regulator	Townsend et al. 2000
Fenpropathrin (C)	Tame 2.4 EC Spray* (EC)	Fenopropathrin	Price et al. 2001; Townsend et al. 2000
Fenpyroximate (C)	Akari 5 SC	Pyrazole	Price et al. 2001
Fish Oil (C)	Organocide** (EC,F,G)	Biorational	Buss and Turner 2006; Osborne et al. 2006
Flonicamid (SY)	Aria (G)	Pyridincarboxamids	Price et al. 2001; Osborne et al. 2006
Imidacloprid (SY)	Bayer Advanced Garden Tree & Shrub Insect Control** (F)	Neonicotinoid	Buss and Turner 2006
	Marathon 1% (F,G)	Neonicotinoid	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006; Bethke 2010
	Marathon 60 G & N in WSP (F,G,WP)	Neonicotinoid	Price et al. 2001; Osborne et al. 2006; Bethke 2010
	Marathon II (F, G)	Neonicotinoid	Price et al. 2001; Osborne et al. 2006; Bethke 2010; Ludwig 2009
	Merit 2 (F)	Neonicotinoid	Buss and Turner 2006
	Merit 75 (WP, WSP)	Neonicotinoid	Buss and Turner 2006

Table 1-5. Continued

Chemical Name Or Common Name	Registered Product Or Trade Name	Chemical Class	References
Isaria fumosorosea (C)	PFR 97®	Biological	Dr. L. S. Osborne, personal communication
Lambda-cyhalothrin (C)	Lambda-Cy (EC)	Pyrethroid	Price et al. 2001
	Scimitar GC*	Pyrethroid	Price et al. 2001
	Scimitar (CS)	Pyrethroid	Buss and Turner 2006
	Scimitar (WP, WSP)	Pyrethroid	Buss and Turner 2006
Malathion (C)	Malathion 5 (SL)	Organophosphate	Buss and Turner 2006
	Malathion 5EC (F,G)	Organophosphate	Osborne et al. 2006
	Malathion 57 (EC)	Organophosphate	Buss and Turner 2006
	Malathion 8 (SL)	Organophosphate	Buss and Turner 2006
	Malathion 8-E (EC)	Organophosphate	Buss and Turner 2006
	Malathion 8F (EC)	Organophosphate	Buss and Turner 2006
	Malathion 8 Spray (SL)	Organophosphate	Buss and Turner 2006
Methiocarb (C)	Mesurol 75WP	Carbamate	Townsend et al. 2000
Naled (C)	Dibrom 8 Emulsive	Carbamate	Price et al. 2001
Mineral Oil (C)	JMS Stylet Oil	Biorational	Bethke 2010
	SafTSide	Biorational	Bethke 2010
	Sunspray Ultra-Fine (F,G)	Biorational	Townsend et al. 2000; Osborne et al. 2006
	Sunspray 6E (EC)	Biorational	Buss and Turner 2006
	Sunspray 11E (EC)	Biorational	Buss and Turner 2006
	Ultra-Fine Oil (F,G)	Biorational	Osborne et al. 2006; Bethke 2010
	Volck** (EC)	Biorational	Buss and Turner 2006
Neem Oil (C)	Triact 70 (EC,F,G)	Biorational	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006; Bethke 2010
	Triact 80	Biorational	Townsend et al. 2000
Permethrin (C)	Astro	Pyrethroid	Price et al. 2008; Bethke 2010
	Perm-UP 3.2 (EC)	Pyrethroid	Price et al. 2008
	Permethrin E-Pro	Pyrethroid	Price et al. 2008
	Permethrin Pro Termite-Turf Ornamental (EC)	Pyrethroid	Buss and Turner 2006
Potassium Salts of Fatty Acids	AllPro Insecticidal Soap 40%	Insecticidal Soap	Price et al. 2008

Table 1-5. Continued

Chemical Name Or Common Name	Registered Product Or Trade Name	Chemical Class	References
Potassium Salts of Fatty Acids	Insecticidal Soap 49.52 CF (F, G)	Insecticidal Soap	Buss and Turner 2006; Osborne et al. 2006
	M-Pede (F,G)	Insecticidal Soap	Price et al. 2001; Townsend et al. 2000
	Safer's Soap (F)	Insecticidal Soap	Buss and Turner 2006
Pyrethrin (C)	PyGanic Crop Protection EC 1.4 (EC)	Pyrethroid	Price et al. 2001
	PyGanic Crop Protection EC 5.0 (EC)	Pyrethroid	Price et al. 2001
	Spectracide Rose & Flower Insect Spray** (F)	Pyrethroid	Price et al. 2001
Pyrethrin (C) & Piperonyl Butoxide (SYN)	1100 Pyrethrum TR	Pyrethroid	Price et al. 2001
	EverGreen EC 60-6 (EC)	Pyrethroid	Price et al. 2001
	PT Pyrethrum TR	Pyrethroid	Bethke 2010
	Pyrethrum TR Micro	Pyrethroid	Price et al. 2001
	Pyrenone Crop Spray	Pyrethroid	Price et al. 2001
Pyrethrin (C) & Rotenone (C) and other associated resins	Pyrellin EC	Pyrethroid	Price et al. 2001; Bethke 2010
Pyriproxyfen (C)	Distance Insect Growth Regulator (EC,F,G)	Insect Growth Regulator	Price et al. 2001; Buss and Turner 2006; Osborne et al. 2006
	Distance 0.86 (EC)	Insect Growth Regulator	Townsend et al. 2000
S-Kinoprene (C)	Enstar II (G)	Insect Growth Regulator	Price et al. 2001; Osborne et al. 2006
	Enstar II 5 (EC)	Insect Growth Regulator	Townsend et al. 2000; Bethke 2010
Spirotetramat (C)	Kontos®	Ketoenole	Ludwig 2009
Tau-fluvalinate (C)	Mavrik Aquaflow	Pyrethroid	Price et al. 2001; Bethke 2010
	Mavrik 2EC	Pyrethroid	Townsend et al. 2000
Thiamethoxam (SY,C)	Flagship 0.22 G	Neonicotinoid	Price et al. 2001
	Flagship 25 WG (F,G)	Neonicotinoid	Price et al. 2001; Buss and Turner 2006

C = Contact; EC = Emulsifiable concentrate; F = Water-dispersible liquid; G = Granule; SC = Water-soluble liquid; SL = Water-soluble liquid; SY = Systemic; SYN= Synergist; WG = Wettable granules; WP = Wettable powder; WSP = Water-solute powder, *Restricted use product; **Homeowner product

CHAPTER 2
DEVELOPMENT OF THE MODEL BIORATIONAL DIP

Introduction

Importation of cryptic, invasive pests as plant contaminants on ornamental cuttings has posed a serious threat to Florida. The United States Department of Agriculture (2007) cited Florida as the leading ornamental propagation state with an estimated annual revenue of $91 million. Approximately 89.4% of United States flower imports and 82% of all air imports in the United States and Latin American/Caribbean Region pass through the Miami Plant Protection Quarantine Inspection Station at the Miami International Airport (Miami-Dade Aviation Department Marketing Division 2013). However, limited resources and trade demands result in the inspection of only 2% of imported plant stock by the United States Department of Agriculture, Animal and Plant Health Inspection Services (Brasier 2008). Additionally, the humid, warm climate of Florida is suitable for the establishment of invasive pests such as aphids, scales, mealybugs, mites, thrips, and whiteflies listed in Table 1-1 (Frank and Thomas 2004).

Effective control measures for limiting the spread of cryptic, invasive species as plant contaminants on ornamental cuttings were made apparent after the invasion of the B-biotype and pesticide-resistant Q-biotype of the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) on poinsettia cuttings. In the 1990s, the B-biotype whitefly was introduced into the United States as a plant contaminant on poinsettia cuttings moving from Israel to Florida to California, and inflicted over a billion dollars' worth of damage to North American cotton, melon, and lettuce farmers (Dalton 2006, De Barro et al. 2008, McKenzie et al. 2009). Similarly, in the mid-2000s, the Q biotype was imported into the United States as a plant contaminant on poinsettia cuttings from Guatemala, Honduras, and southern Mexico that were shipped and grown into infested poinsettia plants found in Encinitas, California (Dalton 2006, Bethe et al. 2009).

Treatment methods for controlling ornamental cutting pests have been limited to on-site synthetic insecticide dips as cuttings lack roots, thus rendering high-volume sprays, soil-based systemic insecticides, and drenches ineffective (Osborne 1986, Conover and Poole 1970, Hansen et al. 1992). In contrast to synthetic insecticide dips (e.g. organophosphates, carbamates, and pyrethroids), biorational dips (e.g. surfactants, anti-transpirants) have multiple modes of action and insecticide resistance has not been reported (Capinera 2008, Gunning et al. 1984, Cahill et al. 1995, Kranthi et al. 2001). Organic oils and surfactants such as detergents have been known to induce mortality in several ways: (1) starvation by preventing plant pests from using their piercing-sucking mouthparts, or (2) death by suffocation or desiccation by halting respiration via spiracle blockage, or (3) toxicity from muscle or nerve damage caused by penetrating and damaging the tracheae (Capinera 2008).

Observations have shown that biorational treatments tended to induce less severe phytotoxicity than synthetic insecticides when applied at the recommended label rate. Popular biorational treatments such as soybean oil and cotton seed oil have been observed to cause slight chlorotic spotting and marginal chlorosis on collard and tomato leaves (Liu and Stansly 2000). Anti-transpirants have only been known to inhibit plant growth on soybean, pine, and corn seedlings (Gale and Hagan 1966, Rowan 1988, Davenport et al. 1969, McConnel 1985, Mmbaga and Sheng 2002). Additionally, surfactants such as Silwet L-77 and Wetcit^{TM} have shown variation in phytotoxicity among different plant types, including stunted plant growth, leaf drop, chlorosis, or necrosis (Beyer et al. 1988, Sun 1996).

In comparison to biorational treatments, Hata and Hara (1988) described severe phytotoxicity on the flower anthurium, *Anthurium andraeanum* Andre following synthetic insecticide application. Organophosphates such as chloropyrifos (Dursban) and acephate

(Orthene 75 and Isotox Insect Killer) induced chlorotic and necrotic spotting on mature leaves, bronzed abaxial surfaces, leaf curling, stem deformation, and spathe discoloration. Oxamyl, a carbamate active ingredient, caused chlorotic spotting and marginal chlorosis on new leaf growth and chlorotic spotting and leaf curling on mature leaves. Pyrethroids such as bifenthrin (Talstar 10) and cyfluthrin (Tempo 2) varied in causing phytotoxicity.

Implementation of a biorational on-site dip may fit well within a Florida nursery and greenhouse operation. In addition to effectively controlling ornamental pests while inducing minimal plant phytotoxicity, biorational treatments have been known to be less expensive than synthetic dips or sprays (Liu and Stansley 2000, Dr. Lance Osborne, personal communication). Additionally, biorational treatments have limited worker, community, and environmental concern as biorationals may either leave no residues or quickly decompose after use (Weinzierl and Henn 1991, United States Environmental Protection Agency 2013, Dr. Eileen Buss, personal communication).

