

Comparative Susceptibilities of Diamondback Moth (Lepidoptera: Plutellidae) and Cabbage Looper (Lepidoptera: Noctuidae) from Minnesota and South Texas to λ -Cyhalothrin and Indoxacarb

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ABSTRACT The susceptibility of early instars of diamondback moth, *Plutella xylostella* (L.), and early (first and second) and late instars (third and fourth) of cabbage looper, *Trichoplusia ni* (Hübner), from Minnesota and south Texas, to indoxacarb and λ -cyhalothrin was determined in the laboratory. Susceptibilities of the two species from the two geographical locations to indoxacarb and λ -cyhalothrin varied greatly. *P. xylostella* from Minnesota was as susceptible to indoxacarb as those from south Texas, whereas both early and late instar *T. ni* from south Texas were significantly more tolerant to indoxacarb than those from Minnesota. The LC_{50} values of indoxacarb for early and later instar *T. ni* at 48 h from south Texas were 4.3- and 34.0-fold greater than those from Minnesota, respectively. Similarly, early instar *P. xylostella* and late instar *T. ni* from south Texas were significantly less susceptible to λ -cyhalothrin than those from Minnesota. Percentage mortality of the two insect species caused by the two insecticides varied with time of exposure and generally exhibited similar patterns of responses to different concentrations for each insecticide.

KEY WORDS indoxacarb, λ -cyhalothrin, reduced-risk insecticide, *Trichoplusia ni*, *Plutella xylostella*

DIAMONDBACK MOTH, *Plutella xylostella* (L.), and cabbage looper, *Trichoplusia ni* (Hübner), are the two most important pests of crucifer crops in Texas (Cartwright et al. 1987, Edelson et al. 1993). In Minnesota, with high parasitism rates of *P. xylostella* (typically 80–100%), and in the absence of insecticide resistance, *T. ni* has often been the most common and most difficult pest of crucifer crops to control during the past decade (Hutchison et al. 1993, Hutchison and Burkness 1999, Hines and Hutchison 2001, Hutchison et al. 2003). The high cash value for these crops, combined with severe insect pressure, results in high insecticide use in both Texas and Minnesota. Most growers continue to apply 5–8 insecticide applications annually, for mid- and late-season cabbage (Hutchison et al. 2003).

Indoxacarb or DPX-KN128 ((*S*)-methyl 7-chloro-2,5-dihydro-2-[[(methoxy-carbonyl) [4-(trifluoromethoxy) phenyl] amino] carbonyl]-indeno [1,2-*e*][1,3,4] oxadiazine-4a(3*H*)-carboxylate), the active ingredient of Avaunt (DuPont, Wilmington, DE), is a broad-spectrum insecticide that was recently registered for use on vegetables. Indoxacarb was designated a reduced-risk product by the U.S. Environmental Protection Agency (DuPont 1998). Indoxacarb provides effective control of

numerous lepidopteran pests of cotton, fruits, and vegetables in the United State (Harder et al. 1997, DuPont 1998, Wing et al. 1998, Allen et al. 1999, Seay et al. 1999, Liu et al. 2002), Australia (Holloway and Forrester 1998), France (Sanchis et al. 1999), and many other countries (Pluschkellm et al. 1998, Tsurubuchi et al. 2001).

The pyrethroid, λ -cyhalothrin, has been used against a wide range of species of Lepidoptera (Rinkleff et al. 1995), Hemiptera (Greene et al. 2001), Homoptera (Liu et al. 2001), Diptera (Zhu et al. 2002), and Coleoptera (Yadav et al. 2001), and it also has some miticidal activity (Yang et al. 2002). λ -Cyhalothrin also exhibits adulticidal, ovicidal and, particularly, larvicidal activity (e.g., Rinkleff et al. 1995, W.D.H., unpublished data). Although it has been reported that many pest insects become resistant to λ -cyhalothrin, including *P. xylostella* (Cho and Lee 1994, Cameron and Walker 1998), it is still used to control numerous vegetable and field crop pests around the world (Cameron et al. 1997, Foster et al. 2002).

