Diamondback Moth (Lepidoptera: Plutellidae) Contamination of Cabbage Transplants and the Potential for Insecticide Resistance Problems[1]

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ABSTRACT Samples collected from 1989 to 1992 document that the diamondback moth, *Plutella xylostella* (L.) was introduced into New York in early spring on cabbage, *Brassica oleracea capitata* (L.), transplants grown in the southern United States. During 1989, transplant shipments from five transplant companies in Florida, Georgia and Maryland were sampled for *P. xylostella*. In 1989, average seasonal infestations per transplant company ranged from 1.3 to 3.5 *P. xylostella* per 100 transplants. During June, when the majority of transplants arrived in New York, *P. xylostella* infestations were as high as 12.8 insects per 100 transplants on an individual shipment. Infestations by cabbage looper, *Trichoplusia ni* (Hübner), imported cabbageworm, *Artogeia* (=*Pieris*) *rapae* (L.), and cabbage webworm, *Hellula rogatalis* (Hulst), on an individual shipment were as high as 19.7 insects per 100 transplants. Compared with a standard susceptible field population, the *P. xylostella* which were collected from transplants demonstrated moderate to high (> than 100-fold in one case) levels of resistance to permethrin or methomyl. In 1990, average seasonal infestations per transplant company varied from 0.3 to 12.0 *P. xylostella* per 100 plants, but an individual shipment from Florida had 30.4 *P. xylostella* per 100 transplants. A population of *P. xylostella* collected in 1990 from Florida transplants had >200-fold resistance to methomyl. Despite intensive treatments, a New York grower who used the transplants with high contamination of resistant *P. xylostella* was unable to achieve acceptable control in his field. Samples collected from 1989 to 1992 from a transplant grower in Maryland indicate that better management in the field can reduce contamination levels to < 0.5%. The introduction of *P. xylostella*, especially those resistant to insecticides, on transplants poses a serious threat to cabbage growers and interregional management strategies should be adopted.

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The diamondback moth, *Plutella xylostella* (L.), is a perennial pest of the approximately 5,000 ha of cabbage, *Brassica oleracea capitata* (L.) grown in New York, but in recent years its importance has increased tremendously. We have observed instances in which growers were unable to control *P. xylostella* even with weekly applications of previously effective materials applied with high volume and high pressure ground sprayers.

In a 1988 study (Shelton et al. 1993a), *P. xylostella* populations were collected from > 40 locations throughout North America and tested in laboratory assays for their susceptibility to permethrin, methomyl, and methamidophos, all commonly-used insecticides for control of this pest in North America. In three of the four populations collected from cabbage growing areas of New York, levels of resistance > 20-fold to permethrin and methomyl were found. Because of the short growing season in New York and the absence of *P. xylostella* overwintering in an adjacent area (Ontario, Canada) (Harcourt 1986), high levels of resistance would not be expected to have developed in New York. Furthermore, we noted that the fields in New York in which we did have resistant populations of *P. xylostella* were planted with transplants grown in Florida and Georgia, whereas those fields in New York which did not have problems with resistance were either direct seeded or grown with transplants from more northern areas.

From 1989 to 1992, we conducted studies to determine if *P. xylostella* were being introduced into New York on transplants and determine if these imported *P. xylostella* were resistant to permethrin and methomyl, commonly used insecticides for control of *P. xylostella* in New York.

Materials and Methods

Transplant Sources. In 1989, cabbage transplants were obtained from growers or brokers in Ontario, Yates, Monroe, Orleans and Genesee counties of New York who received shipments of transplants from Florida, Georgia, and Maryland, the states which supply the majority of transplants to New York. We also obtained locally-grown transplants (Phelps, NY). We sampled cabbage transplants as they arrived in crates or boxes at the growers' fields or at the brokers. Over the course of the spring and summer we sampled 26 different shipments for *P. xylostella* and other insect pests. Sampling began with a shipment of cabbage from Georgia on 25 April and ended with a shipment of locally-grown transplants on 29 June. In 1990, we examined 13 shipments of transplants from Florida, Georgia, and Maryland. The first shipment was received on 26 April from Florida and the last shipment was from Maryland on 11 June. In 1991 and 1992, we examined five shipments per year of plants from Maryland in early to mid-June. In all years, a sample consisted of 500 to 1000 transplants taken randomly from multiple crates or boxes of an individual shipment.

