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# Managing lepidopteran pests in cabbage with herbicide-induced resistance, in combination with a pyrethroid insecticide

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## Abstract

S-ethyldipropylthiocarbamate (EPTC) applied as a soil treatment or over-the-top spray on cabbage plants (*Brassica oleracea* L.) caused the leaves to turn 'glossy' for as long as 30 days. EPTC-induced glossy plants were damaged significantly less than untreated plants by diamondback moth, *Plutella xylostella* (L.), imported cabbage worm, *Pieris rapae* (L.), and cabbage looper, *Trichoplusia ni* (Hbn.). Reductions in damage were equivalent to those obtained from treatment with permethrin. When used in combination with permethrin, EPTC provided additive control of damage by these pests. Our calculations show EPTC-induced resistance to be cost-effective. This use of EPTC has several limitations, however. Younger plants (< 9 leaves) were killed or injured by the herbicide. The growth of older plants was not affected, but plants did not become glossy for ca. 10 days after they were treated with EPTC. The crop must be protected with insecticides until the plants are mature enough to treat with EPTC, and until treated plants become glossy. In addition, since the glossy trait is only effective against first instar larvae, populations of later instars on glossy plants must be reduced with an application of insecticide. Finally, EPTC formulations are water-soluble and can be washed away from the plants by heavy rains and irrigation, which may make this use of EPTC impractical in some situations. Where its use is practical, and the indicated precautions are taken, EPTC-induced resistance could reduce dependence on chemical insecticides and reduce selection for insecticide resistance in diamondback moth.

## Introduction

Host plant resistance to diamondback moth (*Plutella xylostella*) in glossy-leafed *Brassica* results from changes in the quantity, chemistry, and structure of leaf surface waxes (Eigenbrode *et al.*, 1991a; 1991b). Similar alterations in leaf surface waxes occur on cabbage plants treated with S-ethyldipropylthiocarbamate herbicide (EPTC) (Flore & Bukovac, 1974; 1976; 1978; Eigenbrode & Shelton, 1992). In addition, survival of diamondback moth larvae is reduced substantially

on EPTC-treated plants, just as it is on genetic glossies (Eigenbrode & Shelton, 1992). Genetically glossy plants are less damaged by other lepidopteran pests as well as *P. xylostella* (Dickson & Eckenrode, 1980). These data raise the possibility that treatment of *Brassica* crops with EPTC or other thiocarbamate herbicides might provide an alternative strategy for controlling *P. xylostella* and other lepidopteran pests.

To assess the commercial potential of EPTC-induced resistance to Lepidoptera in cabbage, we conducted several experiments to determine the doses of EPTC which effectively produce glossy cabbage plants without causing damage to the crop. We then assessed levels of infestation, and the economic damage caused by *P. xylostella*, *Pieris rapae* (imported cabbage worm), and *Trichoplusia ni* (cabbage looper), on cabbage treated with an optimal dose of EPTC. Finally, to assess the potential risk to consumers, EPTC residues were measuredin EPTC-treated plants at harvest.

## Materials and methods

Field tests were conducted at the Hansen Farm of the New York State Agricultural Experiment Station near Geneva, NY. Test plants were spaced 45 cm within rows and 90 cm between rows with 2 m borders. Pre-plant fertilizer was 560 kg of 15-15-15 N-P-K/ha. Transplant fertilizer was 14 g of 16-32-16 N-P-K/plant. Soil was a Honeyoe silt loam.

In several tests, plants were scored for glossiness by classifying each leaf as 0 = normal, 0.5 = partly glossy, 1 = glossy, and then calculating the mean score for each plant. Herbicide damage was quantified by counting the number of damaged leaves per plant; leaves showing curling and distortion were considered damaged. Marketability of cabbage heads was determined after Sears *et al.* (1985) and lepidopteran damage after Greene *et al.* (1969).

### *Optimal doses of EPTC*

*Transplants.* Two experiments evaluated the possibility of inducing glossiness by treating plants with EPTC at transplant. On 13 June, and again on 10 July 1990, 75 cabbage plants (cv. 'Market Prize', Harris-Moran Co., Rochester, NY) were transplanted into the field. The transplant water (120 ml/plant) contained fertilizer (14 g of 16-32-16 N-P-K/plant) and different amounts of EPTC (Eptam 7E, ICI Americas, emulsifiable concentrate, 95% a.i.). In the first experiment, 0, 20, 40, 60, and 80 mg EPTC a.i. were applied per plant. In the second experiment, 0, 2.5, 5.0, 10, and 20 mg a.i. were applied per plant. Each treatment was replicated 3 times, with 5 plants per replicate in a randomized complete block (RCB) design. The plants in the first experiment were assessed visually 4, 7, 14, 18, 22, and 28 days after treatment for total number of leaves produced, and plant survival. In the second experiment, only the number of plants surviving 6 weeks after treatment was recorded.

