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Pesticide Susceptibility of Two Coccinellids (*Stethorus punctum picipes* and *Harmonia axyridis*) Important in Biological Control of Mites and Aphids in Washington Hops

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Pesticide Susceptibility of Two Coccinellids (*Stethorus punctum picipes* and *Harmonia axyridis*) Important in Biological Control of Mites and Aphids in Washington Hops

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The susceptibility of Stethorus punctum picipes *(Casey) and* Harmonia axyridis *Pallas larvae to pesticides used or with potential for use in Washington hops, was examined in laboratory bioassays. All pesticides tested except the miticide, hexythiazox, the insecticides, chlorpyrifos and pirimicarb, and the fungicide, mycobutanil, produced 100% mortality in* S. punctum picipes *at concentrations equivalent to field rates. The insecticides, pirimicarb, endosulfan, and thiamethoxam were least toxic to* H. axyridis*. Bifenthrin, diazinon, dimethoate, methomyl, carbaryl, malathion, phosmet, imidacloprid, and chlorpyrifos were highly toxic. The miticides, abamectin and fenpyroximate were highly toxic, milbemectin was moderately toxic but all other miticides tested were non-toxic. All fungicides had low toxicity. Selection and use of pesticides compatible with natural enemies and conservation biological control in Washington hop production is discussed.*

Keywords: Stethorus punctum picipes*,* Harmonia axyridis*, pesticides, susceptibility, hops, conservation biological control*

INTRODUCTION

Management of spider mites (*Tetranychus urticae* Koch) and aphids (*Phorodon humuli* Schrank) in Washington hops depends on the frequent use of miticides and aphicides but increasing problems with resistance and the availability/cost of new pesticides, has led to a reevaluation of arthropod management. Integrated pest management strategies, based on encouraging greater levels of biological control and reduced pesticide inputs, are being developed for *T. urticae* and *P. humuli* (James *et al*., 2001; James, 2002).

Aphids and mites are the only significant pests of hops requiring control. Aphids colonize hop yards during late May and June, remaining until September when they return to *Prunus* trees where they overwinter as eggs (Wright *et al*., 1990). Insecticides, primarily imidacloprid, are usually applied in June to reduce establishment of aphids. Other insecticides registered for

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hop aphid control include bifenthrin, diazinon and malathion (Barbour, 2002). Spider mites usually develop damaging populations during late June and July and are capable of 'explosive' increases in numbers, when conditions are hot, dry and dusty and natural enemies are scarce (Sites & Cone, 1985). One to four applications of miticides are usually applied between June and August with abamectin, bifenazate, hexythiazox and fenpyroximate the currently favored materials. Other available miticides include propargite, bifenthrin and dicofol (Barbour, 2002). Powdery and downy mildew are also a problem on Washington hops for which fungicides including sulfur, mycobutanil and trifloxystrobin are applied.

Prospects for increasing levels of mite and aphid predation in Washington hop yards appear to be good (James *et al*., 2001; James, 2003), but a critical factor in making hop yards more hospitable to predators will be the use of selective, narrow spectrum pesticides. Some of the insecticides and miticides currently used in hops (e.g., imidacloprid) are known to be harmful to key spider mite predators like the phytoseiids, *Galendromus occidentalis* Nesbitt, *Neoseiulus fallacis* Garman and *Amblyseius andersoni* (Chant) (James, 2003). However, some currently available pesticides including the miticides, hexythiazox and propargite are known to be selective for some natural enemies (Hoy & Ouyang, 1986; Babcock & Tanigoshi, 1988). Increasing the variety of pesticides available for mite and aphid control in hops that have a good degree of safety to predators and parasitoids of these pests, will be fundamental to increasing levels of biological control. The availability of chemicals that are effective yet selective to natural enemies will also increase grower confidence in biological control and integrated pest management.

James *et al*. (2001) reported that non-phytoseiid predators of *T. urticae* were three times more abundant on 'escaped' or unsprayed hops than on commercial (sprayed) hops in Washington. The mite-eating ladybeetle, *Stethorus punctum picipes* (Casey) is an important component of this guild of predators and appears to be critical to early season regulation of mite populations on hops (James *et al*., 2003). The introduced and primarily aphidophagous ladybeetle, *Harmonia axyridis* Pallas, is a relative newcomer to Washington hops but in recent seasons has developed large populations in some hop yards, providing rapid suppression of *P. humuli* (James *et al*., 2003). *H. axyridis* has also been shown to feed and complete development on *T. urticae* (Lucas *et al*., 1997).

