Impact of intraguild predation and lambda-cyhalothrin on predation efficacy of three acarophagous predators

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Abstract: This laboratory study reports the interaction of three predators found in commercial apple orchards in Quebec, Hyaliodes vitripennis (Say) (Hemiptera: Miridae), Harmonia axyridis Pallas (Coleoptera: Coccinellidae) and Amblyseius fallacis (Garman) (Acarina: Phytoseiidae). First, intraguild predation between H vitripennis and the two other predators was characterized in the absence and presence of their extraguild prey, Tetranychus urticae Koch. The results showed an asymmetrical interaction in favour of the larger predator and the levels of intraguild predation were weak for the two predatory combinations. Presence of the phytophagous mite reduced the intensity of intraguild predation in the predatory combination of H axyridis and H vitripennis. Second, the effects of intraguild predation and the application of lambda-cyhalothrin on predation efficacy of the predators were evaluated. The application of the insecticide reduced prey consumption of H vitripennis and H axyridis but did not affect that of A fallacis. Combination of predators and an insecticide application resulted in two different situations depending on the species involved: a reduced predation efficacy for the combination of H vitripennis and H axyridis due to a knockdown effect caused by the insecticide, and no effect on T urticae consumption for H vitripennis and A fallacis. It is suggested that an integrated pest management program based on H vitripennis, A fallacis and lambda-cyhalothrin may be evaluated to repress phytophagous mites in Quebec orchards.

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1 INTRODUCTION

In Quebec commercial apple orchards, pesticides are used to manage arthropod pests and diseases whenever required.1,2 Among the key pests, phytophagous mites may delay tree growth, reduce fruit size and fruit quality, and induce premature drop of fruit.3 These damages are linked to the timing of mite injury,4 the cultivars5 and the mite population density.6 Repeated pesticide treatments may decrease in efficacy because of the development of resistance in phytophagous mites and the negative impact of these compounds on the predator populations.7

The efficacy of a biological control program for mites may be altered by chemical applications. Pesticide treatments can affect different characteristics of arthropods, such as fertility, fecundity, longevity, developmental rate, mobility, foraging efficacy and oviposition.8–13 Pesticides may also modify arthropod behaviour and consequently predator interactions, but few studies have evaluated the impact of pesticides on predation efficacy and on predator interaction. Roger et al12,13 have recorded a reduction of predation efficacy by the ladybeetle Coleomegilla maculata lengi Timb in the presence of pesticides due to a reduction of time spent searching for prey. Moreover, prey contaminated by pesticides may be rejected by a predator. Consequently, the efficiency of a biological control agent may be reduced.14,15

The efficacy of a biological control program for phytophagous mites may also depend on the
interactions within the guild of natural enemies of these pests. Interaction between predators, such as competition and intraguild predation, may affect the implementation of a new biological agent to manage phytophagous mites. Intraguild predation is an interaction of competition and/or predation among intraguild predators, which share a common prey, resulting in the consumption or death of one of the predators. Hence, intraguild predation may affect the composition, distribution, abundance and evolution of species and may be the cause of failure in an integrated pest management program. However, intraguild predation may also have a stabilizing effect on populations of an ecosystem.

*Hyaliodes vitripennis* (Say) (*Hemiptera: Miridae*) has been reported to be an effective predator of phytophagous mites in Quebec apple orchards. It feeds mainly on phytophagous mites and aphids, as well as on other arthropods, such as predaceous mites, leafhoppers and Lepidoptera. Other acarophagous predators in apple orchards include *Amblyseius fallacis* (Garman) (*Acarina: Phytoseiidae*) and *Harmonia axyridis* Pallas (*Coleoptera: Coccinellidae*). These predators have specific features of interest for integrated pest control programs against phytophagous mites. *Amblyseius fallacis* is a key predator of phytophagous mites, and it has developed resistance to organophosphate and pyrethroid insecticides used in apple orchards. *Harmonia axyridis* is a voracious ladybeetle that can consume 40–50 phytophagous mites per day.