*Later plant growth stages.* Two experiments evaluated the effects of different doses and formulations of EPTC on cabbage at three later growth stages. For the first experiment, 375 cabbage plants (cv. 'Market Prize') were transplanted into the field on 13 June 1990. EPTC was applied to the plants at growth stages 3, 5, and 6 (Andaloro *et al.*, 1983), using two formulations (Eptam 7E emulsifiable concentrate, and Eptam 10G granular), and four concentrations at each growth stage (0, 20, 40, and 60 mg a.i./plant for both stages 3 and 5; 0, 40, 80, 160, 320 mg/plant for stage 6). Each treatment was replicated 3 times with 5 plants/replicate in a randomized complete block design. Eptam 7E was dissolved in 150 ml of water and applied to the base of each plant. Controls received water only. Eptam 10G was placed in a circular trench, about 15 cm in diameter and 5 cm deep centered on the plant stem, and then covered with soil. Plants were evaluated for glossiness, number of leaves per plant, and number of leaves with herbicide damage. Since the purpose of this experiment was to assess herbicide damage and glossiness without the confounding effects of insect damage, insects were controlled. Two weeks before harvest, all plants were treated with permethrin (Ambush, 0.11 kg a.i./ha)

to suppress a heavy infestation of *P. rapae*. On 14 August, four plants from each block, for a total of 12 plants/treatment, were harvested and heads were trimmed and weighed.

For the second experiment, 270 plants (cv. 'Market Prize') were transplanted in the field on 22 June 1990. At growth stages 3, 5, and 6, these plants were treated with the dose and formulation of EPTC considered optimal for producing maximum glossiness without damage, based on data from the 13 June planting. The EPTC doses were: stage 3, 20 mg 10G; stage 5, 80 mg 10G; stage 6, 160 mg 10G. The treatments, and corresponding untreated plants, were replicated 3 times in a randomized split-plot design. Split plots consisted of 15 treated plants, and 15 untreated plants treated with water only. Treatment dates were 26 June for stage 3, 16 July for stage 5, and 27 July for stage 6. Plants were evaluated as above for glossiness, herbicide damage, and harvest head weight (20 August, 15 plants/treatment, 5 plants per block). Heads were also rated for marketability according to the amount of insect damage.

### P. xylostella *survival*

Some of the EPTC-treated plants and untreated plants from the above experiments were infested with *P. xylostella* eggs. Plants infested were stage 3 and stage 5 plants from the 22 June planting and stage 5 plants (80 mg of Eptam 7E) from the 13 June planting. Thirty treated and thirty untreated plants were evaluated in each test. Percentage of *P. xylostella* surviving to 4th instar was calculated as reported previously (Eigenbrode *et al.*, 1991a). Infestation dates were 24 July for stage 3 plants, and 27 July and 7 Aug. for the two tests with stage 5 plants. Evaluation dates were 2, 6, and 17 August, respectively.

### *Control of insect damage*

Two experiments were used to evaluate the economic potential of EPTC for reducing insect damage. In the first experiment, 64 cabbage plants (cv. 'Market Prize') were transplanted to the field on 9 July 1990. All plants were treated with permethrin (Ambush, 0.11 kg a.i./ha) on 16 August to reduce Lepidoptera to low densities on all treatments before the start of the experiment. When the plants reached stage 5 (20 August), 32 were treated with EPTC (Eptam 7E, 160 mg/plant), and 32 with water only. The EPTC (1 ppt aqueous) was applied with a compressed-$CO_2$ backpack sprayer from a one-row boom fitted with 3 nozzles (one over-the-top and two drop nozzles) delivering 58 l/ha at 2.7 atm. When the EPTC-treated plants began to appear glossy (29 August), 16 of the plants and 16 untreated plants were treated with permethrin (Ambush at 0.11 kg a.i./ha). This produced four treatment combinations: 1) EPTC only, 2) permethrin only, 3) EPTC + permethrin, 4) untreated. The four treatment combinations were applied in a RCB design of four blocks × four plants per block. Plants were evaluated twice weekly for glossiness. At harvest (20 Sept.), heads of all plants from each treatment were weighed and graded. The numbers of *T. ni*, *P. rapae*, and *P. xylostella* larvae were also counted on each plant, and the entire plant was scored for insect damage.