***P. xylostella* Infestations.** As soon as it was received, each sample of transplants was visually inspected for *P. xylostella larvae*. In addition, transplants were inspected for cabbage looper, *Trichoplusia ni* (Hübner), imported cabbageworm, *Artogeia* (=*Pieris*) *rapae* (L.), and cabbage webworm, *Hellula rogatalis* (Hulst).

Plutella xylostella larvae collected during the first inspection were counted and transferred to rape seedlings. *Brassica napus,* and reared (Shelton et al. 1991) for insecticide assays. The inspected transplants were then placed in soil in large pots and kept for two additional weeks in a greenhouse at 20-25°C, at which time a second inspection was performed.

Insecticide Resistance. In 1989, we were able to establish four colonies of *P. xylostella*: two from Florida and one each from Maryland and Georgia. In 1990, we established one colony of *P. xylostella* from Florida and one from Georgia. All colonies were established from the *P. xylostella* taken from the transplants and then we used the F2 generations to test for susceptibility to permethrin (Ambush 2E [emulsifiable]; ICI Americas, Goldsboro, NC) and methomyl (Lannate 1.8 [liquid]; E. I. DuPont de Nemours, Wilmington, DE) using a leaf-dip bioassay (Shelton et al. 1993a). The population used as a standard in this study originated from Painter, VA. This was chosen as our standard because it originated from a location which had a susceptible population, and we were able to test the F2 generation out of the field. Previous work (Sun et al. 1986) has demonstrated that insecticide susceptibility increases for permethrin with each generation that a colony is held in the laboratory.

Leaves from the outer layers of cabbage heads (not including wrapper leaves) were cut into 6-cm-diam disks that were dipped into the test solution for 5 s, held vertically to allow excess solution to drip off, and placed on a rack to dry. After 2 h drying time, the disks were placed in a Petri dish and five third-instar *P. xylostella* larvae were placed in each Petri dish. Dishes were placed in a rearing room at 28°C and larval mortality was assessed after 48 h. Larvae were considered dead if they did not move when prodded. Concentrations (mg[AI]/ml) tested were: permethrin: 5.62, 1.78, 0.56, 0.18, 0.056, and 0.018; methomyl: 100, 17.8, 3.16, 0.56, 0.10, 0.018. BOND sticker-spreader (Loveland Industries, Loveland, CO) was added at the rate of 0.25 ml/1000 ml solution. There were three to five replicates at each concentrations as well as the untreated control (distilled water and sticker spreader).

Statistical analysis. Data were analyzed by probit analysis (Russel et al. 1977). A population's response to an insecticide was considered significantly different from another population's response if its LC_{50} confidence interval did not overlap. Resistance ratios (RR), the ratio of the LC_{50} of a given population to that of the standard population, were calculated.

Results

The transplant source is identified only by state and grower (A-C) within the state. In one case, Florida A, there were two growing sites for the same company, and the data from each site are listed separately.

Plutella xylostella infestations. Infestations varied by transplant company and date of collection (Table 1). In 1989, the highest average *P. xylostella* infestations for the season were from Georgia and Maryland companies (3.4 and 3.5 *P. xylostella* per 100 transplants, respectively). Transplants originating in New York had fewer *P. xylostella* larvae (0.6 to 1.1 per 100 transplants) than other states. The highest infestation on an individual shipment was found in a Florida sample in June which had 12.8 *P. xylostella* per 100 transplants, but since more than one shipment from this company was examined in June the monthly average was 8.2.

Table 1. Insects (*P. xylostella* and others) found on cabbage transplants shipped to New York from southern companies, 1989-1990.

		Number of insects found per location source*							
		April		May		June		Season Average	
Company	n	*P.x.*	other**	*P.x.*	other	*P.x.*	other	*P.x.*	other
1989									
Georgia A	2957	0	0	2.7	0.1	†	†	1.3	0
Georgia B	1059	1.3	0.1	†	†	†	†	1.3	0.1
Georgia C	1892	4.3	0.2	†	†	2.7	0.4	3.4	0.3
Maryland A	8755	†	†	0.2	0.5	7.3	5.6	3.5	2.8
Florida A	5702	0	0	0.3	0.1	8.2	0.1	2.5	0
New York A	3190	†	†	†	†	1.1	0.2	1.1	0.2
New York B	1039	†	†	†	†	1.1	0.2	1.1	0.2
New York C	512	†	†	†	†	0.6	0.2	0.6	0.2
1990									
Florida B	2280	6.7	0	17.4	0	†	†	12.0	0
Georgia B	2022	†	†	3.7	0	†	†	3.7	0
Georgia C	1006	†	†	1.8	0	†	†	1.8	0
Maryland A	3599	†	†	0.3	0	0.3	0	0.3	0

* Values listed are (#insects/#plants inspected) × 100].
** Other insects included imported cabbageworm, cabbage looper, and cabbage webworm.
† No transplants intercepted from source during that particular month.

