Topical and Injection Toxicities of Some Pyrethroids to the German Cockroach, *Blattella germanica* (Dictyoptera: Blattellidae)¹

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The topical and injection toxicities of some synthetic pyrethroids to the German cockroach, *Blattella germanica* L., were investigated as part of a study of the selective toxicity of different insecticides in a number of insects. Results of the study indicated that on a per gram body weight basis, the synthetic pyrethroids were not as toxic to the cockroach as they were to the armyworm in topical application treatments. With the exception of fenpropathrin, fenitrothion (an OP insecticide) was more toxic than all the synthetic pyrethroids tested at 24 hr, and was of about equal toxicity with all the pyrethroids at 48 and 72 hr after treatment. Fenvalerate, however, was the most toxic at 72 and 96 hr when LD₅₀ values were compared. All the synthetic pyrethroids were more toxic by injection than by topical application. Cyanide (CN) containing compounds were also relatively more toxic than their non-CN containing analogues. The cuticle of the cockroach provides greater resistance to the penetration of synthetic pyrethroids than the cuticles of the armyworm, cutworm or housefly. Reduced cuticle penetration probably contributes to the lower toxicities of the synthetic pyrethroids in topical application to the German cockroach.

INTRODUCTION

The good qualities of synthetic pyrethroids that continue to make them popular in pest control are very often reported (WOLFENBARGER et al., 1977; HARRIS et al., 1977; LHOSTE and PIEDALLU, 1977; EL-GUINDY et al., 1982, etc.). The synthetic pyrethroids (phenothrin, cyphenothrin, permethrin, cypermethrin, S-5439, fenvalerate and fenpropathrin) were reported to very toxic to the armyworm, *Pseudaletia separata* (WALKER) (BREMPONG-YEBOAH et al., 1982, 1983) and quite toxic to the tobacco cutworm, *Spodoptera litura* (FABRICIUS) (BREMPONG-YEBOAH et al., 1984) in both topical and injection studies although no clear chemical structure/toxicity relationships were observed.

The cockroach is well known as a common household, laboratory and general pest which is thought to feed on almost anything. The peculiar scent associated with cockroaches is also a cause for dislike by many. As part of a study of the selective toxicity of some synthetic pyrethroids, it was decided to include the German cockroach as a test species and also to see if there were any differences between topical and injection toxicities and, if so why.

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MATERIALS AND METHODS

Cockroaches, *B. germanica* L., were obtained from the National Institute of Health, Tokyo, and were maintained on a commercial artificial diet, CE-2, (Nihon Clear Co., Ltd., Tokyo, Japan) at $25 \pm 1^\circ\text{C}$ and a 16–8 light: dark regime.

After CO_2 anaesthesia, adult female insects without oothecae attached were separated on the basis of colour and size (CORNWELL, 1968), into a container apart from the rearing box and provided with CE-2 and water. After 24 hr the selected insects were treated under CO_2 anaesthesia with various doses of the synthetic pyrethroids in $0.72 \mu\text{l}$ of acetone per insect between the coxae on the third thoracic sternum. Insects for injection were similarly anaesthetized and injected with $0.36 \mu\text{l}$ of the insecticide solutions through the 7th–8th or 8th–9th abdominal segments using a glass-fitted micro-applicator (Kiya Seisakusho Co., Ltd., Tokyo, Japan). Initial injection experiments using only acetone revealed that volumes of more than $0.48 \mu\text{l}$ per insect caused mortality in excess of 20% at 24 hr after treatment. Therefore a volume of $0.36 \mu\text{l}$ (half of the topically applied quantity) was adopted in methods similar to those reported for the armyworm by BREMPONG-YEBOAH et al. (1983). Treated insects were supplied with chips of CE-2 and water in paper-padded 250 ml plastic cups for up to 48 hr in injection and 96 hr in topical application treatments and placed at $25 \pm 1^\circ\text{C}$ and a 16–8 light: dark regime throughout the period of observation. Behavioural symptoms following treatment and also mortality results at 24, 48, 72 and 96 hr were taken and analysed according to FINNEY (1951) on a TRS-80 microcomputer (Tandy-Radio-Shack Co., Ltd., Texas, USA). Topical and injection LD_{50} s were compared according to SUN (1950) with fenitrothion as standard, and were also compared according to YAMASAKI and ISHII (1954) with those of the armyworm (BREMPONG-YEBOAH et al., 1982), and with those of the tobacco cutworm (BREMPONG-YEBOAH et al., 1984) and housefly (BREMPONG-YEBOAH et al., unpublished) which had been treated similarly. There were ten insects (mean weight: 117 ± 13 mg per female) per replicate, with four replicates of each dose in the topical application treatments and three in the injection treatments. Where there was uncertainty in the results obtained whole experiments were repeated in two or three more replications and the results were pooled with the previous ones for analyses. Control insects were treated with acetone. Lindane and fenitrothion were included for comparison purposes. The insecticides used were the same as those previously described in BREMPONG-YEBOAH et al. (1982).

