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The influence of post-exposure temperature on the toxicity of insecticides to *Ostrinia nubilalis* (Lepidoptera: Crambidae)

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Abstract: The influence of post-treatment temperature on the toxicities of two pyrethroids (lambda-cyhalothrin and bifenthrin), a carbamate (methomyl) and a spinosyn (spinosad) to *Ostrinia nubilalis* (Hübner) larvae was evaluated in laboratory assays. From 24 to 35 °C, the toxicities of the pyrethroids decreased 9.5- and 13.6-fold while spinosad toxicity decreased 3.8-fold. The toxicity of methomyl did not change significantly. The results demonstrate that the most effective insecticide against a pest may vary with environmental conditions. In situations where comparable products from multiple insecticide classes are available, temperature should be included as a factor in the decision-making process.

Keywords: toxicity; insecticide; pyrethroid; spinosyn; carbamate; temperature coefficient; European corn borer; *Ostrinia nubilalis*

1 INTRODUCTION

Temperature often has a significant effect on the efficacy of insecticides when used on the field. These temperature-dependent differences may be due to changes in coverage,[1] insect behavior[2] or insecticide toxicity.[3] During hot periods in 2002, control of *Ostrinia nubilalis* (Hübner) in sweet corn (*Zea mays*, L) by aerially applied insecticides was poorer than experienced at other times (R Wildman, pers comm). A number of studies were undertaken to understand which factors are influenced by changes in temperature in this system. In this paper we report our findings regarding the impact of temperature on insecticide toxicity.

Insecticides from the same class often have similar temperature responses. Organophosphate and carbamate insecticides generally have stable toxicities at all temperatures, but some studies have found slight positive or negative temperature coefficients.[3] Pyrethroid insecticides often have reduced efficacy at high temperatures, but several studies have found pyrethroids to have a positive temperature coefficient against some species.[3] In addition to insecticides in the pyrethroid, carbamate and organophosphate classes, spinosad now represents an alternative class of insecticides available for control of thrips, Lepidoptera and selected pests in other orders.[4] In the only study found examining temperature effects on spinosad, toxicity was unaffected by changes in temperature.[5]

In addition to differences between insecticide classes there are also differences within insecticide classes and between species. For example, Toth and Sparks[6] found two pyrethroids (*cis*-permethrin and lambda-cyhalothrin) had negative temperature coefficients, while one pyrethroid (esfenvalerate) had no temperature coefficient against *Trichoplusia ni* (Hübner). Sparks *et al*[7] recorded negative temperature coefficients for three pyrethroids against *T ni*, but two of those exhibited neutral or positive temperature coefficients against *Spodoptera frugiperda* (JE Smith) and *Heliothis virescens* (F). As temperature sensitivity varies between insecticide classes and is sometimes pest- and product-specific, more information is needed to allow those responsible for making pest-management decisions to select the best product for the existing environmental conditions. We are not aware of any temperature toxicity research done on the European corn borer, *O nubilalis*, even though this insect is the target of insecticide applications in many important field and vegetable crops.[8] It is the major foliar pest of corn in the USA, with yield losses and control expenditures greater than $1 billion annually.[8] The present study was undertaken to compare the effects of post-treatment temperature on the efficacy of four currently registered insecticides from three insecticide classes against *O nubilalis* larvae.

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2 MATERIALS AND METHODS

2.1 Insects

Ostrinia nubilalis eggs laid on wax paper were obtained from a laboratory colony within 4 days of oviposition. These egg sheets were placed in a plastic bag with a moist paper towel until eggs hatched. First instars were then exposed to pesticides as described in Section 2.2.

2.2 Pesticide preparation

Commercial formulations of four insecticides were used in this assay. Two pyrethroid insecticides, lambda-cyhalothrin 120 g liter^{-1} CS (Warrior, Syngenta, Greensboro, NC, USA) and bifenthrin 240 g liter^{-1} EC (Capture 2EC, FMC, Philadelphia, PA, USA) were compared with the carbamate methomyl 280 g liter^{-1} SL (Lannate LV, DuPont, Wilmington, DE, USA) and with spinosad 240 g liter^{-1} SL (SpinTor 2SC, Dow AgroSciences, Indianapolis, IN, USA). For each insecticide, serial dilutions with distilled water were prepared to cover the range of expected partial mortality of *O nubilalis* at 25 °C on the basis of preliminary tests. At least four concentrations plus a water control were used for each insecticide. Maize (*Zea mays*, L) leaf disks (diameter: 3.2 cm) were dipped into the insecticide solutions for 5 s and then placed in a plastic cup to dry. After 2 h, insects were placed on the leaf disks as described in Section 2.3. At least six leaf disks were used for each insecticide concentration.

