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Management of Insect and Mite Resistance in Ornamental Crops[1]

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Resistance of arthropods to crop management chemicals has been problematic since the early era of synthetic organic pesticides. During the 1970s and early 1980s leafminer *(Liriomyza trifolii*) outbreaks heavily damaged herbaceous ornamental crops such as chrysanthemum, gypsophila, aster, and marigold in fields, shade houses and greenhouses. Several effective insecticides including organophosphates, carbamates, pyrethroids, and a triazine were identified for leafminer control during the outbreak; however, control was short-lived as the leafminer developed resistance to each insecticide.

Poor performance of pesticides does not always indicate pest resistance. Such factors as pesticide degradation in storage, hydrolysis in acid or alkaline preparations, applications to an incorrect life stage of the pest, or other inadequate application procedures may contribute to poor control.

Definition of Resistance

Pest populations can be susceptible or resistant to a pesticide. Resistance occurs when a formerly susceptible pest population becomes significantly less susceptible to a pesticide when properly applied. Pesticide resistance is a population-based phenomenon in which the genetic composition shifts and the population becomes dominated by individuals possessing genes that confer resistance or increased tolerance to the pesticide that results in reduced insecticidal activity.

Establishment of Resistance

Resistant populations are protected from formerly effective pesticides through one or more means. For example, resistant pests may: (1) deactivate (break down), (2) sequester (safely store within their bodies), (3) avoid, or (4) excrete the toxin from their bodies more effectively, (5) have an altered target site that will not accumulate the toxin, or (6) reduce the permeability by the toxin through their exoskeletons ("shells").

Individuals within a susceptible pest population often vary in their level of susceptibility; however, the non-susceptible type occurs only very rarely. When a pesticide is applied repeatedly, the susceptible pests die and the resistant ones survive, mate with other survivors, and reproduce. Some of their offspring inherit the parents' characteristic for survival. Upon additional applications, the more susceptible of the offspring within the remaining population die and the

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less susceptible ones survive, mate with other survivors and produce more similar offspring. Further applications additionally select for the resistant individuals until that form (genotype) is common. The population then is regarded as resistant and the effectiveness of the pesticide is lost.

Resistance Management

Resistance can develop rapidly with pests that have many generations per year, when multiple generations are exposed to a pesticide, and when new individuals do not move into a treated area to dilute the frequency of the resistant genes. Ornamentals production, especially in greenhouses, often incorporates a combination of these factors that contribute to resistance and account for some of the leafminer problems experienced decades ago.

The main objectives of resistance management programs in ornamentals production should be to minimize the number of exposures of pests to pesticides with a similar mode of action and to use non-chemical approaches to arthropod management. (Mode of action is the specific activity of the toxin that results in the death of the pest. For instance, one mode of action is to inhibit mitochondrial complex I electron transport. This causes a failure of the pest to produce energy in affected cells and to die.)

Repeated exposures to a pesticide are the primary drivers of resistance but much can be done to manage pests by means other than chemicals. Care can be taken to rotate crops, establish new ones only after the older crops have been removed, use pest resistant species and varieties, set pest-free transplants, conserve and release natural enemies, etc. Pest-specific tactics are available for particular situations such as elimination of excessive moisture in order to kill fungus gnats in greenhouses.

Crops should be scouted on a regular, frequent schedule and pesticide applications should be made only when pest densities approach economic injury levels. When pesticide use is required, products should be rotated among the different modes of action indicated on many modern product labels. A list of modes of action can be found by selecting "MoA Classification" at the Insecticide Resistance Action Committee Website: http://www.irac-online.org/teams/mode-of-action/.

Tables 1-3 present a mode of action summary for insecticides and miticides intended for ornamentals production in Florida. Sound rotation plans often recommend pesticides of one mode of action for one pest generation and a pesticide of a different mode of action for another generation.

If multiple pesticide applications are required, rotations should continue through all practical modes of action before returning to a previously used one. The use of certain unique products with known general modes of action (such as soaps and oils) is unlikely to result in pest resistance and no codes are assigned. These products can be used without regard to a rotation plan for resistance management.

When pesticides are used, it is important to assure that fresh, fully potent pesticides are prepared and applied in accordance with label directions. Aqueous pesticidal preparations should be adjusted to near neutral pH (pH 7.0) or as specified by the label. Sprayer calibration, nozzle condition and pressure, and spray placement must be correct. Applications also should be timed and directed to contact the most susceptible life stage of the pest.

Conclusion

Episodes of pest resistance to popular pesticides can cause crop yield losses, crop quality reduction, added control costs, increased human exposure to toxins, and degradation of the environment. These consequences can be alleviated if resistance management is practiced throughout Florida's ornamentals industry. If growers minimize pesticide application by depending more on biological and cultural pest control measures, and reduce exposing pest populations to pesticides with identical modes of action, then resistance can be avoided.

