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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, 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 and degradation of the pesticide or improper application is not a factor. 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.

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

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susceptible of the offspring within the remaining population die and the 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 Scheme” at the Insecticide Resistance Action Committee Website: http://www.irac-online.org/Crop_Protection/MoA.asp .

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 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 pest exposures to pesticides with identical modes of action, then resistance can become a rare phenomenon.

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 5.3).

Active Ingredient (Common Name)	Trade Name Examples	Mode of Action Code
1,3-dichloropropene	Telone	
abamectin	Avid Lucid	6
acephate	Orthene Tame/Orthene[a]	1B
acequinocyl	Shuttle	20B
acetamiprid	TriStar	4A
azadirachtin	Aza-Direct Azatin	18B
azinphos-methyl	Guthion	1B
Bacillus thuringiensis aizawai	Xentari	11B1
Bacillus thuringiensis israelensis	Gnatrol	11A1
Bacillus thuringiensis kurstaki	Dipel Javelin	11B2
Beauveria bassiana	Botanigard Mycotrol Naturalis	
bifenazate	Floramite	25
bifenthrin	Allectus[b] Attain Talstar	3
buprofezin	Talus	16
carbaryl	Sevin	1A
carbofuran	Furadan	1A
chlorfenapyr	Pylon	13
chlorpyrifos	Duraguard Duraplex[c] Dursban	1B
clarified hydrophobic extract of neem oil	Triact	
clofentezine	Ovation	10A
clothianidin	Celero	4A
cryolite	Kryocide Prokil Cryolite	9A
cyfluthrin	Decathlon Discus[b] Duraplex[d]	3
cyromazine	Citation	17
deltamethrin	Deltagard	3
diazinon	Diazinon	1B

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 5.3).

Active Ingredient (Common Name)	Trade Name Examples	Mode of Action Code
diflubenzuron	Adept Dimilin	15
dimethoate	Dimethoate	1B
dinotefuran	Safari	4A
disulfoton	Di-Syston	1B
endosulfan	Thionex	2A
esfenvalerate	Asana	3
ethoprop	Mocap	1B
etoxazole	Tetrasan	10B
fenbutatin oxide	ProMite	12B
fenoxycarb	Award Fire Ant Bait Preclude	7B
fenpropathrin	Tame Tame/Orthene[e]	3
fenpyroximate	Akari	21
fipronil	Chipco Choice	2B
flonicamid	Aria	9C
halofenozide	Mach 2	18A
hexythiazox	Hexygon	10A
hydramethylnon	Amdro	20A
imidacloprid	Allectus[f] Discus[c] Marathon Merit	4A
iron phosphate	Sluggo	
kaolin	Surround	
lambda-cyhalothrin	Scimitar	3
malathion	Malathion	1B
metaldehyde	Deadline Prozap	
metam-sodium	Vapam	
methidathion	Supracide	1B
methiocarb	Mesurol	1A
methyl bromide	67-33 Preplant Soil Fumigant	8A
naled	Dibrom	1B
novaluron	Pedestal	15
oxydemeton-methyl	MSR Spray Concentrate	1B
permethrin	Ambush Astro	3

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 5.3).

Active Ingredient (Common Name)	Trade Name Examples	Mode of Action Code
phosmet	Imidan	1B
piperonyl butoxide	Diatect[g] Pyrenone[g] Pyreth-It[g]	27A
polyhedral occlusion bodies of the nuclear polyhedrosis virsus of *Spodoptera exugia*	Spod-X	
potassium salts of fatty acids	AllPro Insecticidal Soap M-Pede	
propargite	Omite Ornamite	12C
pymetrozine	Endeavor	9B
pyrethrin	Diatect[h] PyGanic Pyrellin[i] Pyrenone[h] Pyreth-It[h]	3
pyridaben	Sanmite	21
pyriproxyfen	Distance	7D
refined petroleum distillate	Ultra-Fine Oil	
rotenone	Pyrellin[g]	21
s-kinoprene	Enstar II	7A
s-methoprene	Extinguish	7A
spinosad	Conserve Entrust Justice Fire Ant Bait Spintor	5
spiromesifen	Judo	23
tau-fluvalinate	Mavrik	3
tebufenozide	Confirm Mimic	18A
thiamethoxam	Flagship	4A

[a] This product also contains fenpropathrin, see mode of action code 3 in table 2.
[b] This product also contains imidacloprid, see mode of action code 4A in table 2.
[c] This product also contains cyfluthrin, see mode of action code 3 in table 2.
[d] This product also contains chlorpyrifos, see mode of action code 1B in table 2.
[e] This product also contains acephate, see mode of action code 1B in table 2.
[f] This product also contains bifenthrin, see mode of action code 3 in table 2.
[g] This product also contain pyrethirn, see mode of action code 3 in table 2.
[h] This product also contain piperonyl butoxide, see mode of action code 27A in table 2.
[i] This product also contains rotenone, see mode of action code 21 in table 2.

