Susceptibility of *Phytoseiulus persimilis* and *Neoseiulus californicus* (Acari: Phytoseiidae) to Commonly Used Insecticides Approved for Managing Arthropod Pests in Florida Strawberries[1]

Braden Evans, Karol Krey, and Justin Renkema[2]

Florida Strawberry Production

The Florida strawberry industry is valued at over $300 million, accounting for 15,000 jobs and 15% of total US strawberry production (1). Owing to the subtropical climate, Florida strawberries are produced during the winter months, representing 100% of US winter strawberry production. Nearly all of Florida's strawberries (~95%) are grown in Hillsborough and Manatee counties, centered in the Plant City area. With high production costs and increasing price pressure from strawberry imports grown in Mexico, Florida producers are dependent on effective and efficient pest management programs (1) (Figure 1). The aim of this document is to inform Florida strawberry producers and Extension personnel on the compatibility of registered miticides and insecticides with commercially available predatory mites used as biological controls.

Twospotted Spider Mite

The most important arthropod pest in Florida strawberries is the twospotted spider mite, Tetranychus urticae Koch (1). The twospotted spider mite (TSSM) is a highly polyphagous pest of many horticultural crops throughout the world, with over 1,100 host plant species reported (2). In strawberry cultivation, TSSM inhabits the underside of developed leaves, forming silk webs and causing silvery-white patches (3). The TSSM uses its specially adapted mouthparts to pierce and suck the contents of individual plant cells (3). The feeding removes the sap from the cells, causing pale areas to appear on the upper surface of leaves (3). As TSSM continues to feed, the foliage begins to bronze, becomes dry, and the leaves drop off the plants (Figure 2). Total defoliation can result if an infestation is not controlled (3).

Figure 1. Early season Florida strawberry transplants. Florida strawberries are grown in raised beds with plastic mulch covering over sterilized soil at a production cost of over $27,000 per acre (1). Credits: Babu Panthi, University of Florida.

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2. Braden Evans, postdoctoral associate; Karol Krey, postdoctoral associate; and Justin Renkema, associate professor; Gulf Coast Research and Education Center, UF/IFAS Extension, Wimauma, FL 33598.

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Figure 2. Adult and nymph twospotted spider mites (*Tetranychus urticae*) crawling along webs and stems, and the webbing and foliar discoloration on strawberry plants resulting from a severe twospotted spider mite infestation.
Credits: Lyle Buss and James Castner, University of Florida.

Many miticide products with different modes of action have been developed for TSSM control. Although strawberry producers are dependent on regular miticide applications, TSSM have demonstrated a propensity to develop resistance against a variety of compounds. In a review of reported cases of insecticide/miticide resistance, TSSM ranked first among all insect and mite pests, with control failures due to resistance reported from 95 different active ingredients (4). A high reproductive rate, a short life cycle, and the ability to reproduce without mating are counted among the biological attributes contributing to rapid and frequent resistance development in TSSM (5). Due to the tendency of TSSM to develop resistance to a wide array of miticides, biological control with predatory mites has been developed and is used for TSSM management in Florida strawberry.

Phytoseiulus persimilis

Phytoseiulus persimilis (Athias-Henriot) (Acari: Phytoseiidae) is a predatory mite that is used as a biological control agent against TSSM in a range of horticultural crops. *P. persimilis* is considered a specialist predator and feeds almost exclusively on mites in the genus *Tetranychus* (6, 7, 8). A native of Chile, *P. persimilis* has been introduced throughout the world as a biological control agent targeting spider mites in ornamental, vegetable, and fruit crops, including strawberries (9, 10, 11).

Phytoseiulus persimilis features several characteristics that enable it to effectively control TSSM populations. It is a voracious and efficient predator, able to consume up to 20 individual TSSM of all life stages (eggs, larvae, nymphs, and adults) in a 24-hour period (12) (Figure 3). Nymph and adult *P. persimilis* actively seek out and feed on spider mites, but the larval stage is non-feeding. Under optimal environmental conditions, i.e., temperatures between 20–30°C (68°F–86°F) and relative humidity above 60%, *P. persimilis* may complete its entire life cycle within 5 days, as compared to spider mite development times of up to 20 days (12). Adult *P. persimilis* may live as long as 35 days, with highly fecund females producing 2–3 eggs per day, up to as many as 60 eggs in a lifetime (12). These various attributes have led to the commercialization and widespread use of *P. persimilis* as a biological pest management product.