A similar experiment was conducted in 1991 using the cabbage cultivar 'Bravo' (Harris-Moran). Transplanting was on 7 June. Two treatments of EPTC (8 Aug. and 28 Aug.) were required because heavy rainfall (5 cm on 9–10 Aug.) washed the material away after the first treatment. Pre-treatment with permethrin was on 21 Aug. and the second treatment was on 4 Sept. Sevin 75WP (0.14 kg a.i./ha) and permethrin (0.11 kg a.i./ha) were also applied on 11 July and 26 July, respectively, for control of flea beetles. The design was a RCB with 4 replicates and 5 plants/replicate plot. Plants were harvested and evaluated on 13 Sept.

We assessed the insecticidal activity of EPTC in a laboratory assay. Five 2nd instar *P. xylostella*, *T. ni*, or *P. rapae* were placed on discs of fresh cabbage leaf in a Petri dish. The leaf discs were then sprayed with an aqueous solution of EPTC at the concentration (1 ppt) used in the field assays. Untreated plants were sprayed

with water only. Mortality was assessed after 48 h. The test was replicated 3 times for each species.

*EPTC residues at harvest*

Fifty-gram samples of leaf tissue were taken from EPTC-treated plants and untreated plants at harvest in the damage assessment experiments in 1990 (20 Sept.) and 1991 (13 Sept.). In 1990, middle frame leaves were sampled from permethrin, EPTC, and EPTC + permethrin treatments. In 1991, head, wrapper, and middle frame leaves were sampled from the untreated plants and the EPTC treated plants. Samples were frozen immediately after harvest and later analyzed for EPTC residues using a modification of standard quantitative analytical methods (FDA, 1964; Patchett *et al.*, 1964; Ripley *et al.*, 1982). The frozen 50-g sample was extracted with 350 ml HPLC grade water. The extract was distilled and then washed with redistilled *n*-hexane (3 × 50 ml). The hexane fraction was filtered, dehydrated with sodium sulfate, concentrated to 1 ml, and analyzed for EPTC. A Hewlett Packard capillary gas chromatograph equipped with a 5970B Mass Selective Detector (MSD) (Hewlett Packard, Avondale, PA, U.S.A.), was used for detection, quantitation, and confirmation of EPTC. The capillary column was a Hewlett Packard P5 (SE-54) bonded phase fused silica column, 30 m × 0.2 mm, with a 0.25 micron phase coating coupled directly to the MSD. The chromatographic conditions were: splitless injector, 200 °C; temperature program, 80 °C for 1 min, 10 °C/min to 185 °C, 5 °C/min to 215 °C, 20 °C/min to 250 °C, final time 5 min; carrier gas was chromatographic grade helium at 14 psi and 25 cm/sec flow rate set at 185 °C. Quantitation of EPTC was performed using the abundance of the 189.10 AMU ion, which was free from interference from background ions, compared with the abundance of this ion in the analytical standard (99 + % reagent grade EPTC [Chem Services, West Chester, PA, USA]. The EPTC spectrum obtained was comparable to the NBS Spectral Data Base Library [99.9% match quality]). Minimum detection level with this method was 0.40 ppb or 0.02 μg EPTC/50 g of cabbage.

## Results

*Optimal doses of EPTC*

*Transplants.* All four doses of EPTC in the first experiment severely damaged transplants. Treated plants stopped producing leaves soon after treatment. Many of the remaining leaves were damaged by the herbicide. Twenty-nine days after treatment, most of the transplants treated with EPTC at 80 mg/plant had died, and a substantial number of plants in the other treatments had died as well. Data collection was terminated on day 29. No plants treated with EPTC at transplanting were alive 6 weeks after treatment. In the second experiment, even the much lower doses of EPTC had killed all of the plants by 6 weeks after treatment.

*Later growth stages.* In the first experiment, all doses of EPTC produced glossy plants in stages 3, 5, and 6 (Fig. 1a–c). Most of the frame and head leaves of treated plants in all three growth stages had a high glossy sheen, similar to the glossy appearance of genetically glossy plants. Onset of glossiness was within a few days of treatment, reaching greatest values in 2–3 weeks. Glossiness persisted until harvest in all three stages. Plants inoculated at stage 3 were still glossy 42 days after treatment but the intensity of glossiness began to decline after about 30 days. Glossiness was more pronounced at higher doses of EPTC but the differences between doses were small.

