Tropical Biomedicine 28(1): 111–118 (2011)

Insecticide resistance and synergism of three field-collected strains of the German cockroach *Blattella germanica* (L.) (Dictyoptera: Blattellidae) from hospitals in Kermanshah, Iran

Limoee, M.[1], Enayati, A.A.[2*], Khassi, K.[3], Salimi, M.[3] and Ladonni, H.[4]
[1] Department of Public Health and Health Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran
[2] School of Public Health and Health Research Center, Mazandaran University of Medical Sciences, Sari, Iran
[3] Kermanshah University of Medical Sciences, Kermanshah, Iran
[4] Tehran University of Medical Sciences, Iran
* Corresponding author email: tmaae@liverpool.ac.uk.
Received 31 August 2010; received in revised form 19 November 2010; accepted 29 November 2010

Abstract. The development of insecticide resistance in the German cockroach, *Blattella germanica* (L.) is a serious problem in controlling this medically important household pest. The insecticide resistance status in three hospital-collected strains of the German cockroach using four commonly used insecticides from different classes (permethrin, cypermethrin, bendiocarb and chlorpyrifos) was detected by topical bioassay method and preliminary information on possible involvement of monooxygenases in permethrin resistant strains employing synergist piperonyl butoxide (PBO) was obtained. For each insecticide, four to six concentrations resulting in >0% and <100% mortality were used. Three to six replicates of 10 cockroaches per concentration were conducted. For synergism studies, 100µg PBO per gram body weight of cockroach as the maximum sublethal dose was administered to the first abdominal segment 1 h before insecticide treatment. The differences between LD_{50} (µg/g) values were considered statistically significant only when the 95% confidence intervals did not overlap. The resistance ratio and synergism ratio were calculated for each insecticide. All three hospital-collected strains of the German cockroach showed different levels of resistance to permethrin and cypermethrin based on resistance ratios compared with SUS strain. Permethrin and cypermethrin resistance ratios ranged from 11.61 to 17.64 and 11.45 to 26.45 at LD_{50} levels, respectively. Low to moderate levels of bendiocarb resistance and low level of chlorpyrifos resistance were also observed in the hospital-collected strains under study. The synergist piperonyl butoxide (PBO) significantly enhanced the toxicity of permethrin to all strains with different degrees of synergist ratio, 2.45-, 1.87-, 2.51- and 2.38-fold, suggesting monooxygenase involvement in permethrin resistance.

INTRODUCTION

The German cockroach, *Blattella germanica* (L.) has been recognized as a serious health problem because of its potential to harbour and transmit human disease-causing pathogens as well as inducing asthma (Roberts, 1996; Pai *et al.*, 2003, 2005).

The development of insecticide resistance in the German cockroach, *B. germanica* is a serious problem in controlling this household pest. Cochran (1995) reported the resistance to different classes of insecticides including organochlorines, organophosphates, carbamates and pyrethroids in field strains of the German cockroach. Lee *et al.* (1996)

