Toxicity of insecticides to predators of rice planthoppers: Spiders, the mirid bug and the dryinid wasp

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Abstract

The toxicity of nine insecticides to predators of rice planthoppers was examined with first instars of four spider species, i.e. *Pardosa pseudoannulata, Tetragnatha maxillosa, Ummeliata insecticeps* and *Gnathonarium exsiccatum*, and females of the mirid bug *Cyrtorhinus lividipennis* and the dryinid wasp *Haplogonatopus apicalis*, by dipping the test arthropods into insecticide solution. Deltamethrin was the most toxic to the spiders, with LC_{50} at 0.033 to 1.1 ppm, followed by ethofenprox. The results indicate that the spiders are susceptible to synthetic pyrethroids. Insecticide susceptibilities of the spiders varied among species. *T. maxillosa* was more susceptible to seven insecticides, particularly to diazinon, than the other spiders, but *P. pseudoannulata* was more susceptible to phenthoate and carbaryl than *T. maxillosa*. Many insecticides, particularly phenthoate, imidacloprid and deltamethrin, were toxic to *C. lividipennis*. All insecticides tested were toxic to *H. apicalis*. We also evaluated the effect of insecticides on the spiders and *C. lividipennis* in paddy fields. Deltamethrin had a destructive effect on the spider populations and may have induced a resurgence of the *Nilaparvata lugens* population. Phenthoate reduced the abundance of lycosid spiders, and ethofenprox reduced the abundance of *Tetragnatha*. The *C. lividipennis* abundance decreased to a low level in all insecticide-treated plots except those treated by buprofezin.

Key words: Insecticide susceptibility, side effect, selective toxicity, natural enemy, *Nilaparvata lugens*

INTRODUCTION

Pesticides are major agents used to control agricultural pests. In Japan, insecticides have been widely used for controlling insect pests in most rice paddies, with the exception of those in which organic farming is practiced. Intensive and extensive use of insecticides, however, has caused several problems: development of insecticide resistance in pest insects, environmental pollution, and side effects on non-target organisms including the natural enemies of the target pests (Kiritani, 1979). Some insecticides have disrupted natural enemy complexes and induced a resurgence of the target pests or non-target minor pests in paddies (for review, see Gallagher et al., 1994; Heinrichs, 1994). In contrast, use of selective insecticides that are less toxic to natural enemies than to pests should conserve natural enemy populations, and the surviving natural enemies may suppress the pest populations, which in turn will reduce the rate of insecticide application.

To effectively utilize the natural enemies as biological control agents, we should acquire information about the effects of pesticides on them. Many investigations have assessed the effect of insecticides on predators of rice planthoppers and leafhoppers simply by applying insecticides in paddy fields (e.g. Itô et al., 1962; Toyoda and Yoshimura, 1966, 1967; Heinrichs et al., 1982a, b; Reissig et al., 1982a, b; Tanaka and Sato, 1988). In field tests, various factors affect the action of insecticides and the abundance of predators, and, consequently, the results may remain inconclusive or inconsistent. Hence, toxicity tests should be carried out in the laboratory in addition to field tests. However, in the laboratory, relatively few studies have been conducted to clarify the toxicity of insecticides

to predators of rice planthoppers and leafhoppers (Kawahara et al., 1971; Takahashi and Kiritani, 1973; Chang et al., 1979; Chang, 1981; Fabellar and Heinrichs, 1984, 1986; Tanaka et al., 1990).

