Toxicity of Major Citrus Pesticides to *Aphytis melinus* (Hymenoptera: Aphelinidae) and *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae)

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ABSTRACT The 48-h residual toxicity of major pesticides used for control of citrus thrips, *Scirtothrips citri* (Moulton), and California red scale, *Aonidiella aurantii* (Maskell), in California was evaluated for adults of *Aphytis melinus* DeBach and *Cryptolaeumus montrouzieri* Mulsant. Rates as high as 4-fold the highest recommended field rate revealed little effect of sabadilla to *A. melinus* or of sabadilla, dimethoate, formetanate, or chlorpyrifos to *C. montrouzieri*. Concentration–mortality regressions were quantified for the remainder of the materials; these showed toxicity (at LC_{50}) of chlorpyrifos > carbaryl > dimethoate > acephate > parathion > formetanate > methidathion to *A. melinus* and carbaryl > acephate > parathion > methidathion to *C. montrouzieri*.

TWO MAJOR arthropod pests of California citrus are the citrus thrips, *Scirtothrips citri* (Moulton), and the California red scale, *Aonidiella aurantii* (Maskell). In many areas of California (especially the Central Valley region), management of these two species depends almost entirely on the use of pesticides. Heavy pesticide use for citrus thrips control has historically resulted in resistance to a number of materials, most recently with dimethoate (Elmer 1981) in many areas. Although resistance of California red scale populations to materials used currently has not been reported, widespread resistance in South Africa (Georgala 1979) to similar materials is alarming.

The use of natural enemies in biological control of many major arthropod pests of citrus has been very successful in some areas of California (e.g., Luck 1981, Luck et al. 1986). Unfortunately, citrus pest management has historically been divided into two philosophies: those advocating primarily chemical control and those advocating a biological control approach. The prospect of pesticide resistance in major pest species, the decreased availability and increased cost of efficacious pesticides, and increased land and production costs in the face of high market standards all indicate the need to integrate biological and chemical control techniques so that maximum benefits can be derived from the advantages of both strategies. One major step in integrating these two management techniques is to understand the impact of various pesticides on natural enemies.

Here, we report the results of experiments designed to evaluate the toxicity of the major pesticides used in control of citrus thrips and California red scale to a species representative of each of two major natural enemy groups, the chalcid parasitoids and predaceous Coccinellidae. *Aphytis melinus* DeBach is a fairly delicate external parasitoid of California red scale and is considered to be its major natural control agent in California and many other areas of the world. *Cryptolaemus montrouzieri* Mulsant is a fairly large and robust predator of various mealybug species.

Materials and Methods

Adult female *A. melinus* (24 h old) were tested. The *A. melinus* colony was collected in February 1983 from a commercial lemon grove in Fillmore, Calif., and was reared in the laboratory on oleander scale, *Aspidiotus hederae* (Ballot). Adult *C. montrouzieri* (1–3 days old) of mixed sex were obtained from commercial California insectaries and were fed on honey for 24 h before testing.

Pesticide evaluations were conducted in a manner similar to that described by Morse et al. (1986). Commercial pesticide formulations (dimethoate, Cygon 4EC; acephate, Orthene 75SP; formetanate, Carzol 92SP; sabadilla, Veratran D 0.2%; parathion 25WP; methidathion, Supracide 2EC; chlorpyrifos, Lorsban 4EC; and carbaryl, Sevin 80SP) were applied to clean lemon (*Citrus limon* (L.) Burm. f. 'Eureka') leaves with a laboratory sprayer. Photometric analysis of a water-soluble dye extract sprayed on glass slides indicated sprayer deposition of 0.003 ml/cm^2. Treated leaves were allowed to dry for 1–2 h and were then placed in modified Munger cells (Munger 1942), which provided a closed test arena (3.2 cm diam, 0.9 cm high) with the treated leaf surface as the base. Air was passed through the test arena at an average rate of 5.15 ml/s to reduce fumigation effects. The sides of the arena were streaked with honey as a food source. *A. melinus* were introduced into the Munger cells after anesthesia with CO_2. *C. mon-*

trouzieri were introduced directly into the cells. Untreated leaves were used in control cells.

Five test insects were placed in each Munger cell with 10–20 replicate cells per pesticide rate. For pesticides showing little effect, evaluations were discontinued at 4-fold the recommended field rate (Morse and Bailey 1984). Otherwise, 6–10 rates were tested to obtain concentration–mortality data for each pesticide. Mortality was evaluated by observing treated insects through a microscope after 48 h. All experiments were performed at ambient laboratory conditions of 20–25°C and 30–50% RH. Data were corrected for control mortality with Abbott's (1925) formula and were analyzed with probit analysis (SAS Institute 1982).