This study provides information derived from laboratory bioassays on the susceptibility of *S. punctum picipes* and *H. axyridis* larvae to selected insecticides, miticides and fungicides used or potentially available for use in Washington hops.

MATERIALS AND METHODS

The direct toxicity of pesticides to *S. punctum picipes* and *H. axyridis* was evaluated in a series of bioassays conducted on field-collected mid (second/third) instar larvae during July–October 2000 and 2001. Fewer tests were conducted with *S. punctum picipes* because of limited availability of larvae. As far as possible, the more important pesticides (e.g., current or imminent registrations) were tested for this species. Larvae were obtained from unsprayed hop plants and selected as the test stage because of their likely greater pesticide susceptibility than adults. Bioassays were conducted using a Potter Precision Spray Tower (Potter, 1925). Pesticides tested included: [insecticides], chlorpyrifos (Lorsban™ 4E, Dow AgroSciences), malathion (Malathion™ 57EC, UAP Platte Chemical Co.), phosmet (Imidan™ 70W, Gowan), diazinon (Diazinon™ AG500, UAP Platte Chemical Co.), carbaryl (Sevin™ 4F, Gowan), pirimicarb (Pirimor™ 50DF, Zeneca), methomyl (Lannate™ SP, DuPont), endosulfan (Thiodan™ 3EC, FMC), dimethoate (Dimethoate™ 400, UAP Platte Chemical Co.), imidacloprid (Provado™ 1.6F, Bayer), thiamethoxam (Actara™, Syngenta), bifenthrin (Brigade™ WSB, FMC), [miticides], propargite (Omite™ 30WS, Uniroyal), fenbutatin-oxide (Vendex™ 50WP, Griffin), hexythiazox (Savey™ 50DF, Gowan), dicofol (Kelthane™ 35, Dow AgroSciences), fenpyroximate (Fujimite™, Nichino America), abamectin (Agri-Mek™ 0.15EC, Syngenta), pyridaben (Pyramite™, BASF), Biomite™ (a mixture of terpenoids and a chitin enzyme inhibitor, Nichimen Corp), [fungicides], mycobutanil (Rally™ 40W, Dow AgroSciences), trifloxystrobin (Flint™, Bayer), quinoxyfen (Quintec™, Dow AgroSciences), wettable sulfur (Microthiol Special™, Elf Atochem), and lime sulfur (BSP).

Larvae were transferred from hop leaves using a soft brush onto grape leaf discs placed on wet cotton in individual plastic cups (44 mm diameter). The leaf disc completely covered the cotton wool. Five *S. punctum picipes* larvae were used in each cup while only a single *H. axyridis* larva was used per cup (to prevent cannabalism). Cups with larvae were placed under the Potter Tower and sprayed. The tower spraying pressure was 50 kPa and 2-mL aliquots were sprayed giving 1.6–1.8 mg of liquid per cm^2. Two concentrations (field rate and half field rate for hop or other field crop target pests, using the recommended water volume for hops, 100 gallons per acre) of each pesticide were tested against each species. Five to seven individuals of each species were tested for each concentration of each pesticide with an additional five to seven individuals used in a water-only control. Each test was replicated three or four times and data for each chemical concentration were obtained from 15–28 individuals. Larvae were confined in the cups after spraying using fine muslin lids and held at $28 \pm 1°C$ for 48 h before assessment of mortality. Spider mites (all stages of *T. urticae*) were brushed into each *S. punctum picipes* cup to serve as a food supply with replenishment after 24 h. Hop aphids were provided to *H. axyridis* during the holding period. Mortality was assessed by gently prodding larvae. Individuals displaying coordinated movement were considered alive. Data for all predators were corrected for control mortality (Abbott, 1925) and tests discarded if it exceeded 10%.

RESULTS

S. punctum picipes

All pesticides tested except the miticide, hexythiazox, the insecticides, chlorpyrifos and pirimicarb, and the fungicide, mycobutanil, produced 100% mortality at concentrations equivalent to recommended field rates (Tables 1–3). Mycobutanil was the least toxic (13.2% mortality) followed by hexythiazox (25.3%) and chlorpyrifos (52%). The insecticide, imidacloprid and miticide, propargite, allowed some survival at half field rates (Table 1 and Table 2). Half rates of pirimicarb (Table 1), hexythiazox (Table 2), chlorpyrifos (Table 1) and mycobutanil (Table 3) provided moderate to good survival but all other pesticides produced 100% mortality at the lower rate.

