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Original Article

The Insecticidal Activity of Pyrethroids against Insecticide-Resistant Strains of Planthoppers, Leafhoppers and the Housefly*

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The insecticidal activities of pyrethroids against the susceptible (LE) strain of the rice brown planthopper and the small brown planthopper were lower than the conventional carbamate insecticides, and were similar to or lower than those of malathion and fenitrothion. The malathion- and fenitrothion-resistant (Rm and Rf) strains of the rice brown planthopper did not show cross-resistance to allethrin, but did to resmethrin, permethrin, tetramethrin and fenpropathrin. The Rm and Rf strains of the small brown planthopper did not show cross resistance to pyrethrins, allethrin, permethrin and fenpropathrin, but a lesser degree of resistance was observed to furamethrin, resmethrin and tetramethrin. The insecticidal activities of fenvalerate against the rice brown planthopper, small brown planthopper, and green rice leafhopper were heightened with the increase in malathion resistance levels. The LD_{50} values of fenvalerate in the rice brown planthopper, small brown planthopper and green rice leafhopper having 710-, 144- and 768-fold malathion resistance were 1/8, 1/12 and 1/6 of those in the corresponding susceptible strains, respectively. These results indicated that the insecticidal activity of fenvalerate against the two planthoppers and leafhopper was negatively correlated with the degree of the malathion resistance development. The same phenomenon was not found in the housefly.

INTRODUCTION

Ozaki *et al.*[1] found that pyrethroids showed high insecticidal activity against the green rice leafhopper, *Nephotettix cincticeps* Uhler, and that there was little difference in the susceptibility between susceptible (S) and organophosphate and carbamate-resistant (Rop-c) strains. They also obtained an interesting result that fenvalerate showed higher insecticidal activity against the Rop-c strain than against the S strain.

Recently, the rice brown planthopper, *Nilaparvata lugens* Stål, the small brown planthopper, *Laodelphax striatellus* Fallén and the green rice leafhopper have developed resistance to various organophosphorus and carbamate insecticides in western Japan. A countermeasure toward insecticide resistance in these insects is considered to be an important matter for investigation. It is especially desirable to develop new insecticides which are highly effective to insecticide-resistant strains. Fenvalerate is one example.

In the present study, insecticidal activities of the pyrethroids were evaluated for the susceptible and resistant strains of the rice brown planthopper and of the small brown planthopper. Topical LD_{50} values of fenvalerate were also examined for several populations of the two planthoppers, the leafhopper and the housefly with different levels of malathion

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resistance.

MATERIALS AND METHODS

The susceptible (LE), malathion- and fenitrothion-resistant (Rm and Rf) strains of the rice brown planthopper and the small brown planthopper were used. The history of the LE,[2)] Rm and Rf strains[3)] of the rice brown planthopper and the small brown planthopper[4)] was described by Ozaki and Kassai. The Rm strain of the two planthoppers was crossed with the LE strain of individual planthoppers in different ratios, and the offsprings obtained were further reared for two generations.

The susceptible (S) and organophosphate-carbamate resistant (Rop-c) strains of the green rice leafhopper[1)] were also used. The offsprings obtained by crossing the Rop-c and S strains at different ratios were further reared for two generations. All these insects were reared on rice seedling under 25±1°C, 16-hr illumination per day.

Takatsuki and Sapporo strains of the housefly were also used in this experiment. Takatsuki strain was supplied by Research Laboratory of Dainippon-Jochugiku Co., Ltd., and Sapporo strain by the Laboratory of Applied Entomology and Nematology, Faculty of Agriculture, Nagoya University.

The insecticides used in this experiment are shown in Table 1. These insecticides were diluted to appropriate concentrations with acetone (for the rice brown planthopper, green rice leafhopper and housefly) or methanol (for the small brown planthopper whose body size is much smaller). The acetone or methanol solutions were applied topically to the abdomen of adult females 3 to 5 days after the emergence of the planthoppers and the green rice leafhopper, or to the thorax of houseflies using a microsyringe. Volumes applied were 0.5 μl for the leafhopper and the housefly, 0.25 μl for the rice brown planthopper and 0.036 μl for the small brown planthopper.

In some cases with the small brown planthopper, the residual contact method was also employed as described by Kassai and Ozaki[5)]: 2 μl of acetone solution of various concentrations was dropped into a glass tube (1.1 cm in diameter and 10.4 cm in length), and then 50 μl of acetone was added to each tube in order to spread the insecticide uniformly on the inner surface of the tube. After complete evaporation of acetone, ten fifth-instar larvae were placed in each tube and kept in contact with a thin film of insecticide for 3 hr.