RESULTS AND DISCUSSION

Initial symptoms following topical application were almost uniform in all the insecticides tested although the symptoms for lindane were not pronounced. Treated insects recovered from CO_2 anaesthesia but were paralyzed. With difficulty and great effort, they began to move slowly, sometimes pulling along a paralyzed leg or two. This period of knockdown and paralysis usually lasted for a period of less than 15 min and was followed by a period of hyperactivity. During the hyperactive phase, insects continuously dashed from wall to wall at great speed for 5–10 sec, stopping at intervals. This period of jerky and dashy movements continued for about 20 min in the synthetic pyrethroids and fenitrothion treatments, even when the insects were upside down.

Table 1. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 24 hr after topical application to the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.963(x-0.938)$	8.670	13.29	442.58	11.11	$p>0.90$
Cyphenothrin	$Y=5+2.142(x-0.734)$	5.420	21.27	31.77	154.86	$0.30>p>0.10$
Permethrin	$Y=5+1.414(x-0.813)$	6.501	17.74	94.84	51.89	$0.90>p>0.70$
Cypermethrin	$Y=5+1.387(x-0.418)$	3.006	38.35	46.13	106.65	$0.50>p>0.30$
S-5439	$Y=5+2.419(x-1.099)$	12.560	9.18	60.12	81.84	$0.30>p>0.10$
Fenvalerate	$Y=5+1.401(x-0.119)$	1.315	87.68	19.63	250.64	$0.30>p>0.10$
Fenpropathrin	$Y=5+0.384(x+0.579)$	0.264	436.71	5,046.14	0.97	$0.50>p>0.30$
Lindane	$Y=5+2.034(x-0.773)$	5.929	19.45	38.02	129.40	$0.50>p>0.30$
Fenitrothion	$Y=5+1.009(x-0.062)$	1.153	100.00	49.20	100.00	$0.90>p>0.70$

Table 2. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 48 hr after topical application to the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.776(x-0.766)$	5.834	5.11	769.130	3.89	$0.90>p>0.70$
Cyphenothrin	$Y=5+1.968(x-0.616)$	4.130	7.21	28.314	105.71	$0.05>p>0.01$
Permethrin	$Y=5+1.462(x-0.591)$	3.899	7.64	52.006	57.55	$0.10>p>0.05$
Cypermethrin	$Y=5+1.527(x-0.327)$	2.123	14.03	23.354	128.17	$0.50>p>0.30$
S-5439	$Y=5+2.581(x-0.988)$	9.729	3.06	42.175	70.95	$0.50>p>0.30$
Fenvalerate	$Y=5+1.920(x+0.251)$	0.561	53.12	4.036	741.50	$0.90>p>0.70$
Fenpropathrin	$Y=5+0.409(x+0.751)$	0.260	114.60	2,716.421	1.10	$0.50>p>0.30$
Lindane	$Y=5+1.954(x-0.751)$	5.636	5.28	39.174	76.40	$0.70>p>0.50$
Fenitrothion	$Y=5+0.822(x-0.526)$	0.928	100.00	29.927	100.00	$0.70>p>0.50$

At very high doses (say, 16 μg/g) this activity did not take place and the paralysis period moved more or less directly into death. Control insects treated with acetone exhibited no jerky or dashing movements. Symptoms following the injection treatments did not greatly differ from those by topical application.