H. axyridis

Seven insecticides, bifenthrin, diazinon, dimethoate, methomyl, carbaryl, malathion and phosmet produced 100% mortality at concentrations equivalent to field rates (Table 1). All were highly toxic at half rates as well (80–100% mortality). Pirimicarb and endosulfan were the least toxic insecticides at field rates (6.7 and 11.0% mortality, respectively). Thiamethoxam also had low toxicity (33.3% mortality) while imidacloprid, and chlorpyrifos were highly toxic (80% mortality) (Table 1).

One miticide, fenpyroximate, produced 100% mortality while abamectin and to a lesser extent, milbemectin, were also toxic (Table 2). Pyridaben, propargite, biomite™, fenbutatin-oxide, dicofol and hexythiazox were non-toxic. All of the fungicides had low toxicity to *H. axyridis* with wettable sulfur the most toxic with 30.0% mortality (Table 3).

DISCUSSION

This study provides information on the direct toxicity of pesticides used or potentially available for use in Washington hops, to two important coccinellid predators of mites and aphids. The use of a laboratory-based direct spray technique resulted in mortality estimates that reflect maximum possible contact exposure of the test insects to pesticides. In the field,

TABLE 1. Mean (±SE) % mortality of *S. punctum picipes* and *H. axyridis* larvae after direct application of insecticides in laboratory bioassays

Insecticide	Concentration (% a.i.)	*S. punctum picipes*	*H. axyridis*
Chlorpyrifos	0.125	52.0 (15.4)	80.0 (0)
	0.0625	20.0 (13.1)	13.3 (5.5)
Malathion	0.075	–	100
	0.0375	–	100
Phosmet	0.06	–	100
	0.03	–	80.0 (0)
Diazinon	0.125	–	100
	0.0625	–	100
Dimethoate	0.06	–	100
	0.03	–	93.3 (5.5)
Carbaryl	0.24	–	100
	0.12	–	100
Pirimicarb	0.022	93.2 (5.8)	6.7 (5.5)
	0.011	68.4 (7.7)	6.7 (5.5)
Methomyl	0.11	–	100
	0.055	–	100
Endosulfan	0.05	–	11.0 (5.1)
	0.025	–	0
Imidacloprid	0.013	100	80.0 (9.6)
	0.065	85.3 (11.6)	53.3 (14.7)
Thiamethoxam	0.032	100	33.3 (5.5)
	0.016	100	33.3 (5.5)
Bifenthrin	0.010	100	100
	0.005	100	93.3 (5.5)

many additional factors operate to mitigate or increase exposure, for example, weather conditions and spray equipment calibration. Consequently, actual mortality in the field may be more or less than that obtained in the laboratory. Nevertheless, laboratory-derived estimates of mortality do provide a guide to likely impacts of pesticides on natural enemies in the field. Pesticides that are non-toxic to a predator in the laboratory are invariably safe to the predator in the field.

Insecticides were generally highly toxic to larvae of both *S. punctum picipes* and *H. axyridis*. Exceptions were chlorpyrifos for *S. punctum picipes* and pirimicarb, endosulfan and thiamethoxam for *H. axyridis*. Only one of the six miticides tested *against S. punctum picipes* was non-toxic, hexythiazox, which is an ovicide and therefore still needs to be tested against eggs of *S. punctum picipes*. In contrast, six of the nine miticides tested against *H. axyridis* had low or no toxicity. Abamectin and fenpyroximate had greatest toxicity to *H. axyridis*. Of the five fungicides tested, wettable sulfur showed greatest toxicity to *H. axyridis* (33% mortality) but this is unlikely to have a significant impact on field populations.

This study and James (2002) provide the first reports on pesticide toxicity to *S. punctum picipes*. There are a number of reports on effects of pesticides on the subspecies *S. punctum punctum*, which occurs east of the Rocky Mountains. Colburn and Asquith (1970, 1971,

TABLE 2. Mean (±SE) % mortality of *S. punctum picipes* and *H. axyridis* larvae after direct application of miticides in laboratory bioassays

Miticide	Concentration (% a.i.)	*S. punctum picipes*	*H. axyridis*
Propargite	0.34	100	0
	0.17	91.6 (6.9)	0
Fenbutatin-oxide	0.15	–	0
	0.075	–	0
Hexythiazox	0.02	25.3 (10.7)	0
	0.01	6.0 (2.5)	0
Dicofol	0.5	–	0
	0.25	–	0
Fenpyroximate	0.025	100	100
	0.0125	100	100
Abamectin	0.002	100	93.3 (5.5)
	0.001	100	93.3 (5.5)
Milbemectin	0.004	100	60.0 (18.2)
	0.002	100	21.7 (9.7)
Pyridaben	0.06	–	0
	0.03	–	0
Biomite™	0.6	100	0
	0.3	100	0

