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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, hexythiazox, and spiromesifen have been integrated into strawberry production, overuse of the abamectin has ceased, and it 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, 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 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

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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 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 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 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 such as removal of all ripe strawberries from the field to 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/Crop_Protection/MoA.asp .

Tables 1-3 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 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 growers minimize pesticide application by depending more on biological and cultural pest control measures, and reduce pest exposure 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 strawberry crops (presented by active ingredient). (Insecticide Resistance Action Committee (IRAC) mode of action classification codes version 5.3).

Active Ingredient (common name)	Trade Name Examples	Mode of Action Code
abamectin	Agri-Mek Abacus	6
acequinocyl	Kanemite	20B
azadirachtin	Aza-Direct Azatrol	18B
Bacillus thuringiensis aizawai	Agree Xentari	11B1
Bacillus thuringiensis kurstaki	Dipel Javelin	11B2
Beauveria bassiana	Botanigard Naturalis	
bifenazate	Acramite	25
bifenthrin	Brigade	3
carbaryl	Sevin	1A
chlorpyrifos	Govern Lorsban	1B
diazinon	Diazinon	1B
endosulfan	Thiodan Thionex	2A
etoxazole	Zeal	10B
fenbutatin-oxide	Vendex	12B
fenpropathrin	Danitol	3
hexythiazox	Savey	10A
imidacloprid	Admire Provado	4A
malathion	Malathion	1B
methoxyfenozide	Intrepid	18A
naled	Dibrom	1B
potassium salts of fatty acids	AllPro Insecticidal Soap M-Pede	
propargite	Omite	12C
piperonyl butoxide	Pyrenone Pyreth-It	27A
pyrethrin	Pyrenone Pyreth-It PyGanic Pyrellin	3
pyriproxyfen	Esteem	7D
rotenone	Pyrellin	21
s-methoprene	Extinguish	7A

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Active Ingredient (common name)	Trade Name Examples	Mode of Action Code
spinosad	Entrust Justice Spintor	5
spiromesifen	Oberon	23
thiamethoxam	Actara Platinum	4A

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 5.3).

Mode of Action Code	Active Ingredient (common name)	Trade Name Examples
	Beauveria bassiana	Botanigard Naturalis
	potassium salts of fatty acids	AllPro Insecticidal Soap M-Pede
1A	carbaryl	Sevin
1B	chlorpyrifos	Govern Lorsban
	diazinon	Diazinon
	malathion	Malathion
	naled	Dibrom
2A	endosulfan	Thiodan Thionex
3	bifenthrin	Brigade
	fenpropathrin	Danitol
	pyrethrin	Pyrenone PyGanic Pyrellin Pyreth-It
4A	imidacloprid	Admire Provado
	thiamethoxam	Actara Platinum
5	spinosad	Entrust Justice Spintor
6	abamectin	Abacus Agri-Mek
7A	s-methoprene	Extinguish
7D	pyriproxyfen	Esteem

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 5.3).

Mode of Action Code	Active Ingredient (common name)	Trade Name Examples
10A	hexythiazox	Savey
10B	etoxazole	Zeal
11B1	*Bacillus thuringiensis aizawai*	Agree Xentari
11B2	*Bacillus thuringiensis kurstaki*	Dipel Javelin
12B	fenbutatin-oxide	Vendex
12C	propargite	Omite
18A	methoxyfenozide	Intrepid
18B	azadirachtin	Aza-Direct Azatrol
20B	acequinocyl	Kanemite
21	rotenone	Pyrellin
23	spriomesifen	Oberon
25	bifenazate	Acramite
27A	piperonyl butoxide	Pyrenone Pyreth-It

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 5.3).

Trade Name Examples	Active Ingredient (common name)	Mode of Action Code
Abacus	abamectin	6
Acramite	bifenazate	25
Actara	thiamethoxam	4A
Admire	imidacloprid	4A
Agree	*Bacillus thuringiensis aizawai*	11B1
Agri-Mek	abamectin	6
AllPro Insecticidal Soap	potassium salts of fatty acids	
Aza-Direct	azadirachtin	18B
Azatrol	azadirachtin	18B
Botanigard	*Beauveria bassiana*	
Brigade	bifenthrin	3
Danitol	fenpropathrin	3
Dipel	*Bacillus thuringiensis Kurstaki*	11B2
Diazinon	diazinon	1B

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 5.3).

Trade Name Examples	Active Ingredient (common name)	Mode of Action Code
Dibrom	naled	1B
Entrust	spinosad	5
Esteem	pyriproxyfen	7D
Extinguish	s-methoprene	7A
Govern	chlorpyrifos	1B
Intrepid	methoxyfenozide	18
Javelin	*Bacillus thuringiensis kurstaki*	11B2
Justice	spinosad	5
Kanemite	acequinocyl	20B
Lorsban	chlorpyrifos	1B
M-Pede	potassium salts of fatty acids	
Malathion	malathion	1B
Naturalis	*Beauveria bassiana*	
Oberon	spiromesifen	23
Omite	propargite	12C
Platinum	thiamethoxam	4A
Provado	imidacloprid	4A
PyGanic	pyrethrin	3
Pyrellin	pyrethrin & rotenone	3 & 21
Pyrenone	pyrethrin & piperonyl butoxide	3 & 27A
Pyreth-It	pyrethrin & piperonyl butoxide	3 & 27A
Savey	hexythiazox	10A
Sevin	carbaryl	1A
Spintor	spinosad	5
Thiodan	endosulfan	2A
Thionex	endosulfan	2A
Vendex	fentutatin-oxide	12B
Xentari	*Bacillus thuringiensis aizawai*	11B1
Zeal	extoxazole	10B