Orchard IPM: Insecticide Resistance Management for Codling Moth Control

Insecticide resistance trials at the Penn State Fruit Research and Extension Center, along with recent apple load rejections due to internal worms, indicate a need to re-focus attention on strategies to slow down the development of insecticide resistance in codling moth.

Changes in Product Registrations and Uses

In response to the re-registration process mandate by the Food Quality Protection Act (FQPA) of 1996, over 50 new insecticide products were introduced in the period from about 2000-2009 to replace older neurotoxic compounds such as Guthion, PennCap M, and Thionex. These were eliminated, and the few products that remained, such as Imidan, Lorsban, Lannate, and Diazionon, were generally given much longer re-entry intervals (REI) after sprays, requirements for more personal protection equipment (PPE), and longer pre-harvest intervals (PHI).

In the case of Guthion and Imidan, resistance by codling moth and Oriental fruit moth had begun to limit the effectiveness of these compounds. However, Guthion is missed for its much greater efficacy in controlling both plum curculio and apple maggot than current products. In the case of Lorsban, applications were limited to dormant, but resistance in rosy apple aphid (RAA) and San Jose scale (SJS) was already widespread. Because of this, Lorsban is currently only effective in controlling mid-summer woolly apple aphid (WAA) in most Pennsylvania apple orchards and if eventually eliminated by the US-EPA, it will not be that greatly missed in eastern apple orchards. It remains a critical product for controlling peach tree borers and the American plum borer in cherry with its only effective replacement, Thionex, being already eliminated because it belonged in the same pesticide class as DDT. Diazinon is limited to only a single application each year for only WAA. The Reduced-Risk products that replaced them such as Confirm, Intrepid, Calypso, Provado, Actara, and Avaunt were much safer to people and the environment, although the neonicotinoid insecticides are now often portrayed erroneously by the public as the main cause of bee declines.

Limitations for Managing Pesticide Resistance

The bar by which insecticides are now measured has changed in the last 15 years so that human safety is not enough, and safety for the environment, and especially bees, is required for new pesticide registrations. Because of this and the merging of 25 pesticide companies 15 years ago into only five or six, the development of new insecticides for specialty crops has slowed to a crawl. Most of our current insecticides have now been in use for 12-15 years. Codling moth management has centered on alternations by generation of Delegate and diamide insecticides such as Altacor. It took almost 50 years for codling moth to develop resistance to Guthion and Imidan, but most researchers do not believe it will take that long for the newer products.

Traditionally, insecticide resistance in moth pests of apple orchards has shown much earlier in leafroller pests (remember tufted apple bud moth?) than in codling moth. Resistance to both Delegate and the diamides (Altacor) have been reported in Washington apple orchards, so we should be looking out for it in the mid-Atlantic region as well. Pennsylvania and the rest of the mid-Atlantic, however, have had to deal with a series of invasive pests such as the brown marmorated stink bug (BMSB), spotted wing drosophila (SWD) and now the spotted lanternfly (SLF) about every 3-4 years. The “brush fires” caused by invasive pests have distracted the few remaining tree fruit entomologists in the eastern US from the long-term issues of pesticide resistance with the relatively few
insecticide tools we have for codling moth. These invasive pests, especially BMSB, have also reduced the wide-spread use of pheromone mating disruption and viruses that were two of the most effective tools in managing insecticide resistance in codling moth.

**Slowing the Development of Insecticide Resistance in Codling Moth**

In my insecticide evaluation trials at the Penn State Fruit Research and Extension Center (FREC) in Biglerville, I have become increasingly worried that we may be losing Delegate as an effective rotation partner with the diamide insecticides (e.g., Altacor). High rates of Delegate in up to 7 sprays during the season applied complete rather than Alternate Row-Middle (ARM) have failed to give adequate control for more than one season. Treatments in the same trial with alternations of Delegate and Altacor, have given better control, but still less than expected and programs where Delegate was replaced with another product such as Enkounter (pre-mix of Intrepid and Assail) have performed significantly better. I am also hearing of increasing apple load rejections due to internal worms by some growers. So how do we combat or slow down the development of insecticide resistance in codling moth?

