N O T E

# Insecticide Resistance in Diamondback Moth (Lepidoptera: Plutellidae) in Georgia[1]

Krishna B. Bhandari[2], Philip Torrance, Evan Huffman, John Bennett, and David. G. Riley[3]

Department of Entomology, University of Georgia, Tifton Campus, 122 S. Entomology Drive, Tifton, Georgia 31793 USA

J. Entomol. Sci. 55(3): 416–420 (July 2020)

**Key Words** Plutella xylostella, insecticide resistance

The diamondback moth, *Plutella xylostella* (L) (Lepidoptera: Plutellidae), has generally become resistant to any new insecticide mode of action used extensively for its control. Up to recent times, *P. xylostella* has developed resistance to 95 distinct insecticide active ingredients (Arthropod Pesticide Resistance Database, http://www.pesticideresistance.org/, accessed 19 June 2019) and has become one of the most difficult pests to control in cruciferous vegetables (Furlong et al. 2013, Annu. Rev. Entomol. 58: 517–541). Insecticide resistance levels in *P. xylostella* populations were evaluated in 2012, 2013, 2016, 2017, and 2018 at Tifton (Tift County), GA, for selected insecticides to provide some baseline data on insecticide efficacy. These data were assessed on *P. xylostella* populations in Tift County around which Georgia's acreage of curciferous crops is concentrated. The objective of this study was to establish baseline lethal concentration (LC) data for *P. xyllostella* to chlorantraniliprole (Coragen®, E.I. du Pont de Nemours and Company, Wilmington, DE; a ryanodine receptor modulator, IRAC Group 28 https://www.irac-online.org/modes-of-action/, accessed 19 June 2019) and spinetoram (Radiant®, Dow AgroSciences LLC, Indianapolis, IN; a nicotinic acetylcholine receptor allosteric activator, IRAC Group 5) in Tift County, GA.

Larval *P. xylostella* specimens were collected from the Tifton location (N 31.47°, E 83.53°), a University of Georgia (UGA) organic-designated research farm in Tift County, from April to June of 2012 for 50% lethal concentration ($LC_{50}$) bioassays. A susceptible *P. xylostella* population, which was not exposed to insecticides for several years and also from the Tifton location, was used as a check in 2012. Possible resistant *P. xylostella* populations which were exposed to insecticides in

[1]Received 22 July 2019; accepted for publication 4 August 2019.
[2]Department of Plant and Soil Science, Texas Tech University, Lubbock, TX 79409 USA.
[3]Corresponding author (email: dgr@uga.edu).

recent years were collected from commercial cabbage fields near Omega, GA, in April–June in 2013, 2016, 2017, and 2018. In addition, we had a susceptible laboratory population provided by Dr. T. Shelton (Cornell Univ., Ithaca, NY) as a Coragen-susceptible check in 2018. For Radiant, our laboratory colony was considered the susceptible check. For zeta-cypermethrin (Mustang Max®, IRAC Group 3, FMC Corporation, Philadelphia, PA) and cyantraniliprole (Verimark®, E.I. du Pont de Nemours and Company, Wilmington, DE), we only tested the Hort Hill Farm population, our "field susceptible" population. These *P. xylostella* larval field collections were placed in a Specimen Transfer Cage (1450TC, BioQuip Products, Rancho Dominguez, CA) with cabbage sprouts as larval feeding media. The resulting adults were fed on 10% (v/v) honey solution while in the cage and allowed to lay eggs continuously on cabbage seedlings. The resulting larvae were used in the following bioassays.

