

Impact of Lambda-cyhalothrin on Intraguild Predation Among Three Mite Predators

CAROLINE PROVOST,¹ DANIEL CODERRE,¹ ÉRIC LUCAS,¹ AND NOUBAR J. BOSTANIAN²

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ABSTRACT The impact of a sublethal dose of lambda-cyhalothrin on intraguild predation between three mite predators, *Hyaliodes vitripennis* (Say), *Harmonia axyridis* Pallas, and *Amblyseius fallacis* (Garman) was evaluated in laboratory. The symmetry and level of intraguild predation in selected predator combinations were recorded in the absence and presence of lambda-cyhalothrin. The mobility of the different predatory stages was also recorded in the absence and presence of insecticide. The results showed that lambda-cyhalothrin did not significantly modify intraguild predation but it affected the mobility. A knockdown effect was observed in *H. axyridis* larvae and in *H. vitripennis* nymphs, whereas *A. fallacis* showed an increased mobility. Exposure to a sublethal dose of lambda-cyhalothrin modified predator behavior and must be considered in the implementation of a mite control program in apple orchards.

KEY WORDS intraguild predation, sublethal effects, mite predator, mobility, lambda-cyhalothrin

THE EFFECTS OF SUBLETHAL doses of insecticides to arthropod pests and their natural enemies are complex. Changes have been noted in fertility, fecundity, longevity, developmental rate, mobility, foraging efficiency, and oviposition (Moriarty 1969; Penman et al. 1981; Haynes 1988; Croft 1990; Roger et al. 1994, 1995). A modification in any of these behavioral components has also been shown to affect the interaction between arthropod pests and their host plants and/or the interaction between arthropod pests and their natural enemies (Jackson and Ford 1973, Croft 1990, Wright and Verkerk 1995).

Interactions among predators are common and may generate complex effects on ecosystem dynamics. Intraguild predation is an interspecific interaction between predators sharing a common resource and the outcome is the death and consumption of one of the predators (Polis et al. 1989). When intraguild predation is observed in an ecosystem, the population dynamics may be modified in different ways, which in turn may cause environmental instability (Holt and Polis 1997). Intraguild predation can affect both predator and prey populations, and consequently disrupt biological control programs (Rosenheim et al. 1995). Intraguild predation frequently implicates generalist predators when their resource is limited (Holt and Polis 1997). Several factors, such as predator and prey size, predator voracity, predator and prey mobility, prey defensive mechanisms, feeding specificity, and

the presence of extraguild prey, may determine the intensity and direction of the interaction (Polis et al. 1989, Holt and Polis 1997, Lucas et al. 1998). Therefore, predator density, developmental stage for introduction, timing of introduction, environmental conditions, ecosystem complexity, as well as interaction between introduced and indigenous predators and impact of pesticides on these interactions should be considered when developing an integrated pest management (IPM) program for a crop (Ehler 1992, Lucas et al. 1998).

In Quebec apple orchards, three to four insecticide, one to two acaricide, and eight to twelve fungicide treatments are applied each year (Paradis 1979, Vincent and Roy 1992), which may affect native and/or introduced predators. Several studies have evaluated the toxicity of pesticides to several mite predators present in apple orchards, such as the mirid, *Hyaliodes vitripennis* (Say) (Horsburgh 1969; Hull and Starner 1983; Morin et al. 1995; Bostanian et al. 2000, 2001; Bostanian and Larocque 2000), the mite, *Amblyseius fallacis* (Garman) (Croft 1975, Berkett and Forsythe 1980, Penman et al. 1981, Hull and Starner 1983, Thistlewood and Elfving 1992, Hill and Foster 1998, Stanyard et al. 1998), and the multicolored Asian lady beetle, *Harmonia axyridis* Pallas (Cho et al. 1997). Other studies have shown how pesticide applications interfered with biological control of phytophagous mites in orchards (Clancy and Pollard 1952; Pickett and Patterson 1953; MacPhee and Sandford 1954, 1956; Parent 1957, 1963; Leroux 1960; Lord 1962; Sandford and Lord 1962; Sandford and Herbert 1970). However, the impact of insecticide applications on intraguild predation had never been evaluated.

¹ Département des Sciences Biologiques, Université du Québec à Montréal, C.P. 888 Succursale 'Centre-ville', Montréal, Québec, Canada, H3C3P8.

² Horticultural Research and Development Centre, Agriculture and Agri-Food Canada, 430 Gouin Blvd, St-Jean-sur-Richelieu, Québec, Canada, J3B 3E6.

The evaluation of a sublethal dose of a pesticide on intraguild predation was undertaken in laboratory conditions on three mite predators present in apple orchards, *H. vitripennis*, *H. axyridis*, and *A. fallacis*. The objectives of this study were to determine the effect of lambda-cyhalothrin on the symmetry and intensity of intraguild predation between different combinations of predators, and to determine the effect of the pesticide on predator mobility, because mobility is one of the main factor determining direction and level of intraguild predation.

Materials and Methods

Hyaliodes vitripennis was collected in a commercial apple orchard at Rougemont (73° 03' W, 45° 26' N) Quebec, Canada, and maintained in the laboratory 1–2 d on *Tetranychus urticae* Koch; *H. axyridis* was collected from hibernation sites in the same region and reared in the laboratory on *Ephestia kuehniella* Zeller; and *A. fallacis* came from a permanent rearing from Agriculture and Agri-Food Canada (St-Jean-sur-Richelieu) on *T. urticae* and was subsequently reared on the same prey. Rearing conditions for the three predators were 20° ± 1°C, 60–70% RH and a photoperiod of 16L:8D. All tests were carried out in laboratory under similar conditions (24° ± 1°C, 60–70% RH).

