Synthetic Pyrethroid Resistance in the Brown Planthopper

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ABSTRACT

Brown planthopper, which had developed resistance to organophosphorus and carbamate insecticides, was highly resistant to synthetic pyrethroids of primary alcohol esters, such as permethrin and phenothrin. Resistance to pyrethroids of secondary alcohol esters, such as cypermethrin, was low or moderate. No cross-resistance to DDT was detected. Synergism studies revealed that hydrolysis by esterases, closely associated with resistance to malathion, several other organophosphorus and carbamate insecticides, and, to a lesser extent, microsomal oxidation played decisive roles in the observed resistance. With modification of physicochemical and biological properties of the chemicals, improvement of formulations and application technology as well as better understanding of the nature of resistance, synthetic pyrethroids may become a very important group of insecticides for the control of brown planthopper and some other insect pest of rice.

The modern synthetic pyrethroids, first of which appeared in 1973 (Elliott *et al.*, 1973) possess almost all the favorable characteristics of ideal insecticides. They are extraordinarily toxic to insects and at the same time relatively safe for mammals. They are biodegradable, yet persistent enough for agricultural uses.

In 1979 while working on organophosphorus and carbamate resistance, we found that laboratory and field strains of brown planthopper in Taiwan were resistant to one synthetic pyrethroid, permethrin. Studies have been carried out since then, and their results are reviewed in the following.

Use of Synthetic Pyrethroids for Rice Insect Control in Taiwan

Table 1 lists the synthetic pyrethroids recommended. In 1976, tetramethrin was introduced as a mixture with MTMC. It is believed that this compound was only sparingly, if ever, used. Two years later, permethrin and fenvalerate, and in 1981 phenothrin were recommended for green rice leafhopper control. Then,

Table 1. Synthetic Pyrethroid Insecticides Recommended for the Control of Brown Planthopper and Green Rice Leafhopper in Taiwan

Synthetic Pyrethroid	Year of Introduction[1]	
	Brown Planthopper	Green Rice Leafhopper
Tetramethrin MTMC (1:9)	1976	1976
Fenvalerate	–	1978
Permethrin	1980	1978
Phenothrin BPMC (1:10)	1981	1981
Phenothrin Fenitrothion BPMC (2:5:5)	1981	1981

[1] Compiled from Plant Protection Manual (1978, 1980, 1982).

Table 2. Susceptibility to Several Insecticides of a Susceptible (S), Malathion-Resistant (R-mal), Isoprocarb-Resistant (R-mipc) and 4 Field Strains of Brown Planthopper in Taiwan During 1979-1980 (Chung *et al.*,1982)

Insecticide	LC$_{50}$ µg/ml	RR[1]					
	S	R-mal	R-mipc	Pingtung	Meinung	Chiayi	Taichung
Permethrin	5.8	171	122	74	121	83	71
Fenvalerate	8.3	5	5	1.6	2.9	3.0	1.7
Malathion	23	1183	574	536	359	437	288
Methyl parathion	29	82	44	41	48	84	32
Isoprocarb	21	22	41	14	15	18	10
Propoxur	6.7	72	76	36	46	36	19

[1] Resistance ratio=LC$_{50}$ of each strain/LC$_{50}$ of S strain.

Table 3. Susceptibility to Four Synthetic Pyrethroids and DDT of a Susceptible (S), Isoprocarb-Resistant (R-mipc) and 6 Field-Strains of Brown Planthopper in Taiwan During 1982 (Sun *et al.*, 1984)

Strain	Permethrin		Cypermethrin		Deltamethrin		Fenvalerate		DDT	
	LC$_{50}$ mg/ml	RR[1]	LC$_{50}$ µg/ml	RR	LC$_{50}$ µg/ml	RR	LC$_{50}$ µg/ml	RR	LC$_{50}$ mg/ml	RR
Pingtung	2.53	843	9.17	26	14.6	15	5.32	16	–	–
Meinung	2.38	793	5.53	15	39.2	41	13.22	40	0.121	3.7
Hsinshih	3.27	1090	7.53	21	6.7	7	16.67	51	0.114	3.5
Chiayi	2.15	717	4.0	11	9.1	10	4.70	14	0.112	3.4
Taichung	0.22	73	0.48	1	2.0	2	2.30	7	0.062	1.9
Hsinchu	1.46	487	5.29	15	14.3	15	4.80	15	0.128	3.9
R-mipc	2.64	880	8.47	24	44.2	27	13.76	42	–	–
S	0.003	–	0.36	–	0.95	–	0.33	–	0.022	–

[1] Resistance ratio.