Results and Discussion

A number of studies (Bartlett 1953, 1963, 1966, Strawn 1978, Egan 1979, Meyerdirk et al. 1979, Bellows et al. 1985) have evaluated the toxicity of one or a few pesticide rates to these two natural enemy species. None to date, however, has developed data that could be used in characterizing their response to various pesticides regardless of the rate tested. To specify the response over a range of rates, concentration–mortality regressions were obtained for most of the pesticides evaluated (Table 1). *A. melinus* was much more susceptible to the pesticides tested (except sabadilla, which had little effect on both species). Pesticides showing little effect at rates up to 4-fold the recommended field rate are listed in Table 2.

Of the four pesticides used for California red scale control, the three organophosphates (parathion, methidathion, and chlorpyrifos) are commonly applied using low-volume equipment; the field rates listed in Table 1 are, thus, quite high. Dilute applications are becoming less common in California, but would result in much lower field rates (FR) in terms of g (AI)/liter (thus, higher LC_{50}/ and LC_{90}/FR ratios). Sevin is rarely applied as a low-volume treatment because of lower efficacy to California red scale.

Citrus thrips treatments at 1,871 liters/ha have been shown to be more effective than those using less water and smaller droplet sizes (Elmer and Brawner 1980). Thus, field rates for the three synthetic pesticides used for citrus thrips control (dimethoate, acephate, and formetanate) are listed assuming the use of this method of application, although as little as 468 liters/ha (using the same amount of AI per ha) is often used. Sabadilla is formulated with sugar as a bait for citrus thrips control and is usually applied at 935 liters/ha because greater dilution requires additional sugar to maintain phagostimulation.

Chlorpyrifos was the most toxic to *A. melinus*; methidathion was least toxic (Table 1). Since methidathion and parathion have been used commercially for some time in California, field populations may have developed some tolerance to

Table 1. Toxicity of selected pesticides to adult *A. melinus* and *C. montrouzieri*

Species	Pesticide	Suggested field rate (g [AI]/liter)[a]	No. adults tested	Slope ± SE	LC_{50} (g [AI]/liter)	LC_{50} VS FR[b]	LC_{50} 95% FL	LC_{90} (g [AI]/liter)	LC_{90} VS FR[b]	LC_{90} 95% FL
A. melinus	Parathion	7.2	598	2.073 ± 0.318	0.290	0.040	0.200–0.460	1.202	0.167	0.674–4.432
	Methidathion	12.0	1,107	1.314 ± 0.491	0.504	0.042	0.218–82.000	4.761	0.397	1.101–[c]
	Chlorpyrifos	7.2	502	1.932 ± 0.805	0.016	0.002	[c]	0.073	0.010	0.028–[c]
	Carbaryl	1.2	292	2.607 ± 0.600	0.088	0.077	0.052–0.160	0.274	0.238	0.154–2.457
	Dimethoate	1.2	448	2.138 ± 0.493	0.145	0.121	0.038–0.278	0.577	0.482	0.295–14.006
	Acephate	0.6	988	2.838 ± 0.400	0.201	0.344	0.156–0.262	0.569	0.974	0.404–1.031
	Formetanate	0.6	1,299	2.317 ± 0.324	0.341	0.619	0.254–0.451	1.218	2.210	0.838–2.265
C. montrouzieri	Parathion	7.2	395	4.100 ± 0.619	9.047	1.259	7.328–10.413	18.580	2.585	15.510–26.053
	Methidathion	12.0	1,041	1.835 ± 0.115	9.430	0.787	8.468–10.569	47.078	3.930	37.670–62.204
	Carbaryl	1.2	444	2.735 ± 0.744	0.183	0.159	0.076–0.318	0.539	0.469	0.312–3.066
	Acephate	0.6	946	1.956 ± 0.449	0.988	1.692	0.554–1.859	4.467	7.649	2.239–27.361

[a] Field rates for citrus thrips and California red scale from Morse and Bailey (1984); rates given are at the high end of any range suggested; scalicide field rates are for low-volume application (935 liters/ha) except carbaryl.
[b] LC_{50} and LC_{90} expressed as a fraction of the field rate.
[c] Limit not calculable due to large SE.