reported different levels of resistance to carbamates, organophosphates and pyrethroids in field-collected strains of the German cockroach in Malaysia (Lee *et al.*, 1996). Pai *et al.* (2005) determined the resistance of the German cockroach from hospitals and households to propoxur, chlorpyrifos and cypermethrin. Among the different classes of insecticides, pyrethroids have been extensively used for the German cockroach control because of their effectiveness and low mammalian toxicity, Nevertheless, frequent use of these compounds has resulted in the development of resistance. Scharf *et al.* (1997) reported 80-fold resistance at LD50 level to cypermethrin in a field-collected strain of the German cockroach from Indiana. Wu *et al.* (1998) reported 825-fold resistance at LD50 level to fenvalerate in the Munsyana strain of the German cockroach from Indiana. Valles *et al.* (2000) reported 93-fold resistance at LD50 level to cypermethrin in a field strain of the German cockroach from Florida. Control failures in field populations of the German cockroach have been reported due to the development of permethrin resistance in Iran (Limoee *et al.*, 2006), deltamethrin resistance in Singapore (Choo *et al.*, 2000), and permethrin and deltamethrin resistance in Alabama (Wei *et al.*, 2001). Pai *et al.* (2005) determined the resistance of the German cockroach from hospitals and households in Taiwan concluding that the resistance patterns of propoxur> chlorpyrifos>cypermethrin in hospital strains and propoxur>cypermethrin> chlorpyrifos in household strains, might be due to the frequency of application of the insecticides. Chai *et al.* (2010) studied the resistance status of 22 field-collected strains of the German cockroach from Singapore against six classes of insecticides using topical bioassay method. They found a range of resistance from 3-468-fold against pyrethroid insecticides and more than 20-fold resistance to OPs and carbamate compounds. Synergist bioassays revealed oxidases and esterases involvement in insecticide resistance in most of the strains leaving kdr and Rdl mutations as the probable underlying mechanism of insecticide resistance in the rest of the strains (Chai & Lee, 2010). In a study in Indonesia, relatively high levels of permethrin resistance were detected in field strains of the German cockroach which was attributable to oxidases. However, cypermethrin resistance was not suppressible by synergists, suggesting the involvement of a kdr-like mechanism (Ahmad *et al.*, 2009).

Extensive use of insecticides from different classes such as organochlorine, organophosphates and pyrethroids resulted in development of resistance to different insecticides in various strains of the German cockroaches in Tehran, Iran (Ladonni, 1993, 1997; Ladonni & Sadegheyani, 1998; Limoee *et al.*, 2006). Insecticide resistance was detected and its metabolic mechanisms were found in this pest in Tehran (Limoee *et al.*, 2001), and attempts were made to compare different test methods for detecting resistance of the German cockroach strains (Ladonni, 2000, 2001). In a recent review article, the susceptibility of different strains of the German cockroach to different groups of insecticides were summarized (Nasirian, 2010). There is no information on insecticide resistance status in hospital strains of the German cockroach in Kermanshah, a western province of the country. Therefore, this study was undertaken to detect insecticide resistance status in three hospital-collected strains of the German cockroach using four commonly used insecticides from different classes (permethrin, cypermethrin, bendiocarb and chlorpyrifos), and to obtain preliminary information on possible involvement of monooxygenases in permethrin resistant strains employing synergist piperonyl butoxide (PBO).

MATERIALS AND METHODS

Cockroach strains

Four German cockroach strains were examined in this study: SUS is the standard susceptible strain maintained since 1975 in the insectary at the School of Public Health, Tehran University of Medical Sciences without exposure to insecticide; three strains: T_1, T_2 and IH were collected in 2008 from different hospitals in Kermanshah.

Spraying with different insecticides including pyrethroids, organophosphates and carbamates failed to control the German cockroach in those hospitals (personal communication).

All cockroaches were maintained in an insectary at 27±2°C, 60±10% RH, with a photoperiod of 12:12 h (L:D). Each strain was reared in the same size labeled glass jar. Cockroaches were provided with unlimited cat food and water. Tests were conducted on adult males of F_2-F_4 generations.

Chemicals

Chemical used were permethrin, 93.6% (technical grade) cis:trans 60:40, cypermethrin, 97.5% (technical grade), (Zeneca, Haslemere, UK), bendiocarb, 97% (technical grade), chlorpyrifos 97% (technical grade), (Cyanamid Agro, India) and synergist piperonyl butoxide (PBO) 93,6%, (Zeneca, Haslemere, UK), a monooxygenase inhibitor for synergism study. CO_2 was used as anesthetic and acetone as solvent.

Bioassays methods

Bioassay tests were performed by topical application of 1µl of a known concentration of insecticide and synergist solution to the first abdominal segment of the insects, using a hand micro-applicator (Burkard, Scientific Ltd, UK) equipped with a 1.0 ml Hamilton glass syringe.