It was previously reported that *T. ni* and *P. xylostella* from different geographical locations responded differently to insecticides, and that the same insecticide could be very effective in one location but not in others (Shelton and Soderlund 1983, Zhao et al. 2002). In addition, the frequency and magnitude of crop infestations by each species was greatly influenced by geographical location, via the southern to northern U.S., and populations in the south may receive treatments early and more frequently compared with the

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populations in the north (Chalfant et al. 1974). Thus, for the same pest species, the populations in the north may be more susceptible to certain insecticides than those in the south (Shelton and Soderlund 1983). The objective of this study was to compare the susceptibilities of *P. xylostella* and *T. ni* from Minnesota and Texas to λ -cyhalothrin and indoxacarb.

Materials and Methods

Host Plants and Insecticides. Cabbage (*Brassica oleracea capitata* L. variety 'Grand Slam') was used as oviposition substrate and food for both *P. xylostella* and *T. ni* in all experiments. The field cabbage on which the Texas populations of these two species were collected was the same variety. Two insecticides, λ -cyhalothrin (Warrior with Zeon, one CS; Syngenta, Greensboro, NC) and indoxacarb (Avaunt 30 WP, DuPont, Wilmington, DE), were bioassayed. Five concentrations for each insecticide were used in all bioassays, and reverse osmosis water was used as control. The concentrations used for λ -cyhalothrin were 0, 0.006, 0.012, 0.024, 0.048, and 0.096 g (AI)/liter (0.048 g [AI]/liter was the field recommended rate of 0.03 lb [AI]/ac in 100 gal water). The concentrations used for indoxacarb were 0, 0.00975, 0.0195, 0.039, 0.078, and 0.156 g (AI)/liter, in which 0.156 g (AI)/liter was the field recommended rate of 0.065 lb (AI)/acre in 100 gal of water.

Plutella xylostella. *P. xylostella* pupae (171) were collected from a commercial field in Apple Valley, MN on 5 July, and arrived in Weslaco on 6 July 2001. These pupae were placed in a large cage, and emerged adults were fed with 10% honey-water solution. Adults were allowed to mate and oviposit on four small cabbage plants that each had 4–5 fully expanded leaves. The leaves bearing *P. xylostella* eggs were detached from the plants, and placed in plastic rearing trays (20 × 40 × 15 cm, F1020-No Holes Plastic Flat Tray, T. O. Plastic Inc., Minneapolis, MN). After hatching, the larvae (F₁) were fed with fresh cabbage leaves until they were 4-d-old in an insectary at 26 ± 2°C, 55–60% RH, and a photoperiod of 14:10 (L:D) h. For the Texas population of *P. xylostella*, >200 larvae were collected from a cabbage field at the Texas A&M Agricultural Research and Extension Center at Weslaco, TX. They were reared on cabbage in large cages until they pupated. Emerged adults were reared as described above. *P. xylostella* eggs were allowed to develop into 4-d-old larvae for bioassays.

Trichoplusia ni. Over 200 late instars and pupae of *T. ni* were collected from a commercial field at Rosemount Agricultural Experiment Station, MN, and the Research Farm at the Texas A&M Agricultural Experiment Station at Weslaco. The larvae were fed cabbage leaves until they pupated. The pupae were maintained in wood-framed, large screen cages (60 × 60 × 60 cm) in an insectary. Emerged adults were fed with 10% honey-water solution and were allowed to mate, and females were allowed to deposit eggs on small cabbage plants having 4–5 fully expanded leaves. The leaves with eggs were removed from the plants and main-

Table 1. Comparison of toxicities of indoxacarb (LC₅₀ at 48 h) to early instars of *Pl. xylostella* from Minnesota and south Texas

Population	n	LC ₅₀ (95% FL), g AI/liter ^a	Slope ± SE	χ ² (df)
MN	309	0.1278 (0.0868–0.2312)	1.432 ± 0.164	2.89 (3)
TX	300	0.0728 (0.0425–0.1781)	1.302 ± 0.155	11.58 (3)

^a No significant differences in the LC₅₀ values between the MN and TX populations.

tained in the plastic rearing trays. Hatched larvae (F₁) were fed with cabbage leaves until they developed to 5-d-old (early instars) and 8-d-old (late instars) for bioassays.