Important or abundant predators of rice planthoppers and leafhoppers include several species of spiders, the mirid bug *Cyrtorhinus lividipennis* Reuter, the ripple bugs *Microvelia* spp., and the dryinid wasps *Haplogonatopus* spp. and *Pseudogonatopus* spp. (Kiritani et al., 1972; Kenmore et al., 1984; Teramoto and Yokomizo, 1992; Wada and Nik, 1992; Sawada et al., 1993; Teramoto and Nakasuga, 1994; Tanaka and Watanabe, unpublished). Among these predators, the lycosid spider *Pardosa pseudoannulata* (Bösenberg et Strand) and *C. lividipennis* have been mainly examined for insecticide susceptibility, and there have been a few studies on the lycosid spider *Pirata subpiraticus* (Bösenberg et Strand) (Chang et al., 1979), the linyphiid spiders *Ummeliata insecticeps* (Bösenberg et Strand) (Kawahara et al., 1971) and *Gnathonarium dentatum* (Wider) (Chang, 1981), and the bug *Microvelia atrolineata* (Bergroth) (Fabellar and Heinrichs, 1984). In Kyushu, Japan, where overseas immigrants of rice planthoppers *Nilaparvata lugens* Stål and *Sogatella furcifera* (Horváth) are abundant and their damage to rice is serious, abundant predators include four spiders, *P. pseudoannulata, U. insecticeps, Gnathonarium exsiccatum* (Bösenberg et Strand), and the tetragnathid *Tetragnatha maxillosa* Thorell, two bugs *C. lividipennis* and *Microvelia horvathi* Lundblad, and the wasp, *Haplogonatopus apicalis* Perkins (Tanaka and Watanabe, unpublished). The four spiders and *M. horvathi* are indigenous to Japan. *C. lividipennis* immigrates from overseas to Japan with *N. lugens* and *S. furcifera*, and feeds on eggs, larvae, and probably honeydew of planthoppers (Suzuki and Tanaka, 1996). The ant-like, wingless females of *H. apicalis* deposit their eggs on nymphs and adults of *S. furcifera* in addition to preying on the planthoppers, and their larvae develop by feeding on the hosts. *H. apicalis* immigrates into Japan with the parasitized adults of *S. furcifera*. In this study, we examined the toxicity of nine insecticides to six of these predators (all except *M. horvathi*). We also evaluated the effect of insecticide application on the populations of these species of spiders and *C. lividipennis* in paddy fields.

MATERIALS AND METHODS

Insecticides. In laboratory and field tests, we used diazinon 40% emulsifiable concentrate (EC), phenthoate 50% EC, isoxathion 50% EC, fenobucarb 50% EC, carbaryl 15% EC, a diazinon 3%–carbaryl 1.5% mixture of low-drift dust (DL-D), ethofenprox 20% EC, deltamethrin 1.4% EC, cartap 50% soluble powder (SP), imidacloprid 10% wettable powder (WP), imidacloprid 1% granules (G), and buprofezin 25% WP. Most of these insecticides have been applied to control rice planthoppers, leafhoppers and the rice leaffolder, *Cnaphalocrocis medinalis* Guenée, in paddies in Japan. Deltamethrin is not registered as an insecticide in Japan. However, we examined its effect because synthetic pyrethroids, e.g. deltamethrin and cypermethrin, have been shown to be highly toxic to predators of *N. lugens* and have been proven to induce a resurgence of *N. lugens* populations in Southeast Asia (Heinrichs et al., 1982a; Fabellar and Heinrichs, 1984; Heinrichs, 1994).

Planthoppers and predators used for insecticide susceptibility tests. We obtained *N. lugens* and the predators from the experimental paddy fields of Kyushu National Agricultural Experiment Station, Chikugo, Fukuoka Prefecture, Japan. Adults of *N. lugens* were captured in the fields in October 1987 and have been reared on seedlings of Reiho, a *japonica* rice cultivar, in a laboratory controlled at 25°C, 16L : 8D. Their insecticide susceptibility has been reported by Endo et al. (1988). In this study, first instars and macropterous females of the planthoppers were used for the susceptibility tests.

Since mass rearing of spiders is difficult, first-instar nymphs of spiders were used for the tests (we define the first instars of spiders as nymphs that emerged from an egg sac though these nymphs had molted within the egg sac). Nymphs and adults of *P. pseudoannulata, U. insecticeps* and *G. exsiccatum* were captured in the field in 1988–1990. They were fed on *N. lugens, S. furcifera* and *Drosophila melanogaster*,

and the female spiders deposited egg sacs. Egg sacs of *T. maxillosa* were collected in the field in 1990. As the first instars of *P. pseudoannulata* remain on the mother's abdomen for several days prior to dispersal, the susceptibility tests were carried out one or two days after the dispersal of nymphs in this spider and one or two days after emergence from egg sacs in the other three spiders. In *G. exsiccatum*, adult females were also examined for susceptibility to ethofenprox. For this test, the females collected in the fields in October 1989 were fed on planthoppers for two days prior to examination.

Nymphs of *C. lividipennis* captured in the fields in October 1991 were fed on eggs and nymphs of *N. lugens*. Cocoons of *H. apicalis* were collected in the fields in July and August 1991. The emerging females of *C. lividipennis* and the eclosing females of *H. apicalis* were examined for susceptibility to insecticides.