Figure 3. Adult *Phytoseiulus persimilis* with a recently consumed twospotted spider mite (*Tetranychus urticae*).
Credits: James Castner, University of Florida

Effective control of TSSM is dependent on appropriately timed introductions of predators into infested crops. Successful pest suppression has been reported when *P. persimilis* is applied early in a TSSM infestation, before pest populations increase to severely damaging levels (13, 14). In Florida strawberry fields, TSSM infestations are often patchily-distributed. Inoculation densities of five adult *P. persimilis* per plant can achieve an acceptable level of control. Although *P. persimilis* is blind, it can disperse rapidly throughout the crop, following chemical cues such as kairomones—the volatile compounds emitted by plants in response to feeding damage—as well as physical cues, including the webbing produced by TSSM (15, 16).

Neoseiulus californicus

Neoseiulus (formerly *Amblyseius*) *californicus* McGregor (Acari: Phytoseiidae) is another species of predatory mite that is commercially available as a biological control agent (11). Wild populations of *N. californicus* occur on fruit, vegetable, and ornamental crops throughout the world in temperate and subtropical regions (17). Like *P. persimilis*, *N. californicus* has a preference for feeding on mites in the

family Tetranychidae, and it is commonly employed in cultivated crops against TSSM (Figure 4) (11). However, *N. californicus* is highly polyphagous, as compared to the narrow host range of *P. persimilis*. *Neoseiulus californicus* can subsist on different mite species, small insects, and even pollen in the absence of preferred prey items (18, 19). Whereas *P. persimilis* populations tend to perish when TSSM resources have been exhausted, *N. californicus* can establish permanent populations when it is introduced into new areas. Some of the biological attributes contributing to the success of *N. californicus* in colonizing new areas include its acceptance of a wide range of prey items, generally low food requirements, and low tendency for cannibalism (11, 20, 21). *Neoseiulus californicus* has also demonstrated an ability to develop resistant to pesticides, favoring its persistence in cropping systems where pesticides are used selectively and in moderation (22, 23, 24). *Neoseiulus californicus* favors warm temperatures, but can withstand a range of 10°C–33°C (50°F–91°F), with a preference for 40%–80% relative humidity (25). *Neoseiulus californicus* lay an average of 2 eggs per day and have an adult lifespan of ~20 days, with total lifecycle development time ranging from 26–37 days (25).

Figure 4. Adult *Neoseiulus californicus* attacking a twospotted spider mite (*Tetranychus urticae*).
Credits: Lyle Buss, University of Florida

Adult *P. persimilis* have been shown to consume up to 3 times more TSSM than adult *N. californicus* (26). The lower rate of TSSM consumption by *N. californicus* causes for a slower reduction in TSSM populations, but suppression of TSSM can be sustained over a longer period than with *P. persimilis* (17). Release rates of 1 *N. californicus* adult per 10 TSSM have been shown to effectively suppress TSSM. Different application techniques have been examined, with a predator-in-first technique (low release rates prior to TSSM detection) and site-specific releases (targeting specific "hot spot" areas in infested fields), showing good suppression results at lower cost to the grower (25, 27).

Chemical Pesticides

Approximately 15% of Florida strawberries are produced with the use of predatory mites to control TSSM (1). However, severe TSSM outbreaks and the management of other, less common insect and mite pests regularly require the use of chemical insecticides and miticides (1). Given the importance of the biological control services provided by *P. persimilis* and *N. californicus* in this production system, there is a need to understand potential detrimental effects of pesticides on beneficial predators (28, 29).

Koppert Biological Systems and Biobest Sustainable Crop Management, distributors of commercial predatory mite formulations, produce side-effect manuals designed to summarize the compatibility of common commercial chemical products with beneficial organisms. These manuals can be of significant value to growers, allowing them to anticipate potentially antagonistic interactions among management efforts while addressing complex pest problems. Understanding the potential for undesirable, non-target effects of chemical sprays gives growers the opportunity to plan pesticide application timing to minimize exposure of predator releases, or to select reduced risk pesticides when beneficial organisms are present in the field.

The side-effect manuals can be found at the following links:

https://www.koppert.com/side-effects/

https://www.biobestgroup.com/en/side-effect-manual

The Vegetable Production Handbook of Florida (2017–2018) lists 63 pesticide products as registered for use against arthropod pests in Florida strawberries, including 42 conventional products and 21 OMRI-listed (Organic Materials Review Institute) organic formulations. Appendices A and B has been developed as a tool for growers and extension personnel to cross-reference the effect of each of these products (as well as the most recently registered Nexter WP miticide and Exirel insecticide) on *P. persimilis* and *N. californicus*.

