Film-Coating Seeds with Chlorpyrifos for Germination and Control of Cabbage Maggot (Diptera: Anthomyiidae) on Cabbage Transplants[1]

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Abstract The cabbage maggot, *Delia radicum* (L.), is an important chronic pest of cabbage in the northern U.S. The maggots of this species cause damage to young plants by feeding on roots and stems, resulting in plant stand and yield losses or rendering the crop unmarketable. In New York, the nation's largest producer of cabbage, the most common control practice is to apply a drench or banded spray of chlorpyrifos at transplanting. As an alternative to this practice, we investigated the duration of insecticidal activity of chlorpyrifos film-coated seeds on cabbage transplants. Seeds of the cabbage var. 'Fresco F-1' were film-coated with chlorpyrifos at the rates of 0, 9.6, 19.2 or 28.8 g [AI]/kg seed and then examined for phytotoxic effects on germination in the laboratory as well as effectiveness against immature stages of *D. radicum* under greenhouse and field conditions. Chlorpyrifos film-coated seed treatments did not adversely affect germination in the laboratory tests when plants were grown with peat soil in transplant cell trays and provided significant plant protection against immature stages of cabbage maggot through several weeks after transplanting seedlings with associated soil under greenhouse and field conditions. These results agree with previous European studies showing the potential of seed treatments to reduce damage by *D. radicum* while at the same time dramatically reducing the amount of insecticide compared with a banded spray or drench application.

Key Words Cabbage maggot, *Delia radicum,* cabbage, chlorpyrifos, film-coatings, seed treatment

The cabbage maggot, *Delia radicum* (L.), is a chronic pest of commercial cabbage and other cruciferous vegetable crops in the northern Hemisphere. Feeding by immature stages can kill young plants, reduce yields, or render the crop unmarketable (Pedersen and Eckenrode 1981). Damage is often so predictable on young plants that many growers rely on chemical insecticides applied to the soil as granular or drench applications to protect their crops against *D. radicum* attack. Soil-applied insecticides provide an adequate defense against *D. radicum* during the early growth stages when maggots may cause the greatest reduction in plant stands and yield (Andaloro et al. 1983). In New York, the nation's leading producer of cabbage, chlor-

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pyrifos is the major insecticide used for the control of *D. radicum,* applied as a drench or banded spray to the base of young plants (Anonymous 2001). There are concerns that such an application may disrupt natural enemies and have other adverse effects on the environment and human health. There is also increasing evidence that repeated application of insecticides to the same soil can lead to the development of highly active microbial populations that are able to degrade the insecticide rapidly (Van der Steene et al. 1989).

The search for alternatives to insecticides has focused on a number of cultural and physical management strategies for *D. radicum* populations (Bomford et al. 2000). Cultural practices such as crop rotation, field sanitation, removal of alternate hosts, trap cropping, and timing plantings to avoid critical *D. radicum* flight periods show promise as components of integrated pest management strategies (Finch 1993). Physical control strategies such as the use of tar papers or foam rubber collars placed around the plant stalks to prevent oviposition can also be effective (Schoene 1914, Wheatley 1975, Skinner and Finch 1986). Also, various types of row covers can be used to exclude adult *D. radicum* (Bomford et al. 2000, Haseli and Conrad 1987, Hough-Goldstein 1987, Mathews-Gehringer and Hough-Goldstein 1988, Millar and Isman 1988). Some entomopathogenic nematodes (Schroeder et al. 1996) and insect growth regulators (Young et al. 1987, Gordon et al. 1989) have been tested for control of *D. radicum.* Despite significant efforts in developing these alternative management strategies for *D. radicum,* success has been limited, in part because of prohibitive costs or labor requirements (Schroeder et al. 1996); therefore, insecticides remain the main control tactic.