In the first experiment, stage 3 plants were injured by all doses of EPTC. The response to the two formulations was similar, and only data from 7EC are presented. The number of leaves per plant was reduced by EPTC, and as many as 4 leaves per plant (out of 8 surviving) showed evidence of herbicide damage at 42 days (Fig. 1d and g). Stage 3 EPTC-treated plants produced no

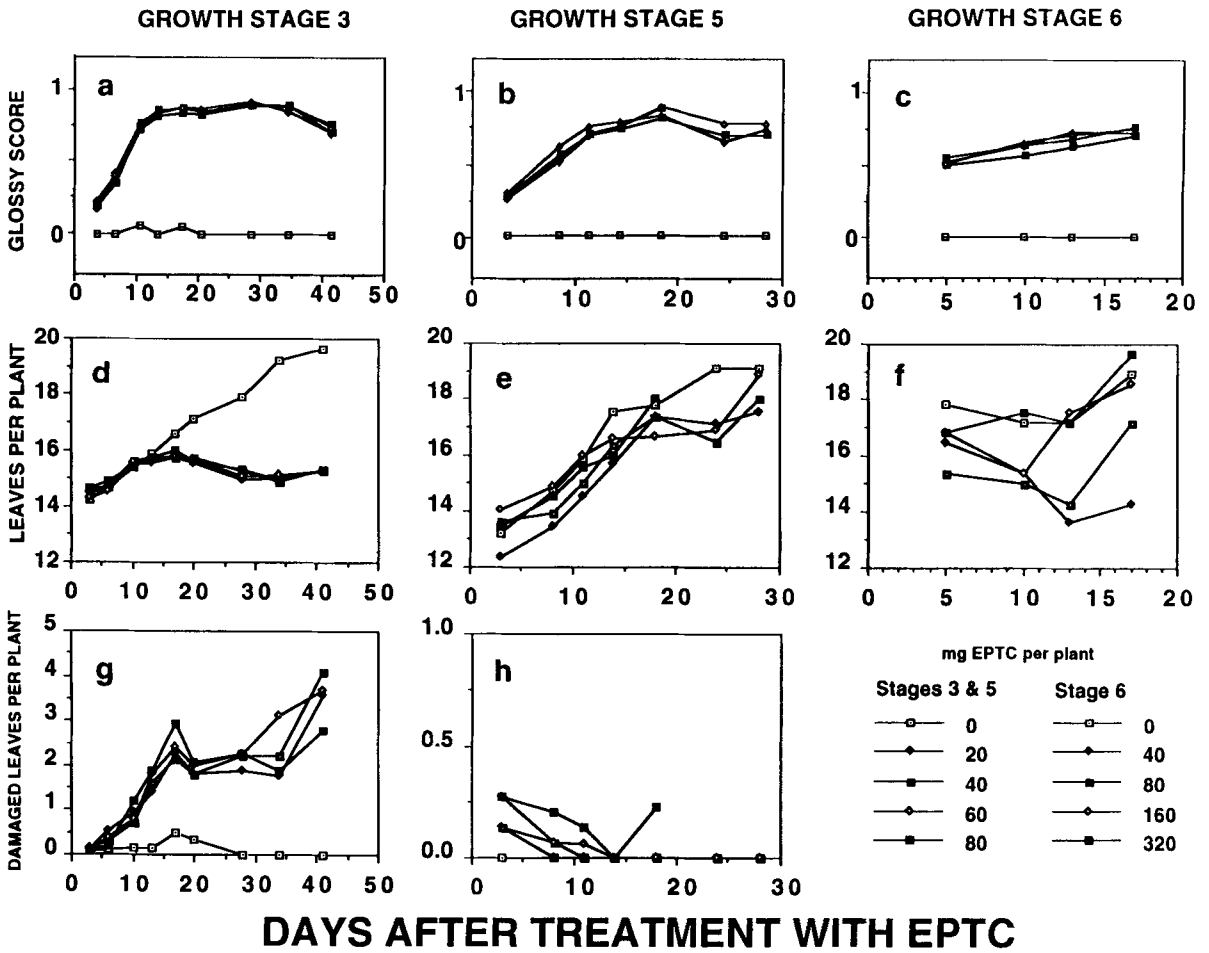


*Fig. 1.* Glossy scores (a, b, c), number of leaves per plant (not including head leaves) (d, e, f), and number of leaves damaged (g, h) on cabbage treated at three growth stages with EPTC at four doses. No leaves were damaged on stage 6 plants so no damaged-leaf plot is presented for this stage. Values are means of 12 to 15 plants per treatment. Glossy score was determined by scoring each leaf of a plant as 0 = normal, 0.5 = partly glossy, and 1 = glossy in appearance, then calculating a mean score for each plant.

heads, due to EPTC damage. In contrast, stage 5 and stage 6 EPTC-treated plants had few or no damaged leaves, and there was little or no effect on the number of leaves per plant (Fig. 1e–h). Head weights of stage 5- and stage 6-treated plants were not different from untreated plants (Table 1).