TABLE 3. Mean (±SE) % mortality of *S. punctum picipes* and *H. axyridis* larvae after direct application of fungicides in laboratory bioassays

Fungicide	Concentration (% a.i.)	*S. punctum picipes*	*H. axyridis*
Mycobutanil	0.018	13.2 (8.3)	0
	0.009	0	0
Trifloxystrobin	0.015	–	13.3 (11.9)
	0.0075	–	0
Quinoxyfen	0.015	–	6.7 (5.5)
	0.0075	–	0
Wettable sulfur	1.0	–	30.0 (11.1)
	0.5	–	0
Lime sulfur	3.0	–	6.7 (5.5)
	1.5	–	6.7 (5.5)

1973) examined the toxicity of a large number of pesticides against *S. punctum punctum* (Le Conte). The only chemical examined in this and the current study was the organophosphate, chlorpyrifos, which caused 70% mortality to adult *S. punctum punctum* and 52% mortality to *S. punctum picipes* larvae. Tolerance by *S. punctum punctum* to organophosphate insecticides has been well documented for populations in Pennsylvanian apple orchards, allowing establishment of a successful integrated mite management program (Hull & Beers, 1985). The relative selectivity of chlorpyrifos to *S. punctum picipes* suggests some organophosphate tolerance may also exist in this subspecies in Washington. Carbamate insecticides are highly toxic to *S. punctum punctum* (Colburn & Asquith, 1970; Biddinger & Hull, 1995) and the only carbamate tested against *S. punctum picipes* in the current study, pirimicarb, was also toxic. The miticide, abamectin, was toxic to *S. punctum punctum* (Biddinger & Hull, 1995) as it is to *S. punctum picipes*. Antonelli *et al*. (1996) reported the destruction of *S. punctum picipes* populations in Washington raspberries by applications of bifenthrin, which accords with the high toxicity of this insecticide reported here.

Very little is known concerning the pesticide susceptibility of *H. axyridis* which is surprising given the abundance and importance of this species in a number of agroecosystems in Japan, Europe and the United States (McClure, 1986; Ongagna *et al*., 1993; Osawa, 2000). The only detailed information on pesticide susceptibility of *H. axyridis* was provided by Cho Jum-Rae *et al*. (1997) for eight insecticides tested against a Korean strain. All of the insecticides were less toxic to *H. axyridis* than to two aphid species, and some materials, especially the synthetic pyrethroid, alphamethrin, were concluded to be promising candidates for use in integrated pest management programs where *H. axyridis* is the major natural enemy. Field and half field rates of most insecticides tested in the current study were highly toxic to *H. axyridis* with only pirimicarb, endosulfan, thiamethoxam, and to a lesser extent imidacloprid and chlorpyrifos, likely to allow some survival of predators in the field. James (2002) showed that a new aphicide, pymetrozine, was non-toxic to *H. axyridis*. Most miticides and fungicides showed good selectivity towards *H. axyridis*.

Spider mites (*T. urticae*) and aphids (*P. humuli*) are the only arthropod pests of Washington hops for which pesticides are routinely applied. The use of insecticides and miticides for these pests which do not substantially interfere with development and maintenance of important predator (phytoseiid mites, coccinellid beetles) populations, is vital if conservation biological control is to become an additional control tactic. *Stethorus punctum picipes* and *H. axyridis* are considered to be two of the most important species in the assemblage of predators, upon which IPM and biological control strategies in Washington hops are being based and developed (James et al., 2001; James, 2003). This study and James (2002) have identified a number of pesticides with selectivity towards predatory mites and ladybeetles. The most important of these for Washington hop growers is the newly registered aphicide, pymetrozine and the miticides, hexythiazox and bifenazate. These pesticides combine efficacy against aphids and mites with relative safety to the natural enemies considered to be of greatest importance, i.e., Phytoseiidae, *S. punctum picipes*, and *H. axyridis*. Consequently, the use of these pesticides in hops has the potential to greatly improve arthropod management by increasing the impact and importance of conservation biological control (James *et al*., 2001). In contrast, this study and James (2002), have highlighted a number of pesticides (imidacloprid, bifenthrin, propargite, fenpyroximate) commonly used by hop growers, which are toxic to important predators, thus inhibitory to biological control in hops. Substitution of the currently favored aphicide, imidacloprid, by pymetrozine and replacement of the miticides, abamectin, propargite and fenpyroximate, with bifenazate and/or hexythiazox, should go a long way towards minimizing disruption to the beneficial arthropod community and improving biological control in hops.

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