The application of insecticides to seeds through film coating appears to be a promising technique of ensuring the safe and efficient use of insecticides, while dramatically reducing the amount of active ingredient (Taylor et al. 1998). Film-coating of seeds for insect and disease control is a recent development originally derived from techniques developed for the pharmaceutical industry (Taylor 1997). This technology consists of spraying a solution or suspension of a film-forming polymer onto a mass of seeds to achieve a uniform deposition of materials. Application of seed treatments by film-coating seeds was compared to in-furrow drench applications for another *Delia* species, the onion fly, *D. antiqua* (Meigen) (Taylor et al. 2001). Film-coating onion seeds with a plant protectant proved to be an effective method of control for this direct-seeded crop and can reduce the amount of active ingredient per hectare by 85%. Film-coating the seed has the advantage of protecting the plants from the moment of sowing.

Most vegetable growers use transplants due to the high cost of many vegetable seeds and the desire to have a full stand of plants. In New York, it is estimated that >75% of the cabbage is transplanted, and much of this consists of transplants grown in small cells of soil. If the insecticide effects of treated seeds can carry over to plants that are transplanted into fields, it would result in reduced rates of active ingredient per hectare. Additionally, sowing film-coated seeds in transplant trays with an artificial soil medium and then transplanting them into the field may prevent soil microorganisms in the field soil from rapidly breaking down the insecticides (Ester et al. 1994). European investigators have evaluated the effect of film-coated seeds of vegetable crops with several insecticides for control of *D. radicum* in cabbage (Ester and De Moel 1992), cauliflower (Ester et al. 1994), and Brussels sprouts (Ester et al. 1997). While their results showed considerable promise for seed treated with chlorpyrifos, their studies were conducted with different soil types, relied on natural populations of

D. radicum so they could not strictly control infestation levels or time of infestation, and did not have frequent intervals of inspection to determine the length of insecticidal activity.

The overall goal of our study was to investigate the duration of insecticidal activity of chlorpyrifos film-coated seed once the seedlings were transplanted. This was done by inoculating plants with eggs of *D. radicum* at various times after transplanting and then assessing insect survival and plant damage. Additional studies were conducted to determine whether our film-coating practices, which were different from those reported by Ester et al. (1992, 1994, 1997), caused any phytotoxicity.

Materials and Methods

Insecticide seed treatment procedures. Chlorpyrifos, formulated as Dursban 75 WG (Dow AgroSciences, Indianapolis, IN), was used in the study. Seeds of the cabbage variety 'Fresco F-1' (Bejo, Holland) were film-coated with chlorpyrifos at rates of 0, 9.6, 19.2 or 28.8 g [AI]/kg seed. These rates were similar to those reported by Ester et al. (1997). The average seed weight of the 'Fresco' lot was 3.3 mg per seed, resulting in an application rate of 3.2, 6.4 and 9.6 g [AI]/100,000 seeds, respectively. We used a different film coating than previously reported by Ester et al. (1992, 1994, and 1997). A commercial film-forming formulation (Opadry AG, Colorcon Inc., West Point, PA) was used to apply the seed treatment. The dry film-forming powder was mixed with water and sprayed onto the seeds with an external air atomization nozzle (Binks model 460, Franklin Park, IL) in the coating pan. The coating pan was ventilated by passing warm air into the opening of the pan during the coating operation (Taylor et al. 2001). All seed treatments were applied in a rotating drum using a laboratory-coating pan.

Germination and phytotoxicity experiment. Chlorpyrifos film-coated seed treatments were assessed for phytotoxicity by evaluating germination and seedling growth. The experiments consisted of five treatments: a noncoated control, and chlorpyrifos film-coated seeds at the rates of 0, 9.6, 19.2 or 28.8 g [AI]/kg seed. All experiments were conducted in a randomized complete block design using four replications of 50 seeds per replication. All germination tests were performed using a roll towel procedure. Seeds were covered with or without peat (Taylor et al. 2001) in germination cabinets at a constant temperature of 20°C in the dark during the spring of 2000. The peat treatment simulated what would be done in a cell transplant. The germination percentage of sprouted seeds was recorded for each treatment after 3 d. Eight days after initiation of the test, the percentage of normal plants was assessed based on examination of the cotyledons, hypocotyl, and roots of the plants (Taylor et al. 2001).