The purpose of this study was to develop an on-site biorational model dip treatment in order to prevent the dissemination of invasive species as plant contaminants on ornamental cuttings being imported and exported from the United States. Such knowledge is important because invasive species threaten the United States agricultural and ornamental industry as contaminants on imported and exported plant cargo. In this study, the Madeira mealybug, *Phenacoccus madeirensis* Green was selected as the model invasive ornamental pest while coleus, *Solenostemon* sp., was designated as the model ornamental cutting. A foliage phytotoxicity rating system redesigned after Hansen et al. (1992) and ornamental cutting health analysis from Osborne et al. (1986) was used to evaluate phytotoxicity for several concentrations for each type of biorational dip. Based on the phytotoxicity results, the highest concentration

from each type of biorational dip with acceptable phytotoxicity was used to determine efficacy against *P. madeirensis*. Afterwards, the treatment with the highest *P. madeirensis* mortality was determined as the model biorational dip treatment.

Materials and Methods

Rearing Colonies of *P. madeirensis*

Separate rearing rooms used for two *P. madeirensis* colonies reared on *Solenostemon* spp. (coleus 'Big Red Judy') and *Acalypha* spp. (copperleaf) were maintained at a 14L:10D photoperiod and standard room temperature (27^0C) (Chong 2003). In order to prevent a complete loss of colony due to the development of entomopathogenic fungal spores, separate *P. madeirensis* rearing rooms were maintained at 20% and 60% relative humidity. Manual watering of host plants for *P. madeirensis* colonies occurred three times per week. Specimens from each colony at UF-MREC were sent to the Florida Department Agriculture and Consumer Services - Division of Plant Industry for mealybug identification and stored afterwards at the Florida State Collection of Arthropods as voucher specimen.

Host Plant Maintenance

Solenostemon spp. (coleus 'Big Red Judy') plants were grown from cuttings in an enclosed greenhouse from January to July 2013 with a 22.8^0C average daily temperature and 68% mean relative humidity at the University of Florida, Mid-Florida Research and Education Center (UF-MREC) in Apopka, FL. Plants were rooted in Faford® Growing Mix 2/C-2 soil composed of Canadian sphagnum peat moss, perlite, vermiculite, dolomitic limestone, and wetting agent (2:1:1:1:1, vol:vol:vol:vol:vol) and were hand-watered daily until soil was evenly moistened. Plants over 30 inches (72.6cm) in height were spaced at least one foot apart and flowering parts were pruned to encourage further branching.

Cutting Preparation

Coleus tip cuttings were prepared by randomly selecting and excising the stem of a stock plant at a slight angle in order to prevent stem damage. All tip cuttings were at least 3 inches (7.62cm) in height and consisted of four mature leaves on the top portion of the plant. Excess basal leaves on the stem and flowering parts on the tip were removed. Tip cuttings with blemishes that resembled phytotoxicity characteristics were discarded. A total of thirty blemish-free tip cuttings were made for each experiment. Cuttings were made once the stock plant was over 30 inches (72.6cm) in height. New stock plants were grown using the same methods described above.

Assessment of Biorational Phytotoxicity on Cuttings

Dip treatment protocol. Four biorational materials were evaluated: Natur'l Oil (93% vegetable oil, Stoller Enterprises, Inc, Houston, Texas); Wetcit^{TM} (8.92% alcohol ethoxylate with selected adjuvants, AGRI Inc, Trophy Club, Texas); Publix Mild & Gentle Ultra Dish Detergent (select anionic and nonionic surfactants, stabilizers, quality control agents, perfume and colorant, Publix Super Markets, Inc, Lakeland, Florida); and Vapor Gard® (96% di-1-p-Methene with 4% select inert ingredients, Miller Chemical & Fertilizer Corporation, Hanover, Pennsylvania). Four concentrations for each biorational material were prepared and thoroughly mixed with a magnetic stirrer for five minutes: 0.10% (1mL of treatment per 999mL of de-ionized water), 0.50% (5mL of treatment per 995mL of de-ionized water), 1.00% (10mL of treatment per 990mL of de-ionized water), and 1.50% (15mLof treatment per 985mL of de-ionized water). The treatment control was 1000mL of de-ionized water. Another 1000mL of de-ionized water was used to treat a second set of control plants to evaluate the effect of the mist irrigation watering system. These control plants served as an early detection measure for fungal or bacterial growth on cuttings that may be mistaken for phytotoxicity character expression. Each dip treatment was

randomly assigned five coleus tip cuttings and evenly re-mixed with a magnetic stirrer for two minutes prior to usage. All five cuttings for each dip treatment were dipped simultaneously for one minute in a 6.5 quart rectangular plastic bin. During each dip, all tip cuttings were fully submerged, lightly agitated, and rotated vertically after 30 seconds to maximize treatment surface area coverage on the tip cuttings. Dipped cuttings were lightly shaken to remove excess runoff and air dried until runoff ceased. Each cutting was transplanted into a labeled 4" square ounce plastic pot filled with moistened Faford® Growing Mix 2/C-2 soil. Two replicates of five cuttings for each biorational material and concentration were conducted on the same day with one replicate completed in the morning and the other in the afternoon. For the phytotoxicity assessment, data collection methodology for foliage phytotoxicity was redesigned after Hansen et al. (1992). The methodology for obtaining data on cutting height, root volume, and root length was modeled after Osborne et al. (1986).

Cutting observation and watering practices. For two weeks, all cuttings were kept under a misting system which actuated every 10 minutes for 30 seconds from 0800 to 2000 hours. Mist control cuttings were placed on a separate bench and hand watered twice every day until soil was moist. Afterwards, all cuttings were removed from the mist and manually watered in the morning three times per week until the end of the fourth week. Observations made for each cutting included the following information: presence of any pests, including the identity, possible life stage, and sex, and any non-pest or non-treatment suspected cutting damage.

Assessment of Biorational Effects on Plants

Plant height. Prior to transplanting treated cuttings, cutting length was recorded. Initial length for cuttings treated with Wetcit™, Natur'l Oil, Publix Mild & Gentle Ultra Dish Detergent, Vapor Gard®, and the control was taken on the same date cuttings were treated and planted: 2 April 2013, 3 April 2013, 4 April 2013, and 8 April 2013, respectively. Cuttings were

measured from the base to the tip for initial and final cutting height. Final plant height for cuttings treated with Wetcit™, Natur'l Oil, Publix Mild & Gentle Ultra Dish Detergent, Vapor Gard®, and the control occurred on 23 April 2013, 24 April 2013, 25 April 2013, and 29 April 2013, respectively.

Foliage damage. Each coleus tip cutting was divided into five sections for phytotoxicity foliage analysis. Each of the four mature leaves on the tip cutting constituted a leaf section. The fifth leaf section was attributed to new flush growth. The initial foliage phytotoxicity ratings for cuttings treated with Wetcit™, Natur'l Oil, Publix Mild & Gentle Ultra Dish Detergent, Vapor Gard® and the control were taken on the same date cuttings were treated and planted: 2 April 2013, 3 April 2013, 4 April 2013, and 8 April 2013, respectively. Similar to the rating system described by Hansen et al. (1992), two raters simultaneously issued independent ratings at the same time dipping occurred but the ratings were not summed. The rating system was modified further in order to characterize the symptoms of phytotoxicity. The symptoms were assigned numerical values ranging from 0-5, with 0 as no damage to stem and leaves to 5 as foliage death. The following modifications were made to the Hansen et al. (1992) rating system to score phytotoxicity of the treatments weekly for four weeks: (1) no injury, (2) slight injury, (3) moderate injury, (4) severe injury, and (5) dead; and eleven distinct phytotoxicity characters were rated for each leaf section: chlorosis (C), leaf curling (Y), chlorotic flecking (CF), necrotic flecking (NF), marginal necrosis (MN), marginal chlorosis (MC), chlorotic streaking (CS), necrotic streaking (NS), tip chlorosis (TC), tip necrosis (TN), and holes (H). Final ratings for cuttings treated with Wetcit™, Natur'l Oil, Publix Mild & Gentle Ultra Dish Detergent, Vapor Gard®, and the control occurred on 23 April 2013, 24 April 2013, 25 April 2013, and 29 April 2013, respectively.

Root volume and length. Soil was gently rinsed and dislodged from the root system of each cutting by using a hose at low pressure and dipping roots in water. Root volume for cuttings treated with Wetcit^{TM}, Natur'l Oil, Publix Mild & Gentle Ultra Dish Detergent, Vapor Gard®, and the control was recorded on 23 April 2013, 24 April 2013, 25 April 2013, and 29 April 2013, respectively. Root volume was evaluated by excising the root system of the cutting and placing the roots into a known volume of water in a 100mL graduated cylinder (Osborne 1986). The total volume of roots with water was recorded. From that value, the volume of water displaced by the roots was determined and evaluated as the root volume of the cutting. Average root length was assessed in the same manner as Osborne (1986) where three of the longest roots for each cutting were measured from the base to root tip and averaged. Data for each treatment was recorded on 23 April 2013, 24 April 2013, 25 April 2013, and 29 April 2013, respectively.

Efficacy of Biorationals on *P. madeirensis* Mortality

Based on the results of the phytotoxicity assessment, the highest concentration from each type of biorational dip with acceptable damage was selected for the efficacy bioassay. A total of four biorational materials were tested with a control: 1.0% Natur'l Oil, 0.1% Wetcit ^{TM}, 1.0% Publix Mild & Gentle Ultra Dish Detergent, and 0.1% Vapor Gard®. Five replicates for each biorational material were conducted in a 5 X 5 randomized complete block design. For each replicate, a total of 25 coleus cuttings, each infested with 15 *P. madeirensis* mealybugs ranging from crawlers to virgin female adults, were evaluated for mortality. Data collection for each replicate began on a separate date and time: 14 March 2013 in the morning, 14 March 2013 in the afternoon, 28 March 2013 in the morning, 1 April 2013 in the morning, and 1 April 2013 in the afternoon.

Dip treatment preparation. Each selected biorational material was prepared and thoroughly mixed with a magnetic stirrer for five minutes: 1.0% Natur'l Oil (10mL of Natur'l

Oil per 990mL of de-ionized water), 0.1% Wetcit™ (1mL of Wetcit™ per 999mL of de-ionized water), 1.0% Publix Mild & Gentle Ultra Dish Detergent (10mL of Publix Soap per 990mL of de-ionized water), and 0.1% Vapor Gard® (1mL of Vapor Gard® per 999mL of deionized water). One 1000mL of de-ionized water was used as a control.

Coleus cutting preparation. To infest cuttings with more than 15 mealybugs, coleus plants were re-infested by exposure to *P. madeirensis* from the colony maintained at UF-MREC one week before the trial. Infested cuttings were made by excising the stems at a 45^{o} angle to avoid stem damage. Cuttings were at least 3 inches (7.62cm) in height with four mature leaves on top. Excess basal leaves on the stem and flowering parts on the tip were removed. Exactly 15 mealybugs were randomly selected to remain on the cutting. The mealybugs left on cuttings ranged from crawlers to the adult females. Excess mealybugs, oviscas, male adults, or male cocoons were removed using a moistened camel hair paintbrush. If there were less than 15 mealybugs present on a cutting, mobile mealybugs from different colony leaves that varied in size and ranged from crawlers to adult females were randomly selected and transferred onto the cutting using a moistened camel hair paintbrush. All transferred mealybugs were left to settle on the cutting for at least fifteen minutes. All cuttings had a random number of active mealybug life stages present. A total of 15 mealybugs were left on each cutting. Each cutting was carefully sealed in a clear Ziploc® bag to maintain cutting moisture and reduce the risk of losing mealybugs when transporting the cutting to the greenhouse for treatment.