Table 1 shows the results of 24 hr topical application treatments. Based on LD₅₀ values, fenpropathrin was most toxic to the German cockroach. Fenitrothion (an organophosphorus (OP) insecticide) was also quite outstanding. At the same LD₅₀ level S-5439 was the least toxic. At the LD₉₅ level however, fenpropathrin turned out to be the least toxic (see slope of regression line), followed by phenothrin, permethrin and S-5439 all non-cyanide (CN) containing compounds. It is noteworthy that all the CN containing compounds were more toxic (LD₅₀ values) than corresponding non-CN-containing analogues.

At 48 hr the synthetic pyrethroids were not especially toxic to the German cockroach (Table 2). Lindane showed about the same toxicities as the synthetic pyrethroids, an observation very different from what had been seen in the armyworm and cutworm (BREMPPONG-YEBOAH et al., 1982, 1984). When LD₉₅ values are compared the CN containing compounds cyphenothrin, cypermethrin and fenvalerate were again more toxic than phenothrin, permethrin and S-5439, their respective non-CN-containing

Table 3. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 72 hr after topical application to the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.834 (x-0.409)$	2.564	9.25	239.883	12.38	$0.90 > p > 0.70$
Cyphenothrin	$Y=5+1.735 (x-0.511)$	3.243	7.31	28.774	103.26	$0.05 > p > 0.02$
Permethrin	$Y=5+1.673 (x-0.454)$	2.844	8.34	27.353	108.62	$0.01 > p > 0.001$
Cypermethrin	$Y=5+1.607 (x-0.099)$	1.256	18.87	13.243	224.40	$0.05 > p > 0.02$
S-5439	$Y=5+2.781 (x-0.961)$	9.141	2.59	— ^a	— ^a	$0.10 > p > 0.05$
Fenvalerate	$Y=5+2.190 (x+0.310)$	0.490	48.37	2.761	1,076.40	$0.50 > p > 0.30$
Fenpropathrin	$Y=5+0.370 (x+1.396)$	0.040	592.50	111.863	26.56	$0.90 > p > 0.70$
Lindane	$Y=5+1.198 (x-0.738)$	5.470	4.33	39.446	75.33	$0.90 > p > 0.70$
Fenitrothion	$Y=5+0.783 (x-0.626)$	0.237	100.00	29.710	100.00	$0.70 > p > 0.50$

^a Data could not be calculated.

Table 4. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 96 hr after topical application to the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.976 (x-0.240)$	1.738	11.29	84.333	11.04	$0.90 > p > 0.70$
Cyphenothrin	$Y=5+1.836 (x-0.441)$	2.761	7.09	21.677	42.84	$0.05 > p > 0.02$
Permethrin	$Y=5+1.756 (x-0.388)$	2.443	8.02	21.135	43.94	$0.01 > p > 0.05$
Cypermethrin	$Y=5+1.981 (x-0.044)$	1.107	17.70	— ^a	— ^a	$0.001 > p$
S-5439	$Y=5+2.776 (x-0.961)$	9.141	2.14	— ^a	— ^a	$0.01 > p > 0.05$
Fenvalerate	$Y=5+2.308 (x+0.317)$	0.482	40.86	2.489	373.08	$0.30 > p > 0.10$
Fenpropathrin	$Y=5+0.318 (x+1.691)$	0.020	980.00	2,999.63	0.31	$0.50 > p > 0.30$
Lindane	$Y=5+1.689 (x-0.684)$	4.830	4.05	45.411	20.41	$0.50 > p > 0.30$
Fenitrothion	$Y=5+0.983 (x+0.708)$	0.196	100.00	9.286	100.00	$0.50 > p > 0.30$

^a Data could not be calculated.

