Obliquebanded Leafroller (Lepidoptera: Tortricidae) Resistance to Insecticides in Michigan Apple and Cherry Orchards

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The native North American pest, obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae), is widely distributed and has a broad range of over 50 hosts, but members of the Rosaceae family are preferred (Sanderson and Jackson 1909; Larocque et al. 1999). The polyphagous larva is the injurious stage of *C. rosaceana*, as it feeds on flower buds, leaves, and developing fruit (Sanderson and Jackson 1909; Reissig 1978). *C. rosaceana* is a foliage and fruit feeding pest in apple, causing significant damage, especially by the summer generation. In cherry, the foliage and fruit injury caused by *C. rosaceana* is less serious compared with apple. However, *C. rosaceana* is a more critical pest in cherry in the late season, when the larvae can be a contaminant in harvested cherries, thus representing a high risk for load rejection due to the U.S. Department of Agriculture zero-tolerance mandate (USDA 1941; Mason and Huber 2002; Wise and Whalon 2009).

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Historically, *C. rosaceana* was considered a secondary pest in fruit orchards, but it became a serious pest causing significant damage since outbreak populations began to occur in the late 1970s (Sial and Brunner 2010a, 2012b). Documentation of many cases of insecticide resistance in *C. rosaceana* populations against conventional insecticides has made this pest problem even more serious (Mushtaq et al. 2002; Smirle et al. 2002, 2003; Sial and Brunner 2012a). Conventional insecticides, especially the organophosphates, were the backbone of control programs at that time, and the resistance phenomenon among *C. rosaceana* populations against these compounds led to field failures in commercial apple control programs (Bostanian et al. 1985; Waldstein and Reissig 2000; Mushtaq et al. 2002; Sial and Brunner 2012b).

Concurrent with the aggravating factor of resistance problems, US Congress passed the Food Quality Protection Act (FQPA) in 1996, which restricted or prevented the use of many conventional insecticides. As a consequence, fruit growers were forced to replace many of the conventional insecticides with new reduced-risk insecticides that have novel modes of action. Most of these new insecticides showed high efficacy against *C. rosaceana* populations (Smirle et al. 2003; Sial and Brunner 2010b, 2010c, 2012a, 2012b; Sial et al. 2010). However, some cases of resistance were recorded against some of these new insecticides, even though some field populations were not exposed to these products previously (Mushtaq et al. 2002; Smirle et al. 2002; Sial et al. 2010).

The escalating concern about resistance in *C. rosaceana* field populations has reinforced the need for continued resistance monitoring and identification of effective tools for integrated pest management (IPM) programs (Waldstein and Reissig 2001; Wise et al. 2006, 2007; Mota-Sanchez et al. 2008; Hoffmann et al. 2009; Wise and Whalon 2009; Sial and Brunner 2010b, VanWoerkom et al. 2014). The aim of the current study was to determine resistance levels against commonly used insecticides in Michigan *C. rosaceana* field populations (Wise et al. 2015).

Materials and methods

Three *C. rosaceana* populations were tested. Two field populations were collected from one commercial apple and one commercial cherry orchard in western Michigan, and the third population was a susceptible laboratory population. The three *C. rosaceana* populations were maintained, reared, and assessed under constant conditions (25±1°C, 16:L8D) following the method of Mushtaq et al. 2002. Details of the insecticides tested are given in Table 1.

Laboratory Toxicity bioassay

A baseline toxicity bioassay was conducted for each insecticide on each of the *C. rosaceana* populations. For this bioassay, a range of 6–13 concentrations of each insecticide was prepared with distilled water, with the control treatment being distilled water alone. For each concentration of each insecticide, a 100-microliter aliquot was applied to the surface of 3 ml of artificial diet (Mushtaq et al. 2002) in 30 ml (1 fl oz) clear plastic soufflé cups. To ensure the solution covered the entire diet surface, the cups were gently rotated. When the solution layer had dried (30–45 min), five 12–24-h old *C. rosaceana* larvae were placed in each cup. Five to 10 replications (cups) were assigned to each concentration of each insecticide. Larval mortality was recorded 120 h after the larvae were placed on the treated diet for all insecticides, except chlorantraniliprole and novaluron, where the larval mortality was recorded after 168 h. The mortality data for each insecticide and each population was analyzed by Probit Analysis using SAS 9.4 (SAS Institute 2013) to calculate the LC_{50} and LC_{90} values. The LC_{50} and LC_{90} values for each *C. rosaceana* field population were compared with those of the susceptible laboratory population to assign a resistance level for each field population. Control mortality was used to adjust the mortality of each treatment using Abbott's formula (Abbott 1925).