Impact of Insecticide Treatment on Intraguild Predation. The experiments were conducted on vertical apple shoots, with three leaves. Each shoot was placed in a 4L plastic box. Shoots were collected from trees in orchard and washed before the beginning of the experiment to eliminate other arthropods. Before each test, predators were starved individually in a Petri dish for a period of 16 h (photoperiod: 8L: 8D), to increase their motivation to forage.

The symmetry and level of intraguild predation were determined on different predator combinations involving *H. vitripennis* with *H. axyridis* or *A. fallacis* in the absence and in the presence of insecticide. Combinations tested involved mobile life stages of *H. vitripennis* (nymph 2, nymph 4, and adult) with a selected developmental stage of the other predator; such as larval stage 4 of *H. axyridis* and adult of *A. fallacis*. Stages were selected according to previous intraguild predation tests (Provost et al., unpublished data). An individual of each predator was placed on a leaf for a period of 7 h. In the insecticide treatments, lambda-cyhalothrin (Warrior), a pyrethroid insecticide commonly used in apple orchards, was sprayed on the experimental leaf with a thin-layer chromatography sprayer set at 10.34 kPa (1.5 PSI) at a distance of 25 cm. The sublethal dose (ppm of active ingredient) applied corresponded to the LC₂₅ for *H. vitripennis*. The LC₂₅ was 1.5 ppm for nymphs and 0.35 ppm for the adult (Bostanian et al. 2001).

After 7 h, the predators were removed and the mortality and evidence for feeding were recorded. Natural predator mortality was determined with a control treatment (with only one predator). The insecticide control treatment consisted of one predator

treated with the insecticide. For each combination of predators, 15 replicates were carried out.

The corrected mortality, attributed to predator interaction, was calculated for each predator, using the following formula:

$$P = (t - a) * ra \text{ (Soares 2000)}$$

P = number of replicates with predation (intraguild predation)

t = total number of replicates (= 15)

a = number of replicates in which the individual was alive

ra = ratio of alive individuals in the control treatment

Then, for each predator combination, the level of intraguild predation (IL: corrected mortality over the total number of replicates) and the symmetry index (SI: number of replicates in which a given predator was eaten over the total number of replicates in which there was intraguild predation) were calculated (Lucas et al. 1998). The level of intraguild predation was compared between treatments (absence or presence of insecticide) for each predator combination and among predator combinations using a likelihood ratio *G* test (Scherrer 1984). In the presence of a significant difference among predator combinations, subsequent pairwise *G* tests were carried out. The symmetry index for each combination was compared with a theoretical

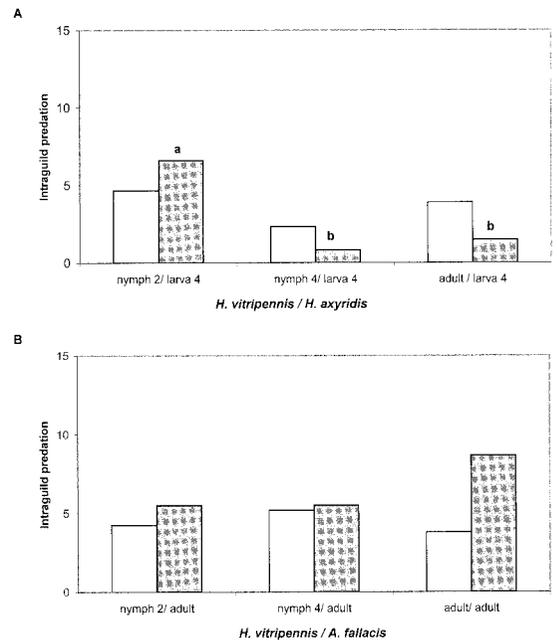


Fig. 1. Levels of intraguild predation (IL) in the absence (open bars) or presence (shaded bars) of lambda-cyhalothrin between (A) *Hyaliodes vitripennis* and *Harmonia axyridis* larva 4. Bars represent the number of *H. vitripennis* killed by *H. axyridis*; (B) *H. vitripennis* and *Amblyseius fallacis* adult. Bars represent the number of *A. fallacis* killed by *H. vitripennis*. Different letters indicate a significant difference in intraguild predation among predator combinations in the presence of lambda-cyhalothrin (*G* test, *P* < 0.05).