Dipping method and planting procedure. The dipping method and planting procedure described in the phytotoxicity assessment section was used during each efficacy bioassay.

Cutting observation and watering practices. For two weeks, all cuttings were kept under a misting system that activated every 10 minutes for 30 seconds from 0800 to 2000 hours.

Afterwards, all cuttings were removed from mist and manually watered in the morning three times per week. Observations made at each mortality time period for each cutting included: mealybug feeding and movement post-treatment; presence of other arthropods, ovisacs, male cocoons or male adults; phytotoxicity symptoms and severity; and handling damage.

Mealybug mortality evaluation. Two raters simultaneously recorded the number of live and dead mealybugs immediately after dipping and on the third, seventh, and fourteenth day. If the mealybug cadaver was present, the life stage of the dead mealybug was recorded. For the analysis, the following time periods were used to determine mealybug mortality: immediately after dipping (Day 1), between Day 1 and the third day (Day 3), between the third day and seventh day (Day 7), and between the seventh and fourteenth day (Day 14). The baseline for an effective biorational treatment was determined at 70% mortality (Dr. Lance Osborne, personal communication).

Mealybug mortality was modified from Hata et al. (1992): (1) no movement after gently touching with a moistened camel hair paintbrush at least three times and (2) a shriveled, hollow, or blackened appearance. Living mealybugs were distinguished by the following: (1) leg movement, (2) mouthpart movement, (3) visible mealybug resistance or displacement when brushed gently with a moistened camel hair paint brush at least three times and (4) detachment from its original position after or prior to being touched.

Statistics

Efficacy bioassay and phytotoxicity assessment summary statistics were prepared using a fit linear model in the GLIMMIX Procedure (General Linear Model for Mixture Distributions) to fit binary outcomes and account for non-normality and non-homogenous variances in SAS 9.3 (SAS Institute Inc., 2002-2010, Cary, NC, USA). For the efficacy bioassay, five replicates were conducted in a 5 X 5 random complete block design. For each replicate, a total of 25 cuttings,

each infested with 15 *P. madeirensis* mealybugs, were evaluated for mortality. Differences between cumulative percentages of dead *P. madeirensis* per selected treatment at each time period were analyzed by using Tukey-Kramer Least Squares Means for multiple comparisons.

The phytotoxicity assessment analyzed cutting height, root volume, average root length, and each of the eleven phytotoxicity characteristics for foliage phytotoxicity. For each biorational material, two replicates were conducted on the same day in a random complete block design with one replicate completed in the morning and the other in the afternoon. A total of 30 cuttings were used for each replicate and evaluated for phytotoxicity. Tukey-Kramer Least Squares Means for multiple comparisons was used to determine significant differences between the following: average ratings per rater, average ratings for each week per foliage phytotoxicity characteristic, average ratings for each biorational material for each foliage phytotoxicity character, average ratings for each concentration of Wetcit™, Vapor Gard®, Publix Soap, and Natur'l Oil, respectively, and average ratings across all biorational material concentrations (SAS Institute Inc., 2002-2010, Cary, NC, USA). Additionally, Tukey-Kramer Least Squares Means for multiple comparisons was also utilized to verify differences between the following: average measurements for each biorational material, average measurements for each concentration of Wetcit™, Vapor Gard®, Publix Soap, and Natur'l Oil, respectively, average measurements across all concentrations, and average measurements in initial and final cutting height, respectively.

Results

Efficacy Bioassay

The cumulative average percent of dead *P. madeirensis* was significantly different between the following selected treatments for each time period: 0.1% Wetcit™, 0.1% Vapor Gard®, 1.0% Publix Soap, 1.0% Natur'l Oil, and the control ($F=48.51$; $df= 4$; $p<0.0001$) (Table

2-1). During each day, the highest percentage mortality occurred with the 1.0% Natur'l Oil and 0.1% Wetcit™ concentration treatments followed by 0.1% Vapor Gard® and 1.0% Publix Soap. Vapor Gard® at 0.1% and 1.0% Publix Soap showed no significant difference in mortality. In comparison to all other treatments, the control had the lowest mortality for each day. None of the selected treatments achieved 100% mortality by Day 14.

Phytotoxicity Assessment

Foliage ratings significantly differed within concentrations for each biorational material over a period of three weeks. Comparisons between the different Wetcit™ concentration treatments showed that 0.1% had the lowest ratings for all characters while 1.0% and 1.5% scored the highest for all of the following characters: chlorosis ($F=83.94$; $df= 4$; $p<0.0001$); chlorotic flecking ($F=50.09$; $df= 4$; $p<0.0001$), necrotic flecking ($F=90.03$; $df= 4$; $p<0.0001$), holes ($F=28.52$; $df= 4$; $p<0.0001$), chlorotic streaking ($F=78.31$; $df= 4$; $p<0.0001$), necrotic streaking ($F=11.88$; $df= 4$; $p=1.000$), leaf curling ($F=1.64$; $df= 4$; $p=0.1610$), marginal chlorosis ($F=7.11$; $df= 4$; $p<0.0001$), marginal necrosis ($F=79.99$; $df= 4$; $p=0.0534$), tip chlorosis ($F=3.18$; $df= 4$; $p=0.0127$), and tip necrosis ($F=2.75$; $df= 4$; $p=0.0266$).

Comparisons within Vapor Gard® concentration treatments also showed that 0.1% had the lowest ratings for 10 characters while 1.0% and 1.5% had the highest ratings for all of the following characters: chlorosis ($F=283.50$; $df= 4$; $p<0.0001$); chlorotic flecking ($F=177.11$; $df= 4$; $p<0.0001$), necrotic flecking ($F=144.50$; $df= 4$; $p<0.0001$), holes ($F=25.26$; $df= 4$; $p<0.0001$), chlorotic streaking ($F=64.45$; $df= 4$; $p<0.0001$), necrotic streaking ($F=0.00$; $df= 4$; $p=1.000$), leaf curling ($F=6.62$; $df= 4$; $p<0.0001$), marginal chlorosis ($F=4.93$; $df= 4$; $p=0.0006$), marginal necrosis ($F=69.55$; $df= 4$; $p<0.0001$), tip chlorosis ($F=9.46$; $df= 4$; $p<0.0001$), and tip necrosis ($F=52.41$; $df= 4$; $p<0.0001$).

Differences within Publix Soap concentration treatments included 0.1% with the lowest ratings for the following 6 characters: chlorosis, chlorotic flecking, necrotic flecking, holes, chlorotic streaking, and tip chlorosis. Publix Soap at1.5% had the highest ratings for all of the following characters: chlorosis ($F=56.71$; $df= 4$; $p<0.0001$); chlorotic flecking ($F=51.72$; $df= 4$; $p<0.0001$), necrotic flecking ($F=12.81$; $df= 4$; $p<0.0001$), holes ($F=12.14$; $df= 4$; $p<0.0001$), chlorotic streaking ($F=111.14$; $df= 4$; $p<0.0001$), necrotic streaking ($F=0.00$; $df= 4$; $p=1.000$), leaf curling ($F=12.55$; $df= 4$; $p<0.0001$), marginal chlorosis ($F=2.76$; $df= 4$; $p=0.0263$), marginal necrosis ($F=3.96$; $df= 4$; $p=0.0033$), tip chlorosis ($F=27.85$; $df= 4$; $p<0.0001$), and tip necrosis ($F=19.93$; $df= 4$; $p<0.0001$).

Similarly, comparisons within Natur'l Oil concentration treatments indicated that 0.1% had the lowest ratings for 4 characters: chlorosis, chlorotic flecking, necrotic flecking, and holes. Natur'l Oil at 1.5% had the highest ratings for all of the following characters: chlorosis ($F=49.55$; $df= 4$; $p<0.0001$); chlorotic flecking ($F=47.41$; $df= 4$; $p<0.0001$), necrotic flecking ($F=17.02$; $df= 4$; $p<0.0001$), holes ($F=4.68$; $df= 4$; $p=0.0009$), chlorotic streaking ($F=40.40$; $df= 4$; $p<0.0001$), necrotic streaking ($F=0.00$; $df= 4$; $p=1.000$), leaf curling ($F=4.91$; $df= 4$; $p=0.0006$), marginal chlorosis ($F=5.17$; $df= 4$; $p=0.0004$), marginal necrosis ($F=3.50$; $df= 4$; $p=0.0074$), tip chlorosis ($F=7.05$; $df= 4$; $p<0.0001$), and tip necrosis ($F=2.65$; $df= 4$; $p=0.0314$).

When all biorational material concentrations were compared together, Wetcit™ at 1.0% and 1.5% had the highest ratings for 6 characters followed by Vapor Gard® at 1.5% (4), Publix Soap at 1.5% (3), and Natur'l Oil at 1.5% (2) (Table 2-2). Natur'l Oil at 0.1%, 0.5%, and 1.0% showed no significant difference but had the lowest ratings for 9 characters: chlorosis, chlorotic flecking, necrotic flecking, holes, tip chlorosis, chlorotic streaking, necrotic streaking, marginal chlorosis, and marginal necrosis. Overall, foliage ratings for all biorational material

concentrations compared together for each phytotoxicity character were significantly different: chlorosis ($F=33.00$; $df= 10$; $p<0.0001$), chlorotic flecking ($F=20.08$; $df= 10$; $p<0.0001$), necrotic flecking ($F=25.72$; $df= 10$; $p<0.0001$), holes ($F=8.92$; $df= 10$; $p<0.0001$), tip chlorosis ($F=11.58$; $df= 10$; $p<0.0001$), tip necrosis ($F=12.25$; $df= 10$; $p<0.0001$), chlorotic streaking ($F=12.00$; $df= 10$; $p<0.0001$), necrotic streaking ($F=2.97$; $df= 10$; $p=0.0004$), marginal chlorosis ($F=2.01$; $df= 10$; $p=0.0196$), marginal necrosis ($F=21.33$; $df= 10$; $p<0.0001$), and leaf curling ($F=6.50$; $df= 10$; $p<0.0001$).

For each phytotoxicity character, Rater 1 issued higher ratings than Rater 2 for 9 out of 11 characters but both raters showed no significant difference between necrotic streaking and marginal necrosis ratings. The following characters showed significant difference between ratings: chlorosis ($F=365.12$; $df= 1$; $p<0.0001$), chlorotic flecking ($F=280.42$; $df= 1$; $p<0.0001$), necrotic flecking ($F=91.38$; $df= 1$; $p<0.0001$), holes ($F=578.15$; $df= 1$; $p<0.0001$), chlorotic streaking ($F=152.46$; $df= 1$; $p<0.0001$), necrotic streaking ($F=0.34$; $df= 1$; $p=0.5577$), leaf curling ($F=3.81$; $df= 1$; $p=0.0509$), marginal chlorosis ($F=346.39$; $df= 1$; $p<0.0001$), marginal necrosis ($F=3.73$; $df= 1$; $p=0.0534$), tip chlorosis ($F=328.83$; $df= 1$; $p<0.0001$), and tip necrosis ($F=21.71$; $df= 1$; $p<0.0001$).