In a previous study, we demonstrated that intraguild predation intensity and symmetry between *Hyaliodes vitripennis* and *Harmonia axyridis* or *Amblyseius fallacis* was not affected by a sublethal dose of lambda-cyhalothrin, but that their mobility was modified depending on the predator species. We noted a knockdown effect on *Harmonia axyridis* and *Hyaliodes vitripennis* and a higher mobility on *Amblyseius fallacis*. Another study showed that mortality of the intraguild predator was higher after the application of lambda-cyhalothrin, but that their mobility was modified depending on the predator species. We noted a knockdown effect on *Harmonia axyridis* and *Hyaliodes vitripennis* and a higher mobility on *Amblyseius fallacis*. Another study showed that mortality of the intraguild predator was higher after the application of lambda-cyhalothrin because the predator was also adversely affected by the consumption of contaminated prey.

The present study characterized the intraguild predation between *Hyaliodes vitripennis* and *Harmonia axyridis*, and between *Hyaliodes vitripennis* and *Amblyseius fallacis*, in the absence and presence of extraguild prey. It also examined the effects of intraguild predation and of a sublethal dose of lambda-cyhalothrin on the predation efficacy of the acarophagous guild.

2 EXPERIMENTAL

2.1 Biological material

*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 days on *Tetranychus urticae* Koch. *Harmonia axyridis* was collected from hibernation sites in the same area and reared in the laboratory on *Ephestia kuehniella* Zeller eggs. *Amblyseius fallacis* was obtained from a permanent colony reared on *T. urticae* at the Agriculture and Agri-Food Canada (St-Jean-sur-Richelieu) research facilities. *Tetranychus urticae* was reared on Lima bean leaves. Rearing conditions for all arthropods were 20 ±1 °C, 60–70% RH and 16:8 h light:dark photoperiod. All tests were carried out in laboratory under similar conditions [24 ±1 °C, 60–70% RH].

2.2 Characterization of intraguild predation

Evaluation of intraguild predation was done in the absence and presence of an extraguild prey, *T. urticae*. Experiments were conducted on vertical apple shoots, with three leaves. Shoots were collected from apple trees (cv McIntosh) in the same orchard, washed before the beginning of the experiment in order to eliminate other arthropods and contaminants, and placed in a 4-litre plastic box. Predators were starved for a period of 16 h (photoperiod: 8:8 light:dark) before tests, in order to increase their motivation to forage.

The level of intraguild predation was determined for two predator combinations: (1) *Hyaliodes vitripennis* and *Harmonia axyridis*, and (2) *Hyaliodes vitripennis* and *Amblyseius fallacis*. Combinations of one individual of each species were selected according to two main factors, the developmental stage and predator mobility (sessile and mobile). Non-predatory combinations and combinations where the probability of encounter between the two predators was low were not studied. Eighteen combinations were tested. The combinations included mobile life stages of *Hyaliodes vitripennis* (nymph II, nymph IV and adult) with selected developmental stages of *Harmonia axyridis*: egg, larva II, larva IV, pupa and adults, as well as adults of *Amblyseius fallacis*.

An individual of each predator species of the selected combination was introduced on separated leaves. Combinations involving eggs included a mass of five eggs placed on the ventral side of the leaf. Two treatments were applied: absence of extraguild prey (*T. urticae*), and presence of extraguild prey. In the presence of extraguild prey, a Lima bean leaf containing 40 eggs and mobile stages of *Tetranychus urticae* were placed on the dorsal side of the leaf 16 h before the beginning of the test to allow extraguild prey dispersion on the apple shoot.

After 7 h, predators were removed and mortality and consumption were recorded. Mortality and consumption of eggs and pupae were determined when egg hatch and adult emergence were completed [24 ±1 °C, 60–70% RH, 16:8 h light:dark]. Natural predator mortality was determined by a control treatment (one predator and no extraguild prey). Fifteen replicates were carried out for each treatment.