Table 5. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 24 hr after injection into the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.833 (x+0.737)$	0.183	1,958.46	17.258	86.88	$0.50 > p > 0.30$
Cyphenothrin	$Y=5+1.231 (x+0.271)$	0.536	668.65	11.614	128.85	$0.50 > p > 0.30$
Permethrin	$Y=5+1.211 (x+0.587)$	0.264	1,357.65	6.030	248.66	$0.90 > p >$
Cypermethrin	$Y=5+0.565 (x+0.208)$	0.619	578.99	504.662	2.97	$0.50 > p > 0.30$
S-5439	$Y=5+1.305 (x-0.184)$	1.528	234.55	27.860	53.82	$0.90 > p > 0.70$
Fenvalerate	$Y=5+1.361 (x+0.123)$	0.735	487.62	12.190	123.80	$0.30 > p > 0.10$
Fenpropathrin	$Y=5+0.969 (x+0.255)$	0.556	644.80	27.669	54.20	$0.30 > p > 0.10$
Lindane	$Y=5+1.980 (x-0.374)$	2.366	151.48	16.030	93.53	$0.50 > p > 0.30$
Fenitrothion	$Y=5+2.360 (x-0.550)$	3.584	100.00	14.994	100.00	$0.50 > p > 0.30$

Table 6. Dosage probit mortality regression equations, LD₅₀, LD₉₅, toxicity indices and probability values of some synthetic pyrethroids 48 hr after injection into the German cockroach, *Blattella germanica* L.

Insecticide	Regression equation	LD ₅₀ (μg/g)	Toxicity index	LD ₉₅ (μg/g)	Toxicity index	Pr
Phenothrin	$Y=5+0.898(x+0.874)$	0.134	1,499.25	9.078	90.20	$0.50 > p > 0.30$
Cyphenothrin	$Y=5+1.437(x+0.588)$	0.258	778.68	3.597	227.61	$0.50 > p > 0.30$
Permethrin	$Y=5+1.073(x+0.698)$	0.200	1,004.50	6.855	119.38	$0.90 > p$
Cypermethrin	$Y=5+0.670(x+0.639)$	0.230	873.47	65.615	12.47	$0.30 > p > 0.10$
S-5439	$Y=5+1.480(x+0.133)$	0.736	272.96	9.506	86.06	$0.50 > p > 0.30$
Fenvalerate	$Y=5+1.863(x+0.458)$	0.348	577.29	2.661	307.62	$0.90 > p > 0.70$
Fenpropathrin	$Y=5+0.819(x+0.713)$	0.194	1,035.61	19.724	41.48	$0.90 > p > 0.70$
Lindane	$Y=5+2.025(x-0.118)$	1.312	153.12	8.511	96.15	$0.50 > p > 0.30$
Fenitrothion	$Y=5+2.697(x-0.303)$	2.009	100.00	8.185	100.00	$0.50 > p > 0.30$

Table 7. A comparison of the topical and injection LD₅₀ values of the synthetic pyrethroids at 24 and 48 hr after treatment to the cockroach, *Blattella germanica* L.

Insecticide	24 hr			48 hr		
	Topical LD ₅₀ (μg/g)	Injection LD ₅₀ (μg/g)	P ₂₄ ^a	Topical LD ₅₀ (μg/g)	Injection LD ₅₀ (μg/g)	P ₄₈ ^a
Phenothrin	8.67	0.18	47.37	5.83	0.13	45.53
Cyphenothrin	5.42	0.53	10.11	4.13	0.25	16.00
Permethrin	6.50	0.26	24.62	3.89	0.20	19.49
Cypermethrin	3.00	0.62	4.85	2.12	0.23	9.23
S-5439	12.56	0.53	23.78	9.27	0.73	13.22
Fenvalerate	1.31	0.75	1.75	0.56	0.34	1.61
Fenpropathrin	0.26	0.55	0.47	0.26	0.19	1.34
Lindane	5.93	2.36	2.51	5.63	1.31	4.29
Fenitrothion	1.15	3.43	0.33	0.29	2.00	0.14

^a 'P' = Topical LD₅₀/Injection LD₅₀ as described by O'BRIEN (1960).