**Defining the Mechanisms of Insecticide/Miticide Resistance**

First, we need to define the causes or mechanisms of insecticide/miticide resistance in tree fruit pests.

**Target site change**

This has really only been shown in mites and pear psylla in our fruit crops, but it is more common in other pests on cotton. It involves a modification of the action site in the pest to make it less sensitive to the pesticide as in the classical studies with the neurotoxic organophosphate insecticides and changes in the neurotransmitter acetylcholine. Many of our older miticides worked by inhibiting the mitochondrial electron transport (METI) system that governs cellular respiration. Changes to this system led to widespread resistance to products like Pyramite, Nexter, Portal, and Fujimite within only three to five years. Alternating products with differing modes of action is usually an effective strategy with this type of resistance.

**Enzymatic detoxification**

This consists of several mechanisms in tree fruit pests where mixed-function oxidases (MFOs) are the most important, as in leafminers, but resistance in most lepidopteran pests like codling moth and leafrollers is thought to be mostly based on a group of esterase enzymes. These enzymatic systems are thought to have evolved in insects to deal with toxic compounds in plants while feeding and have only relatively recently been utilized to also chemically break down pesticides. Predators and parasitoids that eat pests generally do not have some of these enzymes, or they are less effective, because the pest prey or hosts have already broken down these plant poisons. Because of this, predators and parasitoids generally do not have extensive enzymatic detoxification systems and are much less likely to develop resistance to pesticides for this reason.

Since the effectiveness of enzymatic systems is based on the type of chemical bond in the pesticide, mode of action of the pesticide has little to do with its susceptibility to breakdown. Resistance to pesticides of different classes has been shown in our leafrollers where the esterase enzymes that broke down Guthion also broke down the insect growth regulator Dimilin before it had ever been used because of similar chemical bonds between the two compounds, despite completely different modes of action. Alternatively, leaf rollers that were resistant to the OP insecticide azinphos-methyl were not resistant to chlorpyrifos. Guthion and Lorsban are both OPs with the same mode of action, but Lorsban's molecular bonds were not susceptible to the same enzymes that broke down azinphos-methyl. To a lesser extent, glutathione-S transferase enzymes are also important in breaking down pesticides in some fruit pests. Pear psylla is such a potent adversary for pesticide resistance because it not only has target site resistance, but also all the types of enzymatic resistance. Synergism of pesticides with products like piperonyl butoxide (PBO) or some sterol-inhibitor fungicides like Rally occur when these nontoxic compounds bind up the enzymatic systems of resistant pests to allow the pesticide to work uninhibited.

**Ensuring Good Resistance Management from Product Rotations**

Much is made of Insecticide Resistance Action Committee (IRAC) codes for rotating pesticides of differing modes of action. This is most effective on pests where target site modifications are the main source of resistance, such as in diseases where following the FRAC codes as spelled out by Dr. Kari Peter are very effective in combating fungicide resistance. As outlined in the previous section above, the rotation of pesticides with differing modes of action is less effective when enzymatic detoxification is the main source of resistance. It is, however, the best place to start as pesticides of differing classes often have greatly differing chemical structures.
To be truly sure of a good resistance management rotation, however, routine bioassays of field populations of pests should be conducted to determine if their efficacy is holding.

According to the IRAC mode of action classification (see Table 3-7, Penn State Tree Fruit Production Guide), Altacor, Besiege, Exirel, Minecto, and Voliam Flexi have a similar mode of action (i.e., ryanodine receptor modulators); thus they belong to Group 28. Delegate has a totally different mode of action (i.e., nicotinic acetylcholine receptor allosteric activators); thus it belongs to Group 5 (also in Table 3-7).