Table 1. Mode of action of insecticides and miticides registered for use in Florida's ornamental production (presented by active ingredient). (Insecticide Resistance Action Committee mode of action classification codes version 7.2).

Active Ingredient (Common Name)	Trade Name Examples	Mode of Action Code
1,3-dichloropropene	Telone	no code[a]
abamectin	Avid Lucid	6
abamectin & bifenazate	Sirocco	6 & un [b]
acephate	Orthene	1B
acephate & fenpropathrin	Tame/Orthene	1B & 3A
acequinocyl	Shuttle	20B
acetamiprid	TriStar	4A
azadirachtin	Azahar Azatin	un
Bacillus thuringiensis aizawai	Jackpot Xentari	11B
Bacillus thuringiensis israelensis	Gnatrol	11A
Bacillus thuringiensis kurstaki	Dipel Javelin	11B
Beauveria bassiana	Botanigard Mycotrol Naturalis	no code
bifenazate	Floramite	un
bifenazate & abamectin	Sirocco	un & 6
bifenthrin	Attain Talstar OnyxPro	3A
buprofezin	Talus	16
carbaryl	Sevin	1A
carbofuran	Furadan	1A
chlorfenapyr	Pylon	13
chlorpyrifos	DuraGuard Dursban	1B
chlorpyrifos & cyfluthrin	Duraplex	1B & 3A
Chromobacterium subtsugae	MBI-203	no code
clarified hydrophobic extract of neem oil	Triact Trilogy	no code
clofentezine	Ovation	10A
cryolite	Kryocide	un
cyfluthrin	Decathlon	3A
cyfluthrin & chlorpyrifos	Duraplex	3A & 1B
cyfluthrin & imidacloprid	Discus	3A & 4A
cyromazine	Citation	17
deltamethrin	Deltagard	3A
diazinon	Diazinon	1B
diflubenzuron	Adept Dimilin	15
dimethoate	Dimethoate	1B
dinotefuran	Safari	4A
disulfoton	Di-Syston	1B
esfenvalerate	Asana	3A

etoxazole	Tetrasan	10B
fenazaquin	Magus	21A
fenbutatin oxide	ProMite Vendex	12B
fenoxycarb	Award Preclude	7B
fenpropathrin	Tame	3A
fenpropathrin & acephate	Tame/Orthene	3A & 1B
fenpyroximate	Akari	21A
fipronil	Chipco Choice	2B
flonicamid	Aria	9C
hexythiazox	Hexygon Onager	10A
hydramethylnon	Amdro	20A
imidacloprid	Marathon	4A
imidacloprid & cyfluthrin	Discus	4A & 3A
iron phosphate	Sluggo	no code
Isaria fumosorosea	PFR-97	no code
kaolin	Surround	no code
lambda-cyhalothrin	Scimitar	3A
malathion	Malathion	1B
metaldehyde	Deadline Durham Metaldehyde	no code
metam-sodium	Vapam	no code
metam-potassium	Metam KLR	no code
methidathion	Supracide	1B
methiocarb	Mesurol	1A
milbemectin	Ultiflora	6
naled	Dibrom	1B
novaluron	Pedestal	15
orthoboric acid	Niban	8D
oxydemeton-methyl	MSR Spray Concentrate	1B
permethrin	Ambush Astro	3A
phosmet	Imidan	1B
polyhedral occlusion bodies of the nuclear polyhedrosis virsus of *Spodoptera exigua*	Spod-X	no code
potassium salts of fatty acids	AllPro Insecticidal Soap M-Pede	no code
pymetrozine	Endeavor	9B
pyrethrins	Diatect PyGanic Pyrenone Pyreth-It	3A
pyrethrins & rotenone	Pyrellin	3A & 21B
pyridaben	Sanmite	21A
pyridalyl	Overture	un
pyriproxyfen	Distance	7C
refined petroleum distillate	Ultra-Fine Oil	no code

rotenone & pyrethrins	Pyrellin	21B & 3A
s-kinoprene	Enstar II	7A
s-methoprene	Extinguish	7A
sodium ferric EDTA	Dr.T's	no code
sorbitol octanoate	SorbiShield	no code
spinosad	Conserve Entrust	5
spiromesifen	Judo	23
spirotetramat	Kontos Movento	23
sucrose octanoate	SucraShield	no code
tau-fluvalinate	Mavrik	3A
tebufenozide	Confirm Mimic	18
thiamethoxam	Flagship	4A
tolfenpyrad	Hachi-Hachi	21A

[a] When no mode of action code is present, there is no code established and the product can be used without regard to mode of action.
[b] "un" means this compound has an unknown or uncertain mode of action.