The toxic effects in the appendix tables are categorized as non-toxic (i.e. causing less than 25% mortality in *P. persimilis* and/or *N. californicus*), slightly toxic (25–50%), moderately toxic (50–75%), and highly toxic (>75%). Appendix A summarizes all of the products registered for use in conventional fields, and appendix B summarizes all of the products registered for use in organic fields (OMRI-listed products). Commercial formulations containing a combination of two different active ingredients are

assigned the rating of the most toxic component. The data summarized from the side-effects manuals is comprised of mortality rates resulting from foliar spray applications on motile (adult and nymph) stages of predatory mites. When the toxic effects reported in the manuals are inconsistent, a range representing values in both manuals is reported.

Among conventional insecticides and miticides (Appendix A), nearly as many products are rated as highly toxic to both predator species (8) as those rated non-toxic (9), with the majority of products (27) falling into an intermediate toxicity range. Florida strawberry producers have some pest management alternatives that offer reduced risks to beneficial predatory mites. Among OMRI-listed organic pesticides (Appendix B), only M-pede (potassium salts of fatty acids) is rated as highly toxic to both predator species, with five formulations of *Bacillus thuringiensis* rated as non-toxic to both species. While the toxicity ratings of most products are similar for both predator species, *N. californicus* is, generally, less susceptible to insecticides than *P. persimilis*. Nine conventional products are rated as highly toxic to *N. californicus*, versus 13 for *P. persimilis*, while 11 products rank as non-toxic to both species. Among OMRI-listed products, there are 9 non-toxic products and 1 highly toxic product affecting *N. californicus*, as compared to 6 non-toxic and 2 highly toxic products affecting *P. persimilis*. These summaries can serve as a useful tool to growers, helping to inform decisions on insecticide and miticide applications in strawberry fields.

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Appendix A. Summary of non-target toxicity classifications to *Phytoseiulus persimilis* and *Neoseiulus californicus* for selected conventional insecticides and miticides approved for managing arthropod pests of strawberry in Florida as reported in the Side Effects Manuals produced by Koppert Biological Systems and Biobest Sustainable Crop Management.

Product	Toxicity to *P. persimilis*	Toxicity to *N. californicus*	Active ingredient	Mode of action	Application rate/A	Pests targeted
Acramite 50 WS	slightly toxic	non-toxic	bifenazate	20D	0.75–1.0 lb	mites
Actara	highly toxic	slightly toxic	thiamethoxam	4A	1.5–4.0 oz	aphids, fruit flies & spotted wing drosophila, whiteflies
Admire Pro	highly toxic	highly toxic	imidacloprid	4A	soil: 10.5–14 fl oz foliar: 1.3 fl oz	aphids, beetles/weevils, caterpillars, fruit flies and spotted wing drosophila, grubs, whiteflies
Agri-Mek 0.15 EC	highly toxic	highly toxic	abamectin	6	16 oz	mites
Agri-Mek SC	highly toxic	highly toxic	abamectin	6	3.5 oz	mites
Assail 30 SG	moderately to highly toxic	moderately toxic	acetamiprid	4A	1.9–6.9 oz	aphids, armyworms, beetles/weevils, caterpillars, fruit flies & spotted wing drosophila, seed bugs, thrips, whiteflies
Assail 70 WP	moderately to highly toxic	moderately toxic	acetamiprid	4A	0.8–3.0 oz	aphids, armyworms, beetles/weevils, caterpillars, fruit flies and spotted wing drosophila, seed bugs, thrips, whiteflies
Athena	highly toxic	highly toxic	bifenthrin & avermectin B1	3A + 6	7.0–17.0 fl oz	aphids, armyworms, beetles/weevils, mites, seed bugs, whiteflies
Beleaf 50 SG	non-toxic	non-toxic	flonicamid	29	2.8 oz	aphids, seed bugs
Brigade WSB	highly toxic	highly toxic	bifenthrin	3A	6.4–32.0 oz	aphids, armyworms, beetles/weevils, fruit flies and spotted wing drosophila, mites, seed bugs
Brigadier	highly toxic	highly toxic	bifenthrin & imidacloprid	3A + 4A	5.1–6.14 fl oz	aphids, armyworms, beetles/weevils, seed bugs, whiteflies
Carbaryl 4 L	moderately to highly toxic	moderately toxic	carbaryl	1A	1–2 quarts	aphids, caterpillars, crickets, cockroaches, seed bugs
Coragen	non-toxic	non-toxic	chlorantraniliprole	28	3.5–7.5 fl oz	armyworms
Courier SC	non-toxic	non-toxic	buprofezin	16	9.0–13.6 oz	whiteflies
Danitol 2.4 EC	highly toxic	moderately toxic	fenpropathrin	3A	10.67–21.33 fl oz	armyworms, beetles/ weevils, fruit flies and spotted wing drosophila, mites, seed bugs
Diazinon 50W	slightly toxic	slightly toxic	diazinon	1B	1–2 lbs	aphids, caterpillars, crickets, cockroaches, mites
Diazinon AG600 WBC	slightly toxic	slightly toxic	diazinon	1B	12.75–25.5 fl oz	aphids, caterpillars, crickets, cockroaches, mites

