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Pest Management—
Novel Chemicals and Biological Control

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Presented at the 41st Annual IDFTA Conference, February 21-25, 1998, Pasco, Washington.

Codling moth, *Cydia pomonella* L., is the "key" pest at which most management resources are directed. It is the pest of pome fruits in the western US. In the early 1980s the typical number of insecticide sprays applied annually to control codling moth was between 2 and 3, averaging about 2.5 sprays per year. However, by the mid-1990s the average number of control sprays had risen to nearly 3.5. At the same time, growers and crop consultants were reporting that fruit damage by codling moth was on the increase. Unacceptable damage was occurring even while some orchards were using 4, 5 or even more insecticide applications to keep this pest under control. Resistance to the pesticides was evolving. In addition to potentially losing pesticides due to resistance, recent legislative activity endangers the availability of insecticides used to control codling moth. The insecticides currently used, azinphosmethyl (Guthion®) and phosmet (Imidan®), are broad-spectrum in activity and will likely fall prey to the new regulatory environment of the Food Quality Protection Act of 1996 (FQPA) (see Willett and Ewart, "The 1996 Food Quality Protection Act: Potential Impact on IPM Systems," in this volume).

In the mid-1960s in response to very serious spider mite problems in apple, Dr. Stan Hoyt showed the value of a predatory mite, *Typhlodromus occidentalis,* in controlling pest mites. This predatory mite was successful as a biological control agent in apple orchards because it had developed tolerance to low rates of azinphosmethyl and phosmet. Dr. Hoyt's research demonstrated what became known as integrated mite management, wherein codling moth was controlled by low rates of selective insecticides and spider mites were controlled biologically by *T. occidentalis*. In the mid-1980s, a graduate student in my laboratory showed that a new pest, the western tentiform leafminer, *Phyllonorycter elmaella*, could be maintained at nondamaging levels by a small parasitic wasp, *Pnigalio flavipes*. It was later shown in my laboratory that this parasite was tolerant of azinphosmethyl and phosmet, thus allowing it to survive in most orchards. While these are two examples of biological control agents that can survive in an organophosphate-based pest control system, they are exceptions to the norm. Most insect natural enemies are highly susceptible to organophosphate and carbamate insecticides used in apple orchards, and they are frequently eliminated or severely suppressed where these pesticides are used.

The success and adoption of codling moth mating disruption, coupled with the development of novel, highly selective insecticides, promise to create an orchard environment where natural controls can be fully utilized. The challenge is first to understand how the new insecticides will work against pests, then to understand what effects they might have on biological control agents. I will discuss three new insecticides, CONFIRM, COMPLY and SUCCESS, which all show promise as controls for codling moth and leafrollers. Full registration of these insecticides is anticipated in 1998 or 1999.

CONFIRM® (tebufenozide, Rohm and Haas) is a new chemistry that stimulates a premature molt in the larvae of Lepidoptera. Because it is a novel chemistry it should be effective against insect species that have developed resistance to traditional insecticides. CONFIRM is highly selective, acting only on larvae of Lepidoptera, and thus is safe to bees, predatory and parasitic insects, and mammals. The molt that is initiated by CONFIRM is not completed and the larva becomes trapped within its old skin; thus it is unable to feed and eventually dies. Death is often slow and there is indication that although some larvae may survive sublethal doses these develop into adults that are unable to reproduce. CONFIRM is moderately effective against the codling moth, targeting the larvae before they enter the apple, and is very effective against leafroller larvae both in the spring and summer. This should make CONFIRM an ideal tool to use in IPM systems as a highly selective control against Lepidoptera while preserving natural enemies.

COMPLY (fenoxycarb, Novartis) has been used for several years in pear under an emergency exemption (Section 18) to control pear psylla. This chemical is classified as a carbamate insecticide although it does not have a neurotoxic effect against insects like a carbamate. COMPLY acts as an insect growth regulator by mimicking the action of the insect's juvenile hormone. In the normal process of insect development, juvenile hormone is at a high concentration in the younger life stages and declines in concentration as the insect matures; that is, the juvenilizing effect of the hormone becomes less, allowing adult-type structures to be expressed. When COMPLY is introduced at a time in the insect's life cycle when juvenile hormone is supposed to be low, it causes abnormal development to occur, and usually this results in the insect's death.

COMPLY disrupts the normal embryonic development of codling moth and leafminer eggs and is most effective when the eggs are deposited on top of the residue; it is therefore important to have control sprays in place prior to egg laying. The stage of leafroller controlled by COMPLY is the last larval stage. Targeting the last larval instar of leafrollers means that COMPLY treatments should be applied at petal fall and possibly repeated in 14 to 21 days. By coincidence, codling moth egg laying occurs at this same time and thus both insects are controlled by treatments starting at petal fall. COMPLY is generally not toxic to insect natural enemies and therefore is very compatible with pest management approaches that encourage biological control. One caution is that COMPLY can be toxic to bees if pollen is contaminated and fed to brood. In this situation the normal development of bee larvae is disrupted, resulting in death.