Table 2. Mode of action of insecticides and miticides registered for use in Florida's ornamental production (presented by mode of action code). (Insecticide Resistance Action Committee mode of action classification codes version 7.2).

Mode of Action Code	**Active Ingredient (Common Name)**	**Trade Name Examples**
No code[a]	1,3-dichloropropene	Telone
	Beauveria bassiana	Botanigard
		Mycotrol
		Naturalis
	clarified hydrophobic extract of neem oil	Triact
		Trilogy
	iron phosphate	Sluggo
	Isaria fumosorosea	PFR-97
	kaolin	Surround
	metaldehyde	Deadline
		Durham Metaldehyde
	metam-sodium	Vapam
	metam-potassium	Metam KLR
	polyhedral occlusion bodies of the nuclear polyhedrosis virus *Spodoptera exigua*	Spod-X
	potassium salts of fatty acids	AllPro Insecticidal Soap
		M-Pede
	refined petroleum distillate	Ultra-Fine Oil
	sodium ferric EDTA	Dr.T's
	sorbitol octanoate	SorbiShield
	sucrose octanoate	SucraShield
1A	carbaryl	Sevin
	carbofuran	Furadan
	methiocarb	Mesurol
1B	acephate	Orthene
	chlorpyrifos	DuraGuard Dursban
	diazinon	Diazinon
	dimethoate	Dimethoate
	disulfoton	Di-Syston
	malathion	Malathion
	methidathion	Supracide
	naled	Dibrom
	oxydemeton-methyl	MSR Spray Concentrate
	phosmet	Imidan
1B & 3A	acephate & fenpropathrin	Tame/Orthene
	chlorpyrifos & cyfluthrin	Duraplex
2B	fipronil	Chipco Choice

3A	bifenthrin	Attain
		Talstar
		OnyxPro
	cyfluthrin	Decathlon
	deltamethrin	Deltagard
	esfenvalerate	Asana
	fenpropathrin	Tame
	lambda-cyhalothrin	Scimitar
	permethrin	Ambush
		Astro
	pyrethrins	Diatect
		PyGanic
		Pyrenone
		Pyreth-It
	tau-fluvalinate	Mavrik
3A & 1B	cyfluthrin & chlorpyrifos	Duraplex
	fenpropathrin & acephate	Tame/Orthene
3A & 21B	pyrethrins & rotenone	Pyrellin
4A	acetamiprid	TriStar
	dinotefuran	Safari
	imidacloprid	Discus
		Marathon
	thiamethoxam	Flagship
4A & 3A	imidacloprid & cyfluthrin	Discus
5	spinosad	Conserve
		Entrust
		Justice
6	abamectin	Avid
		Lucid
	milbemectin	Ultiflora
6 & un[b]	abamectin & bifenazate	Sirocco
7A	s-kinoprene	Enstar II
	s-methoprene	Extinguish
7B	fenoxycarb	Award
		Preclude
7C	pyriproxyfen	Distance
8D	orthoboric acid	Niban
9B	pymetrozine	Endeavor
9C	flonicamid	Aria
10A	clofentezine	Ovation
	hexythiazox	Hexygon
10B	etoxazole	Tetrasan
11A	*Bacillus thuringiensis israelensis*	Gnatrol
11B	*Bacillus thuringiensis aizawai*	Jackpot
		Xentari

11B	*Bacillus thuringiensis kurstaki*	Dipel
		Javelin
12B	fenbutatin oxide	ProMite
		Vendex
13	chlorfenapyr	Pylon
15	diflubenzuron	Adept
		Dimilin
	novaluron	Pedestal
16	buprofezin	Talus
17	cyromazine	Citation
18	tebufenozide	Confirm
		Mimic
20A	hydramethylnon	Amdro
20B	acequinocyl	Shuttle
21A	fenazaquin	Magus
	fenpyroximate	Akari
	pyridaben	Sanmite
	tolfenpyrad	Hachi-Hachi
21B & 3A	rotenone & pyrethrins	Pyrellin
23	spiromesifen	Judo
	spirotetramat	Kontos
		Movento
un	azadirachtin	Azahar
		Azatin
	bifenazate	Floramite
		Sirocco
	cryolite	Kryocide
	pyridalyl	Overture
un & 6	bifenazate & abamectin	Sirocco

[a] When no mode of action code is present, there is no code established and the product can be used without regard to mode of action.
[b] "un" means this compound has an unknown or uncertain mode of action.

Table 3. Mode of action of insecticides and miticides registered for use in Florida's ornamental production (presented by trade name). (Insecticide Resistance Action Committee mode of action classification codes version 7.2).

