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Causes and Management of Insect and Mite Resistance in Strawberry Production[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 late 1990s, the twospotted spider mite (*Tetranychus urticae* Koch) became resistant to abamectin, the miticide used in strawberry culture. Since then, several new miticides, including acequinocyl, bifenazate, etoxazole, fenpyroximate, hexythiazox, and spiromesifen, have been integrated into strawberry production; overuse of abamectin has ceased; and abamectin once again is effective in rotation with the new materials. This latter development could prove temporary, especially if growers again use abamectin regularly.

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.

A 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 properly applied pesticide. Pesticide resistance is a population-based phenomenon in which the group genetic composition shifts and individuals with genes that confer resistance to a pesticide begin to dominate the population, reducing the pesticide's effectiveness .

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) the toxin; (2) sequester the toxin (safely store it within their bodies); (3) avoid the toxin; (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 susceptible offspring within the remaining population die and the resistant ones survive, mate with other survivors and produce more 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

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not move into a treated area to dilute the frequency of the resistant genes. Some of these factors occurred on strawberry farms in the 1990s, contributing to development of abamectin resistance in spider mites.

The main objectives of on-farm resistance management programs 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 kills pests by preventing them from producing energy in affected cells, essentially "starving" them.)

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 strawberries with other crops, use pest-resistant varieties, plant pest-free transplants, conserve and release natural enemies, etc. Pest-specific tactics are available for particular situations; for instance, removal of all ripe strawberries from a field will eliminate reproductive sites for sap beetles.

Strawberry fields should be scouted weekly and pesticide applications 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 [version 7.2 April, 2012].

Tables 1through 3 present insecticide and miticide modes of action summaries for Florida strawberry production. 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. 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 yield losses, reduction of fruit quality, added control costs, environmental degradation, and emotional stress among farmers. These consequences can be alleviated if resistance management is practiced throughout the strawberry industry. If they minimize pesticide application by depending more on biological and cultural pest control measures, and take care not to expose pest populations to pesticides with identical modes of action, growers can avoid causing pesticide resistance.

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

Active Ingredient (common name)	Trade Name Examples	Mode of Action Code
1,3-dichloropropene	Inline	no code[a]
	Telone	
abamectin	Abacus	6
	Agri-Mek	
acequinocyl	Kanemite	20B
acetamiprid	Assail	4A
avermectin & bifenthrin	Athena	6 & 3A
azadirachtin	Aza-Direct	un[b]
	Azatrol	
Bacillus thuringiensis aizawai	Agree	11A
	Xentari	
Bacillus thuringiensis kurstaki	Dipel	11A
	Javelin	
Beauveria bassiana	Botanigard	no code
	Mycotrol	
	Naturalis	
bifenazate	Acramite	un
bifenthrin	Brigade	3A
bifenthrin & avermectin	Athena	3A & 6
bifenthrin & imidacloprid	Brigadier	3A & 4A
buprofezin	Courier	16
carbaryl	Sevin	1A
chlorantraniliprole	Coragen	28
chlorantraniliprole & thiamethoxam	Voliam Flexi	28 & 4A
chlorpyrifos	Govern	1B
	Lorsban	
Chromobacterium subtsugae	MBI-203	no code
clarified hydrophobic extract of neem oil	Trilogy	no code
diazinon	Diazinon	1B
etoxazole	Zeal	10B
fenbutatin oxide	Vendex	12B
fenpropathrin	Danitol	3A
fenpyroximate	Portal	21A
flubendamide	Synapse	28
hexythiazox	Savey	10A
imidacloprid	Admire	4A
	Provado	
imidacloprid & bifenthrin	Brigadier	4A & 3A
iron phosphate	Sluggo	no code
Isaria fumosorosea	PFR-97	no code
	Preferal	
malathion	Malathion	1B
metaldehyde	Deadline	no code
	Slug-Fest	

Active Ingredient (common name)	Trade Name Examples	Mode of Action Code
metam sodium	Vapam	no code
methoxyfenozide	Intrepid	18
naled	Dibrom	1B
novaluron	Rimon	15
potassium salts of fatty acids	AllPro Insecticidal Soap	no code
	M-Pede	
pyrethrins	Diatect	3A
	PyGanic	
	Pyrenone	
	Pyreth-It	
pyrethrins & rotenone	Pyrellin	3A & 21B
pyriproxyfen	Esteem	7C
refined petroleum distillate	Ultra-Fine Oil	no code
rotenone & pyrethrins	Pyrellin	21B & 3A
s-methoprene	Extinguish	7A
sorbitol octanoate	SorbiShield	no code
spinetoram	Radiant	5
spinosad	Entrust	5
	Spintor	
spiromesifen	Oberon	23
sucrose octanoate	SucraShield	no code
thiamethoxam	Actara	4A
	Platinum	
thiamethoxam & chlorantraniliprole	Voliam Flexi	4A & 28

[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 strawberry crops (presented by mode of action code). (Insecticide Resistance Action Committee mode of action classification code version 7.2).