Table 1. Details of compounds tested.

Treatment Trade name	Chemical class	Active ingredient	Company
Imidan 70W	Organophosphate	Phosmet	Gowan Company, Yuma, AZ
Bifenture 10DF	Pyrethroid	Bifenthrin	United Phosphorus, Inc., King of Prussia, PA
Lannate LV	Carbamate	Methomyl	I.E. du Pont De Nemours and Co., Wilmington, DE
Delegate 25WG	Spinosyn	Spinetoram	Dow AgroSciences, Indianapolis, IN
Altacor 35WG	Anthranilic diamide	Chlorantraniliprole	I.E. du Pont De Nemours and Co., Wilmington, DE
Avaunt 30WG	Oxadiazine	Indoxacarb	I.E. du Pont De Nemours and Co., Wilmington, DE
Proclaim 5SG	Avermectin	Emamectin benzoate	Syngenta Crop Protection Inc., Greensboro, NC
Rimon 0.83EC	Benzoylphenylurea	Novaluron	Chemtura Corporation, Middlebury, CT

Table 2. Baseline toxicity of eight insecticides against C. rosaceana 12/24h-old larvae of apple (K.A.) and cherry (F.C.) field populations compared with susceptible population.

Treatment[a]	Active ingredient	Population	RR_{50}[b]	RR_{90}[b]	X^2 Value
Imidan	Phosmet	Susceptible (120 H)	1.0	1.0	25.62
		F.C. (120 H)	2.5	1.8	18.44
		K.A. (120 H)	5.0	5.7	116.35
Bifenture	Bifenthrin	Susceptible (120 H)	1.0	1.0	21.46
		F.C. (120 H)	4.9	7.6	38.90
		K.A. (120 H)	5.0	12.9	53.56
Lannate	Methomyl	Susceptible (120 H)	1.0	1.0	24.62
		F.C. (120 H)	0.1	0.0	15.75
		K.A. (120 H)	0.4	0.1	37.98
Avaunt	Indoxacarb	Susceptible (120 H)	1.0	1.0	56.59
		F.C. (120 H)	21.0	629.9	52.30
		K.A. (120 H)	620.4	50998.0	26.38
Delegate	Spinetoram	Susceptible (120 H)	1.0	1.0	20.76
		F.C. (120 H)	4.1	3.7	70.41
		K.A. (120 H)	4.3	3.1	86.36
Proclaim	Emamectin benzo-ate	Susceptible (120 H)	1.0	1.0	69.91
		F.C. (120 H)	5.8	4.1	57.19
		K.A. (120 H)	6.3	4.3	78.61
Altacor	Chlorantraniliprole	Susceptible (168 H)	1.0	1.0	25.98
		F.C. (168 H)	1.1	1.5	61.57
		K.A. (168 H)	4.7	6.0	77.53
Rimon	Novaluron	Susceptible (168 H)	1.0	1.0	30.62
		F.C. (168 H)	5.3	5.8	57.89
		K.A. (168 H)	2.4	8.5	83.64

[a] Mortality was recorded after 120h of exposure to insecticides (except for chlorantraniliprole and novaluron mortality, which was recorded after 168h of exposure).
[b] Resistance ratio (RR) = LC value of Field strain/LC value of susceptible strain.

Results and Discussion

Different levels of resistance to the eight tested insecticides were observed in the two *C. rosaceana* field populations. Generally, in comparing the LC_{50} and LC_{90} values, more cases of insecticide resistance were found in both commercial apple field populations than in the commercial cherry population. Additionally, the *C. rosaceana* populations collected from commercial orchards were generally more susceptible to the newer insecticides than to the conventional insecticides (Table 2).

Conventional insecticides

Organophosphates. Considering the historical long-term use of organophosphates in apple and cherry orchards, high levels of resistance against organophosphates in *C. rosaceana* field populations were to be expected (Mota-Sanchez et al. 2008). This expectation was documented by the occurrence of high levels of resistance against organophosphates throughout the United States and Canada (Sial and Brunner 2012; Smirle et al. 2002, 2003). However, our study recorded a low level of resistance to phosmet in the apple field population, and no resistance in the cherry population, compared with the susceptible population (Table 2). Our results for Michigan field populations were in agreement with those of a previous study (Mushtaq et al. 2002), where Michigan *C. rosaceana* populations showed moderate resistance to azinphos-methyl and chlorpyrifos, and low resistance to phosmet. Maintaining a low level of resistance in *C. rosaceana* field populations against an older compound like phosmet over the past decade is a good sign of the effectiveness of the IPM programs in Michigan apple and cherry orchards. Even so, the use of phosmet for *C. rosaceana* control programs should be avoided in these orchards because of the likelihood of rapid resistance build-up if selection pressure were to resume.