Insecticide efficacy trial. The following treatments were evaluated: a non-coated seed control and film-coated seeds at the rates of 0, 9.6, 19.2 or 28.8 g [AI]/kg seed, and a chlorpyrifos banded spray, and a noncoated-seed insect control. These treatments were used to assess the length of insecticidal activity of chlorpyrifos film-coated seed treatments for the control of *D. radicum* on transplants in both greenhouse pot and field plot experiments. The length of insecticidal activity was measured by inoculating the plants with eggs of *D. radicum* over a 6-wk period after transplanting seedlings into greenhouse-pot and field-plot experiments. The plants of non-treated-seed insect control were not inoculated with *D. radicum* in the greenhouse or

field experiments and, therefore, served as a check for the effectiveness of inoculating the plants with insect eggs.

Preparation of transplants. Seeds from these insecticide seed treatments were sown in Speedling® styrofoam trays (Speedling, Inc., Sun City, FL) with 128 cells filled with Cornell Mix (1:2 peat moss: vermiculite). Plants of these treatments were raised in the Styrofoam trays and watered as needed in a greenhouse which was maintained at 21 ± 1°C, with 60 ± 3% RH and contained six 1,500-W metal halide lamps for a photoperiod of 16:8 (L:D) h to supplement natural light.

Insect inoculation procedures. A *D. radicum* population from our laboratory colony was used for egg inoculation in all greenhouse and field experiments. This colony was maintained in the Department of Entomology at the New York State Agricultural Experiment Station, Geneva, NY, and reared on turnips at 21°C, 60% RH and a photoperiod of 16:8 (L:D)-h as described by Reed (1965). This colony is our standard insecticide-susceptible colony and has been used for >10 yr for insecticide bioassays. Plants of each treatment were inoculated with 10 eggs of *D. radicum* (1 to 4 d old) after 1, 2, 3, 4, 5 or 6 wk(s) of transplanting in greenhouse pots or field plots. Eggs were placed at the base of each plant with a fine camel's hair paintbrush, and larvae were allowed to feed on plants for a 3-wk period. After inoculation, plants of the banded spray treatment were sprayed with chlorpyrifos at the standard field rate of 1.4 mL of chlorpyrifos in 313 mL of water to cover 10 plants, using a backpack sprayer. The spray apparatus was a CO_2-pressurized boom type sprayer equipped with 1 TX 6 hollow cone nozzle.

Greenhouse experiment. The greenhouse experiment was conducted with potted plants at the New York State Agricultural Experiment Station, Geneva, NY, during 2000. The experiment was repeated four times in the greenhouse. Three wks after planting, greenhouse-grown plants of each treatment were transplanted individually to 15-cm plastic pots containing a mixture of field soil and sand (50:50). Eggs of *D. radicum* were collected from the colony and, on the same day, each plant was infested with 10 eggs using a fine camel's hair paintbrush. Plants were placed in the greenhouse under the conditions noted above. To assess the efficacy of the treatments over time, the plants of each treatment were divided into 6 wk periods of inoculation with eggs of *D. radicum.* Inoculations occurred at 1, 2, 3, 4, 5 or 6 wk(s) after transplanting into the pots. For each inoculation period, treatments were arranged in a randomized complete block design with 10 plants as replicates. At 3 wks after inoculation with eggs, the plants were uprooted, and the roots and soil were removed and examined for larvae and pupae. The numbers of larvae and pupae were counted from each plant per treatment. The plants of each treatment used in greenhouse experiments were recorded as insect-damaged plants based on the presence of scars on the main stems or roots. The proportion of insect-damaged plants for each treatment was calculated as the ratio of insect-damaged plants divided by the total number of plants used for each treatment. The numbers of dead and live plants also were recorded for each treatment in all greenhouse experiments. The plants were considered dead if they contained no green leaves. The proportion of dead plants was calculated as the ratio of dead plants divided by the total number of plants used for each treatment.