Natur'l Oil ($F=2.27$; $df= 4$; $p=0.0611$), Publix Soap ($F=1.88$; $df= 4$; $p=0.1133$), Wetcit™ ($F=2.71$; $df= 4$; $p=0.0296$), and Vapor Gard® ($F=1.17$; $df= 4$; $p=0.03212$) demonstrated no significant difference in cutting height within concentrations for each biorational material. Similarly, root volume within concentrations for each biorational material exhibited no significant difference: Natur'l Oil ($F=0.03$; $df= 4$; $p=0.9988$), Publix Soap ($F=0.66$; $df= 4$; $p=0.6226$), Wetcit™ ($F=1.24$; $df= 4$; $p=0.2935$), Vapor Gard® ($F=1.39$; $df= 4$; $p=0.2380$). However, root length was significantly different within concentrations for each biorational

material (Table 2-3). Comparisons within Natur'l Oil concentrations showed that the control, 1.0%, and 1.5% had the longest root length ($F=3.79$; $df= 4$; $p=0.0026$). Publix Soap concentrations showed no significant difference ($F=1.95$ $df= 4$; $p=0.0879$). Differences within Wetcit™ concentrations included 1.0% with the shortest root length in comparison to all other Wetcit™ concentrations ($F=3.55$; $df= 4$; $p=0.0041$). In contrast to all other Vapor Gard® concentrations, Vapor Gard® at 1.5% also had the shortest root length ($F=7.88$; $df= 4$; $p<0.0001$).

Model Dip Treatment Determination

At each time period, 1.0% Natur'l Oil and 0.1% Wetcit™ concentration treatments had the highest mortality ($F=48.51$; $df= 4$; $p<0.0001$) (Table 2-1). However, in this study, 0.1% Wetcit™ had significantly higher foliage phytotoxicity ratings than 1.0% Natur'l Oil for each of the following key phytotoxicity characters: chlorosis ($F=33.00$, $df= 12$, $p<0.0001$), chlorotic flecking ($F=20.08$, $df= 12$, $p<0.0001$), necrotic flecking ($F=25.72$, $df= 12$, $p<0.0001$), holes ($F=8.92$, $df= 12$, $p<0.0001$), tip chlorosis ($F=11.58$, $df= 12$, $p<0.0001$), and tip necrosis ($F=12.25$, $df= 12$, $p<0.0001$) (Table 2-2).

Discussion

Efficacy Bioassay

The most effective treatments over time for controlling *P. madeirensis* were 1.0% Natur'l Oil and 0.1% Wetcit™, respectively. Efficacy for both treatments surpassed the baseline, 70% mortality, by Day 3. For both treatments, mortality already exceeded 50% by Day 1 in comparison to 0.1% Vapor Gard® and 1.0% Publix Soap which had less than 50% mortality. By Day 7, 0.1% Vapor Gard® and 1.0% Publix Soap finally reached 70% mortality. The highest mortality for all treatments occurred by Day 14. However, 1.0% Natur'l Oil and 0.1% Wetcit™ showed 90% mortality in comparison to 1.0% Publix Soap and 0.1% Vapor Gard® with 85%

mortality. Differences in *P. madeirensis* mortality over time between treatments may be attributed to the mechanical effects of dipping, insecticidal properties of each treatment, or treatment susceptibility of *P. madeirensis* at various life stages.

The mechanical effects of dipping may have influenced the number of *P. madeirensis* remaining on each treated cutting. The dipping technique was conducted by one designated assistant through the experiment which reduced variation in agitation. However, gentle cutting agitation during each dip may have dislodged *P. madeirensis*. During each dip, cuttings were agitated against the sides and bottom of the dipping container. As a result, mobile or feeding *P. madeirensis* may have been displaced from the cutting or squished altogether by the agitation process. Additionally, the proboscis or legs of *P. madeirensis* may be broken or harmed by the agitation process thus inducing eventual death by starvation or secondary infection.

The number of *P. madeirensis* remaining on each treated cutting over time may have varied due to the active ingredient of each treatment. Although different concentrations were evaluated, 1.0% Natur'l Oil and 0.1% Wetcit™ were the most effective treatments over each time period. Active ingredients differed between treatments: Natur'l Oil (soybean oil), Publix Soap (nonylphenol ethoxylate), Vapor Gard® (di-1-p-menthene), and Wetcit™ (alcohol ethoxylate). Several studies cited exceptional insecticidal control with soybean oil applied at the recommended dosage rate (Liu and Stansly 2000, Pless et al. 1995, Butler et al. 1993, Amer et al. 2001). Additionally, several scientific studies cited alcohol ethoxylate insecticidal activity (Liu and Stansly 2000, Imail et al. 1994, Davidson et al. 1991, Hesler and Plapp 1986, Tattersfield and Gimingham 1927, Wolfenbarger et al. 1967, Imail and Tsuchiya 1995, Cory and Langford 1935). However, few studies cited insecticidal activity with di-1-p-menthene and nonylphenol ethoxylate. Only Allen et al. (1993) reported that di-1-p-menthene reduced Western flower

thrips, *Frankliniella occidentalis* (Pergande) feeding activity by 40%. Nonylphenol ethoxylate has only been reported as an inert ingredient within pesticide products (U.S. Environmental Protection Agency 2007).

The treatment susceptibility of *P. madeirensis* at various instars may have also directly impacted mortality rates for treated cuttings. In this study, varying life stages of *P. madeirensis* ranging from crawlers to females adults were used for the efficacy bioassay. Each instar of *P. madeirensis* has been known to vary in white mealy wax cover production. Townsend (2000) observed that first instar *P. madeirensis* lack a waxy coating on the body and only develop a mealy wax cover after the second instar. Additionally, Buss and Turner (2003) confirmed that crawlers were more susceptible to synthetic insecticides. As a result, cuttings which had more early instars of *P. madeirensis* may have had a higher mortality over time in comparison to cuttings that had more female adults which produce a thick mealy wax cover for protection (Buss and Turner 2003, Townsend 2000, Green 1923).

Overall, the efficacy bioassay may be improved in several ways. High water control mortality was observed throughout this experiment and may be prevented by reducing the impact of mechanical dipping and restricting the number of times mealybugs may be touched. In future studies, mealybug mortality could be evaluated by gently touching the mealybug with a moistened camel hair paint brush three times. Mealybugs on water control cuttings were consistently touched more than three times by both raters during the mortality evaluation and continuous touching may have broken or pierced the proboscis, legs, or thorax thus inducing eventual death by starvation or secondary infection. To reduce the impact of mechanical dipping, mortality by insecticidal activity may be better analyzed by dipping cuttings in a large basin where cuttings do not touch the sides or base when fully submerged and agitated. Additionally,

the impact of insecticidal activity may also be evaluated better by testing each life stage independent from one another. Additional experiments may be conducted for each life stage important for nursery and greenhouse owners to control: ovisacs, crawlers, and gravid females.

Phytotoxicity Assessment

Root volume, average root length, cutting height, and foliage phytotoxicity were factors used to determine the least phytotoxic concentration for each biorational material. However, the root volume and cutting height for each biorational material showed no significant difference so root length and foliage phytotoxicity were analyzed.

In this study, coleus phytotoxicity characters and patterns were similar to those described in Hansen et al. (1992) on the uluhe fern and pothos treated with insecticidal soap and synthetic dips. For example, leaf curling and marginal chlorosis indicated initial cutting fragility during the first rating week. Other characters, such as tip chlorosis, would climax in intensity within the first two weeks and then diminish by the fourth week, thus indicating positive plant health and development. Most foliage characters such as chlorosis, chlorotic flecking, necrotic flecking, holes, marginal necrosis, and tip necrosis were fully expressed by the second week when cuttings were rooted.

Wetcit^{TM} concentrations showed significant differences in ratings where higher ratings were issued to higher concentrations. Observations from Pypekamp (2008) confirmed that Wetcit^{TM} sprayed at 0.5% induced necrotic lesions compared to 0.25% concentration which caused necrotic spotting. Wetcit^{TM} at 0.1% and 0.5% showed no significant difference in root volume, average root length, and root height. However, within Wetcit^{TM} concentrations, 0.1% had the lowest ratings for each phytotoxicity character. Due to these results, 0.1% was determined as the highest Wetcit^{TM} concentration with acceptable damage.

Significant differences in Vapor Gard® concentrations also indicated that higher concentrations resulted in higher phytotoxicity. In general, 0.1% was determined as the highest Vapor Gard® concentration with acceptable damage. While 0.1% and 0.5% showed no significant difference in average root volume, root length, and cutting height, 0.1% had the lowest ratings for 10 characters compared to 0.5%.

Publix Soap concentrations also showed significant differences in ratings where higher concentrations were marked with higher ratings. However, 1.0% was designated as the highest Publix Soap concentration with acceptable damage. Upon final examination on the fourth week, cuttings treated with 1.0% Publix Soap and 0.1% Publix Soap showed similar character expression. Differences in rater perception over time may have attributed to significant differences in ratings where Rater 1 was stricter than Rater 2.

Ratings between Natur'l Oil concentrations significantly differed and showed that as concentration increased, higher ratings were issued. However, observations from Butler et al. (1993) indicated no phytotoxicity after spraying Natur'l Oil at the recommended label rate. Overall, the highest concentration of Natur'l Oil with acceptable damage was 1.0%. When all biorational material concentrations were compared, ratings between 0.1%, 0.5%, and 1.0% Natur'l Oil showed no significant difference and had the lowest ratings for 8 out of 11 characters. Additionally, Natur'l Oil at 0.1%, 0.5%, and 1.0% also showed no significant difference in average root volume, root length, and cutting height.

Future improvements for rating foliage may include more rating training for each rater, averaging ratings between the raters, and issuing ratings underneath a well-lit lamp inside the greenhouse. Other improvements may also be implemented for measuring average root volume,

root length, and cutting height. Roots may be cleaned by dunking and lightly agitating when suspended in water as opposed to being pressure rinsed under a hose.

Model Dip Treatment Determination

Final determination of the model biorational dip was a two step process. First, the highest concentration with acceptable phytotoxicity from each biorational material was selected and designated as a treatment in the efficacy bioassay. Second, the most effective treatment for controlling *P. madeirensis* over time was determined as the model dip treatment. Although 1.0% Natur'l Oil and 0.1% Wetcit™ showed no significant difference in mortality and had the highest mortality compared to all other treatments, 1.0% Natur'l Oil was determined as the best dip treatment because of its lower phytotoxicity.

Several scientific studies cited Wetcit™ for insecticidal activity in comparison to Natur'l Oil as an effective treatment for several pests. In this study, 0.1% Wetcit™ had higher foliage phytotoxicity ratings than 1.0% Natur'l Oil for each key phytotoxicity character. Additionally, results from this study corroborated findings from Butler et al. (1993) where Natur'l Oil used as a spray at the recommended rate was an effective treatment with over 86% nymph mortality of sweetpotato whitefly, *Bemisia tabaci* Gennadius. In this study, insecticidal soaps, petroleum based oil, and 15 other surfactants were evaluated simultaneously under greenhouse conditions. Amer et al. (2001) determined that Natur'l Oil at the recommended label rate was an efficacious spray treatment for egg and adult stages of the two spotted spider mite, *Tetranychus urticae* Koch. Several studies have cited Wetcit™ insecticidal activity (Liu and Stansly 2000, Imail et al. 1994, Davidson et al. 1991, Hesler and Plapp 1986, Tattersfield and Gimingham 1927, Wolfenbarger et al. 1967, Imail and Tsuchiya 1995, Cory and Langford 1935).