Insecticide susceptibility tests. We evaluated the insecticide susceptibilities of *N. lugens* and of predators by dipping them into an insecticide solution, which is a modification of the method described by Hama (1987). The insecticides were diluted to the appropriate concentrations by adding water that contained the spreading agent Rabiden® at 0.02% in volume. The bottom end of a glass tube (35 mm in diameter, 35 mm high) was covered with nylon gauze, which was fixed with a rubber band. Then, ca. ten test arthropods anesthetized with CO_2 were put into the glass tube. The bottom end of the tube was dipped in the insecticide solution in a petri dish for 20 s, then the tube was placed on several sheets of filter paper to remove the solution. In *N. lugens, C. lividipennis* and *H. apicalis*, ca. ten individuals treated with the insecticide were transferred to a plastic container (8 × 11 × 3 cm) that contained rice seedlings. The spiders were kept individually in a glass vial (13 mm in diameter, 65 mm long) containing moist cotton. For most insecticides, mortality of the test arthropods was recorded 24 h after treatment. In the case of imidacloprid, however, mortality of the spiders was recorded 48 h after treatment as their mortality considerably increased from 24 h to 48 h. Five concentrations of each insecticide (four or six concentrations in a few cases) and the control water containing 0.02%

Rabiden® were treated. About 30 individuals of test arthropods were examined for each concentration of insecticide. The observed mortality was corrected by Abbott's equation (Abbott, 1925), and the median lethal concentration (LC_{50}) was calculated by probit analysis (Bliss, 1935).

As buprofezin is an insect growth regulator that inhibits the molting of insects, we could not clarify the toxicity of this insecticide by an accurate lethal effect on arthropods but by the effect on their molting. Thus, we determined its toxicity to *P. pseudoannulata* as follows: First instars of this spider molt eight or nine days after dispersal from the mother at 25°C, and thus we carried out a preliminary test in which the spiders dispersing six days earlier were dipped into the solution with one of six concentrations between 250 and 8,000 ppm of the insecticide. These treatments appeared to show no adverse effect on development or molting of the spiders. Then, we conducted a test in which the spiders were dipped into an insecticide solution of 8,000 ppm 1, 3, 5 or 7 days after dispersal, and their development was observed until they molted or died. Each of these spiders was fed five first instars of *N. lugens* every two days in a glass vial.

Field tests. To appreciate the effects of the insecticides on the populations of planthoppers and their predators, we carried out field tests in the experimental paddy fields of Kyushu National Agricultural Experiment Station in 1988 and 1990 where Reiho was transplanted in late June. Experimental plots were separated by 30 cm-high polyvinyl chloride sheets into 10 × 7 m areas in 1988 and into 7 × 7 m in 1990. Seven insecticides (1988) and four insecticides (1990) were applied at a rate of 150 *l*/10 a in a solution of EC or WP diluted 1,000-fold in weight or at 3 kg/10 a in DL-D or G on 9 September 1988 and 5 September 1990 when the number of *N. lugens* nymphs was increasing. In control plots, no insecticide was applied. Each treatment consisted of two plots, i.e. two replications.

The abundance of planthoppers and predators was surveyed by a sticky board method (Nagata and Masuda, 1978) just prior to, and 1, 3, 7, 17, 28 and 40 days after the insecticide

application in 1988; and just prior to, and 2, 6, 13 and 27 days after the application in 1990. We held a sticky board (25×18 cm) sprayed with Kinryu® adhesive (SDS Biotech, Tokyo, Japan) at the bottom of a rice hill and beat the plants twice so that arthropods would fall onto the board. The samples were collected from ten rice hills, every third (1990) or fifth (1988) hill in a row, with one sticky board, and two boards were used for each plot. The planthoppers and predators captured on the boards were counted in the laboratory. Additionally, spiders of the genus *Tetragnatha* were surveyed by visual observation, since adults and old nymphs of these spiders construct webs on the upper part of rice plants and hence do not easily fall onto a sticky board. We observed ten consecutive rice hills in a row and counted the number of large-sized nymphs and adults of *Tetragnatha* spiders on the webs that were supported by these hills. This counting was conducted in two rows of rice plants, i.e. 20 hills, in one plot, during the morning from 8:00 to 9:00.

RESULTS

LC$_{50}$ of insecticides in *N. lugens* and predators

The LC$_{50}$ of nine insecticides in *N. lugens* and predators are shown in Table 1. In *N. lugens*, the first instars were more susceptible to all insecticides tested than the females. Imidacloprid was the most toxic to the planthoppers, followed by ethofenprox and deltamethrin.

