Mortality and Predation Efficiency of *Coleomegilla maculata lengi* (Coleoptera: Coccinellidae) Following Pesticide Applications

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ABSTRACT We assessed the toxicity of four pesticides on adult *Coleomegilla maculata lengi* Timberlake. Their LC_{50} was estimated by applying the pesticides on the ventral side of adults by micropipette. Malathion and cypermethrin had the highest toxicity followed, in decreasing order, by carbaryl and benomyl. Benomyl, however, caused very low mortality. During 72 h, mortality occurred differentially depending on the pesticides used. Their effects on the predation efficiency (sublethal effect) of adult coccinellids also was evaluated. Only the fungicide benomyl applied at field rate significantly reduced the number of aphids consumed 24 h after treatments.

KEY WORDS Coccinellidae, pesticides, predation efficiency

THE COCCINELLID *Coleomegilla maculata* (Coccinellidae) is a nearctic polyphagous species that is abundant in many crops such as maize (Wright & Laing 1980, Coderre & Tourneur 1988), cereals (Shade et al. 1970), potatoes (Boiteau 1983), and alfalfa (Hodek 1973). It is an efficient predator of many aphid species, which constitute its main food source. *C. maculata* also feeds on eggs and larvae of many lepidopteran (Conrad 1959, Warren & Tadic 1967, Andow & Risch 1985) and chrysomelid species (Shade et al. 1970, Hazzard & Ferro 1991), as well as pollen (Hodek 1973, Coderre et al. 1987).

Given its voracity toward many economically important pest species, *C. maculata* offers interesting potential as a control agent in the context of integrated pest management programs. The success of such programs depends, in part, on the optimal use of selective pesticides that are less damaging to natural enemies (Jepson 1989, Croft 1990). Some studies have evaluated the susceptibility of aphidophagous coccinellids to synthetic insecticides. In the laboratory, carbaryl and malathion were found highly toxic toward adult *Hippodamia quinquesignata* Kirby (Bartlett 1963). All adult *Hippodamia convergens* Guérin-Méneville were dead 6 h after treatment to carbaryl (Moffitt et al. 1972). Croft & Brown (1975) ranked these two products among the five most toxic insecticides to various entomophagous coccinellids, excluding *C. maculata*. In laboratory studies, Mok Yun & Ruppel (1964) observed a high toxicity of carbaryl and malathion toward *C. maculata*. Carbaryl killed all treated beetles within 48 h, whereas 97% of the individuals died 72 h after treatments with malathion. When applied topically in laboratory conditions, cypermethrin was slightly toxic to *C. maculata;* carbaryl was very toxic (Coats et al. 1979, Lecrone & Smilowitz 1980). Cantelo (1986) showed that only one carbaryl treatment could decimate coccinellid populations found in maize fields. In contrast to the results obtained by Coats et al. (1979) with *C. maculata,* topically applied cypermethrin was highly toxic toward adult *Coccinella rependa* Thunberg, *Harmonia octomaculata* F. (Broadley 1983), and *Coccinella septempunctata* L. (Brown et al. 1983, Shires 1985).

Little information is available concerning the effects of fungicides on mortality and behavior of Coccinellidae. Radcliffe et al. (1976) observed an increase in *C. maculata* populations after treatment with the fungicide Dithane M-45. However, Powell et al. (1985) observed no effect of benomyl applied in early season on members of three different families of predators (Coccinellidae, Syrphidae, and Chrysopidae) in wheat fields. Many foliar fungicides nevertheless are known for their toxicity toward beneficial organisms such as *Trichogramma* spp. (Hassan 1974). In wheat fields, Sotherton & Moreby (1988) also have noted a decrease in abundance of natural enemies of aphid populations after a treatment with the fungicide Pyrazophos.

In most studies, predatory coccinellids were less sensitive to insecticides than were their prey (Croft & Brown 1975). Sarup et al. (1964) observed a lower susceptibility of *C. septempunctata* to carbaryl compared with its prey *Aphis*

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craccivora Koch. *C. septempunctata* was also less sensitive to cypermethrin than was the aphid *Methopolophium dirhodum* Walker (Brown et al. 1983).