The seasonal average for all companies except the one in Maryland had fewer than 0.5 other insects (*T. ni. A. rapae,* and *H. rogatalis*) per 100 transplants collected. Maryland transplants were infested with 5.6 additional insects per 100 transplants in the month of June and a seasonal average of 2.8 additional insects per 100 transplants. The majority of these were *A. rapae,* which are relatively easy to control with insecticides. In three out of four cases, when transplants were sampled from the same company over several months, later samples had much higher infestations. By June, when the majority of all transplants arrive in New York, *P. xylostella* infestations were as high as 8.2 insects per 100 transplants for a Florida company, and 7.3 insects per 100 transplants for a Maryland company.

Table 2. Susceptibility to permethrin and methomyl of 3rd instar diamondback moth larvae obtained from companies producing southern transplants.

		Permethrin			Methomyl		
Company		Slope ± SE	LC_{50} (90% CL) (mg [AI]/mg	RR*	Slope ± SE	LC_{50} (90% CL) (mg [AI]/mg	RR
Virginia	105	1.39	0.083	1.0	0.88	0.26	1.0
(standard)		± 0.27	(0.035-0.166)		± 0.17	(0.11-0.52)	
1989							
Florida A	105	1.72	0.687	8.3	2.11	28.5	109.6
(site 1)		± 0.30	(0.285-1.814)		± 0.49	(18.0-47.5)	
Maryland A	105	1.77	0.326	3.9	0.90	3.35	12.9
		± 0.30	(0.176-0.863)		± 0.15	(†)	
Georgia C	105	0.74	0.029	0.3	0.34	1.24	3.8
		± 0.25	(†)		± 0.14	(†)	
Florida A							
(site 2)	105	2.03	0.607	7.3	2.70	8.46	32.5
		± 0.30	(0.381-0.982)		± 0.20	(5.00-14.2)	
1990							
Florida B	175	1.55	1.662	20.0	0.85	52.76	202.7
		± 0.22	(†)		± 0.150	(†)	
Georgia B	175	2.43	0.349	4.2	0.76	2.32	8.9
		± 0.36	(0.236-0.528)		± 0.11	(0.68-9.54)	

* RR is the resistance ratio determined by dividing the LC_{50} for a population by the LC_{50} for the standard population (i.e. Virginia)

** The 90% CL could not be determined because g > 0.5 (Russel et al. 1977).

In 1990, the number of transplants collected was less because New York growers imported fewer plants from these companies. Our samples of transplants from the two companies in Georgia indicated generally similar contamination levels of P *xylostella* as in 1989, while the Maryland company had a much lower rate in 1990. A newly-sampled company for transplants, Florida B., had a seasonal average of *P. xylostella* > 3X of any company in 1989. An individual shipment from this company had > 30 *P. xylostella* per 100 transplants. In 1990, no other insect species was found on any of the transplant shipments. In 1991 and 1992, all five shipments in each year had infestation levels < 0.5 insects per 100 plants.

Insecticide resistance. Based on the non-overlapping confidence intervals for LC_{50} values, in 1989 the Maryland and both Florida populations were significantly less susceptible to permethrin than the standard population. For methomyl, both Florida populations were significantly less susceptible. In 1990, the Georgia population was significantly less susceptible to both insecticides. Comparing RR's, the two 1989 Florida populations had RR's of 7.3 and 8.3 to permethrin and 32.5 and 109.6 to methomyl. The Georgia population had an RR of 0.3 to permethrin and 3.8 to methomyl while the Maryland population had an RR of 3.9 and 12.9 to permethrin and methomyl, respectively. In 1990, the Florida B population had RR values of 20.0 and 202.7 to permethrin and methomyl, respectively, while the Georgia B population had RR values < 10.