Table 8. A comparison of the 'Pseudo-Resistance' offered by the cuticles of the housefly, cutworm and armyworm to the penetration to topically applied insecticides with that offered by the cuticle of the German cockroach, *Blattella germanica* L.

Insecticide	$\frac{T_{ck}^a}{T_{hs}}$	$\frac{I_{ck}}{I_{hs}}$	$\frac{T_{ck}}{T_{ct}}$	$\frac{I_{ck}}{I_{ct}}$	$\frac{T_{ck}}{T_{am}}$	$\frac{I_{ck}}{I_{am}}$
Phenothrin	1.22 >	0.01	1.75 >	0.06	16.67 >>	0.02
Cyphenothrin	7.93 >	0.28	1.17 >	0.59	542.0 >>	0.02
Permethrin	4.36 >	0.13	12.26 >	0.96	19.69 >	1.10
Cypermethrin	18.78 >>	0.12	2.95 >	0.41	2.54 >	0.06
S-5439	11.41 >	0.89	6.15 >	0.60	102.02 >>	1.40
Fenvalerate	1.49 ≤	3.96	0.69 <	2.73	14.54 >>	0.04
Fenpropathrin	0.33 ≤	0.66	0.80 ≤	0.85	0.008 <	0.09
Lindane	5.59 ≥	3.28	— ^b	— ^b	0.001 >>	0.28
Fenitrothion	1.67 ≤	3.13	0.02 <	0.29	0.047 <	0.91

^a T=Topical LD₅₀, I=Injection LD₅₀, ck=cockroach, hs=housefly, ct=cutworm and am=armyworm. For explanation of 'Pseudo-resistance' see YAMASAKI and ISHII (1954). LD₅₀ values for armyworm were taken from BREMPONG-YEBOAH et al. (1982, 1983) and for the cutworm and housefly from unpublished data. ^b Data: impossible to calculate.

counterparts. At 72 and 96 hr (Tables 3 and 4), the order of toxicity was generally as follows: fenpropathrin >> fenitrothion > fenvalerate > cypermethrin > phenothrin = cyphenothrin = permethrin < lindane < S-5439, when the LD₅₀ values were compared. With the slope of the regression line being one of the steepest, fenvalerate became the most toxic at the LD₉₅ level while fenpropathrin became less toxic. Between 72 and 96 hr there were fewer deaths than were observed during the first 48 hr. Thus the effects of topical application of the synthetic pyrethroids tended to approach an 'end point' beyond 72 hr after treatment. The more toxic tendency of the CN compounds was also not observed at 72 and 96 hr after topical application.

Tables 5 and 6 show the results of injection treatments of the synthetic pyrethroids in the German cockroach. By injection all the synthetic pyrethroids were more toxic than fenitrothion at the LD₅₀ level. Cyanide containing compounds were not especially toxic. Although fenitrothion was not particularly toxic, the slope of the regression line of mortality on dose was highest (2.36 and 2.69 at 24 and 48 hr, respectively) followed by lindane, fenvalerate and S-5439 in that order. When the LD₉₅ values are considered, however, the synthetic pyrethroids were no more than 1.2 times the standard (fenitrothion) at 24 hr and no more than 3.0 times at 48 hr after injections.