The effect of sublethal amounts of pesticides on beneficial organisms such as *C. maculata* has not been investigated extensively. Atallah & Newsom (1966) observed a decrease in longevity of *C. maculata* De Geer after topical application of toxaphene and endrin, as well as a 25% decrease in egg hatching at the F1 after DDT treatment. A 60% increase in oviposition, however, was noted after treatment with the latter product. Sublethal doses of pesticide can affect the predation efficiency of insects (Matsumura 1985, Haynes 1988). For example, benomyl and cypermethrin caused a temporary inactivation (apparent mortality) in adult *C. maculata* in laboratory studies, thereby reducing its predation efficiency for 48 h (Roger et al. 1991). Hussain & Saeed (1984) noted a significant reduction in the aphid consumption of *C. septempunctata* after a treatment to malathion.

Our study was done to quantify the toxic properties of four pesticides generally used in crops of economic importance in which *C. maculata* is found. We evaluated the direct effect of the pesticides by estimation of LC_{50}, and the effect of pesticides on the predation efficiency of adults treated with an estimated LC_{20} (sublethal effect).

Materials and Methods

The three first replicates were conducted with adult *C. maculata* that were sampled in maize fields in St-Hyacinthe, Québec, Canada (72° 56' W, 45° 39' N), during July 1989. The insects used for the eight other replicates were collected on 19 October 1989 on hibernation sites near maize fields in St-Hyacinthe. Adults were placed in 375-ml glass containers and kept at 22°C, 65% RH, and a photoperiod of 16:8 (L:D) h. They were fed on a diet of clover pollen.

Estimation of Lethal Concentrations (LC_{50}). Four pesticides were tested at field rate, as well as at dilution fractions thereof. The four pesticides were (1) cypermethrin, a pyrethroid (Cymbush 400 EC [emulsifiable concentrate], ICI, Wilmington, DE); (2) malathion, an organophosphate (Malathion 50 EC, American Cyanamid, Wayne, NJ); (3) carbaryl, a carbamate (Sevin 85 WP [wettable powder], Union Carbide, Danbury, CT); and (4) benomyl, a fungicide (Benlate 50 WP, E.I. DuPont de Nemours, Wilmington, DE). Based on 350 liters of spray per hectare, the mean of a range of rates recommended by the Quebec Ministry of Agriculture (C.P.V.Q. 1987) were 1.2 g [AI]/liter for cypermethrin, 2.85 g [AI]/liter for malathion, and 5.1 g [AI]/liter for carbaryl. For benomyl, the recommended rate was 1 g [AI]/liter for 1,000 liter of spray per ha.

A 5-µl distilled-water solution containing the desired pesticide quantity was applied on the ventral side of each beetle with a Pipetman P20 micropipette (Gilson Medical Electronic, Villiers-le Bel, France). The beetles of the control groups were treated with distilled water only. To slow activity during the topical applications, the beetles were maintained in concavities on aluminum plates deposited on a bed of ice. After treatment, the beetles were placed on a filter paper covering the bottom of a petri dish (9 cm diameter) along with a moistened cotton ball and pollen. The insects then were placed back in growth chambers for observation.

For each concentration of each product tested, the experimental design consisted of 11 replicates of six individuals. The number of concentrations used to estimate LC_{50} was six (n = 396), seven (n = 426), eight (n = 498), and nine (n = 612) for benomyl, carbaryl, cypermethrin, and malathion, respectively. All treatments were done simultaneously, and the replicates were separated by 1-wk intervals. Mortality was assessed on each individual 15 min, 1, 2, 4, 8, 24, 48, and 72 h after application. Mortality was corrected by Abbott's formula (1925).