Discussion

Plutella xylostella and other lepidoptera are being introduced into New York cabbage fields on transplants. It is unclear if the introduction of *P. xylostella* on southern transplants is the sole or main source of *P. xylostella* infestations in New York, but our data indicate that it can be a significant source and can lead to control problems. Although low levels of infestation were found in New York-grown transplants in June, these *P. xylostella* may be offspring from *P. xylostella* which arrived on southern transplants planted in April or May. Other possible sources of *P. xylostella* populations in New York are yearly migrations, or overwintering populations on wild or unharvested cultivated crucifers: neither possibility has been firmly established but, in field tests, we have not been able to overwinter *P. xylostella* eggs, pupae or adults in upstate New York where the majority of cabbage is grown. Additionally, during the winter 1990-91, we were unable to capture *P. xylostella* adults in pheromone traps in or around cabbage in upstate New York.

Information on the source and abundance of *P. xylostella* has important ramifications on resistance management strategies. If the main source of P. xylostella infestations is transplants, an infestation rate of 3 to 4 *P. xylostella* per 100 transplants translates to 760 to 1020 insects per hectare in the parental generation, and each female arising from this parental generation may lay approximately 100 to 200 eggs. Thus, these transported infestations may substantially increase *P. xylostella* populations in New York cabbage fields early in the season. In addition, some transported *P. xylostella* have high levels of resistance to at least permethrin and methomyl. If these insects constitute a sufficiently large proportion of the *P. xylostella* initially infesting a crop, they could contribute to rapid development of resistance to these insecticides during the growing season in New York. This latter possibility may account for the control failures found in some New York cabbage fields established from southern transplants. This probably was the case with the grower who used the transplants from Florida B in 1990 which had an infestation rate of > 30 *P. xylostella* per 100 plants and which had high levels of resistance to permethrin and methomyl. In this case the grower could not suppress the population despite twice weekly treatments with any available insecticide. While we did not examine this Florida B population for resistance to other insecticides besides permethrin and methomyl, a subsequent study (Shelton et al. 1993b) indicated that *P. xylostella* populations resistant to *Bacillus thuringiensis* subsp. *kurstaki* were also present in that area of Florida. The transplant grower did mention that 2 to 3 times per week he applied a "cocktail" mix of insecticides that included *B. thuringiensis* subsp. *kurstaki*.

Problematic levels of resistance to permethrin and methomyl in *P. xylostella* from southern transplants had been previously implicated in the Ransomville and Albion, NY, resistance assays in 1988 (Shelton et al. 1993a). This theory was supported as more *P. xylostella* populations from southern grown transplants were assayed in 1989 and 1990, and this poses a potential threat to cabbage growers in northern regions. As a result of this present work, the Cornell Cabbage IPM Program now recommends that growers inspect transplants before putting them in the field. This may be an unusual request for growers during the busy spring, but a northern grower who plants a field with transplants that are infested with *P. xylostella* resistant to all available classes of insecticides will have an even busier time in the summer and fall.

New York growers require transplants to meet the early season market. Because they are not equipped to grow their own in greenhouses, most growers have traditionally obtained these transplants from southern growers. Transplant growers in the southern states should realize that their management practices may influence the level of *P. xylostella* control that can be obtained by the growers who receive their transplants. If resistance to a particular insecticide develops in the transplant beds, it will likely persist in the transplanted fields. Some practices that can be taken by transplant growers to help alleviate this potential problem would include not locating transplant beds near production beds (a source of *P. xylostella* infestations), raising transplants in screened-in areas, and rotating insecticides to reduce resistance to any single insecticide. One technique that appears to work quite effectively is the use of better application techniques. The Maryland grower who had a seasonal infestation of 3.5 *P. xylostella* in 1989 was able to reduce it to 0.3 in 1990 and keep it < 0.5 per 100 transplants in 1991 and 1992 though improved scouting practices and switching from aerial to ground applications. Further work (Perez et al. 1995) has shown the profound influence of application method on control of *P. xylostella* in the field.

Additional techniques for control of *P. xylostella* in the greenhouse (such as the use of the pheromone to disrupt mating and mass releases of *Trichogramma* spp. and *Microplitus plutellae* to control eggs and larvae, respectively) should be investigated. Despite these efforts, however, it is likely that some contamination of transplants will continue. Thus, New York growers who receive southern transplants may have to try to control *P. xylostella* on transplants soon after they are transplanted. This will be more easily facilitated if transplant growers can advise their clients as to what insecticides were used in the transplant beds, and limit the use of certain insecticides so that some effective insecticides will be available for New York growers.

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