Formulated insecticides used for bioassays included zeta-cypermethrin (Mustang Max 600g ai/liter SC; concentrations mg/liter: 600, 6, 0.06, 0.015, and 0.00), spinetoram (Radiant 120g ai/liter SC; concentrations mg/liter: 120, 12, 1.2, 0.6, 0.12, 0.012, and 0.00), cyantraniliprole (Verimark 200g ai/liter SC; concentrations mg/liter: 50, 0.5, 0.25, 0.125, 0.0625, 0.03125, and 0.00), and chloranthraniliprole (Coragen 200g ai/liter SC; concentrations mg/liter: 50, 10, 1, 0.25, 0.0625, 0.015625, and 0.00). The other insecticides used in these studies included indoxacarb (Avaunt®, IRAC Group 22A, Dupont Crop Protection, Newark, DE), cyclaniliprole (Harvanta®, IRAC Group 28, Summit Agro USA, LLC, Durham, NC), cyantraniliprole (Exirel®, IRAC Group 28, E. I. du Pont de Nemours and Company, Wilmington, DE), naled (Dibrom®, IRAC Group 1B, AMVAC Chemical Corporation, Newport Beach, CA), emamectin benzoate (Proclaim®, IRAC Group 6, Syngenta Crop Protection, Inc., Greensboro, NC), bifenthrin (Brigade®, IRAC Group 3A, FMC Corporation, Philadelphia, PA) and *Bacillus thuringiensis*, subsp. *kurstaki* (Dipel®, IRAC Group 28, Valent USA Corporation, Walnut Creek, CA) in similar dose ranges. Leaf dip bioassay was conducted using 1–2-mo-old cabbage plants which were grown in greenhouse condition. Cut, 6-cm diameter leaf discs were dipped in an insecticide solution with 1.8% (v/v) spreader sticker, Wetcit® (ORO AGRI, INC., Fresno, CA), for 5 s. Control discs were treated with 1.8% Wetcit and water solution only. The leaf discs were dried at room temperature for approximately 1 h. One treated leaf disc with 10 second-to-third instars larvae were placed in a vented 100 $\times$ 15 mm Petri dish (VWR Corporation, Radnor, PA) with an extra 38-mm-diameter cut vent hole in the center of the top dish screened with nylon chiffon. For most $LC_{50}$ evaluations, each concentration tested consisted of three replications of 10 larvae or 30 larvae per seven insecticide concentrations ($n = 210$; but where different, the $n$ value is given in Table 1). The bioassay was conducted with an air-conditioned room temperature of 22.8–23.9°C and a room relative humidity of 44–46%. Mortality was monitored periodically (24, 48, 72, and 144 h). PROC PROBIT (SAS Institute 2003, SAS Institute, Cary, NC) was used for probit analysis for dose-response data and to estimate $LC_{50}$ values (concentration required to kill 50% of the test population). Only significant probit analyses during this time period are reported here.

The $LC_{50}$ values of the insecticides tested (Table 1) show a distinct increase in $LC_{50}$ values (i.e., a reduction in the efficacy) of chlorantraniliprole and spinetoram in 2016–2018 compared to 2012 and the Ithaca susceptible check from Cornell

**Table 1. Median lethal concentrations ($LC_{50}$) for selected insecticides against *P. xylostella* populations collected at Tifton, GA. (—) indicates no ratio was calculated because no susceptible check was available.**

| Commercial Insecticide | Pest Population* | *N* Larvae Tested | Year Collected | Hour Reading | $LC_{50}$ mg ai/liter | 95% Fiducial Limits | RS Ratio** |
|---|---|---|---|---|---|---|---|
| Spinetoram | Tifton collection | 140 | 2012 | 48 | 0.016 | 0.00–0.85 | 1 |
| Spinetoram | Tifton collection | 140 | 2012 | 48 | 0.388 | 0.19–0.75 | 24.3 |
| Spinetoram | Tifton collection | 480 | 2012 | 72 | 0.033 | 0.02–0.05 | 1 |
| Chlorantraniliprole | Tifton collection | 140 | 2012 | 48 | 0.73 | 0.00–4.0 | 1 |
| Chlorantraniliprole | Tifton collection | 360 | 2012 | 48 | 0.76 | 0.56–1.02 | 1 |
| Chlorantraniliprole | Tifton collection | 360 | 2012 | 72 | 0.26 | 0.13–0.39 | 1 |
| Zeta-cypermethrin | Tifton collection | 300 | 2012 | 72 | 82.5 | 41–151 | 1 |
| Zeta-cypermethrin | Omega collection | 300 | 2012 | 72 | 88.5 | 41–171 | 1.1 |
| Cyantraniliprole | Tifton collection | 280 | 2013 | 72 | 0.19 | 0.13–0.29 | 1 |
| Spinetoram | Tifton collection | 210 | 2013 | 48 | 0.158 | 0.04–0.35 | 9.9 |
| Spinetoram | Tifton collection | 210 | 2013 | 72 | 0.173 | 0.10–0.25 | 10.8 |
| Spinetoram | Omega collection | 480 | 2013 | 48 | 0.243 | 0.15–0.40 | 15.2 |
| Spinetoram | Omega collection | 480 | 2013 | 72 | 0.033 | 0.02–0.05 | 2.1 |
| Chlorantraniliprole | Tifton collection | 210 | 2013 | 72 | 1.95 | 0.96–3.99 | 2.7 |
| Cyclaniliprole | Omega collection | 240 | 2016 | 72 | 0.02 | 0.00–0.35 | — |
| Chlorantraniliprole | Omega collection | 360 | 2016 | 72 | 1.77 | 0.30–5.8 | 6.8 |
| Naled | Omega collection | 180 | 2016 | 72 | 1.10 | 0.08–7.7 | — |