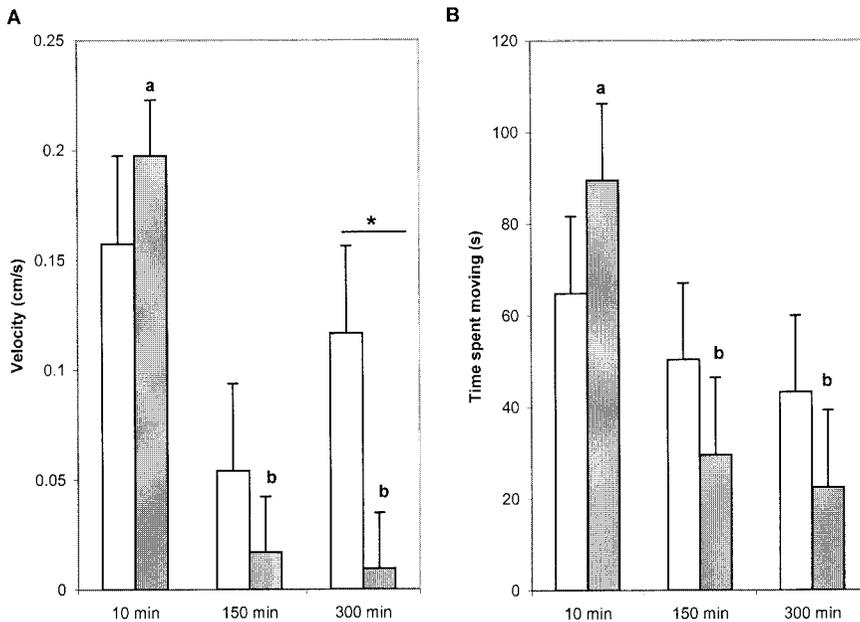


Fig. 2. Mobility of *H. axyridis* larva 4 in the absence (open bars) or presence (shaded bars) of lambda-cyhalothrin, after 10, 150, and 300 min. (A) Velocity (cm/s). (B) Time spent moving. An asterisk indicates a significant difference in the absence and presence of insecticide for the same time (ANOVA, $P < 0.05$). Different letters indicate a significant difference for the same treatment among different times in the presence of lambda-cyhalothrin (ANOVA, $P < 0.05$).

index of 50%, which represented a symmetrical interaction, using a test of conformity (Scherrer 1984).

Impact of Insecticide Treatment on Predator Mobility. The impact of a sublethal dose of lambda-cyhalothrin on predator mobility was evaluated under laboratory conditions. Observations were performed in the absence or presence of an insecticide treatment on a single predator. The experiments were conducted on apple leaves in a Petri dish. The predator was starved for a period of 16 h prior to the study (photoperiod: 8L: 8D).

After the initiation of a test, 2-min observations were carried out with a single predator at 10, 150, and 300 min. The time spent moving and the velocity were recorded. The time spent moving corresponded to the effective time when the predator was in movement, the velocity (speed of movement) was determined as the number of lines crossed on a Petri dish cover that had previously been squared at 0.5-cm intervals. Life stages tested were nymph 2, nymph 4, and adult of *H. vitripennis*; larva 4 of *H. axyridis*; and adults of *A. fallacis*. All the stages were evaluated in absence and presence of a sublethal dose of lambda-cyhalothrin. The experiment was carried out for 5 h (300 min) to detect a possible knockdown effect. Lambda-cyhalothrin was applied to the three predators in the same manner as in the first test. Each observation was replicated eight times.

Time spent moving and velocity (cm/s) at 10, 150, and 300 min after the initiation of the study in absence and presence of an exposure to lambda-cyhalothrin were compared by a one-way analysis of variance (ANOVA). The impact of lambda-cyhalothrin on mo-

bility through time, was also determined by a one-way ANOVA followed by the Tukey-Kramer test for a specific treatment (absence or presence of insecticide treatment) (Scherrer 1984).

Results

Impact of Insecticide Treatment on Intraguild Predation

***Hyaliodes vitripennis* versus *Harmonia axyridis*.** No *H. axyridis* individual was killed by the mirid. Symmetry index (SI) revealed an asymmetrical interaction in favor of *H. axyridis* against *H. vitripennis* (χ^2 , $P < 0.05$) (Fig. 1A) for the two nymphal stages and adult of the mirid irrespective of the presence or absence of lambda-cyhalothrin. Presence of lambda-cyhalothrin did not affect the level of intraguild predation in any of the tested combinations (G test, $P > 0.05$). In absence of insecticide, the level of intraguild predation was similar among the three combinations ($G_2 = 1.78$, $P = 0.4106$). In presence of lambda-cyhalothrin, intraguild predation of *H. vitripennis* by *H. axyridis* was lower for the adult and nymph 4 of the mirid than for the nymph 2 (nymph 2/larva 4 versus nymph 4/larva 4, $G_1 = 6.72$, $P = 0.0095$; adult/larva 4 versus nymph 2/larva 4, $G_1 = 6.48$, $P = 0.0392$).

***Hyaliodes vitripennis* versus *Amblyseius fallacis*.** As in the previous combination, the symmetry index (SI) demonstrated an asymmetrical interaction in favor of *H. vitripennis* against *A. fallacis* for the three predator combinations, both in the absence and presence of insecticide treatment (χ^2 , $P < 0.05$) (Fig. 1B). Lambda-cyhalothrin did not affect the level of intraguild predation in any of the tested combinations (G test,