Each pesticide's toxicity was evaluated at LC_{50} after estimation of probit regressions (PROC PROBIT; SAS Institute 1985). Three-way analysis of variance (ANOVA), followed by a multiple-comparisons test (Fisher's protected least significant difference test), and comparisons of slopes (SAS Institute 1985) were done on counts to identify significant differences among the pesticides. The model of the three-way ANOVA also included the period at which the coccinellids were collected (i.e., spring or fall). Two-way ANOVAs also were done to determine the differences among the doses of a given product. The slopes of each dose were compared among themselves (PROC GLM; SAS Institute 1985) to establish the differences of mortality during the 72 h of observation following the treatment.

Predation Efficiency. Adult *C. maculata* were treated at the LC_{20} estimated from probit lines for the three insecticides. The first five replicates were used in the determination of the LC_{20}. The estimated LC_{20} (g[AI]/liter) for carbaryl, cypermethrin, and malathion were 1.28, 0.016, and 0.07 g, respectively. For benomyl, the mean field rate (1 g[AI]/liter) was used because no significant mortality was obtained during the evaluation of the LC_{50} at any concentrations tested. The topical application of the four pesticides was done as described above. Fifteen minutes after treatment, the beetles were presented 30 pea aphid nymphs, *Acyrthosiphon pisum* Harris, in 375-ml glass containers.

The aphids were mass-reared on vetch plants, *Vicia faba* var. *major* L., in a growth chamber. In each container, a vetch leaf served as food for the

Table 1. Toxicity (after 24 h) of four chemical pesticides applied on the ventral side of adult *C. maculata*

Pesticides	n	Slope ± SEM	LC_{50} g (AI)/liter (95% CL)
Benomyl	396	–[a]	–[a]
Carbaryl	426	2.88 ± 0.35	2.09 (1.57 –2.73)
Cypermethrin	498	1.86 ± 0.68	0.052 (0.003–0.53)
Malathion	612	1.46 ± 0.33	0.028 (0.008–0.06)

[a] Could not be calculated because the mortality obtained was too low; see text.

aphids. After 24 h of contact with the nymphs, the surviving beetles were removed and the remaining number of aphids were counted. The experimental design consisted of 20 replicates with each pesticide. All treatments were tested simultaneously and the replicates were done at 1-wk intervals. Each replicate included a control treatment of distilled water. The data obtained for the predation efficiency were analyzed by a one-way ANOVA followed by a multiple-comparison test (Fisher's protected least significant difference test; SAS Institute 1985).

Results

Direct Mortality. After 24 h, the mortality caused by the four pesticides tested was significantly higher than that of the control group (F = 64.19, df = 4, P = 0.0001). Benomyl caused very little mortality to *C. maculata,* with an LC_{50} $>10^6$ g [AI]/liter. One month after the benomyl treatment, the surviving beetles were still active. Malathion and cypermethrin had the highest toxicity; in decreasing order of toxicity, they were followed by carbaryl and benomyl (Table 1). All the treatments were significantly different from each other except for malathion and cypermethrin (F = 64.19, df = 4, P = 0.0001). Time of collection (i.e., spring or fall) did not significantly affect mortality caused by the pesticides (F = 2.01, df = 1, P = 0.1575).

The LC_{50}s in the laboratory were much lower than the amounts of pesticides recommended by CPVQ (1987). The mean rate of malathion recommended in crops where *C. maculata* is usually found was 102 times higher than the LC_{50} estimated in our study. For carbaryl and cypermethrin, the ratios of the recommended concentration to the estimated LC_{50}s were 2.3 and 2.4, respectively.

The slopes of the treatments differed significantly among themselves (F = 52.55, df = 4, P = 0.0001) except in the case of benomyl, whose slope did not differ significantly (P > 0.05) from that of the control group (Table 1). The pesticide with the steepest slope was carbaryl, followed by cypermethrin and malathion (Table 1).