Model Dip Treatment Implications

As a preventative measure for importing invasive species through cuttings, the one-time use of 1.0% Natur'l Oil as an on-site one minute dip provides Florida growers an efficacious treatment option for cuttings at an acceptable phytotoxicity level. Use of the dip also provides growers an environmentally safe treatment while preventing synthetic insecticide development within a Florida greenhouse operation. Within a systems approach, integration of the dip treatment ultimately may help prevent the establishment of imported mealybugs and other invasive species. Results from this study confirmed that the dip effectively controlled *P. madeirensis* within three days. In future studies, several application techniques could be modified to develop a dip protocol within a systems approach. Factors which impact efficacy could be evaluated and include various host plants and invasive species, dip exposure time, dipping location, and dipping application within a synthetic insecticide treatment program.

Table 2-1. Cumulative average percent of dead *P. madeirensis* per coleus cutting dipped for one minute in selected biorational treatments at each time period.

Biorational Material	Time Period (Days)			
	1	3	7	14
	(Mean ± SE)	(Mean ± SE)	(Mean ± SE)	(Mean ± SE)
Control	20.26% ± 1.629%c	37.17% ± 2.246%c	49.25% ± 2.371%c	65.19% ± 2.206%c
0.1% Wetcit	56.29% ± 2.491%a	74.99% ± 1.967%a	83.10% ± 1.525%a	90.47% ± 0.9958%a
0.1% Vapor Gard	44.90% ± 2.503%b	65.48% ± 2.322%b	75.68% ± 1.932%b	85.72% ± 1.357%b
1.0% Publix Soap	45.82% ± 2.311%b	66.32% ± 2.099%b	76.36% ± 1.759%b	86.17% ± 1.253%b
1.0% Natur'l Oil	57.75% ± 2.422%a	76.09% ± 1.870%a	83.92% ± 1.441%a	90.97% ± 0.9376%a

Within a column, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means; F=48.51; df=4, 1867; p<0.0001).

Table 2-2. Average coleus cutting phytotoxicity rating per biorational material concentration for key phytotoxicity characters.

Biorational Material	Treatment	Chlorosis	Chlorotic Flecking	Necrotic Flecking	Holes	Tip Chlorosis	Tip Necrosis
Natur'l Oil	Control	1.4937i	1.4887j	1.1650hi	1.1500ghi	1.0775cde	1.0263g
	0.1%	1.4325i	1.4325j	1.1600hi	1.1075ghi	1.0225f	1.0400fg
	0.5%	1.5200ghi	1.5100ij	1.1600hi	1.0900hi	1.0275f	1.0200g
	1.0%	1.5425ghi	1.5350jhi	1.2125fghi	1.0750i	1.0200f	1.2100bcd
	1.5%	1.9211d	1.8806de	1.4982bc	1.1828fgh	1.0597cdef	1.0884efg
Publix Soap	Control	1.5000hi	1.4987j	1.1675hi	1.1938fgh	1.0313ef	1.0513fg
	0.1%	1.5350ghi	1.5300jhi	1.2025fghi	1.2125efg	1.0575cdef	1.1600cde
	0.5%	1.6525fg	1.6475gh	1.4075cde	1.2450def	1.0725cdef	1.2025bcd
	1.0%	1.8925de	1.8500de	1.6125ab	1.3050cde	1.1350ab	1.0025g
	1.5%	1.9025d	1.8600de	1.6500a	1.3575bc	1.1600a	1.2300bcd
Wetcit®	Control	1.8425de	1.8187ef	1.2475fgh	1.4300b	1.0275f	1.2313bc
	0.1%	1.7600ef	1.7075fg	1.2900efg	1.4100bc	1.0350def	1.2900ab
	0.5%	2.0700c	1.9550cd	1.4250cd	1.3975bc	1.0675cdef	1.2500bc
	1.0%	2.2950b	2.1275b	1.6075ab	1.6525a	1.0625cdef	1.2575bc
	1.5%	2.2600b	2.0925b	1.6725a	1.5575a	1.0300ef	1.3025ab
Vapor Gard®	Control	1.5300ghi	1.5262ij	1.2013ghi	1.1163ghi	1.0238f	1.0538fg
	0.1%	1.6200fgh	1.6150ghi	1.1300i	1.1575fghi	1.0650cdef	1.0250g
	0.5%	1.8125de	1.7850ef	1.3075def	1.1950fgh	1.0975bc	1.0325fg
	1.0%	2.1875bc	2.0225bc	1.5200bc	1.3325cd	1.0900bcd	1.1325def
	1.5%	2.5775a	2.3100a	1.5200bc	1.3150cde	1.0675cdef	1.3650a
Statistics	F	33.00	20.08	25.72	8.92	11.58	12.25
	df	12, 9408	12, 9408	12, 9408	12, 9408	12, 9408	12, 9408
	P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Within a row, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means).

Table 2-3. Average coleus cutting root length per biorational material.

Treatment	Natur'l Oil (Mean ± SE)	Publix Soap (Mean ± SE)	Wetcit™ (Mean ± SE)	Vapor Gard® (Mean ± SE)
Control	17.7900 ± 0.5303a	17.2900 ± 0.5303a	15.4300 ± 0.5303ab	18.1200 ± 0.5303a
0.1%	15.4000 ± 0.5303b	16.3300 ± 0.5303a	16.6100 ± 0.5303a	18.7900 ± 0.5303a
0.5%	15.8900 ± 0.5303b	17.0900 ± 0.5303a	14.7000 ± 0.5303ab	18.6400 ± 0.5303a
1.0%	17.3400 ± 0.5303ab	16.9900 ± 0.5303a	14.1400 ± 0.5303b	17.2100 ± 0.5303ab
1.5%	16.3000 ± 0.5303ab	15.8900 ± 0.5303a	14.5600 ± 0.5303ab	15.2300 ± 0.5303b
F	3.79	1.95	3.55	7.88
df	5, 216	5, 216	5, 216	5, 216
P	0.0026	0.0879	0.0041	<0.0001

Within a row, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means).

CHAPTER 3
EVALUATION OF THE MODEL BIORATIONAL DIP

Introduction

From the late 1980s to early 1990s, several studies explored the efficacy of fluvalinate and other synthetic insecticides as an adoptable post-harvest treatment for mealybug infested ornamental products in Florida and Hawaii, respectively (Osborne 1986, Hata et al. 1986, Hansen et al. 1992). Several additional studies evaluated factors that impacted the ease and efficacy of synthetic dip treatments for ornamental and agricultural products infested with other cryptic, invasive pests. Aside from pesticide type and concentration, Mann et al. (1995) and Hara et al. (1996) evaluated dipping temperature and Hansen et al. (1992), Hata et al. (1993), Tenbrink et al. (1992), Osborne (1986) studied dipping technique, which encompassed the length of dipping time, submersion depth, or agitation intensity.

Dip efficacy was also evaluated across numerous ornamental and agricultural pests, various types of plants, and dip treatment characteristics, such as the type of treatment used and treatment concentration (Table 3-1, Table 3-2). The timing of when a dip treatment occurred within a season or treatment schedule was also analyzed by Hansen et al. (1992), Hata and Hara (1993) and Hata et al. (1993). Overall, fluvalinate has been the most extensively reviewed treatment for use on various pests, plants, and concentrations.

However, further research is needed to determine how a model biorational dip treatment may serve as an effective and reliable treatment for infested cuttings. As determined from the previous chapter, submersing coleus cuttings for one minute in Natur'l Oil at 1.0% was determined as a model dip treatment due to low phytotoxicity and high *P. madeirensis* mortality. However, several factors may still impact 1.0% Natur'l Oil efficacy. Factors that require further examination include dipping time and impact of various host plants. Determining how these

factors impact dipping efficacy elucidates a more effective method for greenhouse and nursery growers to treat cuttings infested with cryptic, invasive pests such as *P. madeirensis*.

Materials and Methods

Rearing Colonies of *P. madeirensis*

The procedure for rearing colonies of *P. madeirensis* was described in the materials and methods section from the previous chapter and was used for the exposure time and host plant efficacy bioassays conducted at the University of Florida Mid-Research and Education Center (UF-MREC) in Apopka, FL.

Host plant maintenance. The host plant maintenance protocol for *Solenostemon* spp. (coleus 'Big Red Judy') was described in the phytotoxicity assessment section and used for the exposure time bioassay. For the host plant efficacy bioassay, *Mentha* spp. (spearmint) and *Verbena* spp. (verbena) stock plants were grown at UF-MREC. Mint and verbena stock plants were grown from cuttings in an enclosed greenhouse from January to May 2013 with a 22.8^{0}C average daily temperature and 68% mean relative humidity at UF-MREC. Cuttings were rooted in 64-count cutting trays filled with Faford® Growing Mix 2/C-2 soil composed of Canadian sphagnum peat moss, perlite, vermiculite, dolomitic limestone, and wetting agent (2:1:1:1:1, vol:vol:vol:vol:vol). Mint and verbena stock plants were hand-watered daily until soil was evenly moistened and flowering parts were pruned to encourage further branching.

Cutting preparation. Coleus cuttings were prepared using the same procedure described in the materials and methods section from the previous chapter. However, mint and verbena cuttings were made by randomly selecting and excising the stem of a stock plant at a slight angle in order to prevent stem damage. All mint and verbena cuttings were at least 3 inches (7.62cm) in height. Mint or verbena cuttings with blemishes that resembled phytotoxicity characteristics

were discarded. Additionally, mint and verbena cuttings were made once the stock plant was over 6 inches (15.24cm) in height from the 64-count cutting tray.

Evaluation of Natur'l Oil Exposure Time on *P. madeirensis* Mortality

A total of five dip exposure times were tested with 1.0% Natur'l Oil and a water control: 1 second, 15 seconds, 30 seconds, 60 seconds, and 120 seconds. Three replicates were conducted in a 5 X 5 randomized complete block design for cuttings treated with 1.0% Natur'l Oil and the control, respectively. For each replicate, a total of 30 cuttings, each infested with 15 *P. madeirensis* mealybugs ranging from crawlers to virgin female adults, were evaluated for mortality. Data collection for each replicate began on a separate date and time: 11 April 2013, 19 April 2013, and 3 May 2013.

Dip treatment preparation. Five identical solutions of 1.0% Natur'l Oil (10mL of Natur'l Oil per 990mL of de-ionized water) were prepared and thoroughly mixed with a magnetic stirrer for five minutes. Five 1000mL of de-ionized water was used as a control.

Coleus cutting preparation. The protocol for preparing coleus cuttings was described in the evaluation of biorationals on *P. madeirensis* mortality section from the previous chapter.

Dipping method and planting procedure. Five infested coleus cuttings were randomly assigned to each exposure time for 1.0% Natur'l Oil and the control, respectively. Cuttings were dipped simultaneously in a 6.5 quart rectangular plastic bin. For the duration of each dip treatment, cuttings were fully submerged, lightly agitated, and rotated vertically at the middle of the designated exposure time to maximize surface area coverage. Dipped cuttings were lightly shaken to remove excess runoff and air dried until runoff ceased. Each cutting was transplanted into a labeled twelve inch plastic pot filled with moistened Faford® Growing Mix 2/C-2 soil.