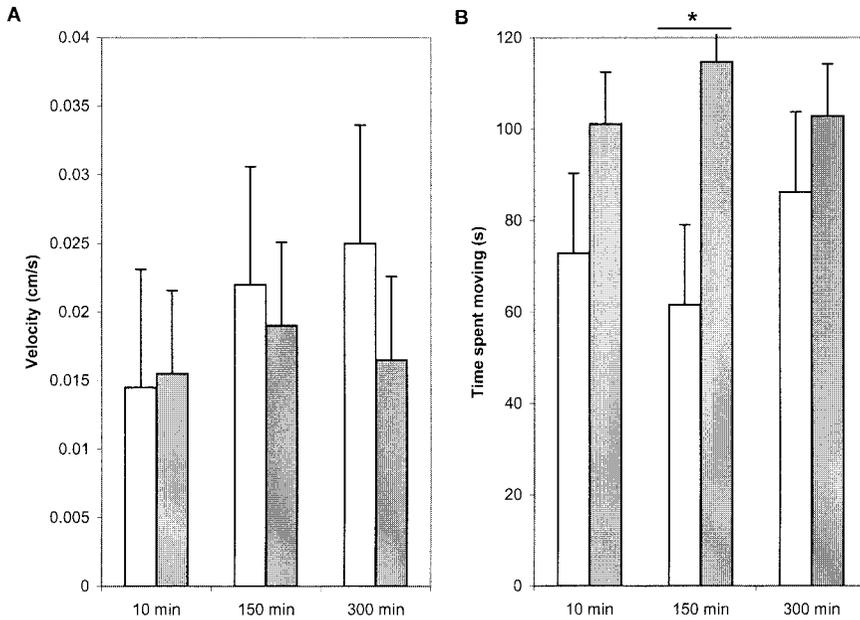


Fig. 3. Mobility of *A. fallacis* adults in the absence (open bars) or presence (shaded bars) of lambda-cyhalothrin, after 10, 150, and 300 min. (A) Velocity (cm/s). (B) Time spent moving. An asterisk indicates a significant difference in the absence and presence of lambda-cyhalothrin for the same time (ANOVA, $P < 0.05$).

$P > 0.05$), however the results were just short of conventional levels of statistical significance for adult/adult ($G_1 = 3.47$, $P = 0.0646$). Intraguild predation levels were similar among the three combinations of predators both in the absence ($G_2 = 0.21$, $P = 0.8987$) and presence of lambda-cyhalothrin ($G_2 = 1.61$, $P = 0.4466$).

Impact of Insecticide Treatment on Predator Mobility

Harmonia axyridis. After 10 and 150 min no difference was observed in the velocity between treatments in absence and presence of insecticide (Fig. 2A). By contrast, after 300 min, the velocity of *H. axyridis* had decreased with lambda-cyhalothrin treatment ($F = 6.45$, $df = 1, 15$, $P = 0.0236$). After 10, 150, or 300 min, the time spent moving was similar in absence and presence of the insecticide (ANOVA, $P > 0.05$) (Fig. 2B). When comparing the different times, both velocity and time spent moving were similar in absence of the insecticide. In contrast, lambda-cyhalothrin reduced both the velocity and the time spent moving after 150 min (velocity: $F = 18.56$, $df = 2, 23$, $P < 0.0001$; time spent moving: $F = 4.98$, $df = 2, 23$, $P = 0.0170$).

Amblyseius fallacis. Lambda-cyhalothrin also affected the mobility of *A. fallacis*. The velocity was similar in absence and presence of the insecticide and among the different times considered (Fig. 3A). However, after 150 min, the presence of lambda-cyhalothrin significantly increased the time spent moving ($F = 5.93$, $df = 1, 14$, $P = 0.03$) (Fig. 3B). A similar tendency was observed after 10 min, and the results

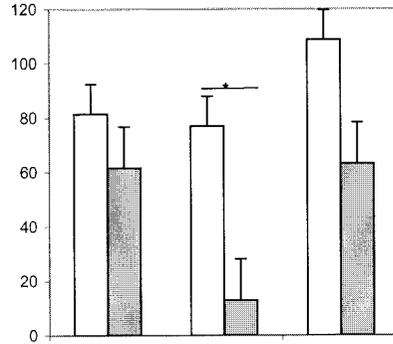
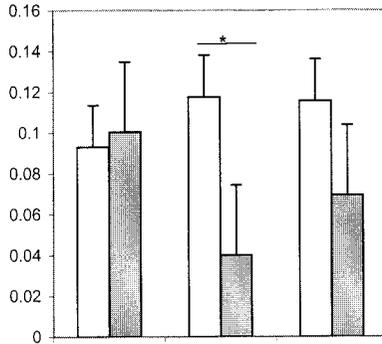
were close to the statistical level of significance ($F = 3.32$, $df = 1, 14$, $P = 0.0915$).

Hyaliodes vitripennis. Generally, *H. vitripennis* nymph 2 was less mobile in the presence of lambda-cyhalothrin (Fig. 4A). After 150 min, the velocity and the time spent moving were significantly reduced in presence of lambda-cyhalothrin (velocity: $F = 6.92$, $df = 1, 15$, $P = 0.0198$; time spent moving: $F = 13.66$, $df = 1, 15$, $P = 0.0024$) (Fig. 4A). For the nymph 4, no difference was observed among the treatments, in absence and presence of insecticide, and among the different times. Nevertheless, an almost significant reduction of time spent moving, $\approx 40\%$, was observed at 150 min after an exposure to lambda-cyhalothrin ($F = 3.71$, $df = 1, 15$, $P = 0.0745$) (Fig. 4B). For adult, after 10, 150, and 300 min, no difference was observed in the velocity and time spent moving between treatments in the absence and presence of the insecticide (Fig. 4C). In the presence of lambda-cyhalothrin, the velocity of *H. vitripennis* adult was lower after 10 min than after 150 min after insecticide application ($F = 3.73$, $df = 2, 23$, $P = 0.0410$).