Significant differences in toxicity were observed between the concentrations for each pesticide over the 72 h following the treatment; i.e.,

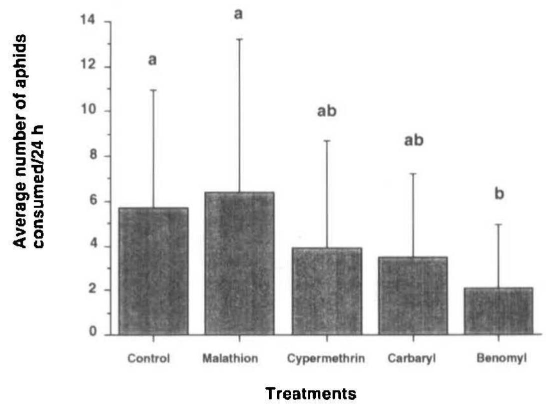

Fig. 1. Toxicity of three chemical insecticides on adult *C. maculata*. Different letters indicate a significant difference between the doses (P = 0.05; Fisher's protected least significant difference test [SAS Institute 1985]).

benomyl (F = 9.29, df = 5, P = 0.0001), carbaryl (F = 219.01, df = 7, P = 0.0001), cypermethrin (F = 249.11, df = 11, P = 0.0001), and malathion (F = 105.13, df = 9, P = 0.0001) (Fig. 1). Generally, the higher the concentration was, the higher the mortality rate. However, benomyl caused low and variable mortality at all concentrations. Only 1.31 and 5.7 g [AI]/liter yielded a significantly higher mortality than the other concentrations tested (6.1 and 9.1%, respectively). Therefore, results for benomyl are not shown in Fig. 1.

The pattern of mortality during the 72 h after the treatment differed depending on the pesticide (Fig. 1 A, B, and C) (F = 12.92, df = 4, P = 0.0001). Malathion was the most toxic product, causing rapid mortality (Fig. 1). At the mean recommended concentration, >80% mortality occurred within 15 min after treatment, and all individuals were dead after only 2 h. Cypermethrin also had a rapid effect; 80% of the mortality was recorded within the 1st h of observation. The mortality rate caused by carbaryl increased progressively during the 72 h after treatment.

Sublethal Effects: Predation Efficiency. Benomyl caused the least mortality among the pesticides tested on *C. maculata.* However, benomyl caused a significant reduction in the number of aphids consumed 24 h after treatments with sublethal concentrations compared with the control group (P = 0.0282) (Fig. 2). The three other pesticides did not significantly affect the mean daily aphid consumption rate at LC_{20} (P = 0.1809).

Discussion

Direct Mortality. *C. maculata* were very susceptible to the application of the three chemical insecticides (Table 1). These results corroborate the results obtained by Mok Yun & Ruppel