There were substantial differences in sensitivity to the insecticides in first instars of the spiders. Of the insecticides tested, deltamethrin was the most toxic to the four spiders, followed by ethofenprox. Thus, these synthetic pyrethroids were highly toxic to the spiders. Diazinon was highly toxic only to *T. maxillosa*, fenobucarb was rather toxic to *T. maxillosa*, and phenthoate was rather toxic to *P. pseudoannulata*. Susceptibilities of the spiders to the insecticides differed considerably among species. *T. maxillosa* was more susceptible to seven out of the nine insecticides than the other spiders, with the greatest difference in susceptibility to diazinon. However, *P. pseudoannulata* was more susceptible to phenthoate and carbaryl than the other spiders. In *G. exsiccatum*, the adult females were far less susceptible than the first in-

stars. In the test of first instars of *P. pseudoannulata* against buprofezin, more than 90% of the spiders successfully molted to the second stadium in every treatment.

To *C. lividipennis*, all insecticides but cartap were toxic, with phenthoate having the highest toxicity and deltamethrin and imidacloprid having high toxicity. To *H. apicalis*, all insecticides were toxic. The LC$_{50}$ of *H. apicalis* was below 1 ppm for diazinon, phenthoate, isoxathion, and imidacloprid.

The relative toxicities, i.e. the ratios of LC$_{50}$ in predators/LC$_{50}$ in pests, are used as an index for assessing selective toxicity of an insecticide to predators and pests (Kawahara et al., 1971; Takahashi and Kiritani, 1973), and these values for the LC$_{50}$ of predators and those of corresponding stages of *N. lugens* are shown in Table 2. Three spiders, *P. pseudoannulata, U. insecticeps* and *G. exsiccatum*, were more susceptible than *N. lugens* only to deltamethrin, while *T. maxillosa* was more susceptible than *N. lugens* to four insecticides. *C. lividipennis* and *H. apicalis* were more susceptible to most or all insecticides than *N. lugens*.

Effect of insecticides on field populations of *N. lugens* and predators

Since the time-series data in the same experimental plot are not independent of each other, we performed repeated measures ANOVA (SAS Institute, 1990) (Table 3). For the planthoppers or predators in which the treatment or the interaction of treatment × time had a significant effect ($p < 0.05$), we tested the effect of treatments on each survey day by the Dunnett method (SAS Institute, 1990) (see Figs. 1–3). For these statistical analyses, we used log-transformed data for the numbers of planthoppers and predators captured in each plot, log ($N + 1$).

Among planthoppers and leafhoppers, only *N. lugens* was abundant during the experimental period. This planthopper was much more abundant in 1990 than in 1988 (Fig. 1), causing hopperburn, i.e. the death of rice plants, in some spots of the control plot area. Before insecticide application, the numbers of captured planthoppers were not significantly different among plots ($p > 0.7$ for 1988, $p > 0.9$ for 1990, ANOVA). Buprofezin and imida-

Table 1. LC$_{50}$ (ppm) of insecticides in *N. lugens* and its predators

Insecticide	*N. lugens* (1st instar)	*N. lugens* (female)	*P. pseudoannulata* (1st instar)	*T. maxillosa* (1st instar)	*U. insecticeps* (1st instar)	*G. exsiccatum* (1st instar)	*C. lividipennis* (female)	*H. apicalis* (female)
Diazinon	19.1	41.5	592[a]	1.9	>8,000[a]	4,869[a]	40.0	0.28
Phenthoate	14.0	134	55[a]	1,073	894[a]	2,572[a]	0.063	0.22
Isoxathion	19.4	98.6	2,104	522	>8,000	>8,000	2.9	0.85
Fenobucarb	21.4	57.6	671[a]	54.9	6,079[a]	5,731[a]	63.3	4.7
Carbaryl	20.4	48.8	109[a]	1,275	449[a]	501[a]	3.7	10.0
Ethofenprox	2.5	12.6	7.7[a]	0.92	5.2[a]	4.7 (163)[a,b]	6.0	11.6
Deltamethrin	1.9	14.7	0.041	0.033	1.1	0.83	0.38	1.9
Cartap	2,552	>8,000	7,549	1,660	>8,000	>8,000	427	19.4
Imidacloprid	0.57	2.6	440	136	995	801	0.36	0.12

[a] From Tanaka et al. (1990).
[b] The figure in parentheses indicates the LC$_{50}$ for adult females.