Table 4. Susceptibility to Some Synthetic Pyrethroids of a Susceptible (S), Malathion-Resistnat (R_m) and Fenitrothion-Resistant (R_f) Strains of Brown Planthopper Using Topical Application Method (Ozaki and Kassai, 1984)

Insecticide	LD$_{50}$ µg/g	RR[1]	
	S	R_m	R_f
Allethrin	10.7	0.8	2
Resmethrin	4.73	22	41
Tetramethrin	127	53	69
Permethrin	4.47	25	35
Fenpropathrin	2.31	26	31
Malathion	3.37	33	21
Fenitrothion	6.59	11	51

[1] Resistance ratio.

Table 5. Susceptibility to Some Synthetic Pyrethroids of a Susceptible (S), Malathion-Resistant (R_m) and Fenitrothion-Resistant (R_f) Strains of Brown Planthopper Using Residual Contact Method (Ozaki and Kassai, 1984)

Insecticide	LC$_{50}$ µg/tube	RR[1]	
	S	R_m	R_f
Pyrethrins	1.27	0.8	1.0
Allethrin	0.50	1.4	1.8
Resmethrin	0.22	7.4	11
Furamethrin	4.31	2.5	2.7
Tetramethrin	14.7	23	19
Permethrin	3.39	0.8	0.9
Fenpropathrin	2.00	1.0	0.7
Malathion	0.24	206	–
Fenitrothion	0.04	–	44

[1] Resistance ratio.

in 1980 and 1981, permethrin and phenothrin were registered, respectively, for brown planthopper control. The latter was recommended to be used as mixtures with BPMC and fenitrothion. Due to the high costs and mediocre performance in the field, these pyrethroids are unable to compete with carbamate and organophosphorus compounds and thus have not gained popularity even until now.

Synthetic Pyrethroid Resistance in Brown Planthopper in Taiwan

A survey in late 1979 and early 1980 using spraying method indicated brown planthoppers from 4 locations were resistant to one synthetic pyrethroid, permethrin (resistance ratios 70-120x), while remaining susceptible to another pyrethroid, fenvalerate (Table 2). The same strains of brown planthopper showed high levels of malathion resistance and moderate resistance to methyl parathion, isoprocarb and propoxur. In addition, laboratory-selected brown planthopper resistant to malathion and isoprocarb possessed similar resistance patterns to these 2 pyrethroids.

Since by then, the brown planthopper had hardly been exposed to the synthetic pyrethroids as a group, we postulated that the permethrin resistance detected must have represented cross-resistance from insecticides used previously, which include organochlorine, organophosphorus and carbamate compounds. We further postulated that permethrin might have a metabolic fate different from that of fenvalerate for the fact that despite of extensive uses of various kinds of insecticides, brown planthopper with ca. 100-fold resistance to permethrin remained susceptible to fenvalerate.

A follow-up survey in 1982 revealed up to 1000-fold resistance to permethrin in field strains of brown planthopper(Table 3). Yet, resistance levels to other 3 synthetic pyrethroids, cypermethrin, deltamethrin and fenvalerate, only ranged from 10- to 50-fold.

Synthetic Pyrethroid Resistance in Brown Planthopper in Japan

Ozaki and Kassai (1982) first reported that two field strains of brown planthopper collected in 1979 with multiple resistance to organophosphorus and carbamate insecticides were still susceptible to natural pyrethrins. In a later study using topical application, the same authors found that brown planthopper resistant to malathion (33-x) and fenitrothion (51-x), while remaining susceptible to allethrin, were resistant to resmethrin, tetramethrin, permethrin and fenpropathrin (22 to 69-x) (Table 4) (Ozaki and Kassai 1984). Using residual contact method, however, they observed somewhat different resistance patterns for the same strains of brown planthopper. The malathion- and fenitrothion-resistant brown planthoppers showed significant resistance to tetramethrin and resmethrin only; no resistance to pyrethrins, allethrin, furamethrin, permethrin and fenpropathrin was detected (Table 5). In the same study, they found that brown planthopper having 710-fold resistance to malathion was more susceptible (8-x) to fenvalerate than the susceptible strain. Later, Kassai and Ozaki (1984) selected malathion-resistant (360-x) brown planthopper with fenvalerate and monitored the changes of susceptibility. While the LD_{50}'s of fenvalerate went up by 11-fold in 19th generation of selection, the LD_{50}'s of malathion decreased significantly in the first five to six generations and reached 1/4 of the parent strain in the 19th generation. The authors suggested that in the course of selection, the changes of susceptibility to fenvalerate and malathion were independent from each other. An increase of susceptibility to several other organophosphorus insecticides during selection with fenvalerate was also observed.