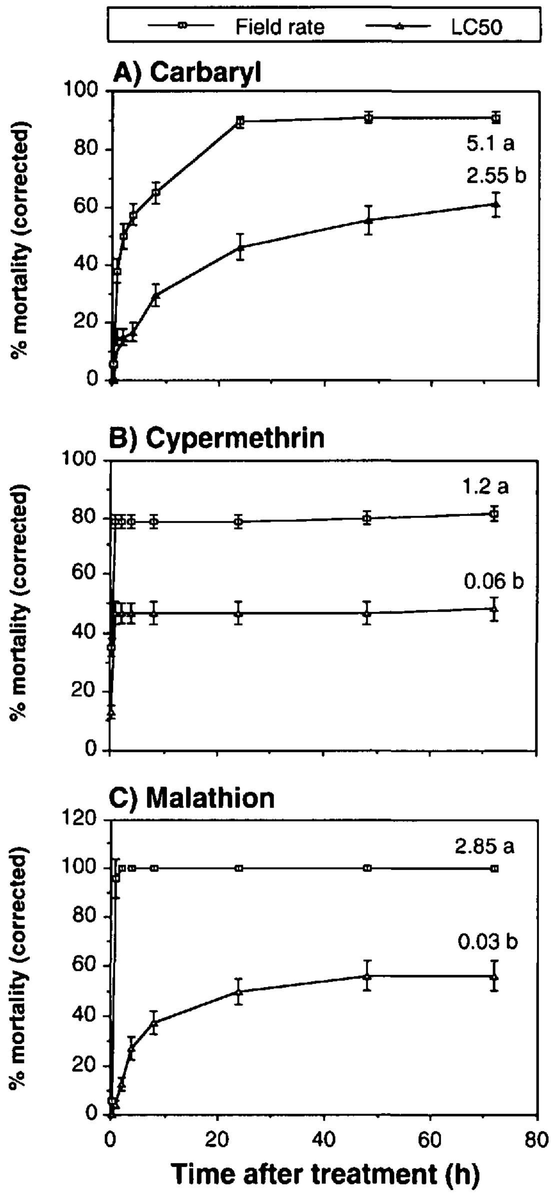

Fig. 2. Mean number of aphids (*A. pisum*) consumed in 24 h by *C. maculata* after pesticide treatments. Different letters indicate a significant difference between the products ($P = 0.05$; Fisher's protected least significant difference test [SAS Institute 1985]).

(1964), who also observed a high mortality for *C. maculata* after an application of carbaryl and malathion on wheat plants in the laboratory. Although cypermethrin was highly toxic and had a rapid action, our results differ from those of Coats et al. (1979), who observed low susceptibility of *C. maculata* to cypermethrin. In our study, benomyl caused only a low mortality in adult *C. maculata* (Table 1), a result that corroborates the results that Powell et al. (1985) obtained for many predatory groups such as the Coccinellidae, Syrphidae, and Chrysophidae.

The pesticides that we tested do not necessarily act immediately after application, and the real extent of the mortality can be visible only a few hours or days later. Malathion and carbaryl caused a constant increase in mortality during the 3 d of observation; this increase was noted for almost all the concentrations tested (Fig. 1). However, the mortality for cypermethrin after 72 h is approximately the same as 1 h after treatment. For malathion and carbaryl, lower concentrations that initially caused low mortality caused as much mortality as higher concentrations after 72 h (Fig. 1). In standard toxicological studies, mortality counts usually are made 24 h after the treatments (Jepson 1989). Longer observation times (e.g., 72 h) thus should be used as standard procedure.

Sublethal Effects: Predation Efficiency. Sublethal concentrations may decrease the efficiency of natural enemies (Croft 1990) by affecting, among other things, insect locomotion capacity (Franz & Fabrietius 1971), feeding (Grapel 1982), and searching (Penman et al. 1981) behaviors. Benomyl, which caused low mortality levels, nevertheless significantly decreased the rate of aphid consumption after topical applications at the recommended field dose (Fig. 2). Nakashima & Croft (1974) showed that, in the laboratory, benomyl had direct contact toxicity to eggs and residue toxicity to immature stages of the predatory mite *Amblyseius fallacis* (Garman). Roger et al. (1991) also have noted a temporary inactivation (apparent mortality) of adult *C. maculata* after benomyl treatments; >20% of the beetles seemingly dead between 1 and 48 h after the treatment later revived. The temporary inactivation could explain the reduction in the predation efficiency observed with benomyl. Cypermethrin also caused a temporary inactivation, but to a lesser degree. We observed periods of intensive cleaning and hyperactivity after treatments of adults with benomyl (Roger et al. 1991). These behaviors, combined with that of the apparent mortality, diminished the predation efficiency of *C. maculata*.

The three chemical insecticides that caused a high mortality in the *C. maculata* ($P = 0.0001$) did not significantly reduce ($P = 0.181$) the predation efficiency at the estimated LC_{20} (Fig. 2). These results contrast with those of Hussain & Saeed (1984), who observed a significant reduction in the aphid consumption rate of *C. septempunctata* in addition to a high toxicity of malathion. In their study, however, the beetles and the substrate on which *C. septempunctata* were kept afterward were both treated, thus increasing the time predators contacted the insecticide.

We conclude that the insecticides tested here could have an important effect on the mortality of adult *C. maculata* when applied at field-recommended concentrations. Benomyl also had an important effect on predation efficiency. A thorough knowledge of a broad range of effects would provide useful information to design programs where coccinellids and pesticides are present concomitantly.

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