Table 2. Relative toxicity (LC_{50} in predators/LC_{50} in the corresponding stage of *N. lugens*) of insecticides to predators

Insecticide	*P. pseudoannulata* (1st instar)	*T. maxillosa* (1st instar)	*U. insecticeps* (1st instar)	*G. exsiccatum* (1st instar)	*C. lividipennis* (female)	*H. apicalis* (female)
Diazinon	31	0.10	>419	255	1.0	0.0067
Phenthoate	3.9	77	64	184	0.00047	0.0016
Isoxathion	108	27	>412	>412	0.029	0.0086
Fenobucarb	31	2.6	284	268	1.1	0.082
Carbaryl	5.3	63	22	25	0.076	0.20
Ethofenprox	3.1	0.37	2.1	1.9	0.48	0.92
Deltamethrin	0.021	0.017	0.58	0.44	0.026	0.13
Cartap	3.0	0.65	>3.1	>3.1	<0.053	<0.0024
Imidacloprid	772	239	1,746	1,405	0.14	0.046

Table 3. Repeated measures ANOVA to test the effects of treatment (insecticide application) and time on abundance of *N. lugens* and its predators

Year Arthropod	Treatment			Treatment × time		
	Wilks' Λ	F	p	Wilks' Λ	F	p
1988						
N. lugens	0.269	3.10	0.068	0.00072	1.54	0.17
Lycosidae	0.269	3.10	0.068	0.00022	2.09	<0.05
Tetragnatha	0.442	1.44	0.31	0.000041	3.17	<0.01
Linyphiidae	0.468	1.30	0.36	0.00053	1.67	0.12
C. lividipennis	0.478	1.25	0.38	0.00096	1.42	0.22
1990						
N. lugens	0.0476	25.0	<0.01	0.00088	9.12	<0.01
Lycosidae	0.108	10.3	<0.05	0.0152	2.65	0.084
Tetragnatha	0.0380	31.6	<0.001	0.000055	27.2	<0.0001
Linyphiidae	0.206	4.82	0.057	0.00125	7.89	<0.01
C. lividipennis	0.128	6.81	<0.05	0.00572	2.81	0.12

cloprid effectively suppressed the planthopper populations in both years. Ethofenprox, the diazinon/carbaryl mixture and the fenobucarb also reduced the planthopper abundance, and phenthoate showed a slight effect on it. On the contrary, in deltamethrin plots, the number of planthoppers was significantly higher than that in control plots on day 13, and large areas of hopperburn occurred on day 27.

Of the predatory arthropods in the plots, abundant species were *C. lividipennis* and three taxa of spiders, i.e. Lycosidae, Linyphiidae and *Tetragnatha*, in both 1988 (Fig. 2) and 1990 (Fig. 3). Major species of the three spider taxa were *P. pseudoannulata* in Lycosidae, *U. insecticeps* and *G. exsiccatum* in Linyphiidae, and *T. maxillosa* in *Tetragnatha*. There were no significant differences in the numbers of each predator taxa among plots before insecticide ap-

plication ($p > 0.05$ for both years, ANOVA).

In the phenthoate plots, the number of lycosid spiders decreased soon after the application and was significantly smaller than that in control plots on day 28. Deltamethrin had a destructive effect on lycosid spiders. Other insecticides, however, did not show any significant effect on lycosid abundance. Deltamethrin almost eliminated *Tetragnatha* spiders from the treatment plots. Ethofenprox immediately reduced *Tetragnatha* abundance in 1990, but its effect was not clear in 1988. In a late experimental period, *Tetragnatha* spiders were less abundant in all insecticide-treated plots than in control plots. Deltamethrin also had a detrimental effect on linyphiid spiders. The linyphiids also appeared to be less abundant in insecticide-treated plots than in control plots.
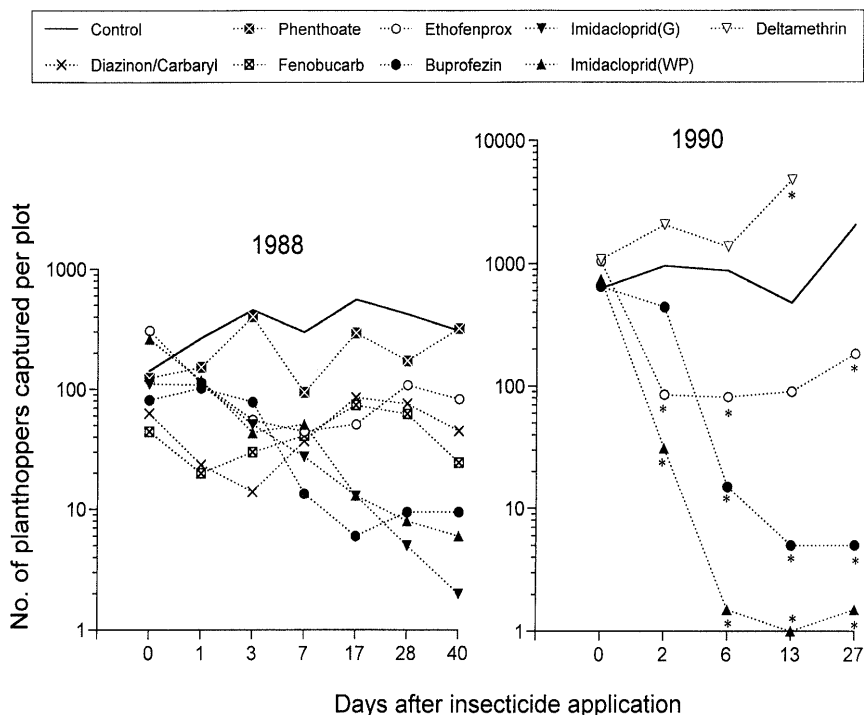
In 1988, the *C. lividipennis* population de-