Table 7 shows a comparison of the topical and injection LD₅₀s at 24 and 48 hr following treatment by the methods of O'BRIEN (1960) and MATSUMURA (1963). The 'P' values obtained indicate that, with the exception of fenpropathrin and fenitrothion, all the insecticides tested had difficulty penetrating the cuticle of the German cockroach. A comparison of the 'resistance' or rather the 'pseudo-resistance' to penetration of the test insecticides offered by the cockroach cuticle with those of the armyworm, tobacco cutworm and housefly was made according to YAMASAKI and ISHII (1954) and the result is shown in Table 8. The data in the 2nd and 3rd columns indicate that the 'resistance' to penetration offered by the cuticle of the cockroach is more than that of the housefly for most of the synthetic pyrethroids. For fenitrothion, fenvalerate and fenpropathrin, however, there were no remarkable differences between the two insects. A comparison of the cockroach and cutworm cuticles (columns 3 and 4, Table 8) showed a similar result; for fenvalerate and fenitrothion, more resistance was offered by the cutworm cuticle than by the cockroach cuticle. The last two columns compare the same factor (resistance to penetration) for the cockroach and armyworm cuticles. The data show that for most of the synthetic pyrethroids the cockroach cuticle offers more resistance to penetration of insecticides than that of the armyworm. For fenpropathrin, fenitrothion and lindane, however, the reverse is true. Thus, the cockroach cuticle is apparently more susceptible to penetration by the OP insecticide, fenitrothion, than by synthetic pyrethroid insecticides. It is not surprising therefore that SHIM and LEE (1979) observed that the German cockroach was more susceptible to ten OP insecticides (i.e. dichlorvos LD₅₀=0.31 µg/female; 3.61 µg/g) than six synthetic pyrethroids, the most toxic of which was fenvalerate (LD₅₀=0.42 µg/female; 4.21 µg/g).

Penetration through the insect cuticle is thought to be a necessary step in causing toxic action by insecticides. MATSUMURA (1963) associated the penetration of malathion with the absorption capability of the cockroach, *Periplaneta americana*, cuticle, and proposed that absorption takes place at the hot water soluble portion of the cuticle, which consists of protein. TREHERNE (1957) showed with seven radioactive non-electrolytes that the rate of penetration of isolated cuticles of *Schistocerca gregaria* was directly related to the solubility of the compounds in water. Using six radioactive

solutes, OLSON and O'BRIEN (1963) also found that the *in vivo* rate of penetration through the pronotum of the cockroach, *Periplaneta americana* increases with the polarity of the penetrating compound, thus going further to associate penetration with the chemical properties of the penetrating compounds. FORD et al. (1977) in topical application studies of ten synthetic pyrethroids in larvae of *Spodoptera littoralis* (BOISD), found that the speed of action of the chemicals was related to both the chemical structure and the applied dose. SCEICZ et al. (1973) pointed out that low rates of insecticidal penetration could contribute significantly toward the resistance to an insecticide in the tobacco budworm, *Heliothes virescens*. In topical and injection studies on the German cockroach, COLLINS (1973) proposed that reduced penetration of insecticides may be a resistance mechanism in a diazinon selected resistance strain which was also cross resistant to three other major classes of organic insecticides, including the pyrethrins.

Results obtained in these experiments are in close agreement with those of SHIM and LEE (1979) that the German cockroach is apparently more susceptible to organophosphorus insecticides than the synthetic pyrethroids. Further, 'P' and 'pseudo-resistance' factors show that the cuticle of the German cockroach offers some resistance to the penetration of synthetic pyrethroids, and probably more resistance than the cuticles of the armyworm, tobacco cutworm and housefly.