**Table 1. Continued.**

| Commercial Insecticide | Pest Population* | *N* Larvae Tested | Year Collected | Hour Reading | $LC_{50}$ mg ai/liter | 95% Fiducial Limits | RS Ratio** |
|---|---|---|---|---|---|---|---|
| Cyclaniliprole | Omega collection | 180 | 2016 | 72 | 0.92 | 0.00–4.98 | — |
| Chlorantraniliprole | Omega collection | 180 | 2017 | 72 | 0.53 | 0.02–6.4 | 2.0 |
| Indoxacarb | Omega collection | 180 | 2017 | 72 | 1.58 | 0.68–2.5 | — |
| Emamectin benzoate | Omega collection | 180 | 2017 | 72 | 1.20 | 0.42–2.5 | — |
| Bifenthrin | Omega collection | 160 | 2017 | 72 | 1.00 | 0.00–11.7 | — |
| Bifenthrin | Omega collection | 160 | 2018 | 72 | 3.44 | 0.22–23.1 | — |
| Cyantraniliprole | Omega collection | 140 | 2018 | 72 | 1.21 | 0.20–3.4 | 6.4 |
| *Bacillus thuringiensis* | Omega collection | 140 | 2018 | 72 | 1.31 | 0.01–11.9 | — |
| Naled | Omega collection | 260 | 2018 | 72 | 1.34 | 0.07–8.86 | — |
| *Bacillus thuringiensis* | Omega collection | 140 | 2018 | 72 | 1.79 | 0.00–23.1 | — |
| Spinetoram | Omega collection | 140 | 2018 | 72 | 1.70 | 0.23–5.59 | 51.5 |
| Cyantraniliprole | Omega collection | 140 | 2018 | 72 | 1.20 | 0.00–9.8 | — |
| Chlorantraniliprole | Parrish collection | 70 | 2018 | 48 | 9.72 | 0.08–61 | 13.3 |
| Chlorantraniliprole | Ithaca susceptible | 210 | 2018 | 72 | 0.21 | 0.00–3.3 | 0.81 |

* Population collection sites include Tifton, GA N31.470, E–83.530 and N31.516, E–83.548, Omega, GA N31.335, E–83.608 and several sites along Omega-Ellenton Road to N31.222, E–83.581, Parrish, FL N27.605, E–82.419, and Ithaca, NY is from Tony Shelton's laboratory, Cornell University.
** The RS or resistant to susceptible ratio was calculated as the $LC_{50}$ value/$LC_{50}$ susceptible value of the Tifton collection in 2012.

University. In 2016, control failures with both of these products were observed in Tift and Colquitt counties (D.G.R., unpubl. data). This was in spite of recommended insecticide rotations (Riley 2013, J. Entomol. Sci. 49: 130–143) purported to reduce insecticide resistance selection pressure (Zhao et al. 2010, Pest Manag. Sci. 66: 1101–1105). Both chlorantraniliprole and spinetoram were highly effective against *P. xylostella* at the time of commercial labeling, which led to over-use of these products for control of this pest. Given the resistance-prone nature of *P. xylostella* and the over-use of these materials, resistance development was a certainty.

Additional insecticides tested were observed to have higher than susceptible $LC_{50}$ values based on previous insecticide resistance documentation for *P. xylostella* for the organophosphates, carbamates, organochlorines, and pyrethroids (Sun et al. 1986, Pp. 359–371 *In* Talekar (ed.), Proceedings 1st International Workshop, Shanhua, Taiwan) and *B. thurengiensis* (Heckel et al. 2004, Pp. 27–36 *In* Ridland and Endersby (eds.), Proceedings 4th International Workshop, Victoria, Australia) spinosyns (Sparks et al. 2012, Pest. Biochem. Physiol. 102: 1–10.), indoxacarb (Sayyed and Wright 2006, Pest Manag. Sci. 62: 1045–1051), emamectin benzoate (Zhao et al. 2006, J. Econ. Entomol. 99: 176–181), and other diamides (Troczka et al. 2012, Insect Biochem. Mol. Biol. 42: 873–880).

One of the reasons for this widespread adaptation to insecticides is the range of resistance mechanisms occurring in *P. xylostella* populations (Cheema et al. 2011, Pesticide Res. J. 23: 123–134). Interestingly, lepidopteran pests have shown more development of resistance to phytochemicals (Bhandari et al. 2018, Agric. Environ. Letters 3:180037) than have hymenopteran pollinators (Bhandari et al. 2018, Crop Sci. 58: 2665–2671) and dipteran pests (Bhandari et al. 2018, Texas J. Agric. Nat. Res. 31: T1–T5). In contrast, some hymenopteran pests, such as red imported fire ants, *Solenopsis invicta* Buren, were found to be very susceptible to phytochemicals (Bhandari et al. 2018, Crop, Forage & Turfgrass Manag. 4:180005) due to the presence of some well-known insect-deterring compounds in the plants (Bhandari et al. 2019, Indust. Crops Prod. 133: 1–9).

**Acknowledgments.** We acknowledge the University of Georgia technical assistance of Charles Gruver. This work was funded in part by E. I. Dupont Crop Protection and the Georgia Commodity Commission for Vegetables and USDA CPPM Grant 12623420. This study was supported by the Georgia Agricultural Experiment Stations.