Carbamates. Similarly to the organophosphates, we expected high levels of resistance against carbamates in *C. rosaceana* field populations, since both classes have the same mode of action as acetylcholinesterase (ache) inhibitors (IRAC 2016). Accordingly, applying either one of these two classes would promote development of field population resistance to that class as well as to the other class of compounds, a phenomenon known as cross-resistance. This phenomenon was documented in apple orchards in Ontario, Canada (Pree et al. 2002) and Michigan (Mushtaq et al. 2002), where *C. rosaceana* organophosphate-resistant field populations were found to be highly resistant to carbamates such as methomyl and carbaryl. However, the current study noted no resistance in field populations, compared with the susceptible population, to the carbamate insecticide methomyl (Table 2). We believe this unexpected result was a consequence of excluding carbamate insecticides from the control programs in Michigan fruit orchards and the reduction of seasonal organophosphate applications in the same control programs over the past decade (Michigan Fruit Management Guide 2015). Nonetheless, carbamate insecticides are not recommended for control of *C. rosaceana*.

Pyrethroids. The *C. rosaceana* field populations in this study showed low resistance to bifenthrin (Table 2), which is consistent with previous work conducted in Michigan (Mushtaq et al. 2002), where low resistance levels were recorded for pyrethroid insecticides such as cypermethrin, zeta-cypermethrin, bifenthrin, deltamethrin and esfenvalerate. This result highlights the effectiveness of Michigan apple and cherry IPM programs in preventing any increase in resistance levels for more than a decade. However, periodic monitoring is required to detect any further increases in the resistance to pyrethroid insecticides, which are not recommended as a first choice for targeted control.

Reduced-risk insecticides.

Both field populations showed similar levels of resistance to insecticides in this group, except for chlorantraniliprole, where both populations had very low resistance to spinetoram and emamectin benzoate, and no resistance to novaluron (Table 2). In the chlorantraniliprole treatment, the apple field population was very slightly resistant, while the cherry field population showed no resistance (Table 2). The very low levels or absence of resistance to the reduced-risk insecticides were expected, as they are relatively new compounds; emamectin benzoate, novaluron, spinetoram, and chlorantraniliprole were first registered in the US in 1999, 2001, 2007, and 2008, respectively (USEPA 2016). However, our results showed slightly higher resistance levels to some of the reduced-risk insecticides compared with previous studies in Washington and Michigan apple orchards, where *C. rosaceana* was not resistant to spinetoram, emamectin benzoate, novaluron, and chlorantraniliprole (Mushtaq et al. 2002; Sial et al. 2010; Sial and Brunner, 2012), except for one Washington field population that showed very low resistance to chlorantraniliprole. Although the resistance levels in our study would still be considered negligible, this early development of resistance to these newer insecticides should be a warning to monitor control programs carefully, especially when these compounds are applied consistently, to prevent losing these tools because of a resistance problem.

Indoxacarb. Indoxacarb was first registered in the US in 2000 (USEPA 2016). In this study, the *C. rosaceana* apple and cherry field populations were highly and moderately resistant to indoxacarb, respectively (Table 2). Similar results were reported 14 years ago in a *C. rosaceana* field population from a Michigan apple orchard with no history of indoxacarb application (Mushtaq et al. 2002). Similarly, *C. rosaceana* populations from apple orchards in the Okanagan and Similkameen Valleys in British Columbia, Canada, were found to have high levels of resistance to indoxacarb (Smirle et al, 2002). These observations were also from populations that had no history of exposure to indoxacarb applications, which supports the notion of cross-resistance from other chemical classes. Indoxacarb is not currently labeled for *C. rosaceana* control, so this is more of academic interest than practical importance. We will continue to study this situation to identify the mechanisms that play a role in indoxacarb resistance.

The levels of resistance against the newer insecticides should be monitored periodically for further increases in resistance levels. A statewide survey of more commercial orchards would help determine the extent of insecticide resistance across the tree fruit production regions.

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