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 5.3).

Mode of Action Code	Active Ingredient (Common Name)	Trade Name Examples
	1,3-dichloropropene	Telone
	Beauveria bassiana	Botanigard Mycotrol Naturalis
	clarified hydrophobic extract of neem oil	Triact
	iron phosphate	Sluggo
	kaolin	Surround
	metaldehyde	Deadline Prozap
	metam-sodium	Vapam
	polyhedral occlusion bodies of the nuclear polyhedrosis virus of *Spodoptera exugia*	*Spod-X*
	potassium salts of fatty acids	AllPro Insecticidal Soap M-Pede
	refined petroleum distillate	Ultra-Fine Oil
1A	carbaryl	Sevin
	carbofuran	Furadan
	methiocarb	Mesurol
1B	acephate	Orthene Tame/Orthene[a]
	azinphos-methyl	Guthion
	chlorpyrifos	Duragard Duraplex[a] Dursban
	diazinon	Diazinon
	dimethoate	Dimethoate
	disulfoton	Di-Syston
	ethoprop	Mocap
	malathion	Malathion
	methidathion	Supracide
	naled	Dibrom
	oxydemeton-methyl	MSR Spray Concentrate
	phosmet	Imidan
2A	endosulfan	Thionex
2B	fipronil	Chipco Choice

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 5.3).

Mode of Action Code	Active Ingredient (Common Name)	Trade Name Examples
3	bifenthrin	Allectus[b] Attain Talstar
	cyfluthrin	Decathlon Discus[b] Duraplex[c]
	deltamethrin	Deltagard
	esfenvalerate	Asana
	fenpropathrin	Tame Tame/Orthene[c]
	lambda-cyhalothrin	Scimitar
	permethrin	Ambush Astro
	pyrethrin	Diatect[d] PyGanic Pyrellin[e] Pyrenone[d] Pyreth-It[d]
	tau-fluvalinate	Mavrik
4A	acetamiprid	TriStar
	clothianidin	Celero
	dinotefuran	Safari
	imidacloprid	Allectus[a] Discus[a] Marathon Merit
	thiamethoxam	Flagship
5	spinosad	Conserve Entrust Justice Fire Ant Bait Spintor
6	abamectin	Avid Lucid
7A	s-kinoprene	Enstar II
	s-methoprene	Extinguish
7B	fenoxycarb	Award Fire Ant Bait Preclude
7D	pyriproxyfen	Distance
8A	methyl bromide	67-33 Preplant Soil Fumigant
9A	cryolite	Kryocide Prokil Cryolite

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 5.3).

Mode of Action Code	Active Ingredient (Common Name)	Trade Name Examples
9B	pymetrozine	Endeavor
9C	flonicamid	Aria
10A	clofentezine	Ovation
	hexythiazox	Hexygon
10B	etoxazole	Tetrasan
11A1	*Bacillus thuringiensis israelensis*	Gnatrol
11B1	*Bacillus thuringiensis aizawai*	Xentari
11B2	*Bacillus thuringiensis kurstaki*	Dipel Javelin
12B	fenbutatin oxide	ProMite
12C	propargite	Omite Ornamite
13	chlorfenapyr	Pylon
15	diflubenzuron	Adept Dimilin
	novaluron	Pedestal
16	buprofezin	Talus
17	cyromazine	Citation
18A	halofenozide	Mach 2
	tebufenozide	Confirm Mimic
18B	azdirachtin	Aza-Direct Azatin
20A	hydramethylnon	Amdro
20B	acequinocyl	Shuttle
21	fenpyroximate	Akari
	pyridaben	Sanmite
	rotenone	Pyrellin[a]
23	spiromesifen	Judo
25	bifenazate	Floramite
27A	piperonyl butoxide	Diatect[a] Pyrenone[a] Pyreth-It[a]

[a] This product also contains an active ingredient with the mode of action code 3.
[b] This product also contains an active ingredient with the mode of action code 4A.
[c] This product also contains an active ingredient with the mode of action code 1B.
[d] This product also contains an active ingredient with the mode of action code 27A.
[e] This product also contains an active ingredient with the mode of action code 21.