Fig. 1. Mean numbers of *N. lugens* nymphs and adults captured per plot in untreated control and insecticide-treated plots in two years. The symbol * indicates a significant difference in the number of *N. lugens* between the control and the insecticide-treated plots on each survey day ($p<0.05$, Dunnett method). The deltamethrin plots were not surveyed on day 27 due to large areas of hopperburn.
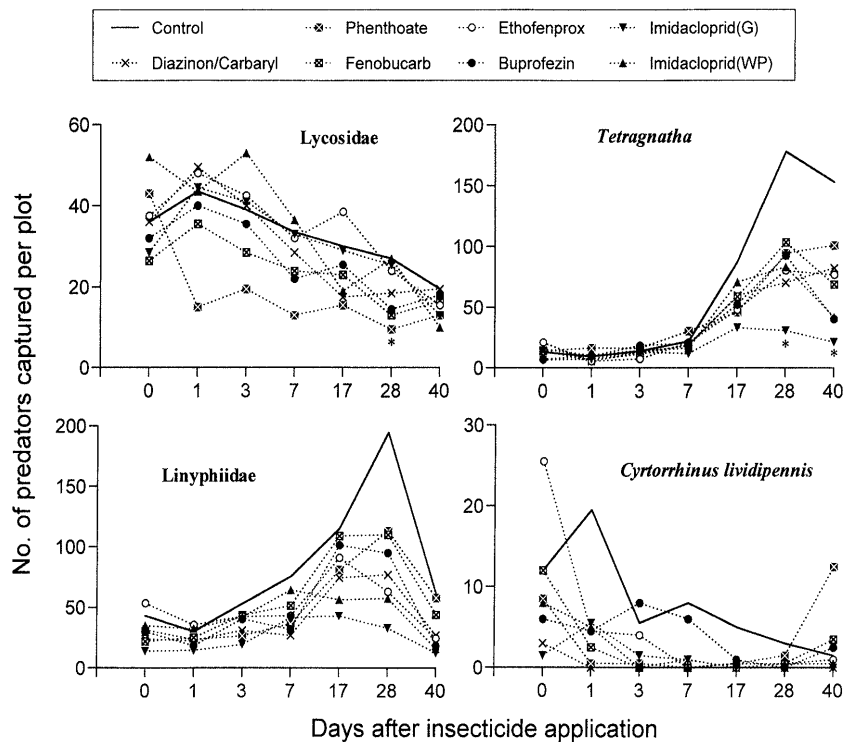

Fig. 2. Mean numbers of predator nymphs and adults captured per plot in control and insecticide-treated plots in 1988. The symbol * corresponds to its meaning in Fig. 1.
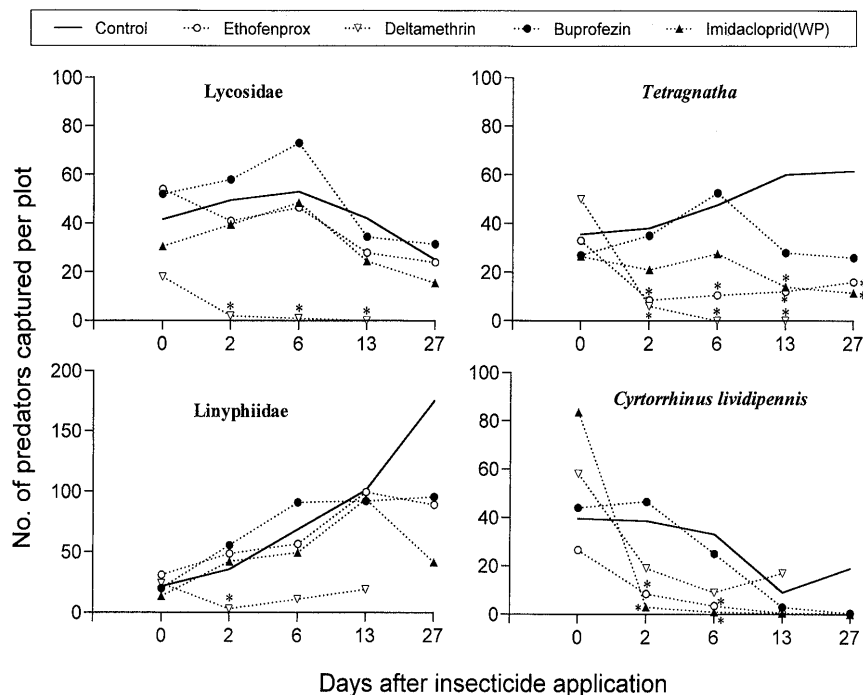
Fig. 3. Mean numbers of predator nymphs and adults captured per plot in control and insecticide-treated plots in 1990. The symbol * corresponds to its meaning in Fig. 1.