In the second experiment, plant vigor and head weight was not significantly affected by EPTC at any growth stage (Table 2). Even in stage-3 plants, the maximum number of leaves damaged was 0.2 per plant, 14 days after treatment, and by 17 days no damage was apparent. These stage-3 plants were slgihtly more mature than the stage-3 plants in the first experiment (8.8 leaves/plant vs. 6.6 leaves/plant). In addition, lower rainfall may have released the EPTC from Eptam 10G more slowly in the second experiment than in the first experiment.

High densities of *P. rapae* and *T. ni* severely reduced the percentage of heads suitable for fresh market in all treatments in the second experiment (Table 2). However, the percentage of fresh marketable heads was related to the amount of time plants were glossy during development; the least damaged treatment (stage 3) was glossy for the longest amount of time, and the most damaged (stage 6) was glossy for the least amount of time.

*Table 1.* Effects of doses and formulations of EPTC on head weight and glossy appearance of cabbage at three growth stages

| Formulation[a] | mg EPTC per plant | n | Head Wt (kg)[b] | Glossy score[c] |
|---|---|---|---|---|
| Growth stage 5 | | | | |
| EC | 20 | 12 | 1.2 ± 0.1 | 0.8 ± 0.03 |
| EC | 40 | 12 | 1.5 ± 0.1 | 0.8 ± 0.05 |
| EC | 60 | 12 | 1.3 ± 0.1 | 0.9 ± 0.02 |
| EC | 80 | 12 | 1.2 ± 0.2 | 0.9 ± 0.02 |
| EC | all rates | 48 | 1.3 ± 0.1 | 0.9 ± 0.03* |
| 10G | 20 | 12 | 1.4 ± 0.2 | 0.4 ± 0.04 |
| 10G | 40 | 11 | 1.3 ± 0.1 | 0.7 ± 0.05 |
| 10G | 60 | 12 | 1.5 ± 0.1 | 0.7 ± 0.04 |
| 10G | 80 | 11 | 1.3 ± 0.1 | 0.8 ± 0.04 |
| 10G | all rates | 46 | 1.4 ± 0.1 | 0.6 ± 0.04* |
| Growth stage 6 | | | | |
| EC | 40 | 12 | 1.1 ± 0.1 | 0.7 ± 0.02 |
| EC | 80 | 12 | 1.4 ± 0.1 | 0.7 ± 0.03 |
| EC | 160 | 12 | 1.2 ± 0.1 | 0.8 ± 0.02 |
| EC | 320 | 12 | 1.1 ± 0.1 | 0.8 ± 0.02 |
| EC | all rates | 48 | 1.2 ± 0.1 | 0.7 ± 0.03 |
| 10G | 40 | 12 | 1.7 ± 0.1 | 0.6 ± 0.03 |
| 10G | 80 | 12 | 1.4 ± 0.1 | 0.6 ± 0.02 |
| 10G | 160 | 11 | 1.3 ± 0.2 | 0.8 ± 0.02 |
| 10G | 320 | 9 | 1.5 ± 0.2 | 0.8 ± 0.02 |
| 10G | all rates | 44 | 1.5 ± 0.1 | 0.7 ± 0.02 |
| Untreated | 0 | 12 | 1.2 ± 0.2 | 0.0 ± 0.0 |

[a] EC = emulsifiable concentrate, 10G granular.

[b] Head weights evaluated at harvest; ANOVA Statistics: stage 5, F = 0.42, P = 0.9047, df = 8, 104; stage 6, F = 2.61, P = 1.1127, df = 8, 104 (untreated plants included in each analysis); *t*-test for the effect of formulation on head weight was also nonsignificant within each growth stage; – = no heads produced in stage 3 plants.

[c] Glossy score: 0 = normal, 0.5 = partly glossy, and 1 = glossy in appearance, average value for all leaves of a plant; scores were determined 17–18 days after treatment.

* Overall glossy score for 10G differs from EC, significant at 0.05, sign test.

### P. xylostella *survival*

In all three experiments in which plants were infested with *P. xylostella* eggs, survival of the insects was reduced significantly on the EPTC treated plants (Table 3). The mean reduction in larval survival compared to untreated plants was 50%.