Adult male cockroaches were anesthetized with carbon dioxide for 20–30 seconds before insecticide treatment (Valles & Koehler, 1994). For each insecticide, four to six concentrations resulting in >0% and <100% mortality were used.

Three to six replicates of 10 cockroaches per concentration were conducted. For synergism study, 100µg PBO per gram body weight of cockroach, as the maximum sublethal dose, was placed on the first abdominal segment 1 h before insecticide treatment (Valles *et al.*, 1997). Control groups received acetone or synergist alone. Treated cockroaches were kept for 24 h in Pyrex glass jars provided with food and water before scoring the mortality. Cockroaches were considered dead when they were unable to turn themselves to normal posture within one minute after being turned onto their dorsum.

Data analysis

Bioassay data were pooled and subjected to probit analysis (Finny, 1972) using a personal computer. The differences between LD_{50} values were considered statistically significant only when the 95% confidence intervals did not overlap. All LD_{50} values were converted from µg/cockroach to µg/g of cockroach body weight to avoid possible effect of weight differences on insecticide susceptibility. The resistance ratio (RR, LD_{50} of the resistant strain divided by LD_{50} of the susceptible strain) and synergism ratio (SR, LD_{50} of insecticide alone divided by LD_{50} of insecticide + synergist) were calculated for each insecticide.

RESULTS

Pyrethroid resistance

All three hospital-collected strains of the German cockroach showed different levels of resistance to permethrin and cypermethrin based on resistance ratios (RRs) compared with SUS strain (Table 1). Permethrin resistance ratios ranged from 11.61 to 17.64 at LD_{50} levels. Comparisons made between the 95% confidence intervals of the LD_{50} values of field strains with susceptible strain (SUS) indicated that all three strains had significantly different RR. The order of resistance levels for the field strains was as follows: IH>T2>T1 with the IH strain exhibiting the highest resistance ratio (RR= 17.64).

Different levels of resistance to cypermethrin were observed in all three hospital-collected strains of the German cockroach (Table 1) showing resistance ratios ranging from 11.45 to 26.45 at LD_{50} levels. Examining the 95% confidence intervals of the LD_{50} values between the resistance ratios of the three field strains with susceptible strain (SUS) indicated that all had significantly different RR. The order of resistance levels for three hospital collected strains was as follows: T2>IH>T1 with the T2 strain showing the highest resistance ratio (RR= 26.45).

Bendiocarb resistance

Low to moderate levels of bendiocarb resistance were also observed in the hospital- collected strains under study (Table 2) with resistance ratios ranging from 2.93 to 4.91 at LD_{50} levels. The order of resistance levels was as follows: IH>T2>T1.

Chlorpyrifos resistance

Chlorpyrifos bioassay data presented in Table 2 shows that T2 and IH strains developed relatively significant resistance when compared with the susceptible strain (SUS) (RR: 2.0 < 2.18). There was no significant difference between LD_{50} values of T1 and susceptible (SUS) strain (Table 2).

Table 1. Lethal dose values for permethrin and cypermethrin for insecticide susceptible and three hospital-collected strains of German cockroach

Strain	n	Y- intercept	S lope (SE)	X^2 (df)	LD50 (95% CL) µg/g[a]	RR[b]
SUS[c]Permethrin	201	0.99	3.89 (0.49)	3.621 (4)	10.70 (9.44-12.1)	1
Cypermethrin	169	3.11	3.3 (0.42)	3.57 (2)	3.74 (3.18-4.44)	1
T1Permethrin	169	-8.27	6.34 (0.86)	0.981 (2)	124.28 (114.31-135.71)	11.61[sig]
Cypermethrin	145	0.78	2.58 (0.39)	3.1 (2)	42.84 (33.01-53.07)	11.45[sig]
T2Permethrin	128	-3.89	4.03 (0.57)	5.283 (2)	161.38 (137.4-188.96)	15.1[sig]
Cypermethrin	170	-0.47	2.74 (0.37)	0.665 (2)	98.91 (81.99-122.6)	26.45[sig]
IHPermethrin	171	-6.73	5.15 (0.76)	2.637 (2)	188.77 (169.35-208.87)	17.64[sig]
Cypermethrin	146	-0.73	3.14 (0.43)	3.086 (2)	66.62 (55.34-80.24)	17.81[sig]