Field experiment. The field plot experiment was conducted at the Fruit and Vegetable Crops Research Farm, NY, during 2000. The experiment was replicated over four time periods. Plants in 'Speedling' trays were moved to cold frames to acclimatize them for 3 d before transplanting into field plots. Thereafter, plants of each treatment

were transplanted individually into the field at 30-cm spacing between plants. The plants of each treatment were divided into 6-wk periods of inoculation with *D. radicum* eggs, as in the greenhouse experiment. Eggs were collected from the laboratory colony and, on the same day, the plants were infested with 10 eggs using a fine camel's hair paint-brush. Inoculations occurred at 1, 2, 3, 4, 5 or 6 wk(s) after transplanting into field plots. For each inoculation period, treatments were arranged in a randomized complete block design with 10 plants as replicates. At 3 wks after inoculation with eggs, plants were cut at ground level using a pair of scissors, and then a turfgrass cutter (10 cm diam × 15 cm deep) was used to dig a core of soil around the base of each plant. The plants with the roots and soil were removed, and the numbers of larvae and pupae were counted from each plant. The criteria used for rating plant damage and mortality were the same as described for the greenhouse study.

Statistical analysis. Data on germination percentage of sprouted seeds and normal seedlings were analyzed in a randomized complete block design using the general linear model (SAS Institute 1995). Each of the four separate greenhouse or four separate field experiments was considered a replicate over time, and the data were combined into a single analysis. Data on the proportion of insect damaged plants were transformed using arcsine square root transformation to stabilize variance before performing an analysis of variance (Steel et al. 1997). The square root transformation of counts of the sum of larvae and pupae was used to stabilize the variance before performing an analysis of variance (Steel et al. 1997). All data were analyzed in a randomized complete block design using the general linear model (SAS Institute 1995). Tukey's studentized (HSD) range test was used for comparison of treatment means.

Results

Germination and phytotoxicity experiment. There were no significant differences in percentage of sprouted seeds between chlorpyrifos film-coated- and the noncoated seed treatments (Table 1). In the absence of peat for the roll towel tests, there was a significant reduction in normal seedlings only at 19.2 g [AI]/kg seed, compared to the noncoated seed treatments (Table 1). In the presence of peat for the roll towel tests, there were no significant differences in germination percentages of normal seedlings between chlorpyrifos film-coated and the noncoated seed treatments.

Greenhouse experiment. All chlorpyrifos treatments resulted in a significant reduction in numbers of *D. radicum* larvae and pupae compared to treatments without chlorpyrifos at each inoculation period (Table 2). All chlorpyrifos film-coated seed treatments were as effective as the banded-spray application for control of larvae and pupae. Significant reductions in insect-damaged plants were recorded among chlorpyrifos-coated seed treatments for all inoculation periods (Table 3). All chlorpyrifos treatments were as effective as or superior to the spray application. Significantly more plants survived with chlorpyrifos treatments than those of non-chlorpyrifos treatments in all periods of inoculation (Table 4). Also, all chlorpyrifos treatments were as effective as or superior to the spray application.

Field experiment. Significant reductions in number of larvae and pupae among insecticide seed treatments were recorded in all periods of inoculation (Table 5). Chlorpyrifos applied as a seed treatment at all rates tested had the same efficiency as the banded spray. Percentage of plants damaged showed similar trends (Table 6). In

Table 1. Germination percentage of sprouted seeds and normal seedlings of chlorpyrifos-treated cabbage seeds under laboratory condition, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Germination %		
		Sprouted seeds	Normal seedlings	
			Without peat	With peat
Noncoated, seed	—	97 ± 2a	97 ± 1a	97 ± 2a
Polymer, film-coated seed	0.0	98 ± 1a	94 ± 2ab	98 ± 1a
Chlorpyrifos, film-coated seed	9.6	99 ± 1a	97 ± 1a	97 ± 1a
Chlorpyrifos, film-coated seed	19.2	97 ± 1a	91 ± 2b	99 ± 1a
Chlorpyrifos, film-coated seed	28.8	97 ± 1a	93 ± 1ab	99 ± 1a
df		4, 12	4, 12	4, 12
F		0.81	4.05	1.15
P		0.5414	0.0263	0.3812

* Means within a column followed by a common letter are not significantly different by Tukey's studentized (HSD) range test ($P \geq 0.05$).

both tables, the plants from noncoated seed that were not inoculated with insects had significantly fewer insects and damage than the plants from noncoated seed that were inoculated with insects, thus showing the value of the inoculation.