Bioassays. Cabbage leaves were dipped in diluted solutions of each insecticide and water for 5 s, and air-dried for ≈1 h. The treated leaves were cut into leaf disks (7–9 cm in diameter), and each leaf disk was placed in a 9-cm petri dish. Normally, 10 larvae for each stage and species were placed in each petri dish. Mortality of larvae was checked at 1, 2, 3, 4, and 5 d depending on the treatments. The petri dishes were held in an insectary at 26 ± 2°C, 55–60% RH and a photoperiod of 14:10 (L:D) h. During the first 3 d after exposure (DAE), leaf disks were replaced as needed with the previously treated leaves, and after three DAE, untreated leaf disks were used. Moribund larvae that stopped feeding for at least 24 h were considered dead. Each treatment had eight replications.

Data Analysis. Percent mortalities were corrected by the Abbott formula (1925). Although mortalities for both species were monitored up to 120 h for both indoxacarb and λ -cyhalothrin, those at 48 h were used for analysis of the LC₅₀ values and related parameters [95% fiducial limits (FL), slope, and SE] using POLO (LeOra Software 1994). The lack of overlap of the 95% FL was used as the criterion for statistical separation for the LC₅₀ values of the Minnesota and Texas populations. For comparison of percent mortalities, data were transformed with arcsine square root [arcsine √(percent mortality/100)] to stabilize error variance (Gomez and Gomez 1984) and analyzed using analysis of variance (ANOVA). Means were separated using the least significant different test [least significant difference (LSD)] following a significant *F*-test at *P* = 0.05 (SAS Institute 2001). Although all tests of significance were based on the transformed data, the untransformed percent mortalities are presented.

Results and Discussion

***Plutella xylostella*—Susceptibility to Indoxacarb.** Early instar *P. xylostella* from Minnesota and south Texas showed similar responses to indoxacarb with no significant differences in the LC₅₀ values (g [AI]/liter) at 48 h, although the LC₅₀ values of indoxacarb for the larvae from Minnesota were numerically higher than those for larvae from south Texas (Table 1). Percent mortality in the first 48 h was relatively low, only 58% for the Texas population and 60% for the Minnesota population at the highest concentration