[a] Micrograms of insecticide/g of cockroach body weight
[b] Resistance Ratio
[c] Susceptible strain
sig Significant

Table 2. Lethal dose values for bendiocarb and chlorpyrifos for insecticide susceptible and three hospital-collected strains of German cockroach

Strain	n	Y- intercept	S lope (SE)	X^2 (df)	LD50 (95% CL) µg/g[a]	RR[b]
SUS[c]bendiocarb	143	0.8	2.96 (0.44)	0.199 (2)	26.4 (21.63-31.9)	1
chlorpyriphos	183	1.31	4.91 (0.64)	6.96 (3)	5.66 (5.11-6.33)	1
T1bendiocarb	164	0.95	2.14 (0.29)	4.714 (2)	77.44 (58.92-98.86)	2.93[sig]
chlorpyriphos	149	1.83	3.8 (0.66)	0.84 (2)	6.81 (5.73-7.84)	1.2[ns]
T2bendiocarb	189	0.8	2.02 (0.29)	5.531 (3)	118.62 (91.63-148.88)	4.5[sig]
chlorpyriphos	159	-1.01	5.7 (0.76)	1.02 (2)	11.31 (9.92-12.57)	2.0[sig]
IHbendiocarb	201	1.65	1.58 (0.26)	0.397 (2)	129.62 (98.83-177.53)	4.91[sig]
chlorpyriphos	154	-0.19	4.76 (0.67)	2.76 (2)	12.32 (10.88-13.83)	2.18[sig]

[a] Micrograms of insecticide/g of cockroach body weight
[b] Resistance Ratio
[c] Susceptible strain
sig Significant
ns Nonsignificant

Table 3. Toxicity of topically applied permethrin with and without PBO to three permethrin resistant strains of the German cockroach compared to the susceptible strain (SUS)

	Insecticide alone			Insecticide + PBO[a]					
Strain	n	LD50 (95% CL) µg/g	RR[b]	n	Slope(SE)	X^2 (df)	LD50 (95%CL) µg/g	SR[c]	RR
SUS[d]	201	10.70 (9.44-12.1)	1	207	3.4 (0.4)	6.83 (3)	4.37 (3.76-5.02)	2.45[S]	1
T_1	169	124.28 (114.31-135.71)	11.61[sig]	183	3.1 (0.41)	2.332 (2)	66.33 (56.27-77.93)	1.87[s]	15.18
T_2	128	161.38 (137.4-188.96)	15.1[sig]	178	3.5 (0.44)	5.119 (2)	64.34 (54.48-74.99)	2.51[s]	14.72
IH	171	188.77 (169.35-208.87)	17.64[sig]	283	2.26 (0.29)	1.99 (3)	79.37 (66.94-93.48)	2.38[s]	18.16

[a] 100 µg/g cockroach body weight
[b] Resistance Ratio : LD50 (µg/g) of resistant strain/ LD50 (µg/g) of susceptible strain
[c] Synergist Ratio : LD50 (µg/g) of insecticide alone/ LD50 (µg/g) of insecticide + PBO
[d] susceptible strain

Synergism of PBO

Pretreatment of adult male German cockroaches of susceptible and three hospital-collected strains with synergist, PBO significantly enhanced the toxicity of permethrin to all strains with different degrees of SRs, 2.45-, 1.87-, 2.51- and 2.38-fold, respectively (Table 3). It can be inferred from the synergist bioassay data that Cytochrome P450 monooxygenases might be contributing to certain degree to the detoxification of permethrin.