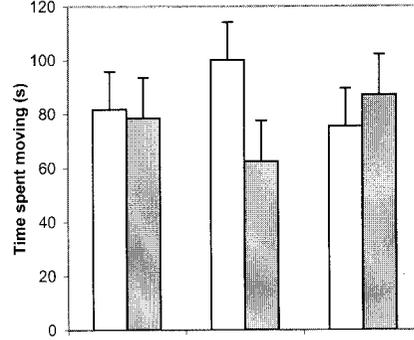
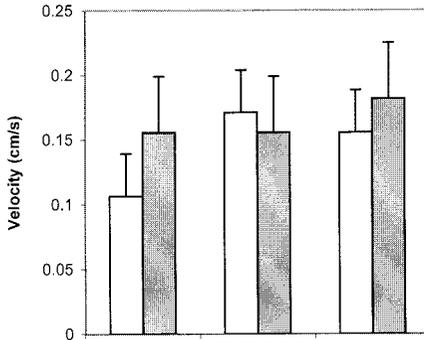
Discussion

Two main conclusions raised from our study. The results of this study suggest that intraguild predation is not clearly affected by a sublethal dose of lambda-cyhalothrin, because we did not observe significant differences between intraguild predation levels in the absence and presence of the insecticide. Nevertheless, in a number of instances the statistical results were close to the probability threshold. Second, the mobility of the

A) Nymph 2



B) Nymph 4



C) Adult

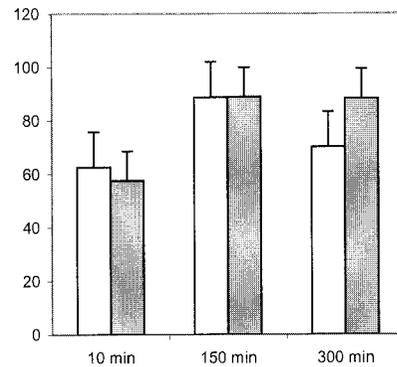
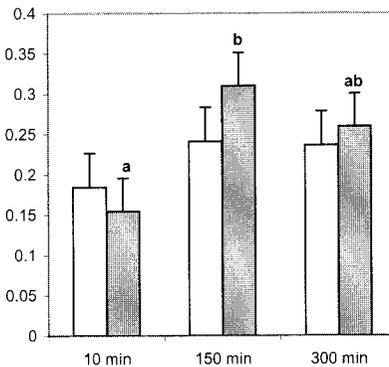


Fig. 4. Mobility (velocity and time spent moving) of *H. vitripennis* in the absence (open bars) or presence (shaded bars) of lambda-cyhalothrin, after 10, 150, and 300 min. (A) Nymph 2. (B) Nymph 4. (C) Adult. An asterisk indicates a significant difference in the absence and presence of lambda-cyhalothrin for the same time (ANOVA, $P < 0.05$). Different letters indicate a significant difference for the same treatment among different times in presence of lambda-cyhalothrin (ANOVA, $P < 0.05$).

three predator species was affected by the lambda-cyhalothrin.

In *H. axyridis* and *H. vitripennis* combination, no predation of the coccinellid by the mirid was observed. *Harmonia axyridis* is a generalist, voracious, and larger predator than the mirid, and the symmetry of intraguild predation is often determined by these two factors (Lucas et al. 1998). Between the insecticide treatment (absence and presence), significant differences in mobility of the three predators were observed, however, no difference in intraguild preda-

tion level was noted. The insecticide reduced the mobility of *H. axyridis* and *H. vitripennis* nymphs, but it had no effect on the adult. *Harmonia axyridis* mobility increased immediately after an exposure to the insecticide and it was considerably reduced subsequently. Croft (1990) noted that an insecticide may cause a knockdown effect and significantly reduce predator activity after a specific time. Roger et al. (1991, 1995) reported a similar period of hyperactivity followed by convulsions with *Coleomegilla maculata lengi* Timberlake after an exposure to benomyl and

malathion. The results of mobility for *H. vitripennis* showed that the young instars were more affected by the insecticide treatment than the adult. However, previous studies on acute toxicity indicated that *H. vitripennis* adult was more vulnerable than nymphs (Bostanian et al. 2000, 2001). The similar level of intraguild predation observed can be explained by a combination of different behaviors in the absence and presence of insecticide that result in similar predation activity. Insecticide treatment may reduce the predator efficiency (Roger et al. 1994), may disrupt the prey defenses, may reduce the probability of encounter (by reducing predator and prey mobility), and the contaminated prey may be rejected by the predator (see Jackson and Ford 1973).

In the *H. axyridis*/*H. vitripennis* combination, different levels of predation were observed as a function of the mirid life stage in the presence of the insecticide. We noted higher levels of predation on the nymph 2 than on older stages. The second instar of the mirid was more susceptible to predation probably because their defensive mechanisms were less effective. A weight gain and improvement of defensive techniques are linked with developmental stages (Edmunds 1974, Sih 1987, Evans and Schmidt 1990). The vulnerability of the second instar of the mirid and the higher mobility of the coccinellid immediately following the insecticide treatment increased the susceptibility of the young instar to predation.

The larger size and specificity of the intraguild predator determined the asymmetrical predation interaction by *H. vitripennis* on *A. fallacis*. The mobility of the predators was affected by lambda-cyhalothrin but no significant difference was observed for the levels of intraguild predation between the absence and presence of insecticide. The mobility of *A. fallacis* was increased in presence of lambda-cyhalothrin. This increased mobility may be caused by the repellent properties of lambda-cyhalothrin (Bostanian and Racette 1997). A similar observation was made on *A. fallacis* by Penman et al. (1981) with fenvalerate, another pyrethroid. In these combinations, similar levels of intraguild predation in the absence and presence of lambda-cyhalothrin were observed and can be explained by the insect behaviors: first, the repellent properties of the insecticide caused an increase mobility and the predator does not search for prey, it searches for an uncontaminated area (Croft 1990); second, the prey is more mobile, then the predator must be more efficient when it attacks; and third the contaminated prey is rejected by the predator (Jackson and Ford 1973).