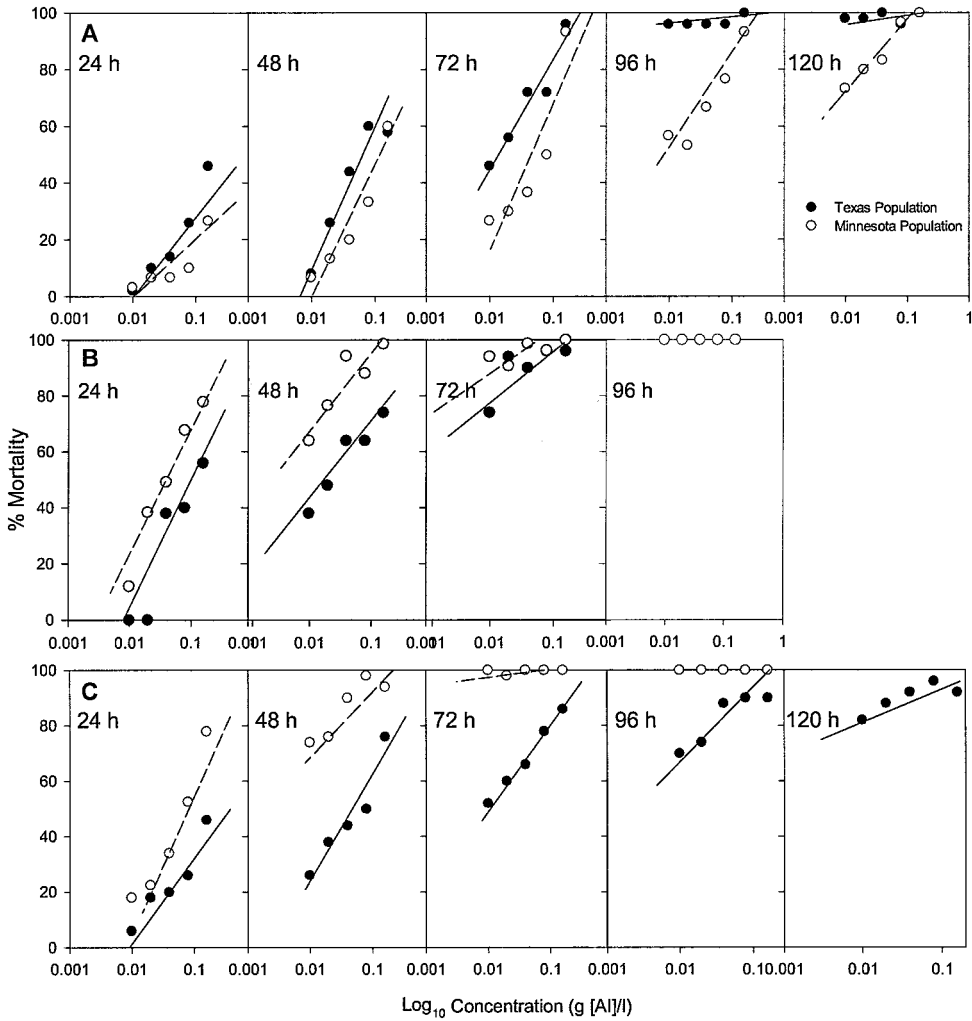


Fig. 1. Response of *P. xylostella* and *T. ni* larvae from Minnesota and south Texas to indoxacarb on cabbage. (A) Early instars of *P. xylostella*, (B) early instars of *T. ni*, and (C) late instars of *T. ni*.

(Fig. 1A). Percent mortality increased at 72 h for both populations. At 96 h, almost all larvae (96–100%) of the Texas population died at all concentrations tested, whereas only 53.3–93.3% died for the Minnesota population at the same concentrations.

***Trichoplusia ni*—Susceptibility to Indoxacarb.** Both early and late instar *T. ni* from south Texas were significantly more tolerant to indoxacarb than those from Minnesota (Table 2). The LC_{50} value of indox-

acarb for early instar *T. ni* of the south Texas populations was 4.3-fold higher than that of the Minnesota populations at 48 h. Although the LC_{50} value of indoxacarb for late instar *T. ni* of the south Texas populations was 34.0-fold of the Minnesota populations at 48 h, field data in the past few years indicated that indoxacarb was still effective against *T. ni* under field conditions in south Texas (Liu 2001, Liu et al. 2002).

Table 2. Comparison of toxicities of indoxacarb (LC_{50} at 48 h) to early and late instars of *Trichoplusia ni* from Minnesota and south Texas

Larval age	Population	n	LC_{50} (95% FL), g AI/liter	Slope \pm SE	χ^2 (df)
Early instars	MN	330	0.0049 (0.0002–0.0110) ^a	1.274 \pm 0.160	10.99 (3)
	TX	300	0.0213 (0.0129–0.0301)	0.769 \pm 0.137	2.00 (3)
Late instars	MN	300	0.0016 (0.0011–0.0033) ^a	0.272 \pm 0.153	33.00 (3)
	TX	300	0.0544 (0.0256–0.1408)	1.043 \pm 0.153	5.42 (3)

^a indicates that the LC_{50} values differ significantly between the MN and TX populations.

Table 3. Comparison of toxicities of λ -cyhalothrin (LC_{50} at 48 h) to early instars of *Pl. xylostella* from Minnesota and south Texas

Population	n	LC_{50} (95% FL), g AI/liter	Slope \pm SE	χ^2 (df)
MN	304	0.0050 (0.0011–0.0091) ^a	1.430 \pm 0.192	8.62 (3)
TX	300	0.0147 (0.0098–0.0200)	0.962 \pm 0.146	2.86 (3)

^a Indicates that the LC_{50} values differ significantly between the MN and TX populations.

Early instar *T. ni* from both south Texas and Minnesota exhibited clear responses to all concentrations of indoxacarb (Fig. 1B), and the percent mortalities increased with time of exposure to the treated cabbage leaves. At 72 h, >90% larvae died in the treatments with higher concentrations of indoxacarb, resulting in

100% mortality at 96 h. Late instar *T. ni* from south Texas and Minnesota showed similar responses to indoxacarb (Fig. 1C). All late instar *T. ni* from Minnesota died at 96 h, whereas 8–18% larvae from south Texas successfully survived and pupated.

***Plutella xylostella*—Susceptibility to λ -Cyhalothrin.** *P. xylostella* larvae from south Texas and Minnesota exhibited similar responses to λ -cyhalothrin (Table 3). The LC_{50} values for the larvae from south Texas were significantly greater than those from Minnesota at 48 h; and the difference between the LC_{50} values for the larvae from Texas and Minnesota was 2.9-fold.