Discussion

In the laboratory experiments film-coated seed, with or without chlorpyrifos, did not affect the rate of sprouting or the percent of normal germination, except for the chlorpyrifos treatment at the rate of 19.2 g [AI]/kg seed without peat. It is unclear why this rate, which was not the highest rate, caused this lower germination. Most importantly, in the presence of peat, chlorpyrifos film-coated seed treatments did not result in any significant differences in percentage of normal seedlings compared to noncoated seed treatments, and peat is the common soil medium used when transplants are grown in cells. Our results on germination differed from those of Kosters et al. (1992) who did not find any phytotoxic effects on germination with chlorpyrifos film-coated seed treatments with cabbage seeds. These differences may be the result of our methods for assessing germination with and without peat (not included in the Kosters et al. (1992) paper), cabbage variety or the different seed coating method we employed. Based on the results presented herein, it appears that our seed coating method will be suitable for cabbage seed grown in cells with peat.

In greenhouse experiments, chlorpyrifos film-coated seed treatments resulted in a significantly lower number of larvae and pupae, a lower percentage of insect-damaged plants, and higher plant survivals than those of noncoated seed treatments for all periods of inoculation. Under field conditions, chlorpyrifos film-coated seed treatments resulted in significantly lower numbers of larvae and pupae, and a lower percentage of insect-damaged plants than those of noncoated seed treatments for all periods of inoculation. Thus, all chlorpyrifos film-coated seed treatments provided

Table 2. Effects of chlorpyrifos film-coated cabbage seed treatments on numbers of *D. radicum* larvae and pupae per plant in at 1, 2, 3, 4, 5, or 6 weeks after transplanting in greenhouse experiments, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Numbers of larvae and pupae per plant from 1 to 6 weeks after transplanting					
		1	2	3	4	5	6
Noncoated, seed	—	3.2 ± 0.5a	3.9 ± 0.5a	3.2 ± 0.5a	4.1 ± 0.5a	4.5 ± 0.6a	4.7 ± 0.6a
Polymer, film-coated	0.0	2.9 ± 0.5a	3.8 ± 0.5a	3.3 ± 0.5a	4.3 ± 0.6a	4.6 ± 0.6a	4.2 ± 0.5a
Chlorpyrifos, film-coated	9.6	0.4 ± 0.2b	0.5 ± 0.2b	0.6 ± 0.2b	0.7 ± 0.2b	0.9 ± 0.3b	0.7 ± 0.3b
Chlorpyrifos, film-coated	19.2	0.3 ± 0.1b	0.3 ± 0.1b	0.4 ± 0.2b	0.4 ± 0.2b	0.5 ± 0.2b	0.6 ± 0.2b
Chlorpyrifos, film-coated	28.8	0.2 ± 0.1b	0.1 ± 0.1b	0.3 ± 0.2b	0.4 ± 0.2b	0.5 ± 0.2b	0.5 ± 0.2b
Chlorpyrifos sprays**	—	1.1 ± 0.3b	1.4 ± 0.3b	0.8 ± 0.2b	1.0 ± 0.3b	1.1 ± 0.3b	1.2 ± 0.3b
Noncoated insect control	—	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b	0.0 ± 0.0b
df		6, 18	6, 18	6, 18	6, 18	6, 18	6, 18
F		12.34	34.50	28.51	55.30	67.68	36.23
P		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

* Means within a column followed by a common letter are not significantly different by Tukey's studentized (HSD) range test ($P \geq 0.05$).