creased to a low level after day 1 and up to day 7 in plots treated with all insecticides but buprofezin, although the population recovered on day 40 in some plots. In 1990, ethofenprox and imidacloprid immediately reduced the bug abundance to the point of nearly eliminating it. In the buprofezin plots, the bug abundance decreased to a low level in a late period in both years.

DISCUSSION

Laboratory tests

This study revealed the toxicities of several insecticides to predators of rice planthoppers in terms of the differences among insecticides and predators. Among the insecticides tested, synthetic pyrethroids including deltamethrin and ethofenprox were the most toxic to the spiders. High toxicity of synthetic pyrethroids to spiders has been demonstrated in other studies: cypermethrin and deltamethrin to *P. pseudoannulata* (Fabellar and Heinrichs, 1984, 1986), for example, and deltamethrin to the linyphiids inhabiting wheat fields (Everts et al., 1989). Among other chemicals, BHC (1,2,3,4,5,6-hexachlorocyclohexane), especially γ-BHC, was also toxic to spiders (Kawahara et al., 1971; Takahashi and Kiritani, 1973).

In general, insecticides other than synthetic pyrethroids and BHC, such as organophosphates and carbamates, were not highly toxic to spiders. Susceptibilities of spiders to these insecticides, however, were substantially different between species. Though the genus *Tetragnatha* is a major group of spiders inhabiting rice paddies, there has been no report on the insecticide susceptibility of these spiders. *T. maxillosa* was more susceptible to many insecticides than the other spiders, i.e. *P. pseudoannulata, U. insecticeps* and *G. exsiccatum*, and this difference in susceptibility was the greatest in diazinon. In contrast, the linyphiids, i.e. *U. insecticeps* and *G. exsiccatum*, were less susceptible than *P. pseudoannulata* and *T. maxillosa* to all insecticides except synthetic pyrethroids. These results are consistent with those of other studies on linyphiids and lycosids (Kawahara et al., 1971; Chang, 1981). On the other hand, *P. pseudoannulata* was rather susceptible to phenthoate. Carbofuran and carbosulfan as well as phenthoate were toxic to the lycosids, *P. pseudoannulata* and *Pirata subpiraticus* (Chang et al., 1979; Fabellar and Heinrichs, 1984).

Kawahara et al. (1971) presented the LC_{50} of insecticides including the compounds investigated in this study, i.e. diazinon EC,

fenobucarb EC and carbaryl EC, for adult females of *P. pseudoannulata* and *U. insecticeps* that were collected in paddy fields in Kochi Prefecture, Japan, using the same method described above, i.e. 20-s dipping of spiders in an insecticide solution. The LC_{50} obtained in this study were 1.4 to 3.0 times higher than those obtained by Kawahara et al., except in the case of carbaryl in *U. insecticeps*. This study tested first instars (Kawahara et al. used females), and first instars are probably more susceptible to insecticides than females. Thus, there may be considerable differences in susceptibility of spiders between the two studies. Although we have no information by which to analyze this difference, we surmise that the spiders may have become tolerant to some pesticides after their repeated use.

To *C. lividipennis*, most insecticides were toxic; phenthoate was the most toxic, followed by deltamethrin and imidacloprid. Fabellar and Heinrichs (1984) also showed that many insecticides were toxic to this bug. To another mirid bug *Dicyphus tamaninii* Wagner, a predator of the whitefly *Trialeurodes vaporariorum* (Westwood), many insecticides were toxic, though insect growth regulators were low in toxicity (Castañé et al., 1996). To our knowledge, this is the first study to report on the insecticide susceptibility of a dryinid wasp, *H. apicalis*, which was susceptible to all insecticides tested. Hence, many insecticides may have a deleterious effect on the dryinid population in paddies, though this study did not survey its population in paddies.