### *Control of insect damage*

EPTC and permethrin provided similar levels of protection against insect damage. The whole-plant damage score and percentage of marketable heads was similar in EPTC-treated and permethrin-treated plants in both years. Damage was reduced approximately additively by the combination of EPTC and permethrin in both experiments (Tables 4 and 5). Insect populations were not reduced additively by the two treatments (Table 4). The number per plant of *P. xylostella* was reduced by each control method, but the combination of EPTC and permethrin did not produce an additional significant reduction. The number per plant of the other two insects was not reduced significantly by EPTC or permethrin, but the combination did result in a significant reduction. There were no detectable differences among the treatments in average head weight in either year, although average head weight was much greater for 'Bravo' in 1991 than 'Market Prize' in 1990.

There was no evidence of direct topical toxicity of EPTC to the three caterpillar species at the concentration applied to the plants in the field (1 ppt aqueous). Forty-eight hours after treatment with EPTC, the mean number of insects surviving (out of 5 per replicate) was 4.7, 5.0, and 4.7 for *P. xylostella*, *T. ni* and *P. rapae*, respectively. The mean number of insects surviving after treatment with water only was 4.7, 5.0, and 4.3 for the three species, respectively.

### *EPTC residues*

EPTC was detected at harvest in the tissues of treated plants at less than 1 ppb (Table 6). These residue levels are far less than the 100 ppb residues of EPTC permitted in leafy vegetables at harvest in the U.S.A. (Code of Federal Regulations, Title 40, Section 180.17). As expected, no residues were detected in the untreated plants in 1991. However, small amounts (0.4 ppb above

*Table 2.* Effects of EPTC treatments on head weight and marketability of cabbage

| Growth stage | Days from treatment to harvest | mg EPTC/ plant | Formulation | n | Percent fresh marketable[a] | Head Wt (kg)[b] |
|---|---|---|---|---|---|---|
| 3 | 40 | 20 | 10G | 14 | 36 ± 13 | 1.3 ± 0.1 |
| 5 | 26 | 80 | 10G | 13 | 15 ± 10 | 1.3 ± 0.1 |
| 6 | 18 | 160 | EC | 14 | 7 ± 7 | 1.2 ± 0.1 |
| Untreated | | 0 | – | 13 | 7 ± 7 | 1.4 ± 8.0 |

[a] ANOVA = 1.10, P = 0.4029, df = 3, 11.
[b] ANOVA F = 0.82, P = 4.874, df = 3, 11.

detection thresholds) were detected in untreated plants in 1990. The presence of EPTC in untreated plants may have resulted from contamination of the samples in the field, either with tissue from treated plants or from contact with contaminated equipment.

## Discussion

Results of these experiments confirm the finding of Eigenbrode & Shelton (1992) that EPTC-glossy cabbage plants significantly reduce *P. xylostella* survival. Lower populations of *P. rapae* and *T. ni* on EPTC-treated plants (Table 4) suggest that survival of these insects is also reduced on EPTC-glossy plants. This is not unexpected because, compared with standard types, genetic glossy plants are less damaged by *P. rapae* and *T. ni* (Dickson & Eckenrode, 1980), have reduced densities of *P. rapae* (Stoner, 1992), and cause reduced survival of *P. rapae* (Shelton & Eigenbrode, unpublished). Characteristics of the leaf waxes are correlated with resistance to *P. xylostella* in genetic glossies (Eigenbrode *et al.*, 1991a, b) and EPTC produces leaf waxes which are very similar to those of genetic glossies (Eigenbrode & Shelton, 1992). Just how these

*Table 3.* Survival of *P. xylostella* larvae on EPTC-treated cabbage plants at different stages of plant development

| mg EPTC per plant | Formulation[a] | Glossy score at infestation[b] | Percentage *P. xylostella* surviving | Percent control[c] | *P* value for *t*-test[d] |
|---|---|---|---|---|---|
| Growth stage 3 | | | | | |
| 20 | 10G | 0.8 ± 0.1 | 43 ± 4 | 43 | 0.0001 |
| 0 | – | 0.0 ± 0.0 | 75 ± 4 | | |
| Growth stage 5 | | | | | |
| 80 | EC | 0.7 ± 0.03 | 11 ± 2 | 58 | 0.0001 |
| 0 | – | 0.0 ± 0.0 | 26 ± 2 | | |
| Growth stage 6 | | | | | |
| 80 | 10G | 0.7 ± 0.1 | 5 ± 1 | 49 | 0.0001 |
| 0 | – | 0.0 ± 0.0 | 9 ± 1 | | |

[a] 10G = granular; EC = emulsifiable concentrate.
[b] Glossy score on day of infestation with *P. xylostella* eggs, n = 15 plants, ca. 14 days after treatment with EPTC; each leaf was scored 0 = maximum glossiness, 2 = normal, and average calculated for each plant.
[c] [1 – (% surv. treated/% surv. untreated)] × 100.
[d] Comparing *P. xylostella* survival on treated and untreated plants, n = 30 plants/treatment.