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 5.3).

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
67-33 Preplant Soil Fumigant	methyl bromide	8A
Adept	diflubenzuron	15
Akari	fenpyroximate	21
Allectus	imidacloprid & bifenthrin	4A & 3
AllPro Insecticidal Soap	potassium salts of fatty acids	
Ambush	permethrin	3
Amdro	hydramethylnon	20A
Aria	flonicamid	9C
Asana	esfenvalerate	3
Astro	permethrin	3
Attain	bifenthrin	3
Avid	abamectin	6
Award Fire Ant Bait	fenoxycarb	7B
Aza-Direct	azadirachtin	18B
Azatin	azadirachtin	18B
Botanigard	*Beauveria bassiana*	
Celero	clothianidin	4A
Chipco Choice	fipronil	2B
Citation	cyromazine	17
Confirm	tebufenozide	18A
Conserve	spinosad	5
Deadline	metaldehyde	
Decathlon	cyfluthrin	3
Deltagard	deltamethrin	3
Diatect	pyrethrin & piperonyl butoxide	3 & 27A
Diazinon	diazinon	1B
Dibrom	naled	1B
Dimethoate	dimethoate	1B
Dimilin	diflubenzuron	15
Dipel	*Bacillus thuringiensis kurstaki*	11B2
Di-Syston	disulfoton	1B
Discus	imidacloprid & cyfluthrin	4A & 3
Distance	pyriproxyfen	7D
Duragard	chlorpyrifos	1B
Duraplex	cyfluthrin & chlorpyrifos	3 & 1B

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 5.3).

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
Dursban	chlorpyrifos	1B
Endeavor	pymetrozine	9B
Enstar II	s-kinoprene	7A
Entrust	spinosad	5
Extinguish	s-methoprene	7A
Flagship	thiamethoxam	4A
Floramite	bifenazate	25
Furadan	carbofuran	1A
Gnatrol	*Bacillus thuringiensis israelensis*	11A1
Guthion	azinphos-methyl	1B
Hexygon	hexythiazox	10A
Imidan	phosmet	1B
Javelin	*Bacillus thuringiensis kurstaki*	11B2
Judo	spiromesifen	23
Justice Fire Ant Bait	spinosad	5
Kryocide	cryolite	9A
Lucid	abamectin	6
M-Pede	potassium salts of fatty acids	
Mach 2	halofenozide	18A
Malathion	malathion	1B
Marathon	imidacloprid	4A
Mavrik	tau-fluvalinate	3
Merit	imidacloprid	4A
Mesurol	methiocarb	1A
MSR Spray Concentrate	oxydemeton-methyl	1B
Mimic	tebufenozide	18A
Mocap	ethoprop	1B
Mycotrol	*Beauveria bassiana*	
Naturalis	*Beauveria bassiana*	
Omite	propargite	12C
Ornamite	propargite	12C
Orthene	acephate	1B
Ovation	clofentezine	10A
Pedestal	novaluron	15
Preclude	fenoxycarb	7B
Prokil Cryolite	cryolite	9A

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 5.3).

Trade Name Examples	Active Ingredient (Common Name)	Mode of Action Code
ProMite	fenbutatin oxide	12B
Prozap	metaldehyde	
PyGanic	pyrethrin	3
Pyrellin	pyrethrin & rotenone	3 & 21
Pyrenone	piperonyl butoxide & pyrethrin	27A & 3
Pyreth-It	piperonyl butoxide & pyrethrin	27A & 3
Pylon	chlorfenapyr	13
Safari	dinotefuran	4A
Sanmite	pyridaben	21
Scimitar	lambda-cyhalothrin	3
Sevin	carbaryl	1A
Shuttle	acequinocyl	20B
Sluggo	iron phosphate	
Spintor	spinosad	5
Spod-X	polyhedral occlusion bodies of the nuclear polyhedrosis virus of *Spodoptera exugia*	
Supracide	methidathion	1B
Surround	kaolin	
Talstar	bifenthrin	3
Talus	buprofezin	16
Tame	fenpropathrin	3
Tame/Orthene	fenpropathrin & acephate	3 & 1B
Telone	1,3-dichloropropene	
Tetrasan	etoxazole	10B
Thionex	endosulfan	2A
Triact	clarified hydrophobic extract of neem oil	
TriStar	acetamiprid	4A
Ultra-Fine Oil	refined petroleum distillate	
Vapam	metam-sodium	
Xentari	*Bacillus thuringiensis aizawai*	11B1