Cutting observation and watering practices. The procedure for observing and watering cuttings was described in the evaluation of biorationals on *P. madeirensis* mortality section from the previous chapter.

Mealybug mortality evaluation. The method for evaluating *P. madeirensis* mortality was also explained in the evaluation of biorationals on *P. madeirensis* mortality section from the previous chapter.

Evaluation of Natur'l Oil on *P. madeirensis* Mortality on Various Host Plants

Two types of host plants were used for the host plant efficacy bioassays: mint and verbena. A total of four Natur'l Oil concentrations were tested with a water control: 0.1%, 0.5%, 1.0%, and 1.5%. Three replicates for each host plant was conducted in a 5 X 5 randomized complete block design. For each replicate, a total of 25 cuttings, each infested with 15 *P. madeirensis* mealybugs ranging from crawlers to virgin female adults, were evaluated for mortality. Data collection for each verbena replicate began on 8 May 2013 in the morning, 8 May 2013 in the afternoon, and 9 May 2013 in the morning. Data collection for each mint replicate began on 9 May 2013 in the afternoon, 10 May 2013 in the morning, and 10 May 2013 in the afternoon.

Dip treatment preparation. For each host plant replicate, four concentrations of Natur'l Oil were prepared and thoroughly mixed with a magnetic stirrer for five minutes: 0.10% (1mL of Natur'l Oil per 999mL of de-ionized water), 0.50% (5mL of Natur'l Oil per 995mL of de-ionized water), 1.0% (10mL of Natur'l Oil per 990mL of de-ionized water), and 1.50% (15mLof Natur'l Oil per 985mL of de-ionized water). One 1000mL of de-ionized water was used as a control.

Mint and verbena cutting preparation. To insure that cuttings had more than 15 mealybugs, mint and verbena plants were re-infested by exposure to *P. madeirensis* from the colony maintained at UF-MREC one week before the trial. Infested cuttings were made by

excising the stems at a 45^{o} angle to avoid stem damage. Cuttings were at least 3 inches (7.62cm) in height. Exactly 15 mealybugs were randomly selected to remain on the cutting. Mealybugs left on cuttings ranged from crawlers to adult females. Excess mealybugs, oviscas, male adults, or male cocoons were removed using a moistened camel hair paintbrush. If there were less than 15 mealybugs present on a cutting, mobile mealybugs from different colony leaves that varied in size and ranged from crawlers to adult females were randomly selected and transferred onto the cutting using a moistened camel hair paintbrush. All transferred mealybugs were left to settle on the cutting for at least fifteen minutes. All cuttings had a random number of active mealybug life stages present. A total of 15 mealybugs were left on each cutting. Each cutting was carefully sealed in a clear Ziploc® bag to maintain cutting moisture and reduce the risk of losing mealybugs when transporting the cutting to the greenhouse for treatment.

Dipping method and planting procedure. The method for evaluating *P. madeirensis* mortality was explained in the phytotoxicity assessment section from the previous chapter.

Cutting observation and watering practices. The procedure for observing and watering cuttings was described in the evaluation of biorationals on *P. madeirensis* mortality section from the previous chapter.

Mealybug mortality evaluation. The protocol for determining mealybug mortality was explained in the evaluation of biorationals on *P. madeirensis* mortality section from the previous chapter.

Statistics

Summary statistics for the exposure time and host plant efficacy bioassay were prepared using a fit linear model in the GLIMMIX Procedure (General Linear Model for Mixture Distributions) to account for non-normality and non-homogenous variances in SAS 9.3 (SAS Institute Inc., 2002-2010, Cary, NC, USA). For the exposure time bioassay, three replicates were

conducted in a 5 x 5 randomized complete block design for cuttings treated with 1.0% Natur'l Oil and the control, respectively. For each replicate, a total of 30 cuttings, each infested with 15 *P. madeirensis* mealybugs, were evaluated for mortality. For the host plant efficacy bioassay, three replicates for each host plant was performed in a 5 x 5 randomized complete block design. Each replicate had a total of 25 cuttings where each cutting was infested with 15 *P. madeirensis* mealybugs and evaluated for mortality. Significant difference between each time period, the average number of dead *P. madeirensis* per treatment over each time period, and the percentage of dead *P. madeirensis* per treatment over each time period were analyzed using Tukey-Kramer Least Squares Means for multiple comparisons (SAS Institute Inc., 2002-2010, Cary, NC, USA).

Results

Exposure time bioassay. The cumulative average percent of dead *P. madeirensis* was significantly different between each exposure time ($F=2.02$; $df=4$; $p=0.0887$) (Table 3-3).Across each time period for 1.0% Natur'l Oil, the 120, 60, and 30 second exposure time had the highest percentage of dead *P. madeirensis*. All control exposure times had a lower percentage of dead *P. madeirensis* than 1.0% Natur'l Oil.

Efficacy bioassay using verbena. Comparisons between Natur'l Oil concentrations showed a significant difference in the cumulative average percent of dead *P. madeirensis* between each post- treatment time period after being used as a dip for one minute ($F=53.22$; $df=4$; $p<0.0001$) (Table 3-4). At each time period, 1.5% and 1.0% Natur'l Oil had the highest percentage of dead *P. madeirensis* followed by 1.0% and 0.5% Natur'l Oil and 0.5% and 0.1% Natur'l Oil.

Efficacy bioassay using mint. The cumulative average percent of dead *P. madeirensis* was significantly different between Natur'l Oil concentrations in each post-treatment time period after being used as a one-minute dip ($F=78.50$; $df=4$; $p<0.0001$) (Table 3-5). Natur'l Oil at 1.5%

had the highest percentage of dead *P. madeirensis* in comparison to all other Natur'l Oil concentrations at each time period. Natur'l Oil at 1.0% and 0.5% had a higher percentage of dead *P. madeirensis* than 0.1% Natur'l Oil at each time period. The control consistently had the lowest percentage of dead *P. madeirensis* at each time period.

Discussion

Exposure time bioassay. The most efficacious 1.0% Natur'l Oil exposure times for controlling *P. madeirensis* on coleus was from 30 to 120 seconds since efficacy for each exposure time surpassed 70% mortality by Day 7. Initially on Day 1, mortality exceeded 35% mortality for each aforementioned exposure time whereas the 15 and 1 second 1.0% Natur'l Oil dips achieved significantly less than 30% mortality. The 15 and 1 second dip only exceeded 70% mortality by Day 14. The highest mortality for all exposure times occurred by Day 14 where all 1.0% Natur'l Oil exposure times achieved greater than 80% mortality. Differences in *P. madeirensis* mortality over time between exposure times may be attributed to the mechanical effects of dipping, susceptibility of *P. madeirensis* at various life stages, and most importantly, length of exposure time to 1.0% Natur'l Oil.

In the previous chapter, the mechanical act of dipping and treatment susceptibility differences at various instars of *P. madeirensis* were described in depth as potential factors that may have influenced differences in *P. madeirensis* mortality and caused high mortality in the water controls. These factors have also remained relevant to the exposure time bioassay. *Phenacoccus madeirensis* mortality most likely differed between treatments as a result of variation in dip exposure time to 1.0% Natur'l Oil. Increase in dip exposure time may have also amplified the likelihood of 1.0% Natur'l Oil direct adhesion onto the cuticle therefore inducing wax removal, suffocation, or cell membrane disruption faster than shorter dip exposure times (Butler et al. 1993, Hodgson and Kuhr 1990, Larew and Locke 1990).

Overall, the 30 second dip exposure time was determined as the ideal dipping time due to differences in phytotoxicity and *P. madeirensis* mortality. Only slight chlorosis, chlorotic flecking, and tip curling were readily observed for the 1, 15, and 30 second exposure times. However, the 60 and 120 second dip induced slight chlorosis, chlorotic flecking, necrotic flecking, tip curling, and holes. Additionally, *P. madeirensis* mortality between the 30, 60, and 120 second dip exhibited no significant difference.

The exposure time bioassay may be improved in several ways. As described in the previous chapter, adjustments regarding the impact of mechanical dipping and evaluating each *P. madeirensis* life stage independent from one another remain applicable for future exposure time studies. Additionally, each dip exposure time may be evaluated on separate days to reduce the frequency of transferring mobile mealybugs from various mealybug colony leaves. High water control mortality may also be prevented by having both raters only touch the mealybugs three times with a damp camel hair brush during the mealybug mortality evaluation.

Efficacy bioassays using mint and verbena. The most efficacious Natur'l Oil concentrations for controlling *P. madeirensis* on verbena cuttings were 1.5% and 1.0%. On Day 1, only 1.5% and 1.0% Natur'l Oil surpassed 30% mortality. Efficacy steadily increased for 1.5% and 1.0% where both dips exceeded 80% mortality by Day 7. Natur'l Oil at 0.5% and 1.0% only slightly surpassed 70% mortality by Day 7. The highest mortality for all treatments occurred by Day 14 where all treatments exceeded 80% mortality. 1.0% and 1.5% Natur'l Oil were the only treatments that surpassed 90% mortality by Day 14.

Natur'l Oil at 1.5% was determined as the most effective concentration for controlling *P. madeirensis* on mint cuttings. On Day 1, 1.5% reached over 60% mortality while all other Natur'l Oil concentrations had less than 50% mortality. By Day 3, 1.5% exceeded 80% mortality

followed by 1.0% with 70% mortality. The highest mortality for all treatments occurred by Day 14 as 0.5%, 1.0%, and 1.5% Natur'l Oil had over 90% mortality. Only 1.5% Natur'l Oil exceeded 95% mortality by Day 14.

Phenacoccus madeirensis mortality between treatments for the verbena and mint efficacy bioassay may mostly be influenced by differences in concentration as opposed to the mortality evaluation and the act of agitating cuttings via the dipping or transplanting technique described in the efficacy bioassay discussion from the previous chapter. Increase in mortality with higher concentrations mirror results from Liu and Stansly (2000) where the 1.0% and 0.5% vegetable oil dip induced the silverleaf whitefly, *Bemisia argentifolii* Bellow & Perring, 53% and 60% mortality, respectively, on collard and tomato dipped leaves.

The mint and verbena host plant surface in addition to the repellant activity of mint may have also impacted differences in *P. madeirensis* mortality between host plants. Mint and verbena surface area varied in texture and plant hair presence thus Natur'l Oil deposition was different between host plants and may be attributed towards differences in efficacy (Odenwald and Turner 2006, Gilman 1999). Additionally, species in the genus *Mentha* have been known to exhibit repellant activity to several insect species and therefore may have impacted the number of *P. madeirensis* found on each cutting over each time period (Ansari et al. 2000, Mekuaninte et al. 2011, Kumar et al. 2011).

The model dip concentration for various host plants was 1.0% Natur'l Oil due to differences in phytotoxicity. Several phytotoxicity characters were present on mint and verbena cuttings dipped in 1.5% Natur'l Oil and included moderate chlorosis, chlorotic flecking, necrotic flecking, holes, tip chlorosis, and eventually tip necrosis. Few phytotoxicity characters were readily observed with mint and verbena cuttings dipped in 1.0% Natur'l Oil. Slight chlorosis,

chlorotic flecking, and tip chlorosis were observed with 1.0% Natur'l Oil. As a result, the most practical application from the host plant bioassays includes using 1.0% Natur'l Oil as the model dip. The results showed that 1.0% Natur'l Oil was the most effective concentration that induced acceptable phytotoxicity expression. Thus greenhouse productivity may be higher due to the economical savings derived from using 1.0% rather than 1.5% Natur'l Oil.