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
Adept	diflubenzuron	15
Akari	fenpyroximate	21A
AllPro Insecticidal Soap	potassium salts of fatty acids	no code [a]
Ambush	permethrin	3A
Amdro	hydramethylnon	20A
Aria	flonicamid	9C
Asana	esfenvalerate	3A
Astro	permethrin	3A
Attain	bifenthrin	3A
Avid	abamectin	6
Award	fenoxycarb	7B
Azahar	azadirachtin	un[b]
Azatin	azadirachtin	un
Botanigard	*Beauveria bassiana*	no code
Chipco Choice	fipronil	2B
Citation	cyromazine	17
Confirm	tebufenozide	18
Conserve	spinosad	5
Deadline	metaldehyde	no code
Decathlon	cyfluthrin	3A
Deltagard	deltamethrin	3A
Diatect	pyrethrins	3A
Diazinon	diazinon	1B
Dibrom	naled	1B
Dimethoate	dimethoate	1B
Dimilin	diflubenzuron	15
Dipel	*Bacillus thuringiensis kurstaki*	11B
Di-Syston	disulfoton	1B
Discus	imidacloprid & cyfluthrin	4A & 3A
Distance	pyriproxyfen	7C
DuraGuard	chlorpyrifos	1B
Duraplex	cyfluthrin & chlorpyrifos	3A & 1B
Durham Metaldehyde	metaldehyde	no code
Dursban	chlorpyrifos	1B
Endeavor	pymetrozine	9B
Enstar II	s-kinoprene	7A
Entrust	spinosad	5
Extinguish	s-methoprene	7A
Flagship	thiamethoxam	4A
Floramite	bifenazate	un
Furadan	carbofuran	1A
Gnatrol	*Bacillus thuringiensis israelensis*	11A
Hachi-Hachi	*tolfenpyrad*	21A
Hexygon	hexythiazox	10A

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
Imidan	phosmet	1B
Jackpot	*Bacillus thuringiensis aizawai*	11B
Javelin	*Bacillus thuringiensis kurstaki*	11B
Judo	spiromesifen	23
Kontos	spirotetramat	23
Kryocide	cryolite	un
Lucid	abamectin	6
M-Pede	potassium salts of fatty acids	no code
Magus	fenazaquin	21A
Malathion	malathion	1B
Marathon	imidacloprid	4A
Mavrik	*tau*-fluvalinate	3A
MBI-203	*Chromobacterium subtsugae*	no code
Mesurol	methiocarb	1A
Metam KLR	metam-potassium	no code
Mimic	tebufenozide	18
Movento	spirotetramat	23
MSR Spray Concentrate	oxydemeton-methyl	1B
Mycotrol	*Beauveria bassiana*	no code
Naturalis	*Beauveria bassiana*	no code
Niban	*orthoboric acid*	8D
Onager	*hexythiazox*	10A
OnyxPro	*bifenthrin*	3A
Orthene	acephate	1B
Ovation	clofentezine	10A
Overture	pyridalyl	un
Pedestal	novaluron	15
Preclude	fenoxycarb	7B
PFR-97	*Isaria fumosorosea*	no code
ProMite	fenbutatin oxide	12B
PyGanic	pyrethrins	3A
Pyrellin	pyrethrins & rotenone	3A & 21B
Pyrenone	pyrethrins	3A
Pyreth-It	pyrethrins	3A
Pylon	chlorfenapyr	13
Safari	dinotefuran	4A
Sanmite	pyridaben	21A
Scimitar	*lambda*-cyhalothrin	3A
Sevin	carbaryl	1A
Shuttle	acequinocyl	20B
Sirocco	bifenazate & abamectin	un & 6
Sluggo	iron phosphate	no code
sodium ferric EDTA	Dr. T's	no code
SorbiShield	sorbitol octanoate	no code
Spod-X	polyhedral occlusion bodies of the nuclear polyhedrosis virus of *Spodoptera exigua*	no code

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
SucraShield	sucrose octanoate	no code
Supracide	methidathion	1B
Surround	kaolin	no code
Talstar	bifenthrin	3A
Talus	buprofezin	16
Tame	fenpropathrin	3A
Tame/Orthene	fenpropathrin & acephate	3A & 1B
Telone	1,3-dichloropropene	no code
Tetrasan	etoxazole	10B
Triact	clarified hydrophobic extract of neem oil	no code
Trilogy	clarified hydrophobic extract of neem oil	no code
TriStar	acetamiprid	4A
Ultiflora	milbemectin	6
Ultra-Fine Oil	refined petroleum distillate	no code
Vapam	metam-sodium	no code
Vendex	fenbutatin oxide	12B
Xentari	*Bacillus thuringiensis aizawai*	11B

[a]*When no mode of action code is present, there is no code established and the product can be used without regard to mode of action.*
[b]"un" means this compound has an unknown or uncertain mode of action.