DISCUSSION

According to Milio *et al.* (1987), Scott *et al.* (1990), Choo *et al.* (2000) and Ladonni (2001), the lethal dose (LD) method especially by topical application may be more appropriate for insecticide toxicological tests because the amount applied is precisely measured. Hence, this method was used throughout this study.

Different levels of permethrin and cypermethrin resistance were observed in field strains of the German cockroaches from hospitals of Kermanshah. These results are consistent with our previous studies on pyrethroid resistance in some populations of the German cockroaches from Tehran, Iran in which resistance ratios ranged from 6.28 to 23.7 for permethrin and 5.26 to 20.7 for cypermethrin (Limoee *et al.*, 2006). Also the results of the present study are in accord with those of another study on permethrin resistance in some populations of the German cockroach, reporting RRs ranging from 17 to 23.24 (Ladonni & Sadegheyani, 1998). High levels of pyrethroid resiatance have been reported from Singapore and Indonesia (Chai & Lee 2010; Ahmad *et al.*, 2009).

The following factors might be attributable to the development of pyrethroid resistance in the field strains of German cockroaches. Pyrethroid insecticides such as permethrin and cypermethrin have been used to control these cockroach populations in Tehran, Kermanshah and other provinces for the last two decades. They have recently been replaced with a mixture of carbamate and cypermethrin. Therefore, this continued use of pyrethroids has led to a relatively high selection pressure. Zhai & Robinson (1991) reported high level of resistance to cypermethrin and control failure of this pyrethroid insecticide against the German cockroach after about 4 years of use.

Milio *et al.* (1987) compared three methods for measuring the susceptibility of adult German cockroaches to formulated chlorpyrifos based on resistance ratios. The Lethal dose (LD) method showed the highest resistance ratio compared with the other test methods.

According to Reierson *et al.* (1998), 10-fold resistance measured by topical application is the critical point above which operational control failures are likely to occur while, resistance ratio at 5x and below may still achieve a good control of the German cockroach population. Thus, the low resistance ratios of the three strains to chlorpyrifos compared with the susceptible strain probably reflect a relatively low levels of resistance to this compound because these strains have not been selected by chlorpyrifos for several generations. Hence, bendiocarb and specially chlorpyrifos may still provide adequate control of these strains.

On the other hand, Robinson & Zhai (1990, 1994) previously reported that when cypermethrin is replaced with chlorpyrifos against the German cockroach for three years, resistance levels to cypermethrin decreased. Therefore this negative cross-resistance may be of importance in the susceptibility of the strains tested in our study to chlorpyrifos.

The continued susceptibility of the hospital-collected strains of the German cockroach in this study to chlorpyriphos, could be due to the low frequency of application of this organophosphate insecticide, as Pai *et al.* (2005) had previously mentioned, and also the fact that permethrin has recently been replaced with chlorpyrifosin for controlling cockroaches.

The results of synergist study demonstrated that toxicity of permethrin to three hospital strains was slightly enhanced (1.87 – 2.38) by PBO, suggesting the possible involvement of monooxygenases in permethrin resistance. These findings were similar to those of our previous studies, Lee *et al.* (1996), Limoee *et al.* (1996, 2007) and Chai & Lee (2010) on PBO effect in decreasing permethrin resistance in different populations of the German cockroach. However, resistance levels to permethrin in T1 strain increased from 11.61 to 15.18 when pretreated with PBO. Also PBO caused a marginal increase in RR from 17.64 to 18.16 in IH strain. This effect has been reported frequently (Lee *et al.*, 1996; Valles & Yu, 1996; Valles, 1998; Scott, 1999; Pridgeon *et al.*, 2002; Limoee *et al.*, 2007) and may be explained by the following reasons: (a) Cytochrome p450s exist in a number of different related forms and PBO may not inhibit all isozymes involved in the metabolism of the insecticide in question (Valles & Yu, 1996; Valles, 1998; Pridgeon *et al.*, 2002), (b) The higher susceptibility of Cytochrome p450 isoform (s) to the synergist in the SUS strain than T_1 strain resulted in a greater effect of PBO on the SUS strain and (c) It is also reported that PBO enhances the absorption of insecticide molecules into the insect body (Rouch & Bruce, 1990). Further studies on the effect of synergist DEF on permethrin resistance and its cross resistance pattern to DDT are necessary for providing further *in vivo* evidence about the underlying resistance mechanisms to permethrin.