Table 1 Name and purity of insecticides tested.

Common name	Purity (%)
Pyrethrins	67.7
Allethrin	83.8
Resmethrin	94.0
Furamethrin	87.2
Tetramethrin	98.0
Fenpropathrin	97.0
Malathion	95.5
Fenitrothion	97.3
Carbaryl	99.3
MTMC	100

Ten treated planthoppers or green rice leafhoppers were transferred into a glass vial (3 cm in diameter and 12 cm in length) containing rice seedlings (5 to 7 cm in length, three per vial). Ten treated houseflies were transferred into each petri dish (9 cm in diameter) where a piece of sponge soaked in a 10% sugar solution was placed. These containers were kept in a room maintained at 25±1°C. Mortality was recorded 24 hr after application.

RESULTS AND DISCUSSION

1. *Insecticidal Activity of Pyrethroids against the Planthoppers*

LD_{50} values of the pyrethroids except fenvalerate in the susceptible (LE), Rm and Rf strains of the rice brown planthopper (topical application method) and the small brown planthopper (residual contact method) are given in Tables 2 and 3. The LD_{50} values of resmethrin, permethrin and fenpropathrin in the LE strain of the rice brown planthopper were comparable or higher than the conventionally used malathion, carbaryl and MTMC (*m*-tolyl methylcarbamate). It may be indicated that these three pyrethroids are potentially active enough to control this insect. However, the LD_{50} values of allethrin and tetramethrin were larger than that of fenitrothion. It is suggested that they might not be effective for its control.

The resistance level of the Rm and Rf strains

Table 2 LD_{50} values by topical application method of pyrethroids in susceptible (LE), malathion- and fenitrothion-resistant (Rm and Rf) strains of the rice brown planthopper.

Insecticide	LE strain		Rm strain		Rf strain	
	LD_{50}[a]	$1/b$[b]	LD_{50}	$1/b$	LD_{50}	$1/b$
Allethrin	10.7	0.31	8.36	0.34	20.9	0.36
Resmethrin	4.73	0.41	106	0.56	196	0.48
Tetramethrin	127	0.43	6711	0.36	8724	0.39
Permethrin	4.47	0.44	113	0.51	156	0.63
Fenpropathrin	2.31	0.36	60.3	0.58	71.5	0.52
Malathion	3.37	0.28	112	0.33	71.8	0.46
Fenitrothion	6.59	0.32	71.4	0.38	336	0.29
Carbaryl	0.53	0.27	1.61	0.29	1.82	0.25
MTMC	1.24	0.15	4.10	0.20	—	—

[a] μg per gram of body weight of the female adult.
[b] Heterogeneity in susceptibility.

Table 3 LD_{50} values by residual contact method of pyrethroids in susceptible (LE), malathion- and fenitrothion-resistant (Rm and Rf) strains of the small brown planthopper.

Insecticide	LE strain		Rm strain		Rf strain	
	LD_{50}[a]	$1/b$	LD_{50}	$1/b$	LD_{50}	$1/b$
Pyrethrins	1.27	0.32	1.05	0.30	1.25	0.32
Allethrin	0.50	0.28	0.68	0.41	0.88	0.26
Resmethrin	0.22	0.40	1.62	0.42	2.51	0.35
Furamethrin	4.31	0.37	10.9	0.57	11.8	0.59
Tetramethrin	14.7	0.68	333	0.30	281	0.24
Permethrin	3.39	0.44	2.75	0.47	3.02	0.41
Fenpropathrin	2.00	0.43	2.00	0.56	1.38	0.57
Malathion	0.24	0.26	49.5	0.44	—	—
Fenitrothion	0.040	0.15	—	—	1.77	0.90
MTMC	0.029	0.13	0.078	0.18	0.047	0.23

[a] μg per test tube (1.1×10.4 cm).

of the rice brown planthopper were 33- and 51-folds to malathion and fenitrothion, respectively. LD_{50} values of allethrin in the Rm and Rf strains were almost the same as those in the LE strain. However, both Rm and Rf strains were found to have cross-resistance to resmethrin, tetramethrin, permethrin and fenpropathrin.

