IRAC

Insecticide Resistance Action Committee

Maintaining Effective Control Strategies for Codling Moth, *Cydia pomonella*

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Introduction and Background

Codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae) is one of the most serious insect pest of apple and can also infest pear, crab apple, quince, walnut and other fruits. Codling moth is native to south eastern Europe and is now reported from parts of Africa, Asia, North America, South America, Australia and New Zealand.

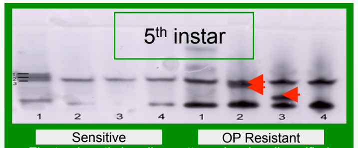
Depending on environmental conditions, codling moth has two to three generations per year. It overwinters in the pupal stage in protected areas on the trunk or in leaf litter at the base of trees. Timely, effective control is very critical because females emerge with mature eggs and can mate and lay eggs within a two-day period. Codling moth neonate larvae cause direct injury by boring into fruit which can result in significant crop losses. Upon entering the fruit larvae are well-protected and consequently, control tactics have strongly relied on chemical insecticides targeting eggs and/or newly hatched larvae. Due to the strong reliance on chemical control to manage codling moth, resistance and cross-resistance to multiple insecticide classes such as organophosphates, carbamates, chlorinated hydrocarbons and pyrethroids have been documented.

Codling Moth Resistance Mechanisms & IRM

Mechanisms

Resistance to a specific insecticide can be due to different resistance mechanisms

- ✓ Metabolic resistance (modified enzymatic activity: MFO, GST, EST)
- ✓ Target-site resistance (KDR, MACE)
- ✓ Reduced penetration and behavioural changes



Electrophoretic banding pattern showing diversified esterase isoforms in OP resistant 5th instar Codling Moth larvae (Courtesy of Dr. Manicardi)

When the mechanism(s) of resistance is not characterized and in order to prevent the onset of resistance phenomena (resistance avoidance) intelligent use of MoA alternation (i.e. between consecutive codling moth generations) and other semio-chemical, bio-technical and cultural tools remains best IRM practice, since such practice will always minimize selection pressure.

Metabolic cross-resistance and its diversity: a major threat

- Metabolic resistance is the most relevant type of resistance in codling moth
- Different metabolic profiles (enzymatic activity) can impact different MoA/products
- It can concern insecticides across different MoA, but differential response between products within the same MoA can be observed
- There can be diverse patterns of metabolic resistance (differential enzymatic activity)
- The diversity of the metabolic resistance found in codling moth can be significant across the different geographical areas

Bioassay and Monitoring for Resistance

Diagnosing metabolic resistance

- The analysis of the enzymatic activity (MFO, GST, EST) in a codling moth population is a key element for resistance evaluation
- There is a differential enzymatic activity between life-stages within the same population
- In resistant strains, the enzymatic activity may not only differ in quantitative terms, but also qualitatively (e.g. esterase isoforms)
- By itself, knowing the enzymatic profile of a given population does not allow to predict the field resistance nor the effectiveness of insecticide "X"
- Cross-resistance does not always concern all the insecticides with the same MoA. Azinphos-resistant codling moth may be susceptible to Chlopyrifos and vice versa.

Routine vs. validatory assays

- In the last decade, large scale monitoring for field resistance mostly relied on topical application to diapausing codling moth larvae
- Recent authoritative studies have confirmed their validity for IGRs, but questioned their reliability for the prediction of field resistance with some neurotoxic insecticides
- By itself, significantly higher response in a routine monitoring conducted on non-target insect stage, does not allow to predict field resistance, unless validated with additional target-specific assays
- Validation tests should include multiple insecticide concentrations

Bioassaying the target-stage

- Resistance monitoring should be preferentially done on the target instar
- For larvicidal products, ingestion bioassays on neonate larvae (F1 or F2 of the feral population) normally provide a more reliable indication of the field situation than topical application to diapausing larvae

Scenario Changes & Trends

	2000	2012	2017
No. of MoA available for codling moth control */**	8	10	n.a.
No. of individual insecticides available ***	High	Decreasing	Fewer
Use of semiochemicals (mating disruption)	Minor	Moderate	Increasing
Microbial insecticides	Minor	Moderate	Moderate
Biological control	Minor	Minor	Minor
Regulatory pressure	Low	High	Decreasing
Food chain pressure	Low	High	Decreasing
Field resistance issues ***/****	Moderate	Decreasing	Low
Resistance knowledge and investigation tools	Moderate	Increasing	High

* Four introduced in 1997-2000, two in 2007-10

** According to IRAC MoA classification (version 7.2)

*** In terms of chemical control measures, the criteria introduced in the revision of EU Directive 91/414 may concern a significant number of the available insecticides, with an impact on sustainable control options

**** Dependent on the implementation of the other factors. Assumption is that sustainable insecticide use will continue to be possible and implemented. In this respect, increased use of non-chemical tools will play a key role

Major factors affecting the current scenario vs year 2000

- Increased adoption of semio-chemicals for mating disruption
- Reduction of chemical toolbox due to regulatory & food-chain pressure
- Improved investigation tools for resistance detection and confirmatory assays

Insecticides & MoA for Codling Moth

MoA	Primary Target Site	Chemical Class	Common Name
1A	Acetylcholinesterase inhibitors	Carbamates	Carbaryl, Methomyl
1B	Acetylcholinesterase inhibitors	Organo-phosphates	Azynphos-methyl, Chlorpyrifos, Diazinon, Malathion, Parathion, Phosmet, Phosalone, etc
3A	Sodium channel modulators	Pyrethroids	*lambda*-Cyhalothrin, *beta*-Cyfluthrin, Cypermethrin, Deltamethrin, Etofenprox, etc
15	Chitin biosynthesis inhibitors, type 0	Benzoylureas	Diflubenzuron, Flufenoxuron, Lufenuron, Novaluron, Teflubenzuron, Triflumuron, etc
4A	Nicotinic acetylcholine receptor agonists	Neonicotinoids	Acetamiprid, Thiacloprid
22A	Voltage-dependent sodium channel blockers	Oxadiazines	Indoxacarb
5	Nicotinic acetylcholine receptor allosteric activators	Spinosyns	Spinosad, Spinetoram
18	Ecdyson agonists	Diacylhydrazines	Tebufenozide, Methoxyfenozide
7B	Juvenile hormone mimic	Phenoxyphenoxy-ethylcarbamate	Fenoxycarb
6	Chloride channel activators	Avermectins	Emamectin-benzoate
28	Ryanodine receptor modulators	Diamides	Flubendiamide, Chlorantraniliprole

- The toolbox is not empty. Ten different modes of action are currently available for control of codling moth. Although efficacy level may vary, all of them are critical to ensure the MoA diversity needed for sustainable control.
- The available toolbox should be locally qualified with the number of authorized MoA/products, the year of consistent introduction for codling moth control and the relative efficacy level provided.

Photograhs courtesy: *Cydia pomonella* pupae - Whitney Cranshaw, Colorado State University, Bugwood.org; *Cydia pomonella* eggs – Bayer CropScience

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