Plutella xylostella larvae showed clear response to the concentrations of λ -cyhalothrin (Fig. 2A). At 24 h, the highest concentration (0.096 g [AI]/liter) caused 93.3% mortality for the larvae from Minnesota and 68%

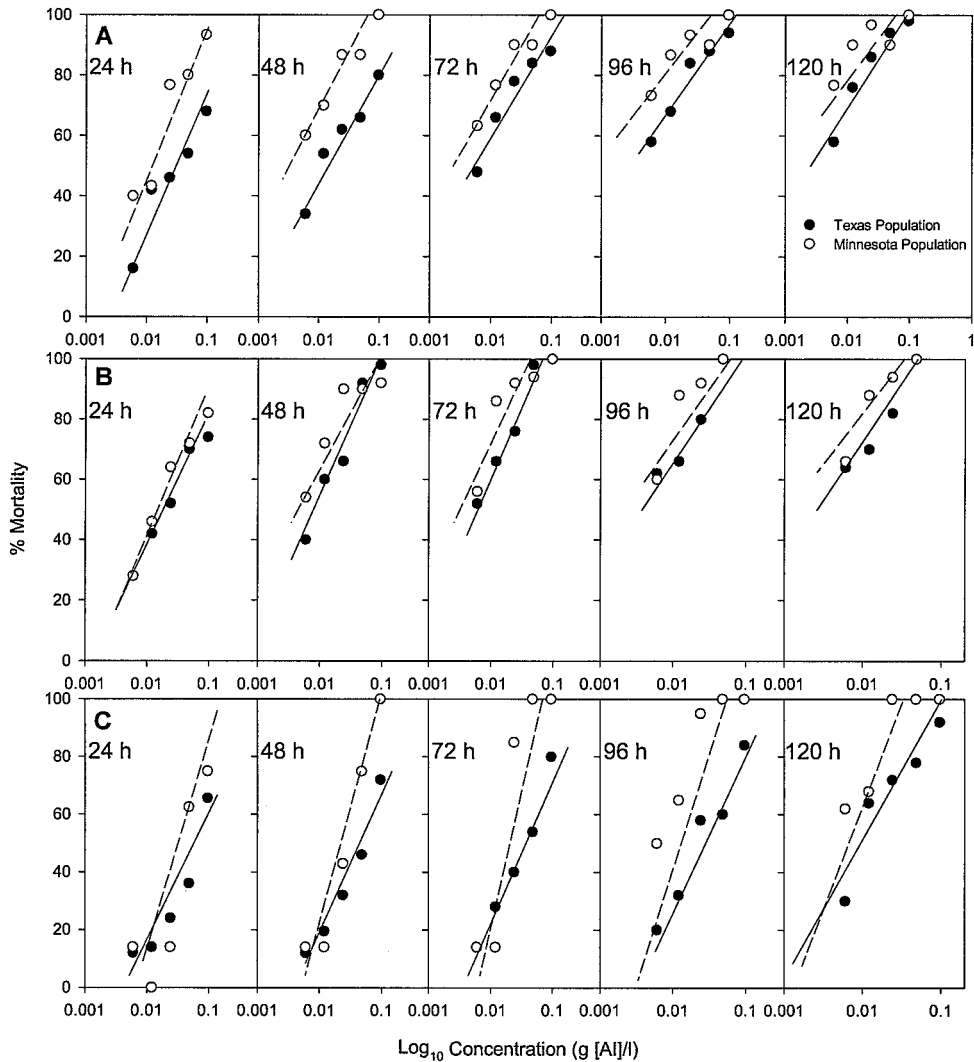


Fig. 2. Response of *P. xylostella* and *T. ni* larvae from Minnesota and south Texas to λ -cyhalothrin on cabbage. (A) Early instars of *P. xylostella*, (B) early instars of *T. ni*, and (C) late instars of *T. ni*.

Table 4. Comparison of toxicities of λ -cyhalothrin (LC₅₀ at 48 h) to early and late instars of *Trichoplusia ni* from Minnesota and south Texas

Larval age	Population	n	LC ₅₀ (95% FL), g AI/liter	Slope \pm SE	χ^2 (df)
Early instars	MN	330	0.0042 (0.0002–0.0090)	1.203 \pm 0.169	6.82 (3)
	TX	300	0.0100 (0.0038–0.0163)	1.799 \pm 0.186	7.98 (3)
Late instars	MN	298	0.0097 (0.0073–0.0121) ^a	1.532 \pm 0.165	2.31 (3)
	TX	300	0.0464 (0.0379–0.0595)	1.433 \pm 0.153	2.45 (3)

^a Indicates that the LC₅₀ values differ significantly between the MN and TX populations.

for those from south Texas. However, *P. xylostella* larvae were dying relatively slowly over a 5-d period of observation, and the two populations exhibited similar responses over time of exposure to treated cabbage leaves and to the concentrations of λ -cyhalothrin.