Acknowledgements. The authors would like to express their sincere gratitude to the authorities of the Deputy for Research and School of Public Health of Kermanshah University of Medical Sciences for providing the research grant and administrative assistance.

REFERENCES

Ahmad, I., Sriwahjuningsih, Astari, S., Putra, R.E. & Permana, A.D. (2009). Monitoring pyrethroid resistance in field collected *Blattella germanica* Linn. (Dictyoptera: Blattellidae) in Indonesia. *Entomological Research* **39**: 114-118.

Chai, R.Y. & Lee, C.Y. (2010). Insecticide resistance profiles and synergism in field populations of the German Cockroach (Dictyoptera: Blattellidae) from Singapore. *Journal of Economic Entomology* **103**: 460-471.

Choo, L.E.W.C., Tang, C.S., Pang, F.Y. & HO, S.H. (2000). Comparison of two bioassay methods for determining deltamethrin resistance in German cockroach (Blattodea: Blattellidae). *Journal of Economic Entomology* **93**(3): 905-910.

Cochran, D.G. (1995). Misuse of the tarsal-contact method for detecting insecticide resistance in the German cockroach (Dictyoptera: Blattellidae). *Journal of Economic Entomology* **90**: 1441-1444.

Finny, D.J. (1972). *Probit analysis*, third ed., Cambridge University, London. 333pp.
Ladonni, H. (1993). Susceptibility of *Blattella germanica* to different insecticides in different hospitals in Tehran-Iran. *Journal of Entomology Society of Iran* **12 & 13:** 23-28.
Ladonni, H. (1997). Susceptibility of different field strains of *Blattella germanica* to four pyrethroids (Orthoptera: Blattellidae). *Iranian Journal of Public Health* **26**: 35-40.
Ladonni, H. & Sadegheyani, S. (1998). Permethrin toxicity and synergistic effect of piperonyl butoxide in the first nymphal stage of *Blattella germanica* (Dictyoptera: Blattellidae). *Iranian Journal Public Health* **27**: 44-50.
Ladonni, H. (2000). Permethrin resistance ratios compared by two methods of testing nymphs of the German cockroach, *Blattella germanica*. *Medical and Veterinary Entomology* **14**: 213-216.
Ladonni, H. (2001). Evaluation of three methods for detecting permethrin resistance in adult and nymphal *Blattella germanica* (Dictyoptera: Blattellidae). *Journal of Economic Entomology* **94**(3): 694-697.
Lee, C.Y., Yap, H.H., Chong, N.L. & Lee, R.S.T. (1996). Insecticide resistance and synergism in field collected German cockroach (Dictyoptera Blattellidae) in Peninsular Malaysia. *Bulletin Entomological Research* **86**: 675-682.
Limoee, M., Ladonni, H., Enayati, A.A., Vatandoost, H. & Aboulhasni, M. (2006). Detection of pyrethroid resistance and cross-resitance to DDT in seven field-collected strains of the German cockroach *Blattella germanica* (L.) (Dictyoptera:Blattellidae). *Journal of Biological Sciences* **6**(2): 382-387.
Limoee, M., Enayati, A.A., Ladonni, H., Vatandoost, H., Baseri, H. & Oshaghi M.A. (2007). Various mechanisms responsible for permethrin metabolic resistance in seven field-collected strains of the German cockroach from Iran, *Blattella germanica* (L.) (Dictyoptera: Blattellidae). *Pesticide Biochemistry and Physiology* **87**: 138-146.