Several improvements may be implemented towards prospective host plant studies. As described in the previous chapter, modifications regarding the impact of mechanical dipping and evaluating each *P. madeirensis* life stage independent from one another also remain applicable to future host plant studies. The addition of coleus as a host plant control in the mint and verbena host plant efficacy bioassay may also be implemented.

Model dip protocol implications. Preventing the importation of invasive species on cuttings has driven the need for using of an effective dip protocol with acceptable phytotoxicity. Results from this study showed that the dip protocol could be 1.0% Natur'l Oil as a 30 second dip. Reduction in exposure time from one minute to 30 seconds showed no significant difference in mortality and lower phytotoxicity. Additionally, more than 70% *P. madeirensis* mortality was achieved within seven days and expressed marginal phytoxicity. In future studies, the dip protocol could be evaluated on additional host plants, invasive species, and various dipping locations.

Table 3-1. Dip treatment efficacy evaluated on various arthropod ornamental and agricultural pests.

Pest Groups	Scientific Name	Common Name	Dip Treatments	Reference
Ants	*Technomyrmex difficilis* Forel	White-footed ant	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
Aphids	*Aphis gossypii* Glover	Cotton aphid	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
	Myzus persicae (Sulzer)	Green peach aphid	Mavrik Aquaflow	Osborne 1986
	Pentalonia nigronervosa Coquerel	Banana aphid	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Fluvalinate, insecticidal soap, hot water treatment	Hara et al. 1996
			Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
			Mavrik Aquaflow, Tempo 2, Safer insecticidal Soap	Hansen et al. 1992
Beetles	*Diaprepes abbreviatus* L.	Diaprepes root weevil	Mavrik Aquaflow, Tempo 2, Safer insecticidal Soap	Simanton and Bullock 1973
	Phyllotocus ustulatus Blanch		Agral, deltamethrin, fluvalinate, petroleum oil, bifenthrin	Seaton et al. 1993
Earwigs	*Chelisoches morio* (Fabricius)	Black earwig	Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
Hard and Soft Scales	*Coccus viridis* (Green)	Green scale	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
	Mesolecanium nigrofasciatum (Pergande)	Terrapin scale	Soybean oil, petroleum oil	Pless et al. 1995

Table 3-1. Continued

Pest Groups	Scientific Name	Common Name	Dip Treatments	Reference
Hard and Soft Scales	*Pseudaulacaspis cockerelli* (Cooley)	False oleander scale	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
	Quadraspidiotus perniciosus Comstock	San Jose scale	Soybean oil, petroleum oil	Pless et al. 1995
Mealybugs	*Nipaecoccus nipae* (Maskell)	Coconut mealybug	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
	Phenacoccus solani Ferris	Solanum mealybug	Mavrik Aquaflow	Osborne 1986
	Planococcus citri (Risso)	Citrus mealybug	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
			Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
	Pseudococcus affinis (Maskell)	Obscure mealybug	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
			Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
	Pseudococcus longispinus (Targioni-Tozzetti)	Longtailed mealybug	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
			Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
			Mavrik Aquaflow, chlorpyrifos	Hata et al. 1992
Mites	*Panonychus ulmi* (Koch)	European red mite	Soybean oil, petroleum oil	Pless et al. 1995
			Sunspray Ultra Fine	Agnello et al. 1994

Table 3-1. Continued

Pest Groups	Scientific Name	Common Name	Dip Treatments	Reference
Mites	*Tetranychus urticae* Koch	Two-spotted spider mite	Mavrik Aquaflow	Osborne 1986
Moths	*Epiphyas postvittana* Walker	Lightbrown apple moth	C15 Ampol CPD, C23 Ampol DC-Tron NR	Taverner et al. 1999
Thrips	*Frankliniella occidentalis* (Pergande)	Western flower thrips	Insecticidal soap, isopropyl alcohol, insecticidal fog, hot water immersion	Mann et al. 1995
			Abamectin, chlorpyrifos, oil-soap	Hata et al. 1993
	Scirtothrips cardamoni (Ramakr)	Cardamom thrips	Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
	Thrips palmi Karny	Melon thrips	Insecticidal soap, isopropyl alcohol, insecticidal fog, hot water immersion	Mann et al. 1995
Thrips	*Thrips palmi* Karny	Melon thrips	Abamectin, chlorpyrifos, oil-soap	Hata et al. 1993
Whiteflies	*Bemisia argentifolii* Bellow and Perring	Silverleaf whitefly	Sunspray oil, M-Pede, extract of Nicotiana, bifenthrin	Liu and Stansly 1995
			M-Pede, Sunspray oil, Margosan-O, bifenthrin	Liu and Stansly 1995
	Tialeurodes vaporariorum (Westwood)	Greenhouse whitefly	Mavrik Aquaflow	Osborne 1986

Table 3-2. Dip treatment efficacy evaluated on various ornamental and agricultural plants.

Scientific Name	Dip Treatment	Reference
Alinia purpurata (Vieill.) K. Schum	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
	Orthene T, T&0, Talstar F, Tempo 2EC, Tame 2.4EC	Hata and Hara 1993
	Fluvalinate, insecticidal soap, hot water treatment	Hara et al. 1996
	Mavrik Aquaflow, chlorpyrifos, insecticidal soap	Hata et al. 1992
Anthurium sp. L.	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
Anthurium andraeanum Linden	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Arundina graminifolia (D. Don) Hochr	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Calathea insignis Petersen	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Calathea lancifolia Boom	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
Chamelaucium uncinatum Schuaer	Agral, deltamethrin, Mavrik Aquaflow, petroleum oil, bifenthrin	Seaton et al. 1993
Cissus rhombifolia Vahl	Mavrik Aquaflow	Osborne 1986.
Citrus sp. L.	C15 Ampol CPD, C23 Ampol DC-Tron NR	Taverner et al. 1999
	Mavrik Aquaflow, Tempo 2, Safer insecticidal Soap	Simanton and Bullock 1973
Codiaeum variegatum (L.) Blurne	Mavrik Aquaflow	Osborne 1986.
Cordyline terminalis (L.) Kunth	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
	Mavrik Aquaflow	Osborne 1986.
	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Curculigo capitulate (Lour.) Kuntze	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Cycas circinalis L.	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992

Table 3-2. Continued

Scientific Name	Dip Treatment	Reference
Cycas revolute Thunb.	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Dendrobium phalaenopsis Fitzg.	Insecticidal soap, isopropyl alcohol, insecticidal fog, hot water immersion	Mann et al. 1995
	Abamectin, chlorpyrifos, oil-soap	Hata et al. 1993
	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Dicranopteris linearis (Burm.f.) Underw.	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
Dieffenbachia maculate (Lodd.) G. Don.	Mavrik Aquaflow	Osborne 1986.
Dracaena fragans (L.) Ker-Gawl	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Dracaena marginata Lam.	Mavrik Aquaflow	Osborne 1986.
Epipremnum aureum (Linden & Andre) Bunt.	Mavrik Aquaflow	Osborne 1986.
	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Ficus pumila L.	Mavrik Aquaflow	Osborne 1986.
Gleichenia linearis (Brum. f.)	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Glycine max L.	Soybean oil, petroleum oil	Pless et al. 1995
Hedera helix L.	Mavrik Aquaflow	Osborne 1986.
Hoya carnosa (L.f.) R. Br.	Mavrik Aquaflow	Osborne 1986.
Lycopodium cernuum L.	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992
	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Maranta leuconeura E. Morr. Kerchoviana	Mavrik Aquaflow	Osborne 1986.
Monstera deliciosa Liebm.	Mavrik Aquaflow, Tempo 2, Safer Insecticidal Soap	Hansen et al. 1992
Perperomia obtusifolia (L.) A. Dietr.	Mavrik Aquaflow	Osborne 1986.
Philodendron scandens oxycardium (Schott) Bunt.	Mavrik Aquaflow	Osborne 1986.

Table 3-2. Continued

Scientific Name	Dip Treatment	Reference
Solanum lycopersicum L.	Sunspray oil, M-Pede, extract of Nicotiana, bifenthrin	Liu and Stansly 1995
	M-Pede, Sunspray oil, Margosan-O, bifenthrin	Liu and Stansly 1995
Strelitzia reginae Aiton	Insecticidal soap, Mavrik Aquaflow	Tenbrink et al. 1992

Table 3-3. Cumulative average percent of dead *P. madeirensis* per coleus cutting dipped in varying dip exposure times for each time period.

Treatment	Pesticide	Time Period (Days)			
		1	3	7	14
		(Mean ±SE)	(Mean ±SE)	(Mean ±SE)	(Mean ±SE)
1 second	1.0% Natur'l Oil	24.78% ±2.225%c	41.62% ±2.822%c	60.53% ±2.781%c	81.28% ±1.849%c
	Control	6.296% ±0.8548%e	12.69% ±1.560%e	23.82% ±2.492%e	46.96% ±3.333%e
15 seconds	1.0% Natur'l Oil	32.96% ±2.621%bc	51.54% ±2.921%bc	69.59% ±2.512%bc	86.63% ±1.444%bc
	Control	8.798% ±1.099%d	17.27% ±1.897%d	30.99% ±2.769%d	55.97% ±3.146%d
30 seconds	1.0% Natur'l Oil	35.37% ± 2.725%abc	54.21% ±2.920%abc	71.81% ±2.420%abc	87.82% ±1.346%abc
	Control	11.34 % ±1.336%d	21.68% ±2.185%d	37.32% ±2.935%d	62.78% ±2.917%d
60 seconds	1.0% Natur'l Oil	36.21% ±2.751%ab	55.12% ±2.918%ab	72.54% ±2.395%ab	88.21% ±1.315%ab
	Control	6.562% ±0.8432%e	13.19% ±1.524%e	24.63% ±2.398%e	48.07% ±3.143%e
120 seconds	1.0% Natur'l Oil	46.59% ±2.937%a	65.37% ±2.677%a	80.24% ±1.928%a	92.00% ±0.9454%a
	Control	12.87% ±1.514%d	24.21% ±2.410%d	40.73% ±3.112%d	66.06% ±2.892%d

Within a column, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means; F=2.02; df=4, 2239; p=0.0887).

Table 3-4. Cumulative average percent of dead *P. madeirensis* per verbena cutting dipped for one minute in each Natur'l Oil concentration for each time period.

Natur'l Oil Treatment	Time Period (Days)			
	1	3	7	14
	(Mean ±SE)	(Mean ±SE)	(Mean ±SE)	(Mean ±SE)
Control	5.123% ± 0.7634%d	10.82% ± 1.456%d	31.47% ± 2.976%d	51.05% ± 3.271%d
0.1%	21.82% ± 2.349%c	38.54% ± 3.187%c	70.35% ± 2.847%c	84.35% ± 1.920%c
0.5%	28.26% ± 2.556%bc	46.95% ± 3.036%bc	77.01% ± 2.274%bc	88.38% ± 1.460%bc
1.0%	32.60% ± 2.625%ab	52.08% ± 2.881%ab	80.44% ± 1.977%ab	90.33% ± 1.230%ab
1.5%	41.63% ± 2.880%a	61.58% ± 2.777%a	85.85% ± 1.585%a	93.23% ± 0.9172%a

Within a column, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means; F=53.22; df=4, 1115; p<0.0001).