*Table 4.* Head weights, insect counts, insect damage, and marketability on 'Market Prize' cabbage plants protected with EPTC and permethrin, 1990

| Treatment | Mean glossy score[a] | *T. ni*[b] | Insects/plant *P. rapae* | *P. xylostella* | Plant damage score[e] | Head weight (kg)[f] | Percent marketable fresh[g] |
|---|---|---|---|---|---|---|---|
| EPTC | 0.2 ± 0.03b | 4.1 ± 0.4a | 1.6 ± 0.6ab | 7.3 ± 1.1a | 2.9 ± 0.2 | 1.6 ± 0.2 | 58 ± 16a |
| Permethrin | 0.1 ± 0.02a | 4.4 ± 0.6a | 1.7 ± 0.4ab | 7.3 ± 1.5a | 3.0 ± 0.5 | 1.4 ± 0.2 | 58 ± 16a |
| EPTC + Permethrin | 0.2 ± 0.1b | 1.2 ± 0.3b | 0.2 ± 0.2a | 5.9 ± 1.3a | 1.9 ± 0.2 | 1.6 ± 0.2 | 92 ± 6a |
| Untreated | 0.01 ± 0.01a | 6.0 ± 0.8a | 2.9 ± 0.6bc | 18.2 ± 3.1b | 4.0 ± 0.3 | 1.2 ± 0.2 | 0.0 ± 0.0b |

[a] ANOVA F = 17.44; P = 0.0001. Scores with different letters are significantly different (Tukey's HSD, P < 0.01).
[b] ANOVA F = 13.53; df = 3, 15; P = 0.0001. Values with different letters are significantly different (P ≤ 0.01).
[c] ANOVA F = 5.43; df = 3, 15; P = 0.003. Values with different letters are significantly different (P = 0.001).
[d] ANOVA F = 8.97; df = 3, 15; P = 0.0001. Values with different letters are significantly different (P ≤ 0.0001).
[e] Scores are different (P = 0.0001) based on Kruskal-Wallis ANOVA of ranks.
[f] ANOVA F = 0.943; df = 3, 15; P = 0.428. Treatment did not significantly affect head weight.
[g] ANOVA F = 10.87; df = 3, 15; P = 0.001. Values with different letters are significantly different (P = 0.05).

traits increase larval mortality is still unclear, but a behavioral mechanism has been suggested (Eigenbrode *et al.*, 1991a, b; Eigenbrode & Shelton, 1990).

The control of Lepidoptera provided by EPTC in these experiments apparently was not due to direct topical or post-ingestive acute toxicity of the compound. In the laboratory, no increase in mortality of 2nd instar *P. xylostella*, *T. ni*, or *P. rapae* resulted from topical application of EPTC in the same concentration as sprayed onto the plants in the field. The test insects also consumed the EPTC residues sprayed onto the cabbage discs in the laboratory experiment. Additionally, EPTC residues in treated plants are too low as early as 7 days after treatment (3 ppb) to reduce *P. xylostella* larval survival (Eigenbrode & Shelton, 1992). These concentrations would also probably be inadequate to affect *T. ni* survival; the $LC_{50}$'s of thiocarbamate herbicides thiobencarb and endothall to *T. ni* in artificial diet are 298 and 476 ppm respectively (Brown, 1987). All these tests were evaluated within 48 h, and cannot eliminate the possibility that EPTC produces

*Table 5.* Head weight, marketability, and insect damage on 'Bravo' cabbage plants protected with EPTC and permethrin, 1991

| Treatment | Plant damage score[a] | Head weight (kg)[b] | Percent marketable fresh[c] |
|---|---|---|---|
| EPTC | 3.1 ± 0.2 | 3.6 ± 0.2 | 35 ± 5b |
| Permethrin | 2.5 ± 0.2 | 3.6 ± 0.3 | 35 ± 5b |
| EPTC + Permethrin | 2.0 ± 0.1 | 3.6 ± 0.2 | 65 ± 10a |
| Untreated | 4.7 ± 0.2 | 3.5 ± 0.2 | 0.0 ± 0.0c |

[a] Scores are different (P = 0.0001) based on Kruskal-Wallis ANOVA of ranks.
[b] ANOVA F = 0.07; df = 3, 15; P = 0.9769. Treatment did not significantly affect head weight.
[c] ANOVA F = 19.94; df = 3, 15; P = 0.0001. Values with different letters are significantly different (0.05).