Causes of Resistance to Synthetic Pyrethroids in the Brown Planthopper

Non-metabolic mechanism. This mechanism is excluded for two reasons. A non-metabolic resistance mechanism is generally extended to all pyrethroids. Yet, resistance levels to permethrin were much greater than those to three other pyrethroids (Table 3). Secondly, cross-resistance to DDT should exist if nerve insensitivity were involved in resistance. Hardly any resistance to DDT was detected in the field strains showing hundred-folds of resistance to permethrin (Table 3).

Metabolic mechanism. Soderlund and Casida

(1977) studied the metabolism rates of 44 pyrethroids in mouse liver microsomal systems and concluded that the highly insecticidal α-cyano-3-phenoxy-benzyl esters were least susceptible to metabolic attack due to both reduced esterase and oxidase rates. Upon this assumption, a number of pyrethroid insecticides of primary and secondary alcohol esters were tested on a susceptible and a resistant strains of brown planthopper.

All secondary alcohol esters were much more toxic against the susceptible strain than the primary alcohol esters (Table 6). Similarly, those pyrethroids without an α-cyano group were much less toxic than those with an α-cyano group against the resistant Hsinshih strain. Furthermore, the resistant strain developed much lower levels of resistance to the secondary alcohol esters as a group, except fenpropathrin.

Table 6. Toxicity of Two Types of Synthetic Pyrethroids Against a Susceptible (S) and a Resistant Hsinshih Strains of Brown Planthopper (Dai and Sun 1984)

Synthetic Pyrethroid	S	Hsinshih	
	LC$_{50}$ μg/ml	LC$_{50}$ μg/ml	RR[1]
Primary alcohol ester			
Kadethrin	24.9	2221	89
Phenothrin	407	3849	10
Tetramethrin	670	76680	115
Permethrin	7.3	2751	377
Secondary alcohol ester			
Cypermethrin	0.13	5.1	51
Deltamethrin	0.95	6.7	7
Fenvalerate	0.33	16.7	56
Fenpropathrin	1.74	185	106
Flucythrinate	1.84	6.0	3
Tralomethrin	0.62	9.5	16

[1] Resistance ratio.

a. *Esterases*. To assess the involvement of esterases in the detoxication of synthetic pyrethroids in brown planthopper, a synergist known to inhibit the esterases, TBPT, was tested for its effect on the killing and knockdown actions of these insecticides. While only phenothrin was significantly synergized in the susceptible strain, the toxicity of permethrin, phenothrin and fenpropathrin was enhanced to definitely significant extents against the resistant field strains of brown planthopper (Table 7). Synergism of cypermethrin by TBPT was much limited. In terms of doses of insecticides to produce 50% knockdown within 30 min, the synergistic effect of TBPT on permethrin was much more pronounced than on cypermethrin in the resistant strains (Table 8). Besides, TBPT reduced the recovery of brown planthopper knocked down by permethrin, to a lesser extent by cypermethrin (Dai and Sun, 1984).

Pyrethroids of primary alcohol esters may have been easily hydrolyzed by the esterases which were present with high activity in the brown planthopper resistant to organophosphorus and carbamate insecticides as reported by Chung and Sun (1983), while pyrethroids with an α-cyano group may have been attacked by the esterases only slightly. The enzyme previously shown to cause resistance to organophosphorus insecticides carboxylesterase E_4 in *Myzus persicae* was reported to be responsible for cross resistance to permethrin (Devonshire and Moores, 1982). Esterases from organophosphorus-resistant strain of the green rice leafhopper were found active in hydrolyzing malathion, paraoxon, as well as fenvalerate (Motoyama *et al.*,1984).

Fenpropathrin, an α-cyano-3-phenoxybenzyl alcohol ester, contains 2, 2, 3, 3-tetramethyl cyclopropanecarboxylic acid. Its high intrinsic toxicity to the susceptible brown planthopper (Table 6) might be attributed to the cyano-group, while its low efficacy against a resistant field strain might be due to this unique moiety which made this compound more vulnerable to hydrolysis than the other secondary alcohol esters as evidenced by the synergism by TBPT detected (Table 7).

b. *Microsomal oxidases.* Chung and Sun (1983) stated that microsomal oxidation did not seem to be the primary degradation pathway involved in the metabolic resistance to organophosphorus and carbamate insecticides in brown planthopper as it usually is in many other insects. However, the involvement of microsomal oxidation as revealed by the synergistic effect of pb was considerable (Tables 7 and 8). In the case of phenothrin and fenpropathrin, the extent of synergism by pb actually approached that by TBPT.