All of these products are highly active against CM, OFM, and the two major leafrollers, TABM and OBLR. Since five of the products have a similar mode of activity (i.e., they are chemically related), to delay the onset of resistance to either group for many years, we highly suggest that they be used only against a specific generation of a pest(s) and that the grower should rotate to other compound(s) or to other chemical classes (e.g., Group 1—organophosphates and carbamates, Group 4—Nicotinic acetylcholine receptor agonists [Assail, etc.] of compounds to control the next generation of the targeted pest(s).

For example, if a grower decides to use Delegate (Group 5) during the first generation of CM flight and egg hatch, then the grower should rotate to products in Group 28 or some other nonrelated group for the second-generation flight of CM. The same approach applies to OFM and the leafrollers. If Enkounter (Intrepid/Assail premix) is registered by next spring, it would bring Insect Growth Regulators (IGRs) in as a rotation partner. It may be worth looking at another older IGR insecticide, Rimon, for codling moth control in a rotation. This product was heavily used for a couple of years before Delegate and Altacor were registered, but its use was generally discontinued because it was less effective than the products that replaced it. While it is technicall an IGR insecticide, it belongs to a different sub-class than Confirm and Intrepid and was very toxic to many biological control agents and often caused flare-ups of mites and SJS.

A new trend in pesticide companies is the use of prepackaged mixtures to make a selective product more broad spectrum—in a sense, making a “new azinphos-methyl.” While this may at first give some level of synergism (not always proven) which sometimes leads to less than full rates of each product in the mixture, it can lead to the creation of a “super bug,” which has developed enzymes that break down both types of pesticides. For resistance management, the most current thought is to rotate pesticides rather than to mix them in each spray for this reason. The use of premixes can also mean loss of biocontrol of mites, aphids, and scales and are not always appropriate for each application since only one type of pest (e.g., codling moth) might be present. While premixes may be convenient when applying for codling moth and brown marmorated stink bug at the same time, growers may lose some flexibility in what they want to apply. I still do not advocate pyrethroids or pre-mixes with pyrethroids (e.g., Endigo) as codling moth rotation partners in most cases, because they cause flare-ups of secondary pests such as mites, aphids, and scale insects due to their destruction of biological control agents. I have also documented up to 80-fold increases in overwintering mite eggs from late-season pyrethroid use due to sublethal effects on adult mites.

### Other Options for Growers Experiencing Internal Worm Problems

- Normally, I advocate the use of two Delegate complete sprays for the four week-long 1st generation of codling moth and two complete sprays of Altacor or other diamide for the 2nd generation of codling moth which lasts six weeks. Altacor has the residual life to last the full six weeks with only two full cover applications, and switching Delegate to the fall timing would require adding a 3rd complete spray and additional costs. Delegate in the fall has also been shown to interfere with the biological control of mites, aphids, and scale, but the spring timing is much less harmful. Discussions with several apple growers with worm problems that switched to the stronger product first of Altacor/diamides for 1st generation and three applications of Delegate (only two applications not working) might be a temporary fix for growers experiencing more load rejections in recent years.

- Another temporary fix for apple growers experiencing internal worm problems would be to try going to complete/full cover sprays every 12-14 days rather than ARM applications. Damage in my old Intrepid trials showed a 6-fold increase in fruit injury using ARM sprays on a 7-day schedule vs. complete sprays on the 12-14 day schedule.

- Don’t cut rates and try to maximize coverage by increasing water volume applied (at least 100 gal/A depending on tree size) and/or by using a good spreader/sticker.

- Reduce resistance selection pressure on a CM population by using pheromone mating disruption and/or codling moth viruses now that BMSB has greatly declined in many fruit-growing regions.

Refer to the “Fungicides, Herbicides, Insecticides, Nematicides, and Plant Growth Regulators” section in Part III of the Penn State Tree Fruit Production Guide: Chemical Management and Table 3-7 for a further description of modes of action, a list of registered uses and activity against various pests.

We highly encourage growers to use these products carefully and sparingly for codling moth control, so we do not lose them to pest resistance in the future.