The corrected mortality, attributed to predator interaction, was calculated according to Soares et al.:

\[
P = (t - a) \times ra
\]

where \(P\) = number of replicates with predation (intraguild predation),
Results

3.1 Characterization of intraguild predation

Hyaliodes vitripennis versus H. axyridis

In the absence of T. urticae, intraguild predation between H. vitripennis and H. axyridis was recorded in approximately 20% of the replicates (Fig 1A). Asymmetrical interaction in favour of H. axyridis was observed in 67% of the combinations (H. vitripennis nymph II: $\chi^2 = 8.549, df = 1, P = 0.0035$; H. vitripennis nymph IV: $\chi^2 = 30.188, df = 1, P < 0.0001$). We also observed similar levels of intraguild predation on the different developmental stages of H. vitripennis by H. axyridis ($G_2 = 0.240, P = 0.8868$). Harmonia axyridis pupae were attacked more by H. vitripennis than larvae IV and adults (pupa/larva IV: $G_1 = 4.262, P = 0.0390$; pupa/adult: $G_1 = 4.262, P = 0.0390$). Eggs of H. axyridis [larvae emerged in control: $3.21 \pm (0.27)$] were consumed by H. vitripennis nympha IV [larvae emerged: $1.27 \pm (0.32)$] (Wilcoxon, Z = 3.61, P = 0.0003) and adults [larvae emerged: $2.27 \pm (0.37)$] (Wilcoxon, Z = 1.99, P = 0.0456).

In the presence of T. urticae, predation interaction between H. vitripennis and H. axyridis was observed in approximately 10% of the replicates (Fig 1B). Levels of intraguild predation for the three developmental stages of H. vitripennis by H. axyridis were similar ($G_2 = 4.892, P = 0.0866$). However, we noted higher intraguild predation by H. vitripennis on H. axyridis larvae II than on larvae IV and adults (larva II/larva IV: $G_1 = 4.262, P = 0.0390$; larva II/adult: $G_1 = 4.262, P = 0.0390$). Larval emergence of H. axyridis in the presence of H. vitripennis adults [larvae emerged: 2.13 ($\pm 0.42$)] was significantly lower than the control [larvae emerged: 3.21 ($\pm 0.27$)] (Wilcoxon, Z = 2.06, P = 0.0393). The presence of the extraguild prey significantly reduced intraguild predation of H. vitripennis adults ($G_1 = 5.464, P = 0.0194$) by H. axyridis, the level of intraguild predation was reduced by 27% on the mirid nymphs IV ($G_1 = 3.473, P = 0.0624$). The predation on H. axyridis eggs...
Intraguild predation levels were similar for the three asymmetrical in favour of the mirid (Fig 2A). Levels of intraguild predation by 30% of replicates and the interaction was always in absence of extraguild prey, *Tetranychus urticae* combinations of *Harmonia axyridis* and shaded bars show intraguild predation on *H vitripennis* extraguild prey. Open bars show intraguild predation on *H axyridis* and *Amblyseius fallacis* in the presence of extraguild prey, *Amblyseius fallacis* was present in approximately 15 10 5 0 5 10 15 0001; insecticide application: F = 138, P = 0.0244).

Hyaliodes vitripennis versus *A fallacis*

In absence of *T urticae*, intraguild predation between *H vitripennis* and *A fallacis* was present in approximately 30% of replicates and the interaction was always asymmetrical in favour of the mirid (Fig 2A). Intraguild predation levels were similar for the three predatory combinations (G = 2.66, P = 0.2643). In presence of *T urticae*, intraguild predation between *H vitripennis* and *A fallacis* was observed in approximately 35% of replicates and also asymmetrical in favour of the mirid (Fig 2A). Levels of intraguild predation by the mirid were similar for all combinations (G = 0.63, P = 0.7397).