Mode of Action Code	Active Ingredient (common name)	Trade Name Examples
no code[a]	1,3-dichloropropene	Inline
		Telone
	Beauveria bassiana	Botanigard
		Mycotrol
		Naturalis
	Chromobacterium subtsugae	MBI-203
	clarified hydrophobic extract of neem oil	Trilogy
	iron phosphate	Sluggo
	Isaria fumosorosea	PFR-97
		Preferal
	metaldehyde	Deadline
		Slug-Fest
	metam sodium	Vapam
	potassium salts of fatty acids	AllPro Insecticidal Soap
		M-Pede
	refined petroleum distillate	Ultra-fine Oil
	sorbitol octanoate	SorbiShield
	sucrose octanoate	SucraShield
1A	carbaryl	Sevin
1B	chlorpyrifos	Govern
		Lorsban
	diazinon	Diazinon
	malathion	Malathion
	naled	Dibrom
3A	bifenthrin	Brigade
	fenpropathrin	Danitol
	pyrethrins	Diatect
		PyGanic
		Pyrenone
		Pyreth-It
3A & 21B	pyrethrins & rotenone	Pyrellin
3A & 4A	bifenthrin & imidacloprid	Brigadier
3A & 6	bifenthrin & avermectin	Athena
4A	acetamiprid	Assail
	imidacloprid	Admire
		Provado
	thiamethoxam	Actara
		Platinum
4A & 28	thiamethoxam & chlorantraniliprole	Voliam Flexi
4A & 3A	imidacloprid & bifenthrin	Brigadier
5	spinetoram	Radiant
	spinosad	Entrust
		Spintor

Mode of Action Code	Active Ingredient (common name)	Trade Name Examples
6	abamectin	Abacus
		Agri-Mek
6 & 3A	avermectin & bifenthrin	Athena
7A	s-methoprene	Extinguish
7C	pyriproxyfen	Esteem
10A	hexythiazox	Savey
10B	etoxazole	Zeal
11A	*Bacillus thuringiensis aizawai*	Agree
		Xentari
	Bacillus thuringiensis kurstaki	Dipel
		Javelin
12B	fenbutatin oxide	Vendex
15	novaluron	Rimon
16	buprofezin	Courier
18	methoxyfenozide	Intrepid
20B	acequinocyl	Kanemite
21A	fenpyroximate	Portal
21B & 3A	rotenone & pyrethrins	Pyrellin
23	spiromesifen	Oberon
28	chlorantraniliprole	Coragen
	flubendamide	Synapse
28 & 4A	chlorantraniliprole & thiamethoxam	Voliam Flexi
un[b]	azadirachtin	Aza-Direct
		Azatrol
	bifenazate	Acramite

[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 strawberry crops (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**
Abacus	abamectin	6
Acramite	bifenazate	un[a]
Actara	acetamiprid	4A
Admire	imidacloprid	4A
Agree	*Bacillus thuringiensis aizawai*	11A
Agri-Mek	abamectin	6
AllPro Insecticidal Soap	potassium salts of fatty acids	no code[b]
Assail	acetamiprid	4A
Athena	avermectin & bifenthrin	6 & 3A
Aza-Direct	azadirachtin	un
Azatrol	azadirachtin	un
Botanigard	*Beauveria bassiana*	no code
Brigade	bifenthrin	3A
Brigadier	bifenthrin & imidacloprid	3A & 4A
Coragen	chlorantraniliprole	28
Courier	buprofezin	16
Danitol	fenpropathrin	3A
Deadline	metaldehyde	no code
Diatect	pyrethrins	3A
Dipel	*Bacillus thuringiensis kurstaki*	11A
Diazinon	diazinon	1B
Dibrom	naled	1B
Entrust	spinosad	5
Esteem	pyriproxyfen	7C
Extinguish	s-methoprene	7A
Govern	chlorpyrifos	1B
Intrepid	methoxyfenozide	18
InLine	1,3-dichloropropene	no code
Javelin	*Bacillus thuringiensis kurstaki*	11A
Kanemite	acequinocyl	20B
Lorsban	chlorpyrifos	1B
M-Pede	potassium salts of fatty acids	no code
Malathion	malathion	1B
MBI-203	*Chromobacterium subtsugae*	no code
Mycotrol	*Beauveria bassiana*	no code
Naturalis	*Beauveria bassiana*	no code
Oberon	spiromesifen	23
PFR-97	*Isaria fumosorosea*	no code
Platinum	acetamiprid	4A
Portal	fenpyroximate	21A
Preferal	*Isaria fumosorosea*	no code
Provado	imidacloprid	4A
PyGanic	pyrethrins	3A
Pyrellin	pyrethrins & rotenone	3A & 21B

Trade Name Examples	Active Ingredient (common name)	Mode of Action Code
Pyrenone	pyrethrins	3A
Pyreth-It	pyrethrins	3A
Radiant	spinetoram	5
Rimon	novaluron	15
Savey	hexythiazox	10A
Sevin	carbaryl	1A
Slug-Fest	metaldehyde	no code
Sluggo	iron phosphate	no code
SorbiShield	sorbitol octanoate	no code
Spintor	spinosad	5
SucraShield	sucrose octanoate	no code
Synapse	flubendamide	28
Telone	1,3-dichloropropene	no code
Trilogy	clarified hydrophobic extract of neem oil	no code
Ultra-Fine Oil	refined petroleum distillate	no code
Vapam	metam sodium	no code
Vendex	fenbutatin oxide	12B
Voliam Flexi	thiamethoxam & chlorantraniliprole	4A & 28
Xentari	*Bacillus thuringiensis aizawai*	11A
Zeal	etoxazole	10B

[a]"un" means this compound has an unknown or uncertain mode of action.
[b]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.