Product	Toxicity to *P. persimilis*	Toxicity to *N. californicus*	Active ingredient	Mode of action	Application rate/A	Pests targeted
Dibrom 8-E	highly toxic	no information	naled	1B	1 pint	aphids, caterpillars, mites, thrips
Esteem 0.86 EC	moderately toxic	moderately toxic	pyriproxyfen	7D	10 fl oz	whiteflies
Esteem Ant Bait	moderately toxic	moderately toxic	pyriproxyfen	7	1.5–2.0 lbs	ants
Evergreen EC 60-6	highly toxic	highly toxic	pyrethrins & piperonyl butoxide	3A	2–16 fl oz	aphids, armyworms, fruit flies and spotted wing drosophila, seed bugs, thrips, whiteflies
Exirel	non-toxic	no information	cyantraniliprole	28	10-20.5 fl oz	caterpillars, fruit flies and spotted wing drosophila, mites
Extinguish fire ant bait	non-toxic	no information	S-methoprene	7A	See label	ants
Govern 4E	moderately toxic	moderately toxic	chlorpyrifos	1B	See label	beetles/weevils, grubs
Intrepid 2F	non-toxic	non-toxic	methoxyfenozide	18	6–12 fl oz	armyworms
Kanemite 15 SC	non-toxic to slightly toxic	non-toxic	acequinocyl	20B	21–31 fl oz	mites
Lorsban 75WG	moderately toxic	moderately toxic	chlorpyrifos	1B	1.33–2.67 lbs	beetles/weevils, grubs
Malathion 5EC	slightly toxic	slightly toxic	malathion	1B	1.5–3.2 pints	aphids, caterpillars, crickets, cockroaches, mites, seed bugs, thrips, whiteflies
Malathion 8F	slightly toxic	slightly toxic	malathion	1B	1.5–2.0 pints	aphids, caterpillars, crickets, cockroaches, mites, seed bugs, thrips, whiteflies
Nealta	non-toxic	non-toxic	cyflumetofen	25	13.7 fl oz	mites
Nexter 75 WP	highly toxic	highly toxic	pyridaben	21A	1.6-3.3 lbs	mites
Oberon 2SC	moderately toxic	moderately toxic	spiromesifen	23	12–16 fl oz	mites, whiteflies
Platinum 75 SG	highly toxic	moderately toxic	thiamethoxam	4A	1.7–4.01 oz	aphids, grubs, whiteflies
Portal XLO	moderately to highly toxic	moderately toxic	fenpyroximate	21A	2 pints	mites, whiteflies
Radiant SC	moderately toxic	highly toxic	spinetoram	5	6–10 fl oz	armyworms, caterpillars, thrips
Rimon 0.83EC	non-toxic	non-toxic	novaluron	15	9–12 fl oz	armyworms, beetles/ weevils, crickets, cockroaches, seed bugs
Savey 50 DF	non-toxic	non-toxic	hexythiazox	10A	6 oz	mites
Sevin 4F	moderately to highly toxic	moderately toxic	carbaryl	1A	1–2 quarts	armyworms, caterpillars, seed bugs
Sevin 80 Solupak	moderately to highly toxic	moderately toxic	carbaryl	1A	1.25–2.5 lbs	armyworms, caterpillars, seed bugs
Sivanto Prime	no information	no information	flupyradifurone	4D	7–14 fl oz	aphids, whiteflies
Vendex 50 WP	non-toxic	non-toxic	fenbutatin oxide	12B	1.5–2.0 lbs	mites
Vetica	non-toxic	non-toxic	buprofezin & flubendiamide	16 + 28	12.0–18.5 fl oz	whiteflies
Voliam Flexi	highly toxic	moderately toxic	thiamethoxam & chlorantraniliprole	4A + 28	2–5 oz	aphids, armyworms, whiteflies
Zeal	moderately toxic	moderately toxic	etoxazole	10B	2–3 oz	mites

Appendix B. Summary of non-target toxicity classifications to *Phytoseiulus persimilis* and *Neoseiulus californicus* for selected OMRI listed insecticides and miticides approved for managing arthropod pests of strawberry in Florida as reported in the Side Effects Manuals produced by Koppert Biological Systems and Biobest Sustainable Crop Management.