Table 3-5. Cumulative average percent of dead *P. madeirensis* per mint cutting dipped for one minute in each Natur'l Oil concentration for each time period.

Natur'l Oil Treatment	Time Period (Days)			
	1	3	7	14
	(Mean ±SE)	(Mean ±SE)	(Mean ±SE)	(Mean ±SE)
Control	7.337% ± 1.1017%d	17.66% ± 2.039%d	33.65% ± 2.919%d	58.29% ± 3.096%d
0.1%	19.88% ± 2.212%c	40.20% ± 3.211%c	61.39%% ± 3.158%c	81.41% ± 2.167%c
0.5%	43.64% ± 3.135%b	67.71% ± 2.822%b	83.22% ± 1.922%b	93.18% ± 0.9848%b
1.0%	49.07% ± 3.011%b	72.30% ± 2.477%b	86.06% ± 1.621%b	94.45% ± 0.8057%b
1.5%	63.85% ± 2.994%a	82.71% ± 1.964%a	91.88% ± 1.113%a	96.89% ± 0.5003%a

Within a column, means followed by the same letter are not significantly different (P> 0.05; Tukey-Kramer Grouping for Least Squares Means; F=78.50; df=4, 1116; p<0.0001)

CHAPTER 4
IMPLICATIONS AND FUTURE DIRECTIONS

Florida greenhouse operations are susceptible to invasive pests due to the warm, humid climate and the high movement of people, tourism and product shipments along 30 ports of entry (U.S. Department of Homeland Security 2013). Pest management and control for invasive and native ornamental pests costs Florida growers 16-20% of their production expenses (Hodges 1998). As a result, further research to control invasive species is needed to meet the need for clean ornamental commodities.

In this study, *P. madeirensis* was used for modeling the control of other invasive cryptic species not known to occur in the United States for several reasons. Hemiptera is the most commonly intercepted order at United States ports of entry (McCullough et al. 2006, Jenkins et al. 2014). As an invasive, cosmopolitan mealybug, *P. madeirensis* is one of several successfully established invasive species in Florida (Frank and Thomas 2004). Scales and mealybugs continue to be a top concern in relation to the movement of cryptic species. Crawlers and nymphs are small and easily hidden on the underside of leaves, notches created by plant nodes or buds on the stems, or crevices on the leaves and stems (Buss et al. 1992, Hollingsworth and Hamnet 2009).

The use of synthetic insecticide dips as a control for scales and mealybugs on ornamental commodities has been extensively analyzed with fluvalinate (Osborne 1986, Hata et al. 1992, Hansen et al. 1992) (Table 3-1). However, mealybugs such as *Phenacoccus madeirensis* have been one of the most difficult mealybugs to manage with synthetic insecticides (Chong 2005, Ludwig 2009). Resistance and overuse of synthetic insecticides coupled with the demand for using a cost-effective, environmentally safe, non-phytotoxic and efficacious treatment for

controlling invasive species on ornamental stock has led to evaluating biorational insecticides as a viable treatment.

To determine a model biorational dip, four insecticides were used as a one minute dip and evaluated for efficacy and phytotoxicity at varying concentrations on coleus cuttings infested with *P. madeirensis*: Natur'l Oil (soybean oil), Publix Soap (nonylphenol ethoxylate), Vapor Gard® (di-1-p-menthene), and Wetcit™ (alcohol ethoxylate). Six foliage phytotoxicity characters were key indicators: chlorosis, chlorotic flecking, necrotic flecking, tip chlorosis, tip necrosis, and holes. The highest concentration for each biorational insecticide with acceptable damage included the following: 1.0% Natur'l Oil, 1.0% Publix Soap, 0.1% Wetcit, and 0.1% Vapor Gard. Final determination for the model biorational dip was based on using each selected biorational insecticide for controlling coleus cuttings infested with *P. madeirensis*. Modifications to the mealybug mortality protocol from Hata et al. (1992) were used to determine that the highest mealybug mortality was achieved with 1.0% Natur'l Oil (90.97%) and 0.1% Wetcit (90.47%), followed by 1.0% Publix Soap (86.17%), 0.1% Vapor Gard (85.72%), and the control (65.19%). Overall, 1.0% Natur'l Oil was determined as the model dip treatment over 0.1% Wetcit. Natur'l Oil at 1.0% was less phytotoxic than 0.1% Wetcit for each key foliage phytotoxicity character and has been known to effectively control various ornamental pests. Liu and Stansly (2000), Pless et al. (1995), Butler et al. (1993), and Amer et al. (2001) reported soybean oil at the recommended dosage rate as an efficacious insecticidal control for the silverleaf whitefly, *Bemisia argentifolii* Bellow & Perring, sweetpotato whitefly, *Bemisia tabaci* (Gennadius), San Jose scale, *Quadraspidiotus perniciosus* (Comstock), terrapin scale, *Mesolecanium nigrofasciatum* (Pergande), European red mite, *Panonychus ulmi* (Koch), and two spotted spider mite, *Tetranychus urticae* Koch. In comparison, several studies only observed

alcohol ethoxylate insecticidal activity (Liu and Stansly 2000, Imail et al. 1994, Davidson et al. 1991, Hesler and Plapp 1986, Tattersfield and Gimingham 1927, Wolfenbarger et al. 1967, Imail and Tsuchiya 1995, Cory and Langford 1935).

Dipping time and host plant efficacy were also tested with the model biorational dip. Natur'l Oil at varying concentrations, modified from the Hata et al. (1992) protocol, was evaluated for efficacy at different exposure dip times and on various types of host plants. Results for the exposure dip times for 1.0% Natur'l Oil showed that highest mortality was achieved with the 30 (87.82%), 60 (88.21%), and 120 (92.00%) second dip. Host plant efficacy results differed between mint and verbena. Results for mint cuttings showed the highest mortality for 1.5% Natur'l Oil (96.89%) while verbena cutting results confirmed the highest mortality for 1.0% (90.33%) and 1.5% Natur'l Oil (93.23%). Overall, 1.0% Natur'l Oil as a 30 second dip was determined as the model dip protocol for treating ornamental cuttings due to phytotoxicity. At the shortest exposure time, the 30 second dip showed the most acceptable phytotoxicity of the three highest mortality dipping times. Additionally, mint and verbena cuttings treated with 1.5% Natur'l Oil showed moderate phytotoxicity: moderate chlorosis, chlorotic flecking, necrotic flecking, hole, tip chlorosis, and tip necrosis. However, only marginal phytotoxicity was observed with 1.0% Natur'l Oil on mint and verbena cuttings: slight chlorosis, chlorotic flecking, and tip chlorosis.

Developing a model dip protocol provides Florida growers a viable, on-site treatment option for importing clean ornamental commodities. Results from this study showed 1.0% Natur'l Oil surpassing 70% *P. madeirensis* mortality by Day 7 for coleus and verbena cuttings and Day 3 for mint cuttings. As a single on-site dip, 1.0% Natur'l Oil induced marginal phytotoxicity and greatly reduced the number of *P. madeirensis* within a nursery operation after

fourteen days. As a result, surveys similar to Hodges et al. (1998) and Hodges (2011) could evaluate Florida growers on the demand and application of using the model dip as part of a systems approach. Future on-site dip studies could also analyze 1.0% Natur'l Oil compatibility with other synthetic insecticide applications in terms of percent mortality since 98% of all Florida nurseries use at least one synthetic insecticide (Hodges et al. 1998, Hodges 2011). Modifications to the model dip protocol may be warranted for developing a postharvest dip protocol as described in Hata et al. (1986).

Several invasive, cryptic ornamental pests should also be evaluated in future efficacy studies with the model dip protocol. Hemiptera is the most commonly intercepted order at United States ports of entry and includes several of the most damaging ornamental pest groups: scales, mealybugs, whiteflies, and aphids (McCullough et al. 2006, Jenkins et al. 2014, Oetting et al. 2006). As a result, model pests for future efficacy studies could include the following: the pink hibiscus mealybug, *Maconellicoccus hisutus* (Green), passionvine mealybug, *Planococcus minor* (Maskell), lobate lac scale, *Paratachardina pseudolobata* (Kondo and Gullan), melon aphid, *Aphis gossypii* Glover, green peach aphid, *Myzus persicae* (Sulzer), sweetpotato whitefly, *Bemisia tabaci* Gennadius, and citrus mealybug, *Planococcus citri* (Risso) (Table 1-1) (Frank and Thomas 2004, McCullough et al. 2006, Oetting et al. 2006, Jenkins et al. 2014).

More work is also needed to assess phytoxicity on other host plant cuttings. Additional surveys similar to Hodges et al. (1998) and Hodges (2011) could also evaluate Florida growers on the type, number, and buyers of host plant cuttings. For future phytotoxicity assessments with *P. madeirensis*, cuttings made from the most commonly infested *P. madeirensis* host plants in Florida could be evaluated: *Hibiscus* spp., *Acalypha* spp., *Mandevilla* spp., *Jatropha* spp., *Salvia* spp., *Cestrum* spp., *Plectranthus* spp., *Ruellia* spp., *Leucophyllum* spp., *Bidens* spp., *Lantana*

spp., *Schefflera* spp., *Orthosiphon* spp., *Crossandra* spp., *Capsicum* spp., *Chrysanthemum* spp., *Sida* spp., *Pelargonium* spp., *Thunbergia* spp., *Pentas* spp., and *Solanum* spp. (Stocks 2012).

In conclusion, preventing the spread of invasive species on ornamental cuttings may be achieved by carefully modifying and integrating the dip protocol within a systems approach. However, more phytotoxicity and efficacy information is needed to refine the dip protocol for field application. Phytotoxicity assessments on a variety of ornamental cuttings and efficacy analysis on several ornamental invasive pests should be conducted in the future. Results from both studies may ultimately be used to develop a comprehensive dosage rate list for acceptable phytotoxicity damage and effective invasive pest control for imported cuttings.

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BIOGRAPHICAL SKETCH

Sarahlynne Guerrero grew up in Palm Bay, FL and graduated from the Sebastian River High School International Baccalaureate Program in May of 2007. After graduation, she enrolled at the University of Florida and majored in Entomology and Nematology under the encouragement of Drs. Carl Barfield and Rebecca Baldwin. During this time, her interest in biosecurity and invasive species blossomed through her United States Department of Agriculture, Animal and Plant Health Inspection Services, Plant Protection and Quarantine student internship, where she proudly served as assistant to the Regional Identifier, Julieta Brambila, and member of the Florida Cooperative Agricultural Pest Survey Program under Dr. Leroy Whilby. While at UF, Sarahlynne also joined the laboratory of Dr. Robert Meagher and worked on evaluating the efficacy of invasive moth traps for her senior project.

Sarahlynne was offered a graduate research assistantship at UF beginning January 2012 under the direction of Dr. Amanda Hodges. While at UF, her research project was co-advised by Drs. Amanda Hodges and Lance Osborne. Her project mirrored her strong interest in preventing the dissemination of invasive species. Sarahlynne's career goals include helping to prevent the spread of invasive pests through her work with Dow AgroSciences. She began working in the structural fumigation market for Dow AgroSciences in California on September 2013.