***Trichoplusia ni*—Susceptibility to λ -Cyhalothrin.** Although the LC₅₀ value of λ -cyhalothrin for the early instar *T. ni* of the Texas populations at 48 h was 2.4-fold higher than those for the Minnesota populations, the susceptibilities between the two populations were not significantly different (Table 4). However, the LC₅₀ value of λ -cyhalothrin for late instar *T. ni* from Texas was significantly greater than those from Minnesota. The LC₅₀ value of λ -cyhalothrin for the late instars from south Texas was 4.8-fold greater than that of Minnesota's at 48 h.

Early instar *T. ni* from both south Texas and Minnesota showed similar response over time to λ -cyhalothrin, to the treated cabbage leaves (Fig. 2B). Although the mortality of larvae from Minnesota was slightly greater at the higher concentrations at the same time of exposure than those from south Texas, the differences were not always significant. However, percent mortalities of late instar *T. ni* from both south Texas and Minnesota varied greatly (Fig. 2C). In the treatments with lower concentrations (0.006–0.024 g [AI]/liter), only 72% larvae from south Texas died at 120 h, whereas at the same concentrations and same period of exposure, 100% of the larvae from Minnesota died.

Cabbage and many other crucifer crops are produced in the spring and the fall in south Texas, and *P. xylostella* and *T. ni* occur on these host plants almost year round (Wolfenbarger 1967). Application of synthetic organic insecticides has historically been the major management tool for controlling many insect pests in south Texas (Edelson et al. 1993, T.X.L. unpublished data). Although more reduced-risk insecticides, including spinosad, indoxacarb, and several formulations of *Bacillus thuringiensis* (Bt), have been used to control *P. xylostella* and *T. ni* in recent years, some pyrethroids and other chemical insecticides (i.e., bifenthrin, permethrin, methomyl, etc.) are still used. Because of the subtropical climate in south Texas, more insecticides are used than those in Minnesota (T.X.L. unpublished). However, the results of our study indicate that although responses of the *P. xylostella* and *T. ni* from south Texas and Minnesota to indoxacarb and λ -cyhalothrin vary, the differences are not consistently related to geographical location, but

are likely because of insecticide exposure, migration patterns, particularly with *T. ni*, and host plant availability in each region.

Chalfant et al. (1974) found that *T. ni* migrates northward along the east coast, and that the looper cannot overwinter in the northern states where winter temperatures are $<10^{\circ}\text{C}$. Because of the migratory nature of these insects and higher frequency of insecticide applications in the southern locations, one could expect a trend of reducing susceptibility of insecticides in northern U.S. locations. Shelton and Soderlund (1983) tested *T. ni* from 11 eastern states and California for susceptibility to methomyl and permethrin. They found that the susceptibilities of *T. ni* to these insecticides varied greatly among locations, and within each location, but did not find consistently significant trends reflecting increased tolerance in the northern states. In this study we did not find clear evidence and correlation of reduced susceptibility to the tested insecticides in Minnesota as compared with those in south Texas. However, we did find that the differences in susceptibility were dependent upon the insecticide tested. For example, the Texas population of *T. ni* and *P. xylostella* were more tolerant to λ -cyhalothrin and indoxacarb than the Minnesota population. However, the same populations for each species from south Texas were not consistently more tolerant to indoxacarb than the Minnesota population. λ -Cyhalothrin has also been used in both south Texas and Minnesota for many years, whereas indoxacarb has been used only in the past few years. The evidence that the south Texas *T. ni* and *P. xylostella* have become more tolerant to λ -cyhalothrin than those in Minnesota and similar susceptibility to indoxacarb maybe related to the long history of exposure to λ -cyhalothrin. In any case, results from this study will serve as necessary baseline efficacy data for future monitoring of resistance to these insecticides by *P. xylostella* and *T. ni* in the central U.S.

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