Table 2. Pesticides evaluated showing little effect on adult *A. melinus* and *C. montrouzieri*

Species	Pesticide	Suggested field rate (g [AI]/liter)[a]	% corrected mortality at rate indicated (*n*)			
			0.5-fold	1-fold	2-fold	4-fold
A. melinus	Sabadilla + sugar bait	0.02 + 9.6[b]	0.00 (98)	6.87 (100)	0.00 (88)	0.00 (100)
C. montrouzieri	Chlorpyrifos	7.2[b]	2.04 (100)	1.02 (100)	5.43 (150)	4.07 (150)
	Dimethoate	2.4	0.00 (50)	0.00 (50)	2.04 (50)	0.00 (50)
	Formetanate	1.1	0.00 (50)	0.00 (50)	0.00 (100)	0.00 (100)
	Sabadilla + sugar bait	0.02 + 9.6[b]	4.04 (100)	2.58 (198)	0.00 (100)	0.00 (100)

[a] Per Morse and Bailey (1984).
[b] Low-volume field rate (935 liter/ha).

them. In contrast, chlorpyrifos was registered for use on citrus in 1983; thus, little tolerance (other than that conferred from possible cross-selection by other organophosphates) would be expected. When LC_{90}/FR ratios (a measure of efficacy of field applications) were compared, methidathion (0.994; 1.0 implies LC_{90} = FR) was the least toxic and chlorpyrifos was by far the most toxic (0.010).

In contrast to the scalicides, the three synthetic thripsicides were more similar in terms of their efficacy to *A. melinus*. In terms of efficacy of the active ingredient and LC_{90}/FR ratios (Table 1), dimethoate was more toxic and formetanate was less toxic. Dimethoate has been the major pesticide used for citrus thrips control in California since 1969. Formetanate and acephate have been used extensively only since 1982. Nonetheless, dimethoate currently is somewhat more toxic to *A. melinus* compared with the other two materials.

Although the material is less effective as a thripsicide (Morse et al. 1984), the use of sabadilla has been promoted for use in integrated control programs because of its much lower toxicity to natural enemies. Minimal toxicity of rates as high as 4-fold that used in the field was confirmed in this study (Table 2).

Another factor useful in evaluating the impact of thripsicides on *A. melinus* is the persistence of residues weathered in the field. Although the 48-h residual toxicity of acephate is intermediate (Table 1), Bellows et al. (1985) found that acephate residues weathered in the field were more persistent than those of dimethoate or formetanate. In a lemon field trial, Phillips et al. (1983) also found that an acephate treatment resulted in a slightly greater decrease in numbers of *A. melinus* over time compared with dimethoate.

C. montrouzieri was much less susceptible to all pesticides evaluated, although carbaryl was highly toxic compared with the other pesticides. In contrast to *A. melinus*, the toxicity of chlorpyrifos to *C. montrouzieri* was quite low (Table 2). Although concentration–mortality regressions were obtained for both parathion and methidathion, their toxicities were comparatively low as demonstrated by LC_{50}'s in excess of the low-volume field rates. The four thripsicides had little impact on *C. montrouzieri* at 4-fold the field rate, with the exception of acephate, for which the LC_{50} was close to the field rate (ratio of 0.846, Table 1).

The above residual pesticide toxicity evaluations do not account for possible sublethal effects (e.g., behavior-modifying effects, impacts on fecundity, etc.). Based on 48-h LC_{50}'s to adults, however (regardless of the recommended field rate), the above materials can be ranked from high toxicity to low as chlorpyrifos > carbaryl > dimethoate > acephate > parathion > formetanate > methidathion for *A. melinus* and carbaryl > acephate > parathion > methidathion for *C. montrouzieri*.

If comparisons are based on LC_{90}/FR ratios with these two natural enemy species, these data indicate that sabadilla residues are nearly harmless and that formetanate is the least toxic of the remaining thripsicides. The four scalicides are similar in their toxicity, with the exception of chlorpyrifos, which is more toxic to *A. melinus* but less harmful to *C. montrouzieri*; and carbaryl, which is more toxic to *C. montrouzieri*. Other factors may influence choice of a pesticide in the field, including efficacy to various pest species, impact on other natural enemies, cost, ease of application, safety, and preharvest intervals.

Information of this type may prove of value when selecting pesticides for use in systems where integration of chemical and biological control is desirable. By combining results on immediate residual toxicity (this study) and the length of time residues weathered in the field remain toxic (Bellows et al. 1985), pesticide selections can be made with an approximate understanding of both the immediate and long-term impact on populations of beneficial organisms. In this way, concerns about target and nontarget pest resurgence, due to suppression of natural enemies, may be addressed and relatively selective materials (where they are available) may be used to help reduce this risk.

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