The results of the combination of *H. vitripennis* adult and *A. fallacis* were short of the conventional level of statistical significance. The increased level of intraguild predation observed by the mirid on *A. fallacis* after the insecticide treatment could be related to the mobility of the two predators. The results showed that the predators were more mobile after lambda-cyhalothrin treatment. Mobility has been shown to be a major factor influencing predation and defense (Lucas et al. 1997a, 1998). Thus, probabilities of encounters were higher in presence of lambda-cyhalothrin

and resulted in increased attack rates of *H. vitripennis* adult on *A. fallacis*. A larger number of replicates and a longer experimental time would possibly have shown a significant difference for this combination.

Several studies have indicated that pesticide applications in orchards affect predator populations (Leroux 1960, Lord 1962, Sandford and Herbert 1970, Hull and Starner 1983). Several methods (laboratory, semifield, and field) have been developed to evaluate the effects of a pesticide on natural enemies. Laboratory evaluations are accurate and specific, but do not take into account the complexity of the natural ecosystem and generally underestimate the impact of the pesticide to natural enemies (Wright and Verkerk 1995). Therefore, intraguild predation between the three mite predators may be modified in apple orchards after a pesticide treatment, because mobility should be affected by the insecticide and this is a major factor in predation interaction (Croft 1990).

IPM may be affected by different factors, including intraguild predation (Rosenheim et al. 1995) and pesticide applications (Hill and Foster 1998, Stanyard et al. 1998). In Quebec apple orchards, an average of six pesticide treatments is recommended during the growing season to control arthropod pests (Vincent and Roy 1992). To reduce these applications, several methods have been considered. Several studies have highlighted the potential of *H. vitripennis* on mite repression (Arnoldi 1986, Arnoldi et al. 1992, Morin et al. 1995, Chouinard et al. 1999, Brodeur et al. 1999) and the predator demonstrated a good compatibility with specific pesticides, such as phosalone (Zolone 50 FI) (Bostanian et al. 2000), permethrin, fenvalerate (Hull and Starner 1983), and lambda-cyhalothrin (Warrior T) (Bostanian et al. 2001). Also, *A. fallacis* is an effective mite predator in apple orchards (McMurtry et al. 1970, Croft 1975, Berkett and Forsythe 1980), and is compatible with several pesticides, including Captain 50 WP, Imidan 50 WP, Omite 30 WP, Polyram 80 WP (Croft 1975), endosulfan, and azinphosmethyl (Watve and Lienk 1975), and resistant to others, including organophosphates (Croft and Meyer 1973), pyrethroids (Whalon et al. 1982), and to lambda-cyhalothrin (Bostanian and Racette 1997). By contrast, despite its voracity on *Panonychus ulmi* (Koch) (Lucas et al. 1997c) and *T. urticae* (Lucas et al. 1997b), *H. axyridis* demonstrated a significant preference for aphids over mites (Lucas et al. 1997b) and then shall be considered as a secondary enemy of phytophagous mites in apple orchard. Then, a combination of *H. vitripennis* and *A. fallacis* with harmless pesticides may be considered in the implementation of mite control program. Nevertheless, our results showed that a sublethal dose of the insecticide can modify predator behavior and consequently affect predator efficacy. Clearly, this study should be completed by semifield and field studies in apple orchards to confirm the potential impact of pesticide treatments on intraguild predation and consequently on mite repression by some predator combinations including *H. vitripennis*.