This study evaluated the accurate toxicity of insecticides to arthropods, based on mortality at 24 or 48 h after treatment. Cartap caused paralysis in *P. pseudoannulata* as long as 15 days after treatment (Takahashi and Kiritani, 1973). For insecticides having a unique mode of action, effects other than short-term mortality should be properly evaluated. Buprofezin appeared to have no detrimental effect on survival and development in the first instars of *P. pseudoannulata*. We need to examine its effect on other predators and parasitoids.

Field tests
Deltamethrin significantly affected abundance

of all spiders. Phenthoate also reduced lycosid abundance. Ethofenprox had a detrimental effect on *Tetragnatha* in 1990, but this effect was not clear in 1988 as *Tetragnatha* abundance was low in 1988. There have been reports showing that synthetic pyrethroids, e.g. cypermethrin and deltamethrin, reduced abundance of paddy-dwelling spiders (Heinrichs et al., 1982a, b; Reissig et al., 1982a, b; Kenmore et al., 1984) and also ethofenprox affected *Tetragnatha* abundance (Tanaka and Sato, 1988). Thus, we can conclude that, among insecticides, synthetic pyrethroids have a detrimental effect on spider populations in paddies.

In all plots treated with insecticide except buprofezin plots, the abundance of *C. lividipennis* decreased immediately after treatment. These results indicate that many insecticides are toxic to *C. lividipennis*. Deltamethrin reduced the abundance of both spiders and of *C. lividipennis*, and a substantial degree of hopperburn occurred in deltamethrin plots. Thus, deltamethrin may have induced a resurgence of the *N. lugens* population.

In a late experimental period, spiders, particularly linyphiids and *Tetragnatha*, were less abundant in insecticide-treated plots than in untreated control plots. The long-term effect of insecticides on predator populations may be due not only to the direct effect of toxicity to predators but also to the possibility that the predators emigrate from the plots or reduce their rates of reproduction as a response to decrease in prey availability.

Most insecticides used in these field tests were sprayed as a solution of emulsifiable concentrate or wettable powder. Predators are exposed to pesticide solution or dust by three routes of uptake: direct uptake after exposure to droplets or dust of pesticides, uptake of residues by contact with contaminated surfaces of vegetation and soil, and oral uptake by feeding on contaminated prey. In the case of imidacloprid, the granules and the wettable powder were tested. Predators were not directly exposed to the granule formulation of pesticides. However, the imidacloprid granules appeared to affect *C. lividipennis*. The bugs may ingest this chemical from residues on rice plants or from oral uptake of prey. To date, a few studies have in-

vestigated the routes of uptake of pesticides by predators. Mullié and Everts (1991) reported uptake of deltamethrin by a linyphiid spider, *Oedothorax apicatus*, showing 56% of residual uptake, 32% of direct uptake, and 12% of oral uptake. In paddy fields, residual uptake from rice plants is possibly a major source of ingestion, and some predators that walk on the surface of the water, e.g. lycosid spiders, may absorb a pesticide from paddy water in which the pesticide is dissolved. Additionally, food-chain toxicity of some chemicals is important to predators (Kiritani and Kawahara, 1973). Recently in Japan, granule application by farmers to nursery boxes has grown pervasive. We should note that even in the case of granule application by which predators are not directly exposed to pesticides, some effects may occur on predator populations.

In this study, the results of field experiments were approximately consistent with those of toxicity tests in the laboratory as follows: Deltamethrin was the most toxic to spiders in both the laboratory and the field. *T. maxillosa* was more susceptible to ethofenprox than other spiders, the LC$_{50}$ for this spider being 0.1 to 0.2 times that for other spiders, and *Tetragnatha* was more affected by ethofenprox than other spiders in the field. Phenthoate had a greater effect on lycosids than on other spiders in the laboratory and the field. Many insecticides, especially phenthoate and imidacloprid, were toxic to *C. lividipennis* in the laboratory and reduced its field population. However, some field results differed somewhat from those in the laboratory: Diazinon was toxic to *T. maxillosa* and ethofenprox was noxious to all spiders in the laboratory, but there was no significant effect of diazinon on *Tetragnatha* or that of ethofenprox on lycosids and linyphiids in the field. In the laboratory, the first instars of spiders were examined. Hence, when the spider populations are in later stadia or of low density at the time of insecticide spraying, the effect of insecticides might be indistinct. We should analyze both field and laboratory data to interpret the effects of pesticides on natural enemies. Further, to select appropriate pesticides and establish an optimal method of pesticide use, we need to quantify the role of natural enemies in pest control.

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