SUCCESS® (spinosad, DowElanco) is a new insecticide discovered by DowElanco scientists. You may have heard this product referred to as "spinosad," which is the proposed common name for the chemical. The name "spinosad" comes from the active chemicals in the insecticide called spinosyns. Spinosyns are naturally derived compounds with insecticidal activity produced from a new species of Actinomycetes fungi, *Saccharopolyspora spinosa*. Two of the most active spinosyns, A and D, make up the product called SUCCESS. SUCCESS acts on the insect's nervous system, causing involuntary muscle contractions and tremors, paralysis and eventually death. However, SUCCESS has very little negative impact on the environment or human health. SUCCESS is toxic to honey bees when applied directly, but dried residues have little, if any, effect so it should be possible to use SUCCESS during or near the blossom period if applied at times when bees are not actively foraging.

SUCCESS has been shown to provide excellent control of leafrollers and leafminers. For leafrollers, the target of SUCCESS is the larval stage, and good control of all stages has been achieved. Both spring and summer control trials have demonstrated that SUCCESS is highly effective against leafrollers when applied as either dilute or concentrate sprays as long as good foliage coverage is achieved. SUCCESS should be an ideal tool to use in IPM systems as a fairly selective control of leafroller and leafminer while preserving natural enemies. SUCCESS has been shown to be toxic to some parasitic hymenoptera and may affect biological control of certain insects; however, residues are toxic to parasitic wasps for only a relatively short time, 5 to 7 days.

INTEGRATION OF NEW CHEMICALS WITH BIOLOGICAL CONTROL OF LEAFROLLERS

With the development of new insecticides that are highly selective and have less effect on the agroecosystem than past broad-spectrum insecticides, the integration of chemical and biological control tactics has taken on new hope. To fully understand how to integrate new insecticides with biological controls it is important to know if the new chemicals have any impact on predators or parasites. We have developed protocols to evaluate the effects of new insecticides against selected predators and parasites that are important, or have potential to become important, in biological control of pests in apple orchards.

I will briefly describe protocols used to evaluate insecticides against a parasitic wasp, *Colpoclypeus florus*, that attacks leafroller larvae. Initially, adult female wasps are exposed to direct sprays of an insecticide and mortality is evaluated after a period of time, usually 48 hours. This test shows if an insecticide is inherently toxic to adult *C. florus*. Survivors of these tests are placed in small arenas along with a host and male *C. florus*. Following about 3 weeks, the number of parasites that successfully attacked leafroller hosts is determined and number of offspring and sex ratio determined. This test shows if an insecticide causes sublethal effects on the reproduction of *C. florus*. Just because an insecticide is toxic to a biological control agent when applied directly does not mean that it cannot be an important component of an IPM program. The duration of the negative effect of an insecticide must also be determined so bioassays using field-aged residues are conducted. In these tests an insecticide is applied to trees, and leaves are then collected at time intervals following the application. Punches of leaves are removed and placed in a small arena with female *C. florus*. After 48 hours of exposure, the mortality caused by residue on the leaf punch is determined.

The practical result of our insecticide screening program against selected biological control agents is a table in the annual bulletin recommending chemical controls for pests. This table (Table 1) gives a relative toxicity rating for an insecticide against several biological control agents based on direct, sublethal and field-aged residual bioassays. Crop consultants and growers can consult this table when choosing insecticides for pest control and possibly avoid chemicals with greatest negative impact on biological control.

Mating Disruption

The potential to use pheromones to disrupt mating of codling moth has been discussed in the article in this volume by Ted Alway ("Codling Moth Mating Disruption and Its Role in Orchard Pest Management Programs"). A dual codling moth-leafroller pheromone dispenser has been tested in Washington (Dr. Alan Knight, USDA-ARS, Wapato, WA), and it has shown some promise in reducing leafroller damage while also providing codling moth control. Sprayable formulations of pheromone for leafrollers are under development, and research trials suggest that they are another promising tactic to battle leafrollers in fruit orchards. Sprayable pheromones are also being developed for codling moth, and new “puffer” type pheromone dispenser systems for this pest are being evaluated in commercial orchards.

Attract and Kill

SIRENE®-CM (IPM Technologies) is a new product for codling moth control that uses removal of male moths as the mode of action. SIRENE-CM combines a pheromone and insecticide (a synthetic pyrethroid) in a black, tacky, tar-like substance that is placed as a small drop on a tree.