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References Cited

- Arnoldi, D. 1986. Predation studies of mirids (Hemiptera: Miridae) in an apple orchard in southwestern Quebec. M. Sc. thesis, McGill University, Montreal.
- Arnoldi, D., R. K. Stewart, and G. Boivin. 1992. Predatory mirids of the green apple aphid *Aphis pomi*, the two-spotted spider mite *Tetranychus urticae* and the european red mite *Panonychus ulmi* in apple orchards in Quebec. *Entomophaga* 37: 283–292.
- Berkett, L. P., and H. Y. Forsythe Jr. 1980. Predaceous mites (Acari) associated with apple foliage in Maine. *Can. Entomol.* 112:497–502.
- Bostanian, N. J., and N. Larocque. 2000. The use of LC₅₀ ratios to determine the toxicity of three insecticides used in Quebec apple orchards to the mirid *Hyaliodes vitripennis* (Say). *Pesticides Beneficial Organisms, IOBC/WPRS Bull.* 23: 93–98.
- Bostanian, N. J., N. Larocque, G. Chouinard, and D. Coderre. 2001. Baseline toxicity of several pesticides to *Hyaliodes vitripennis* (Say) (Hemiptera: Miridae). *Pest. Man. Sci.* 57: 1007–1010.
- Bostanian, N. J., N. Larocque, C. Vincent, G. Chouinard, and Y. Morin. 2000. Effects of five insecticides used in apple orchards on *Hyaliodes vitripennis* (Say) (Hemiptera: Miridae). *J. Environ. Sci. Health.* B35: 143–155.
- Bostanian, N. J., and G. Racette. 1997. Residual toxicity of lambda-cyhalothrin on apple foliage to *Amblyseius fallacis* and the tarnished plant bug, *Lygus lineolaris*. *Phytoparasitica* 25: 193–198.
- Brodeur, C., G. Chouinard, G. Laplante, and Y. Morin. 1999. Études préliminaires sur l'activité et l'efficacité du prédateur indigène *Hyaliodes vitripennis* (Heteroptera: Miridae) pour la lutte biologique contre les acariens en vergers de pommiers au Québec. *Ann. Soc. Entomol. Fr.* 35 (suppl.): 458–462.
- Cho, J.-R., K. J. Yoo, J. R. Bang, and J. O. Lee. 1997. Comparative toxicity of selected insecticides to *Aphis citricola*, *Myzus malisuctus* (Homoptera:Aphididae) and the predator *Harmonia axyridis* (Coleoptera:Coccinellidae). *J. Econ. Entomol.* 90: 11–14.
- Chouinard, G., Y. Morin, N. J. Bostanian, J. Brodeur, C. Vincent, and C. Brodeur. 1999. Efficacité du prédateur *Hyaliodes vitripennis* pour la lutte biologique contre les insectes et acariens en vergers. Research report, CORPAQ #4312.
- Clancy, D. W., and H. N. Pollard. 1952. The effect of DDT on mite and predator populations in apple orchards. *J. Econ. Entomol.* 45: 108–114.
- Croft, B. A. 1975. Integrated control of apple mites. Michigan State University, Extension Bulletin E-825.
- Croft, B. A. 1990. Arthropod biological control agents and pesticides. Wiley, New York.
- Croft, B. A., and R. H. Meyer. 1973. Carbamate and organophosphorus resistance patterns in populations of *Amblyseius fallacis*. *Environ. Entomol.* 2: 691–695.
- Edmunds, M. 1974. Defence in animals. A survey of anti-predator defences. Longman, New York.
- Ehler, L. E. 1992. Guild analysis in biological control. *Environ. Entomol.* 21: 26–40.
- Evans, D. L., and J. O. Schmidt. 1990. Insect defenses. Adaptive mechanisms and strategies of prey and predators. State University of New York Press, New York.
- Haynes, K. F. 1988. Sublethal effects of neurotoxic insecticides on insect behavior. *Annu. Rev. Entomol.* 33: 149–168.
- Hill, T. A., and R. E. Foster. 1998. Influence of selective insecticides on population dynamics of European red mite (Acari:Tetranychidae), apple rust mite (Acari:Eriophyidae), and their predator *Amblyseius fallacis* (Acari:Phytoseiidae) in apple. *J. Econ. Entomol.* 91: 191–199.
- Holt, R. D., and G. A. Polis. 1997. A theoretical framework for intraguild predation. *Am. Nat.* 149: 745–764.
- Horsburgh, R. L. 1969. The predaceous mirid *Hyaliodes vitripennis* (Hemiptera) and its role in the control of *Panonychus ulmi* (Acari: Tetranychidae). Ph.D. Thesis. Pennsylvania State University, Philadelphia, PA.
- Hull, L. A., and V. R. Starmer. 1983. Impact of four synthetic pyrethroids on major natural enemies and pests of apple in Pennsylvania. *J. Econ. Entomol.* 76: 122–130.
- Jackson, G. J., and J. B. Ford. 1973. The feeding behaviour of *Phytoseiulus persimilis* (Acarina: Phytoseiidae), particularly as affected by certain pesticides. *Ann. Appl. Biol.* 75: 165–171.
- Leroux, E. J. 1960. Effects of 'modified' and 'commercial' spray programs on the fauna of apple orchards in Quebec. *Ann. Soc. Entomol. Que.* 6: 87–121.
- Lord, F. T. 1962. The influence of spray programs on the fauna of apple orchards in Nova Scotia. XI. Effects of low dosages of DDT on predator populations. *Can. Entomol.* 94: 204–216.
- Lucas, É., D. Coderre, and J. Brodeur. 1997a. Instar-specific defense of *Coleomegilla maculata* Lengi (Col.: Coccinellidae): influence on attack success of the intraguild predator *Chrysoperla rufilabris* (Neur.: Chrysopidae). *Entomophaga* 42: 3–12.
- Lucas, É., D. Coderre, and J. Brodeur. 1998. Intraguild predation among aphid predators: characterization and influence of extraguild prey density. *Ecology* 79: 1084–1092.
- Lucas, É., D. Coderre, and C. Vincent. 1997b. Voracity and feeding preference of two aphidophagous coccinellids on *Aphis citricola* and *Tetranychus urticae*. *Entomol. Exp. Appl.* 85: 151–159.
- Lucas, É., S. Lapalme, and D. Coderre. 1997c. Voracité comparative de trois coccinelles prédatrices contre le tétanyque rouge du pommier (Acarina:Tetranychidae). *Phytoprotection* 78: 117–123.
- MacPhee, A. W., and K. H. Sanford. 1954. The influence of spray programs on the fauna of apple orchards in Nova Scotia VII. Effects on some beneficial arthropods. *Can. Entomol.* 86: 128–135.
- MacPhee, A. W., and K. H. Sanford. 1956. The influence of spray programs on the fauna of apple orchards in Nova Scotia. X. Supplement to VII. Effects on some beneficial arthropods. *Can. Entomol.* 88: 631–639.
- McMurtry, J. A., C. B. Huffaker, and M. van de Vrie. 1970. I. Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia* 40: 331–390.
- Morin, Y., G. Chouinard, C. Vincent, and N. J. Bostanian. 1995. Potentiel de prédation et stratégies d'utilisation des mirides prédateurs du genre *Hyaliodes* comme agent de lutte biologique en arboriculture fruitière. Rapport de fin de projet soumis au Bureau des nouvelles méthodes de lutte antiparasitaire. Ottawa, Ontario, Canada.