** Spray was applied at the rate of 1.4 ml of formulated product per 313 ml of water sprayed on 10 plants.

Table 3. Effects of chlorpyrifos film-coated cabbage seed treatments on percentage of plants damaged by *D. radicum* at 1, 2, 3, 4, 5 or 6 weeks after transplanting in greenhouse experiments, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Percentage of plants damaged from 1 to 6 weeks after transplanting					
		1	2	3	4	5	6
Noncoated, seed	—	58 ± 8a	60 ± 8a	55 ± 8a	63 ± 8a	68 ± 8a	68 ± 8a
Polymer, film-coated	0.0	48 ± 8ab	58 ± 8a	53 ± 8a	65 ± 8a	68 ± 8a	68 ± 8a
Chlorpyrifos, film-coated	9.6	15 ± 6c	13 ± 5b	18 ± 6b	21 ± 6bc	25 ± 7bc	20 ± 6bc
Chlorpyrifos, film-coated	19.2	13 ± 5c	10 ± 5b	13 ± 5b	13 ± 3bc	18 ± 6bc	20 ± 6bc
Chlorpyrifos, film-coated	28.8	10 ± 5c	8 ± 4b	10 ± 5b	13 ± 5bc	15 ± 6bc	13 ± 5bc
Chlorpyrifos sprays**	—	25 ± 7bc	40 ± 8a	23 ± 7b	29 ± 7b	30 ± 7b	33 ± 8b
Noncoated insect control	—	0 ± 0c	0 ± 0b	0 ± 0b	0 ± 0c	0 ± 0c	0 ± 0c
df		6, 18	6, 18	6, 18	6, 18	6, 18	6, 18
F		21.19	33.57	40.82	69.16	36.22	27.85
P		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

* Means within a column followed by a common letter are not significantly different by Tukey's studentized (HSD) range test ($P \geq 0.05$).

** Spray was applied at the rate of 1.4 ml of formulated product per 313 ml of water sprayed on 10 plants.

Table 4. Effects of chlorpyrifos film-coated cabbage seed treatments on percentage of plant survival at 1, 2, 3, 4, 5 or 6 weeks after transplanting in greenhouse experiments, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Percentage of plants surviving from 1 to 6 weeks after transplanting					
		1	2	3	4	5	6
Noncoated, seed	—	63 ± 8b	60 ± 8b	58 ± 8b	68 ± 8b	68 ± 8b	68 ± 8b
Polymer, film-coated	0.0	50 ± 8b	63 ± 8b	63 ± 8b	65 ± 8b	70 ± 7b	70 ± 7b
Chlorpyrifos, film-coated	9.6	95 ± 4a	98 ± 3a	95 ± 4a	98 ± 2a	98 ± 3a	100 ± 0a
Chlorpyrifos, film-coated	19.2	100 ± 0a	100 ± 0a	98 ± 3a	98 ± 3a	98 ± 3a	98 ± 3a
Chlorpyrifos, film-coated	28.8	100 ± 0a	100 ± 0a	98 ± 3a	100 ± 0a	98 ± 3a	100 ± 0a
Chlorpyrifos sprays**	—	95 ± 4a	90 ± 5a	93 ± 4a	97 ± 3a	93 ± 4a	95 ± 4a
Noncoated insect control	—	100 ± 0a	100 ± 0a	100 ± 0a	100 ± 0a	100 ± 0a	100 ± 0a
df		6, 18	6, 18	6, 18	6, 18	6, 18	6, 18
F		20.12	19.44	28.89	15.90	13.09	14.32
P		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

* Means within a column followed by a common letter are not significantly different by Tukey's studentized (HSD) range test ($P \geq 0.05$).