3.2 Impact of intraguild predation and lambda-cyhalothrin application on predation efficacy

Predation efficacy of the predator combinations were affected by the application of lambda-cyhalothrin (ANOVA 2, model: F = 31.72, P < 0.0001; predator combination: F = 28.98, P < 0.0001; insecticide application: F = 138.43, P < 0.0001; predator combination x insecticide application: F = 16.68, P < 0.0001). In the absence of lambda-cyhalothrin, *H axyridis* and *H axyridis + H vitripennis* were the more efficient treatments to repress *T urticae* (Tukey–Kramer, P < 0.05) (Fig 3). In the presence of the insecticide, *H axyridis* and *H axyridis + H vitripennis* were also the more efficient treatments to manage the phytophagous mite (Tukey–Kramer, P < 0.05).

Lambda-cyhalothrin did not kill *T urticae* in the control treatment and all the predators were alive after 4 h. The insecticide affected the three predators differently (Fig 3). *Harmonia axyridis* consumed *T urticae* seven times more in absence than in presence of lambda-cyhalothrin (F = 81.00, P < 0.0001). *Hyaliodes vitripennis* consumed 75% more *T urticae* in the absence than in the presence of lambda-cyhalothrin (F = 8.08, P = 0.0108). In contrast, predation efficacy of *A fallacis* was not affected by the lambda-cyhalothrin (F = 2.32, P = 0.1451). The predation efficacy of the more efficient combination (*H vitripennis* and *H axyridis*) was reduced by 67% in presence of lambda-cyhalothrin (F = 35.66, P < 0.0001), whereas the predation efficacy of *H vitripennis* and *A fallacis* was not adversely affected (F = 0.62, P = 0.4407).

Figure 1. Levels of intraguild predation (IL) of different life stage combinations of *Harmonia axyridis* and *Hyaliodes vitripennis*: (A) in the absence of extraguild prey, *Tetranychus urticae*; (B) in the presence of extraguild prey. Open bars show intraguild predation on *H axyridis* and shaded bars show intraguild predation on *H vitripennis*.

Figure 2. Levels of intraguild predation (IL) of different life stage combinations of *Hyaliodes vitripennis* and *Amblyseius fallacis*: (A) in the absence of extraguild prey, *Tetranychus urticae*; (B) in the presence of extraguild prey. Open bars show intraguild predation on *A fallacis*.
Figure 3. Predation efficacy of different predatory combinations, in the absence (open bars) and the presence (shaded bars) of lambda-cyhalothrin. Lower case letters indicate a significant difference between predatory treatments in absence of lambda-cyhalothrin (ANOVA, $P < 0.05$). Upper case letters indicate a significant difference between predatory treatments in presence of lambda-cyhalothrin (ANOVA, $P < 0.05$). Asterisks indicate a significant difference of predation efficacy in absence versus in presence of insecticide application (ANOVA, $P < 0.05$).

4 DISCUSSION

Our experiments have produced two main conclusions. First, we observed intraguild predation between *H. vitripennis* and *H. axyridis*, as well as between *H. vitripennis* and *A. fallacis*. However, the intensity of the interaction was weak. Second, following the application of lambda-cyhalothrin, the *H. vitripennis* and *A. fallacis* combination consumed more *T. urticae* than each predator alone, while no such effect was observed in the *H. axyridis* and *H. vitripennis* combination. Thus, the application of lambda-cyhalothrin affected the predators and their interactions differently.

Intraguild predation for the two predatory combinations was generally asymmetrical in favour of the larger predator. In the combination of *H. axyridis* and *H. vitripennis*, we noted intraguild predation in less than 20% of the replicates, and in the combination of *H. vitripennis* and *A. fallacis*, intraguild predation was observed in approximately 30% of the replicates. Lucas et al.\(^{32}\) and Agarwala and Dixon\(^{35}\) showed higher levels of intraguild predation in Coccinellidae, between 50 and 100%. Moreover, the intensity of intraguild predation in the combination of *H. axyridis* and *H. vitripennis* was reduced in the presence of *T. urticae*. Lucas et al.\(^{32}\), Yasuda and Shinya\(^{36}\) and Agarwala and Dixon\(^{35}\) have demonstrated a reduction of the intraguild predation intensity between two predators when they were placed in the presence of an extraguild prey. The direction of our intraguild predation interactions was determined by size and vulnerable stages. The larger predator usually attacked the smaller one. The predator size ratio had been shown to influence intraguild predation in Coccinellidae, Heteroptera and Acari.\(^{32,37-40}\) Young stages and immobile stages were susceptible to intraguild predation. Eggs and pupa were vulnerable sessile stages as they did not have active defence mechanisms. This resulted in higher susceptibility to predation.\(^{35,36,41}\) Intraguild predation has frequently been observed on immature and immobile stages because their defensive mechanisms are less effective and their mobility reduced.\(^{42}\)