Product	Toxicity to *P. Persimilis*	Toxicity to *N. Californicus*	Active Ingredient	Mode of Action	Application Rate	Pests Targeted
Agree WG	non-toxic	non-toxic	*Bacillus thuringiensis subspecies aizawai* strain GC-91	11A	0.5–2.0 lbs	armyworms
Aza-Direct	slightly to moderately toxic	non-toxic	azadirachtin	--	1–2 pints	aphids, armyworms, crickets, cockroaches, fruit flies and spotted wing drosophila, mites, thrips, whiteflies
Azera	highly toxic	non-toxic	azadirachtin & pyrethrins	3A	See label	aphids, armyworms, beetles/weevils, caterpillars, thrips, whiteflies
Biobit HP	non-toxic	non-toxic	*Bacillus thuringiensis subspecies kurstaki*	11A	0.5–2.0 lbs	armyworms, caterpillars
Botanigard ES	no information	no information	*Beauvaria bassiana* strain GHA	--	0.25–1 quart	aphids, caterpillars, crickets, cockroaches, grubs, seed bugs, thrips, whiteflies
Deliver	non-toxic	non-toxic	*Bacillus thuringiensis subspecies kurstaki*	11A	0.25–1.5 lbs	armyworms, caterpillars
DiPel DF	non-toxic	non-toxic	*Bacillus thuringiensis subspecies kurstaki*	11A	0.5–2.0 lbs	armyworms, caterpillars
Entrust	slightly toxic	moderately toxic	spinosad	5	1.25–1.5 oz	armyworms, caterpillars, fruit flies and spotted wing drosophila, thrips
Grandevo	no information	no information	*Chromobacterium subtsugae* strain PRAA4-1	--	1–3 lbs	aphids, armyworms, caterpillars, mites, thrips, whiteflies
Javelin WG	non-toxic	non-toxic	*Bacillus thuringiensis subspecies kurstaki*	11A	0.25–1.5 lbs	armyworms, caterpillars
JMS Stylet Oil	moderately toxic	moderately toxic	paraffinic (mineral) oil	--	3 quarts/100 gal water	mites, whiteflies
MET52 EC	no information	no information	*Metarhizium anisopliae strain F52*	--	Drench: 40–80 fl oz/100	beetles/weevils, mites, thrips, whiteflies
M-Pede	highly toxic	highly toxic	potassium salts of fatty acids	--	See label	aphids, mites, whiteflies
Mycotrol ESO	no information	no information	*Beauvaria bassiana* strain GHA	--	0.25–1 quart	aphids, beetles/weevils, caterpillars, crickets, cockroaches, grubs, seed bugs, thrips, whiteflies
Neemix 4.5% EC	slightly to moderately toxic	non-toxic	azadirachtin	--	4–16 fl oz	aphids, armyworms, caterpillars, thrips, whiteflies
PFR-97 20%WDG	no information	no information	*Isaria fumosoroseus* Apopka strain 97	--	1–2 lbs	aphids, caterpillars, mites, seed bugs, thrips, whiteflies
PyGanic EC 5.0	no information	no information	pyrethrins	3A	See label	aphids, armyworms, fruit flies and spotted wing drosophila, seed bugs, thrips, whiteflies

Product	Toxicity to *P. Persimilis*	Toxicity to *N. Californicus*	Active Ingredient	Mode of Action	Application Rate	Pests Targeted
SuffOil-X	no information	no information	unsulfonated residue of petroleum oil	--	1–2 gallons	aphids, mites, whiteflies
Trilogy	moderately toxic	moderately toxic	neem oil	--	0.5–2%	aphids, mites
Venerate XC	no information	no information	*Burkholderia* spp. Strain A396	--	1–8 quarts	caterpillars
Xentari	non-toxic	non-toxic	*Bacillus thuringiensis subspecies aizawai*	11A	0.5–2.0 lbs	armyworms, caterpillars