*Table 6.* Residues of EPTC (ppb) at harvest in cabbages treated with EPTC and in untreated plants

| Year | Sampled tissue | EPTC[a] | Control |
|---|---|---|---|
| 1990 | Pooled[c] | 0.83 | 0.49 |
| 1991 | Head | 0.69 | < 0.40[b] |
| | Mid-frame | 1.05 | < 0.40[b] |
| | Wrapper | < 0.40[b] | < 0.40[b] |

[a] Treated with 160 mg EPTC per plant, 20 days before this analysis.
[b] Below minimum for detection with analytical method used.
[c] Average of samples from EPTC-treated and EPTC + permethrin-treated plants.

longer term effects on larval survival at these concentrations.

EPTC may have insecticidal activity against other arthropods. Populations of soil insects have been observed to decrease substantially following treatment with other thiocarbamate herbicides at field application rates (Ulber, 1979; Schaefer *et al.*, 1982). The possible impact of EPTC on beneficials and other pest insects should be considered in developing its use for control of lepidopteran pests in cabbage.

EPTC residues detected in treated plants at harvest were well below permissible amounts in the U.S.A. These levels should also be acceptable in most other countries, but we have not examined other national regulations.

There are some limitations to this use of EPTC. Protection of plants with EPTC earlier than growth stage 3 is impossible because of phytotoxicity. After treatment with EPTC, plants do not become glossy for an additional 10 days. Other materials must be used to control pests during the early stages of crop development. As with genetically glossy plants (Eigenbrode, 1990; Lin *et al.*, 1983), EPTC-induced glossy plants are apparently only resistant to early instars. As a result, even after the onset of glossiness, insecticides may be required to control higher instars already present on the plants. In our experiments EPTC-glossy plants that were not pretreated with insecticides before becoming glossy were heavily damaged (Table 2). In contrast, EPTC-glossy plants pretreated with permethrin were less damaged, compared to nonglossy plants pretreated with permethrin (Tables 4 and 5). Because of these limitations, in areas in which no chemical pesticides remain effective against *P. xylostella*, EPTC-induced resistance probably will not be of value.

Another limitation of EPTC-induced resistance is the difficulty in producing adequately glossy plants during very rainy periods, as we experienced in 1991. In seasons of heavy rain or when constant irrigation is required to produce a crop, EPTC may be difficult or impossible to use for insect control.

Under the right conditions and used appropriately, EPTC can provide protection against damage by *P. xylostella*, *T. ni*, and *P. rapae* without the risk of adversely affecting the yield. Glossiness can be induced effectively and conveniently by applying EPTC to the plants with standard spray equipment. This method of protection could be integrated easily into existing grower practices. Based on current U.S. retail prices, the cost of a single application of permethrin at 0.11 kg/ha is ca. $12.94/ha (Ambush, $112/gallon and 25.6% a.i.). The EPTC rate used in our economic trials (160 mg/plant) would cost ca. $30.87/ha (24,700 plants/ha, $26.00/gallon of 87.8% a.i. [Eptam 7E]). A single application of EPTC, however, potentially can provide protection for as long as 30 days, after a reduction of existing larval populations with a standard insecticide, and would be cost-effective. This would be especially true where conventional chemical controls must be applied 1–2 times weekly to control *P. xylostella*. There is also an eight-fold potential for improving the effectiveness of EPTC by refining the method of application. The drop boom method is inefficient because it relies on the material running off the plants and into the soil where it is taken up through the plant roots. Only 20 mg of EPTC applied directly to the roots will produce a more intense glossy appearance than 160 mg applied with a drop boom (compare Tables 1 and 4). Where agricultural chemicals are applied routinely with backpack sprayers or similar equipment, growers can induce glossiness efficiently by directing the EPTC at the base of the plant.

Alternatives for management of lepidopteran pests of crucifers, especially *P. xylostella*, are needed urgently. Reliance on insecticides has resulted inevitably in the development of resistance in *P. xylostella* populations (Shelton & Wyman, 1992). *P. xylostella* resistance to *Bacillus thuringiensis* toxins is now documented in populations of this insect (Tabashnik, 1990). Using a variety of management practices can help slow the development of resistance. Although EPTC-induced resistance cannot replace existing insecticides, in combination with other controls it can reduce the necessary number of insecticide applications and help slow the development of insecticide resistance in *P. xylostella*.

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