As shown in Table 3, the LD_{50} values of pyrethroids in the LE strain of the small brown planthopper ranged from 0.22 μg/test tube for resmethrin to 14.7 μg/test tube for tetramethrin. As compared to fenitrothion and MTMC, pyrethroids have less insecticidal activity against this insect. However, resmethrin and allethrin showed insecticidal activity similar to that of malathion, and thus they have enough potential activity to control this insect.

The resistance level of the Rm and Rf strains of the small brown planthopper to malathion and fenitrothion were about 206- and 44-fold, respectively. Insecticidal activities of pyrethrins, allethrin, permethrin and fenpropathrin against the Rm and Rf strains were similar to those against the LE strain. Thus the Rm and Rf strains of the small brown planthopper did not show cross-resistance to these four pyrethroids.

Relative toxicity of various pyrethroids to malathion was calculated on the basis of LD_{50} values in both planthoppers (Table 4). The

Table 4 Relative toxicity of pyrethroids against the rice brown planthopper and the small brown planthopper.

Insecticide	Relative toxicity	
	RBP[a]	SBP[b]
Allethrin	31	48
Resmethrin	71	109
Tetramethrin	2.7	1.6
Permethrin	75	7.8
Fenpropathrin	146	12
Malathion	100	100

[a] Rice brown planthopper.
[b] Small brown planthopper.

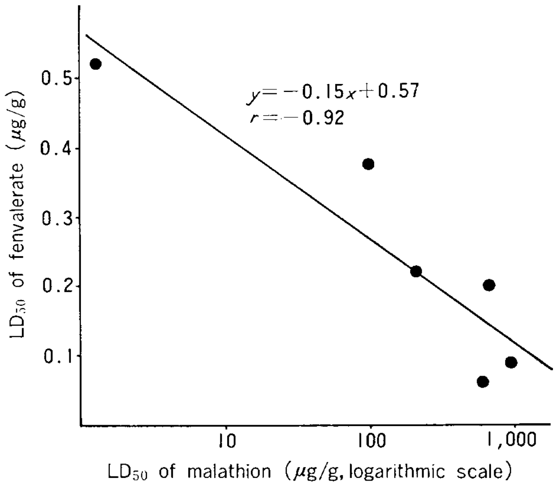

Fig. 1 Relationship between the insecticidal activity of malathion and that of fenvalerate against green rice leafhopper.

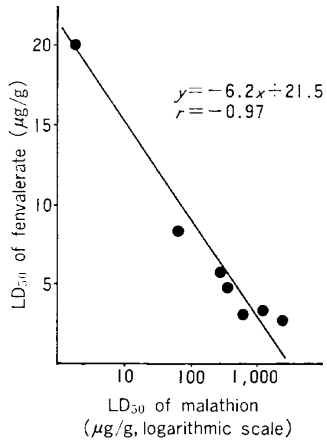

Fig. 2 Relationship between the insecticidal activity of malathion and that of fenvalerate against brown planthopper.

relative toxicities of allethrin, resmethrin and tetramethrin seemed to be equivalent between the two planthoppers. In contrast, insecticidal activities of permethrin and fenpropathrin to the rice brown planthopper were comparable to that of malathion, but were lower to the small brown planthopper. It is suggested that some of the pyrethroid insecticides have species specificity for the two planthoppers.

2. *Malathion Resistance Level and the Insecticidal Activity of Fenvalerate to the Two Planthoppers, the Leafhopper and the Housefly*

The relationships between the malathion resistance level and the LD_{50} values of fenvalerate in the green rice leafhopper and the rice brown planthopper were shown in Figs. 1 and 2. The various resistant populations of the green rice leafhopper used in this experiment showed 75-, 190-, 481-, 523- and 768-fold resistance to malathion. Higher insecticidal activity of fenvalerate to these populations was observed in more resistant strains. The LD_{50} value in the Rop-c strain having 768-fold malathion resistance was 1/6 of that in the S strain.

The various resistant populations of the rice brown planthopper showed 19-, 81-, 102-, 187-, 358- and 710-fold resistance to malathion. The LD_{50} values of fenvalerate in these populations became smaller as the malathion resistance level became higher. Relatively sharp decrease of the LD_{50} values against the rice brown planthopper was observed as compared with the green rice leafhopper, so that the LD_{50} value in the Rm strain with a 710-fold malathion resistance level was 1/8 of that in the LE strain.

The LD_{50} values of fenvalerate in the LE strain and two malathion resistant (Rm-1 and Rm-2) populations of the small brown planthopper are shown in Table 5. The insecticidal activity of fenvalerate was stronger to the highly resistant population than to the slightly resistant one. Although only two strains of this insect were tested, a relationship between the malathion resistance level and the insecticidal activity of fenvalerate similar to those in the rice brown planthopper and the green rice leafhopper may be assumed.