That pyrethroid ester cleavage could be both hydrolytic and oxidative in *Periplaneta americana* was proposed by Holden (1979), and in higher animals by several workers as reviewed by Casida

Table 7. Synergism of Permethrin, Cypermethrin, Phenothrin and Fenpropathrin by pb and TBPT in a Susceptible (S) and Two Resistnat Strains of Brown Planthopper (Dai and Sun, 1984)

Treatment	S			Taichung			Hsinshih		
	LC_{50} μg/ml	SR[1]	SD[2] μg/ml	LC_{50} μg/ml	SR	SD μg/ml	LC_{50} μg/ml	SR	SD μg/ml
Permethrin									
alone	7.3			59.5			2751		
+ pb[3]	3.3	2	4.0	7.9	8	51.6	816	3	1935
+ TBPT[3]	3.2	2	4.1	1.0	60	58.5	24.1	114	2727
Cypermethrin									
alone	0.1			0.6			5.1		
+ pb	0.1	1	0	0.4	2	0.2	1.4	4	3.7
+ TBPT	0.1	1	0	0.1	6	0.5	0.4	13	4.7
Phenothrin									
alone	407			–			3849		
+ pb	277	2	130	–	–	–	275	14	3574
+ TBPT	63.4	6	344	–	–	–	107	36	3742
Fenpropathrin									
alone	0.7			–			185		
+ pb	0.6	1	0.1	–	-	–	7.0	26	178
+ TBPT	0.4	2	0.3	–	–	–	2.7	69	182

[1] Synergism ratio = LC_{50} unsynergized/LC_{50} synergized.

[2] Synergism difference = LC_{50} unsynergized - LC_{50} synergized.

[3] Maximal sublethal concentrations of the synergists were sprayed on the planthoppers 1 h before insecticide treatment. pb: 2 μg/ml for S and 5 μg/ml for field strains, TBPT: 2 μg/ml for S and 10 μg/ml for field strains.

Table 8. Synergism by pb and TBPT of the Knockdown Action of Permethrin and Cypermethrin in a Susceptible (S) and Two Resistant Strains of Brown Planthopper (Dai and Sun, 1984)

Treatment	S			Taichung			Hsinshih		
	EC_{50}[1] μg/ml	SR[2]	SD[3] μg/ml	EC_{50} μg/ml	SR	SD μg/ml	EC_{50} μg/ml	SR	SD μg/ml
Permethrin									
alone	1.7			54.1			231		
+ pb[4]	1.3	1.3	0.4	45.6	1.2	8.5	159	1.5	72
+ TBPT[4]	0.7	2.4	1.0	31.3	1.7	22.8	61.9	3.7	169
Cypermethrin									
alone	1.2			1.8			3.0		
+ pb	0.9	1.3	0.3	0.8	2.3	1.0	1.8	1.7	1.2
+ TBPT	0.3	4.0	0.9	0.6	3.0	1.2	1.0	3.0	2.0

[1] The concentration to produce 50% knockdown of the population in 30 min.

[2] Synergism ratio.

[3] Synergism difference.

[4] The container was coated with a mixture of the insecticide and the synergist. The concentrations not producing any knockdown within 60 min were used. pb: 2 μg/ml, TBPT: 5 μg/ml.

and Ruzo (1980). Therefore, one possible explanation for the phenomenon observed in our study is that the microsomal oxidative enzymes of brown planthopper might be unusually active toward the ester linkage of these pyrethroids of primary alcohol ester and fenpropathrin. In the case of phenothrin and fenpropathrin, the ester bond might be more or less equally vulnerable to both hydrolytic and oxidative cleavage. *In vitro* studies are being carried out to confirm this speculation.

The Future of Synthetic Pyrethroids for Brown Planthopper Control

Although the pyrethroids are comparably effective against the brown planthopper as the carbamate insecticides in laboratory and greenhouse tests, they have not been extensively used in the field. In addition to the high cost, great fish toxicity and less-than-satisfactory performance in the field, one pyrethroid, deltamethrin, was reported to induce resurgence of this planthopper (Chelliah and Heinrichs, 1980). Lack of volatility and systemic property limits their effectiveness in controlling brown planthopper feeding at the base of the rice plants where little foliar spray reaches. Improvements of the physicochemical and biological properties, the formulations and application technology, and better understanding of the factors causing resurgence and resistance may eventually lead to the development of pyrethroids with efficacy in the rice field equivalent to or better than the carbamate insecticides now being used for brown planthopper control.

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