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REFERENCES

- BREMPONG-YEBOAH, C. Y., T. SAITO and T. MIYATA (1983) The selective toxicity of some synthetic pyrethroids in the armyworm, *Pseudaletia separata* (WALKER) (Part 2). Injection toxicity of some pyrethroids. *J. Pesticide Sci.* **8**: 95-98.
- BREMPONG-YEBOAH, C. Y., T. SAITO and T. MIYATA (1984) Topical and injection toxicities of some pyrethroids in the tobacco cutworm, *Spodoptera litura* (FABRICIUS). *J. Pesticide Sci.* **9**: 481-488.
- BREMPONG-YEBOAH, C. Y., T. SAITO, T. MIYATA and Y. TSUBAKI (1982) The selective toxicity of some synthetic pyrethroids in the armyworm, *Pseudaletia separata* (WALKER) (Part 1). Topical toxicity of some pyrethroids. *J. Pesticide Sci.* **7**: 47-51.
- COLLINS, W. J. (1973) German cockroach, *Blattella germanica* (Blatt: Blattellidae) resistance. 1. Resistance to diazinon includes cross resistance to DDT, pyrethrins and propoxur in a laboratory colony. *J. Econ. Entomol.* **66**: 44-47.
- CORNWELL, P. B. (1968) *The Cockroach, A Laboratory Insect and an Industrial Pest*. Vol. 1. Hutchison of London Press, London, 391 pp.
- EL-GUINDY, M. A., S. M. MADI, M. E. KEDDIS, Y. A. ISSAH and M. A. ABDEL-SATTAR (1982) Development of resistance to pyrethroids in field populations of the cotton leafworm, *Spodoptera littoralis* (BOISD.) *Int. Pest Control* **24**: 7-11.
- FINNEY, D. J. (1951) *Probit Analysis*. 3rd ed., Cambridge University Press, Cambridge, 333 pp.
- FORD, M., R. C. REAY, D. PERT, P. E. ELLIS and L. J. MCVEIGH (1977) Toxicity of pyrethroids to the larvae of the Egyptian cotton leafworm, *Spodoptera littoralis* (BOISD.). 1. Relative toxicity and knock-

- down activities of benzyl and 5-benzyl-3-furylmethyl cyclopropane carboxylates. *Pestic. Sci.* **8**: 203-210.
- HARRIS, C. R., H. J. SVEC and R. A. CHAPMAN (1977) Potential for pyrethroid insecticides for cutworm control. *J. Econ. Entomol.* **71**: 692-696.
- LHOSTE, J. and W. C. PIEDALLU (1977) Control of insects on cotton crops in Africa with some pyrethroids. *Pestic. Sci.* **8**: 254-257.
- MATSUMURA, F. (1963) The permeability of the cuticle of *Periplaneta americana* to malathion. *J. Insect Physiol.* **9**: 207-221.
- O'BRIEN, R. D. (1960) *Toxic Phosphorus Esters*. Academic Press, New York, 317 pp.
- OLSON, W. P. and R. D. O'BRIEN (1963) The relation between physical properties and the penetration of solutes into the cockroach cuticle. *J. Insect. Physiol.* **9**: 777-786.
- SCEICZ, F. M., F. W. PLAPP and S. B. VINSON (1973) Tobacco budworm: The penetration of several insecticides into the larva. *J. Econ. Entomol.* **66**: 9-15.
- SHIM, J. C. and K. R. LEE (1979) Toxicity tests of public health insecticides against the cockroach, *Blattella germanica*, in Korea. *Korean J. Entomol.* **9**: 93-97.
- SUN, Y. P. (1950) Toxic index, an improved method of comparing the selective toxicity of insecticides. *J. Econ. Entomol.* **43**: 45-52.
- TREHERNE, J. E. (1957) The diffusion of non electrolytes through the isolated cuticle of *Schistocerca gregaria*. *J. Insect Physiol.* **1**: 178-186.
- WOLFENBARGER, D. A., J. A. HARDING and J. W. DAVIS (1977) Isomers of 3-(phenoxybenzyl)-methyl-(+/-) *cis, trans*-(2, 2-dichloroethenyl)-2, 2-dimethyl cyclopropane carboxylate against bollweevils and cotton budworms. *J. Econ. Entomol.* **70**: 226-228.
- YAMASAKI, T. and T. ISHII (1954) Studies on the mechanism of action of insecticides. Part XI. The susceptibility of insects to insecticides and methods of its investigation. *Oyoo Kontyu* **11**: 169-172 (in Japanese).