The LD_{50} values of malathion and fenvalerate

Table 5 LD_{50} values of malathion and fenvalerate in the malathion resistant strains of the small brown planthopper.

Populathion (Strain)	Malathion		Fenvalerate	
	LD_{50} (μg/g)	*R/S*	LD_{50} (μg/g)	*S/R*
Rm-1	244	144	0.10	12.2
Rm-2	77.5	46	0.15	8.1
S (LE)	1.70	—	1.22	—

Table 6 LD_{50} values of malathion and fenvalerate in the Takatsuki and Sapporo strains of the housefly.

Insecticide	LD_{50} (μg/g)		Ratio
	Takatsuki	Sapporo	
Fenvalerate	3.92	6.04	1.5
Malathion	19.9	10,198	512

in the Takatsuki and Sapporo strains of the housefly are shown in Table 6. Although the malathion resistance level of the Sapporo strain was 512 times as high as that of the Takatsuki strain, the LD_{50} value of fenvalerate in the former was slightly higher, indicating that malathion-resistant houseflies did not show cross-resistance to this insecticide. It may, therefore, be considered that the negative relationship between the malathion resistance level and the insecticidal activity of fenvalerate is specific to the planthoppers and the green rice leafhopper. However, further examination of this relationship should be made using as many species and/or strains as possible.

As indicated above, the insecticidal activities of fenvalerate against the two planthoppers and the green rice leafhopper were higher in the resistant strains than in the susceptible strains. The insecticidal activity of fenvalerate against the rice brown planthopper, the small brown planthopper and the green rice leafhopper was negatively correlated with the degree of the development of malathion resistance.

Fenvalerate showed more specific insecticidal activities to the two planthoppers and the green rice leafhopper than other pyrethroid insecticides, because Rm strains of the two planthoppers showed cross-resistance to several pyrethroids of cyclopropane carboxylate. Tanaka *et al.*[6] and Ozaki and Kassai[4] reported that the insecticidal activities of DDT and γ-BHC to malathion-resistant strains were two to four times higher compared with susceptible strain of the green rice leafhopper or the small brown planthopper. Yamamoto *et al.*[7] reported that the inhibitory activity of *N*-propyl carbamate on modified acetylcholinesterase is negatively correlated with the *N*-methyl carbamate resistance level, and revealed that combined application of *N*-methyl and *N*-propyl carbamates showed a marked synergistic effect to the Rop-c strain of the green rice leafhopper.[8] It is of interest that the insecticidal pattern of fenvalerate to various resistant strains of the two planthoppers and the leafhopper examined here is similar to that of DDT or γ-BHC. The reason why the insecticidal activities of DDT, γ-BHC and fenvalerate to the Rm strains of the two planthoppers and the Rop-c strain of the green rice leafhopper are larger than those of the corresponding susceptible strains should be clarified in further studies.

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要 約

ウンカ・ヨコバイ類およびイエバエの薬剤抵抗性系統に対するピレスロイド剤の殺虫作用

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トビイロウンカとヒメトビウンカの感受性 (LE) 系統に対するピレスロイド剤の殺虫力はカーバメート剤より低く，malathion と fenitrothion と同等かやや低かった．トビイロウンカの malathion と fenitrothion 抵抗性 (Rm と Rf) 系統は allethrin に交差抵抗性を示さなかったが，resmethrin, permethrin, tetramethrin と fenpropathrin には交差抵抗性を示した．ヒメトビウンカの Rm と Rf 系統は pyrethrins, allethrin, permethrin と fenpropathrin に交差抵抗性を示さなかったが，furamethrin, resmethrin と tetramethrin には低レベルの抵抗性を示した．

トビイロウンカ，ヒメトビウンカとツマグロヨコバイに対する fenvalerate の殺虫力は malathion に対する抵抗性レベルが高くなるにつれて増大し，malathion に 710 倍，144 倍と 768 倍のトビイロウンカ，ヒメトビウンカとツマグロヨコバイにおける fenvalerate の LD_{50} 値はそれぞれの感受性系統の 1/8, 1/12 と 1/6 であった．このような諸結果はイネを加害するウンカ・ヨコバイ類に対する fenvalerate の殺虫作用が malathion に対する抵抗性の発達程度に負の関連性のあることを示している．なお，イエバエには同様な現象はみられなかった．