Male moths are attracted to the drop by the pheromone and upon touching the "false female" receive a lethal dose of insecticide. There is good potential that this same approach could be used as a control for leafrollers and other pests.

Summary

There are several insecticides that are near registration on apple that have novel modes of action. This is particularly important because EPA, under the FQPA, will combine the effects of all insecticides with similar modes of action. These new insecticides are much more selective than traditional chemicals used in apple pest control, being primarily effective against larvae of Lepidoptera. Selectivity provides safety for people, the environment, and in most cases for insect biological control agents. Because insecticides can have subtle effects on insect reproduction or can have short effects in the field against biological control agents, a series of tests is required to understand how new insecticides can be integrated with biological control. In general, new insecticides have been shown to be safe to most biological control agents found in Washington apple orchards. The combination of mating disruption, new insecticides and biological control provide hope for the future of Washington apple IPM programs in the era of FQPA. The real challenge will be to discover controls for pests for which new insecticides are not effective, for which biological controls are not known, or for which biological controls are not effective enough to prevent crop loss.

ADDITIONAL READING

Alway, T. 1998. Codling moth mating disruption and its role in Washington orchard pest management programs. Compact Fruit Tree, this volume.

Willett, M. and W. Ewart. 1998. The 1996 food quality protection act: Potential impact on IPM systems. Compact Fruit Tree, this volume.

Table 1. Natural enemy toxicity guide for tree fruits.

The table is intended as a guide to the relative toxicity of commonly applied pesticides to natural enemies that are important components of an integrated pest management program on tree fruits. The toxicity of some insecticides may vary considerably with the history of use in a given orchard. This is especially true relative to their effect on the western predatory mite (WPM) and the apple rust mite (ARM).

		Relative toxicity rating for natural enemies[z]				
Compound	Trade Name	WPM[y]	ARM[y]	*Colpoclypeus florus*[y]	*Pnigalio flavipes*[y]	Coccinellids[y]
Abamectin	Agri-Mek	H	H	M	M	M
amitraz	Mitac	H	-	-	-	-
azadirachtin	Neemix 4.5%	-	-	L		L
azinphosmethyl	Guthion 50WP	L	L	H	L	H
Bacillus thuringiensis (Bt)	Dipel, Javelin, Crymax, Biobit	L	L	L	L	L
Bacillus thuringiensis (Bt)	MVPII	L	L	L	L	-
carbaryl	Sevin 50WP	M-H	L-M	H	L	H
chlorpyrifos	Lorsban 4EC	L-M	L	H	H	H
chlorpyrifos	Lorsban 50WP	L-M	L	H	H	H
clofentezine	Apollo 50SC	L	L	-	-	-
diazinon	Diazinon 50WP	L	L	H	-	H
dimethoate	Dimethoate 2.67EC	L-M	L	H	-	H
encapsulated methyl parathion	Penncap-M 2F	L	L	H	H	H
endosulfan	Thiodan 50WP	L	M-H	M	M	M-H
esfenvalerate	Asana 0.66EC	H	L	M	M-H	-
fatty acids (soap)	M-Pede	M	M			L
fenbutatin-oxide	Vendex 4L	M	H	L	-	-
fenbutatin-oxide	Vendex 50WP	M	H	L	-	L
formetanate hydrochloride	Carzol 92SP	M-H	M-H	H	-	L
hexythiazox	Savey 50WP	L	L	-	-	-
imidacloprid	Provado 1.6F			M	-	M
lime-sulfur		M	H			-
methomyl	Lannate 1.8L	H	L	-	-	-
methomyl	Lannate 90SP	H	L	-	-	-
oil, petroleum		M	M	L	-	L
oxamyl	Vydate 2L	M-H	-	H	L-M	M
oxythioquinox	Morestan	M	M	-	-	-
permethrin	Ambush 2EC	H	L	M	-	-
permethrin	Pounce 3.2EC	H	L	M	-	-
phosmet	Imidan 70WP	L	L	H	L	H
pyridaben	Pyramite 60WP	M	H	-	-	-

[z] Rating system: L = low toxicity, M = moderate toxicity, H = high toxicity, - no data available.

[y] WPM = western predatory mite, *Typhlodromus occidentalis*. ARM = apple rust mite, *Aculus schlechtendali*; although ARM is a plant feeding species, its presence is very useful in maintaining populations of *Typhlodromus occidentalis*. *C. florus* is a wasp parasitoid of leafrollers. *P. flavipes* is a wasp parasitoid of western tentiform leafminer. Coccinellid data based on bioassays of late instar larvae of *Harmonia axyridis*, *Hippodamia convergens*, and *Coccinella transversoguttata*.