- Moriarty, F. 1969. The sublethal effects of synthetic insecticides on insects. *Biol. Rev.* 44: 321–357.
- Paradis, R. O. 1979. Comment réduire l'emploi des pesticides en vergers de pommiers. *Phytoprotection*. 60: 69–78.
- Parent, B. 1957. 2. Essais d'acaricides sur le tétranyque rouge du pommier, *Metatetranychus ulmi* (Koch), dans leq Québec. *Ann. Soc. Entomol. Que.* 3: 21–27.
- Parent, B. 1963. Efficacité comparée de plusieurs pesticides contre le Tétranyque Rouge du Pommier, *Panonychus ulmi* (Koch) (Acariens: Tetranychidae), dans le sud-ouest duq Québec. *Phytoprotection*. 44: 78–95.
- Penman, D. R., R. B. Chapman, and K. E. Jesson. 1981. Effects of fenvalerate and azynphosmethyl on two-spotted spider mite and phytoseiid mites. *Entomol. Exp. Appl.* 30: 91–97.
- Pickett, A. D., and N. A. Patterson. 1953. The influence of spray programs on the fauna of apple orchards in Nova Scotia IV. A Review. *Can. Entomol.* 85: 472–478.
- Polis, G. A., C. A. Myers, and R. D. Holt. 1989. The ecology and evolution of intraguild predation: potential competitors that eat each other. *Annu. Rev. Ecol. Syst.* 20: 297–330.
- Roger, C., D. Coderre, and C. Vincent. 1991. Apparent mortality of *Coleomegilla maculata* Timb. (Coccinellidae) following pesticide treatments: possibility of overlooking predator populations, pp. 329–336. *In* Polgar, L., R. J. Chambers, A.F.G. Dixon and I. Hodek [eds.], *Behavior and impact of aphidophage*. SPB Academic, The Hague.
- Roger, C., D. Coderre, and C. Vincent. 1994. Mortality and predation efficiency of *Coleomegilla maculata lengi* (Coleoptera:Coccinellidae) following pesticide applications. *J. Econ. Entomol.* 87: 583–588.
- Roger, C., C. Vincent, and D. Coderre. 1995. Mortality and predation efficiency of *Coleomegilla maculata lengi* (Coleoptera:Coccinellidae) following application of neem extracts (*Azadirachta indica* A. Juss., Meliaceae). *J. Appl. Entomol.* 119: 439–443.
- Rosenheim, J. A., H. K. Kaya, L. E. Ehler, J. J. Marois, and B. A. Jaffe. 1995. Intraguild predation among biological-control agents: theory and evidence. *Biol. Control* 5: 303–335.
- Sandford, K. H., and H. J. Herbert. 1970. The influence of spray programs on the fauna of apple orchards in Nova Scotia. XX. Trends after altering levels of phytophagous mites or predators. *Can. Entomol.* 102: 592–601.
- Sandford, K. H., and F. T. Lord. 1962. The influence of spray programs on the fauna of apple orchards in Nova Scotia XIII. Effects of perthane on predators. *Can. Entomol.* 94: 928–934.
- Scherrer, B. 1984. *Biostatistique*. Gaëtan Morin éditeur. Chicoutimi, Canada.
- Sih, A. 1987. Predators and prey lifestyles: an evolutionary and ecological overview, pp. 203–224. *In* W. C. Kefford and A. Sih [eds.], *Predation. Direct and indirect impacts on aquatic communities*. University Press of New England, London.
- Soares, A.O.C.M. 2000. Importância do polimorfismo na biologia de *Harmonia axyridis* Pallas. Provas de Doutorado. Universidade dos Açores, Ponta Delgada.
- Stanyard, M. J., R. E. Foster, and T. J. Gibb. 1998. Population dynamics of *Amblyseius fallacis* (Acari:Phytoseiidae) and European red mite (Acari: Tetranychidae) in apple trees treated with selected acaricides. *J. Econ. Entomol.* 91: 217–225.
- Thistlewood, H.M.A., and D. C. Elfving. 1992. Laboratory and field effects of chemical fruit thinners on tetranychids and predatory mites (Acari) of apple. *J. Econ. Entomol.* 85: 477–485.
- Vincent, C., and M. Roy. 1992. Entomological limits to biological control programs in Quebec apple orchards. *Acta Phytopathol. Entomol. Hungarica* 27: 649–657.
- Watve, C. M., and S. E. Lienk. 1975. Responses of two phytoseiid mites to pesticides used in New York apple orchards. *Environ. Entomol.* 4: 797–800.
- Whalon, M. E., B. A. Croft, and T. M. Mowry. 1982. Introduction and survival of susceptible and pyrethroid-resistant strains of *Amblyseius fallacis* (Acari: Phytoseiidae) in a Michigan apple orchard. *Environ. Entomol.* 11: 1096–1099.
- Wright, D. J., and R.H.J. Verkerk. 1995. Integration of chemical and biological control systems for arthropods: evaluation in a multitrophic context. *Pestic. Sci.* 44: 207–218.

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