2.3 Treatments

Insecticide residues can kill insects through contact and ingestion, and the contribution of these sources of exposure varies among insecticides. With the goal of standardizing the bioassay method for products with potentially different routes of penetration, we used the following protocol. Thirty first-instar *O nubilalis* were transferred from egg sheets within 24 h of hatching onto each treated maize leaf disk using a fine brush. Larvae were kept in the plastic cup with the treated leaf disk for 3 h in the light at room temperature. All insecticide exposure was done at a common temperature to isolate insecticide toxicity from insect factors that are affected by temperature. After this exposure period, a fine brush was used to transfer ten larvae into each of three 30-ml cups with artificial diet.[9] Each cup of larvae was placed into a growth chamber kept under a 16:8 h light:dark photoperiod, 60% RH and a constant temperature of 24, 29 or 35 °C for 7 days. Three growth chambers were used for each temperature to ensure that temperature effects were independent of the growth chamber used. After 7 days *O nubilalis* mortality was recorded for all treatments. Growth chamber was not a significant mortality factor, so it was not used in analysis. Mortality was analyzed using probit analysis[10] corrected for control mortality at each temperature.[11] Temperature coefficients were calculated as the ratio of higher to lower LC_{50} and called negative when the lower LC_{50} was at the lower temperature.[7]

3 RESULTS AND DISCUSSION

Both pyrethroid insecticides and spinosad had negative temperature coefficients for *O nubilalis* over the 11 °C temperature range tested, with the temperature coefficient being greater for the pyrethroid insecticides (Table 1). Lambda-cyhalothrin, with a temperature coefficient of −13.6, required an insecticide concentration 13.6 times higher at 35 °C than needed at 24 °C to achieve equal control levels. In contrast, methomyl toxicity was stable over the temperatures tested. In the three products with a significant overall temperature coefficient, the individual coefficients at 5 and 6 °C temperature differences were always in the same direction as the overall coefficient, providing evidence that this trend occurs throughout the range of temperatures frequently encountered during insecticide applications. Our pyrethroid and carbamate results are consistent with the majority of assays on other species that have examined temperature impacts.[3] In limited research, a negative temperature coefficient has not previously been reported for spinosad.

The slopes did not significantly differ between temperatures for any of the insecticides, so that temperature coefficients similar to those reported for LC_{50} could be calculated for all lethal concentrations. The slopes are not as steep as frequently encountered in insecticide assays. This was likely due to an observed repellent effect of the insecticides at the higher doses. Larvae were always placed directly onto the leaf disk. However, at the high doses many larvae quickly left the leaf and stayed on the untreated plastic cup, while at low doses the larvae fed on the leaf and thereby acquired more of the insecticide. As a result, the dose acquired by the insects at different concentrations was not as great as the difference in the insecticide concentrations. This did not alter the temperature impact as all insecticide exposure was done at room temperature.

Translating these results to field efficacy requires that we also consider several other factors that are influenced by temperature. Within the range of the temperatures studied, higher temperatures lead to increased insect activity,[12] reduced residual life of insecticides[13,14] and reduced deposition of insecticides, especially when aerially applied.[1] These changes may further alter insect control from insecticides at higher temperatures and are likely crop- and insect-specific. However, regardless of these other impacts, when insecticides from different classes are available to control a pest, knowledge of a product's temperature coefficient will enable pest managers to select a product that is efficacious under the given environmental conditions.

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Table 1. Impact of post-treatment temperature on insecticide toxicity for *Ostrinia nubilalis*

Insecticide	Temp (°C)	n[a]	LC_{50} (95% CL) (mg AI liter^{-1})	Slope (±SE)	χ^2, (*df*)	Temp coefficient[b] 5–6 °C	Temp coefficient[b] 11 °C
Bifenthrin	24	680	2.33 (1.07–4.05)	0.83 (±0.10)	2.03 (4)		
						−5.0[c]	
	29	550	11.6 (NE)	1.09 (±0.23)	6.91 (3)[d]		−9.5[c]
						−1.9	
	35	660	22.1 (8.63–45.4)	0.71 (±0.13)	5.44 (4)		
Lambda-cyhalothrin	24	480	2.42 (0.440–5.30)	0.87 (±0.19)	0.29 (2)		
						−4.8[c]	
	29	480	11.7 (5.84–18.6)	0.86 (±0.15)	3.83 (2)		−13.6[c]
						−2.8[c]	
	35	480	33.0 (17.9–53.1)	1.15 (±0.22)	0.13 (2)		
Methomyl	24	360	39.5 (21.3–59.6)	1.66 (±0.27)	4.62 (3)		
						+2.5	
	29	420	15.7 (NE)	1.11 (±0.30)	12.3 (4)[d]		+1.7
						−1.5	
	35	420	22.7 (10.3–37.2)	1.60 (±0.27)	6.94 (4)		
Spinosad	24	320	0.050 (0.028–0.083)	1.12 (±0.16)	2.73 (4)		
						−1.6	
	29	310	0.079 (0.044–0.125)	1.33 (±0.22)	2.83 (4)		−3.8[c]
						−2.4	
	35	300	0.189 (0.077–0.378)	1.07 (±0.25)	5.72 (4)		

[a] Total number of *O nubilalis* tested for each temperature/insecticide treatment.
[b] Ratio of higher to lower LC_{50} value for 5–6 and 11 °C differences in temperature. A negative coefficient indicates a higher LC_{50} at the higher temperature.
[c] Statistically significant at $P < 0.05$.
[d] χ^2 significantly different from expected ($P < 0.10$), confidence limit of LC_{50} not estimated.

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