** Spray was applied at the rate of 1.4 ml of formulated product per 313 ml of water sprayed on 10 plants.

Table 5. Effects of chlorpyrifos film-coated cabbage seed treatments on numbers of *D. radicum* larvae and pupae per plant at 1, 2, 3, 4, 5 or 6 weeks after transplanting in field, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Numbers of larvae and pupae per plant from 1 to 6 weeks after transplanting					
		1	2	3	4	5	6
Noncoated, seed	—	2.8 ± 0.4a	3.8 ± 0.6a	3.8 ± 0.6a	2.6 ± 0.4a	2.7 ± 0.5b	2.4 ± 0.4a
Polymer, film-coated	0.0	2.5 ± 0.4a	3.9 ± 0.6a	3.8 ± 0.6a	2.7 ± 0.5a	3.4 ± 0.5a	2.4 ± 0.4a
Chlorpyrifos, film-coated	9.6	0.4 ± 0.1b	0.6 ± 0.2b	0.7 ± 0.2b	0.5 ± 0.2b	0.6 ± 0.2c	0.6 ± 0.2b
Chlorpyrifos, film-coated	19.2	0.2 ± 0.1b	0.3 ± 0.1b	0.5 ± 0.2b	0.5 ± 0.1b	0.3 ± 0.1c	0.5 ± 0.2b
Chlorpyrifos, film-coated	28.8	0.1 ± 0.1b	0.3 ± 0.1b	0.5 ± 0.2b	0.3 ± 0.1b	0.2 ± 0.1c	0.3 ± 0.1b
Chlorpyrifos sprays**	—	0.8 ± 0.2b	0.9 ± 0.3b	0.9 ± 0.2b	0.8 ± 0.2b	0.8 ± 0.2c	1.1 ± 0.2b
Noncoated insect control	—	0.4 ± 0.1b	0.5 ± 0.2b	0.9 ± 0.3b	0.6 ± 0.2b	0.8 ± 0.3c	1.0 ± 0.3b
df		6, 18	6, 18	6, 18	6, 18	6, 18	6, 18
F		12.03	5.46	5.43	9.04	10.19	4.01
P		0.0001	0.0023	0.0023	0.0001	0.0001	0.0100

* Means within a column followed by a common letter are not significantly different by Tukey's studentized Range (HSD) test ($P \geq 0.05$).

** Spray was applied at the rate of 1.4 ml of formulated product per 313 ml of water sprayed on 10 plants.

Table 6. Effect of chlorpyrifos film-coated cabbage seed treatments on the percentage of plant damage by *D. radicum* at 1, 2, 3, 4, 5 or 6 weeks after transplanting in field, Geneva, NY*

Treatments	Rate g [AI]/kg seed	Percentage of plants damaged from 1 to 6 weeks after transplanting					
		1	2	3	4	5	6
Noncoated, seed	—	63 ± 8a	63 ± 8a	65 ± 8a	60 ± 8a	53 ± 8ab	48 ± 8a
Polymer, film-coated	0.0	70 ± 7a	65 ± 8a	65 ± 8a	58 ± 78ab	58 ± 8a	48 ± 8a
Chlorpyrifos	9.6	20 ± 6b	28 ± 7b	43 ± 8ab	30 ± 7bc	18 ± 6c	25 ± 7ab
Chlorpyrifos, film-coated	19.2	10 ± 5b	25 ± 7b	28 ± 7b	30 ± 7bc	13 ± 3c	18 ± 6b
Chlorpyrifos, film-coated	28.8	10 ± 5b	20 ± 6b	30 ± 7b	25 ± 7c	13 ± 5c	15 ± 6b
Chlorpyrifos sprays**	—	33 ± 8b	30 ± 7b	40 ± 8ab	35 ± 8abc	28 ± 7bc	30 ± 7ab
Noncoated insect control	—	18 ± 6b	20 ± 6b	30 ± 7b	33 ± 8abc	23 ± 7c	28 ± 7ab
df		6, 18	6, 18	6, 18	6, 18	6, 18	6, 18
F		9.67	6.10	4.73	33.69	6.38	36.23
P		0.0001	0.0013	0.0047	0.0001	0.0010	0.0001

* Means within a column followed by a common letter are not significantly different by Tukey's studentized Range (HSD) test ($P \geq 0.05$).

** Spray was applied at the rate of 1.4 ml of formulated product per 313 ml of water sprayed on 10 plants.

substantial protection of inoculated plants against larvae and pupae compared with noncoated seed treatments under both greenhouse or field conditions.

Seed coating is an excellent method of applying plant-protectant chemicals and is recommended for integrated pest management (Taylor et al. 2001). Film-coating seeds with chlorpyrifos can replace the spray treatment applied to trays of plants raised in modules before transplanting or to each plant in the field after planting (Gray 1986). Chlorpyrifos film-coated treatments can protect the plants from the moment of sowing until at least 6 wks after transplanting into the field. Collectively, the seed treatments provided protection of plants against *D. radicum* attack for a total of 10 wks. Furthermore, seed treatment may help minimize the risks of timing control measures, reduce exposure to farm workers, and avoid potential detrimental effects on natural enemies, such as predators and parasitoids.

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