Our results indicated that in the absence of lambda-cyhalothrin, the intensity of intraguild predation between *H. axyridis* and *H. vitripennis* and between *H. vitripennis* and *A. fallacis* was low, and the interaction did not affect the predation efficacy. Thus an additive effect was reported on the shared prey. Different types of response have been reported from the literature: (1) the pest was not controlled efficiently when several predators had been used because of intraguild predation and/or competition,\(^{43,44}\) (2) an additive or synergistic (more than additive) effect was observed on the shared prey when several generalist predators were used together\(^{45-48}\) and (3) different results were obtained depending on the life stages\(^{49}\) or predatory species\(^{39,50}\) involved.
The impact of lambda-cyhalothrin application differed depending on the treatment. In the predatory combination of *H. axyridis* and *H. vitripennis*, the number of *T. urticae* consumed was three times lower than in the absence of the insecticide treatment, whereas, in the *H. vitripennis* and *A. fallacis* combination, consumption of *T. urticae* was not affected by the application of lambda-cyhalothrin. Such results may be due to the impact of the insecticide on: (1) the extraguild prey (*T. urticae*), (2) the intraguild predator, (3) the intraguild prey, (4) the intraguild predation level and (5) on a combination of previous effects. No mortality of *T. urticae* was caused by lambda-cyhalothrin application. The intraguild predators and intraguild prey were affected differently by the insecticide application; we noted a reduced predation efficacy of *H. axyridis* and *H. vitripennis*, whereas consumption of *T. urticae* by *A. fallacis* was not affected by the insecticide application. A previous study demonstrated that the mortality of *H. axyridis* and *H. vitripennis* was reduced after exposure to lambda-cyhalothrin while *A. fallacis* increased its time spent moving post-application. Moreover, we observed a knockdown effect of lambda-cyhalothrin on *H. axyridis*, the coccinellid being inactive for a long period following the insecticide application. The reduced mobility and the knockdown effect can explain the lower consumption of *T. urticae* by *H. axyridis* and *H. vitripennis* in the presence of this insecticide. Increased movements of *A. fallacis* may suggest an increased predation efficacy; however, the higher mobility could also be explained as an escape behaviour caused by the repellent properties of lambda-cyhalothrin.

In our predation efficacy experiments, no intraguild predation was noted during the test period. Predation efficacy of *H. axyridis* and *H. vitripennis* in combination was significantly reduced after the insecticide application. The predation efficacy of each predator was reduced by the application of lambda-cyhalothrin and resulted in lower suppression of *T. urticae*. Predation efficacy of the *H. vitripennis* and *A. fallacis* combination was not affected by the insecticide application. Few studies have evaluated the combination of predators and pesticides on pest suppression. Fagan *et al.* have reported effective pest control when the treatment (predator or pesticide) was applied alone, but when applied in concert, these treatments cancelled the effect of each other. These authors suggested that the failure of the control of the target pest was caused by the elimination of a secondary predator by the pesticide and intraguild predation. In an earlier study, the application of lambda-cyhalothrin did not significantly affect the intensity of intraguild predation between *H. axyridis* and *H. vitripennis* and between *H. vitripennis* and *A. fallacis*. However, in the present study, the consumption of *T. urticae* by the combination of *H. vitripennis* and *A. fallacis*, was slightly increased after insecticide application (3.8) when compared with the individual consumption of each predator alone (summed, 1.9). It is likely that the lambda-cyhalothrin did not affect the intensity of intraguild predation but influenced the consumption of *T. urticae* when the two predators were combined, generating a more than additive effect on the shared prey.

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