Milio, J.F., Koehler, P.G. & Patterson, R.S. (1987). Evaluation of three methods for detection of chlorpyrifosresistance in an German cockroach (Dictyoptera: Blattellidae) population. *Journal of Economic Entomology* **80**: 44-46.
Nasirian, H. (2010). An overview of German cockroach, *Blattella germanica*, studies conducted in Iran. *Pakistan Journal of Biological Sciences* **13**(22): 1077-1084.
Pai, H.H., Chen, W.C. & Peng, C.F. (2005). Isolation of bacteria with antibiotic resistance from household cockroaches (*Periplaneta americana* and *Blattella germanica*). *Acta Tropica* **93**: 259-265.
Pai, H.H., Ko, Y.C. & Chen, E.R. (2003). Cockroaches (*Periplaneta americana* and *Blattella germanica*) as potential mechanical dissemination of *Entamoeba histolytica*. *Acta Tropica* **87**: 355-359.
Pai, H.H., Wu, S.C. & Hsu, E.L. (2005). Insecticide resistance in German cockroach (*Blattella germanica*) from hospitals and households in Taiwan. *International Journal of Environmental Health Research* **15**(1): 33-40.
Pridgeon, J.W., Appel, A.J., Moar, W.J. & Liu, N. (2002). Variability of resistance mechanisms in pyrethroid resistant German cockroach (Dictyoptera: Blattellidae). *Pesticide Biochemistry and Physiology* **73**: 149.
Reierson, D.A., Rust, M.K., Slater, A.J. & Slater, T.A.M. (1998). Insecticide resistance affects cockroach control. *California Agriculture* **42**: 18-20.
Roberts, J. (1996). Cockroaches linked with asthma. *British Medical Journal* **312**: 1630.
Robinson, W.H. & Zhai, J. (1990). Pyrethroid resistance in German cockroach. *Pest Control Techniques* **18**: 26-28.
Robinson, W.H. & Zhai, J. (1994). Insecticide resistance in German cockroach. Good news from the field. *Pest Control Techniques* **22**: 64, 66 & 98.

Rouch, R.T. & Bruce, E.T. (1990). *Pesticide resistance in arthropods.* Chapman and Hall, New York, London, p.303.

Scharf, M.E., Kaakeh, W. & Bennett, G.W. (1997). Changes in an insecticide resistant field-population of German cockroach following exposure to an insecticide mixture. *Journal of Economic Entomology* **90**: 38-48.

Scott, J.G. (1999). Cytochromes p450 and insecticide resistance. *Insect Biochemistry and Molecular Biology* **29**: 757-777.

Scott, J.G. & Cochran, D.G. (1990). Insecticide toxicity, synergism, and resistance in the German cockroach (Dictyoptera: Blattellidae). *Journal of Economic Entomology* **83**(5): 1698-1703.

Valles, S.M. (1998). Toxicological and biochemical studies with field population of the German cockroach, *Blattella germanica*. *Pesticide Biochemistry and Physiology* **62**: 190-200.

Valles, S.M., Dong, K. & Brenner, R.J. (2000). Mechanisms responsible for cypermethrin resistance in a strain of German cockroach, *Blattella germanica* (L.). *Pesticide Biochemistry and Physiology* **66**: 195-205.

Valles, S.M. & Koehler, P.G. (1994). Influence of carbon dioxide anesthesia on chlorpyrifostoxicity in the German cockroach (Dictyoptera: Blattellidae). *Journal of Economic Entomology* **87**: 709-713.

Valles, S.M., Koehler, P.G. & Brenner, R.J. (1997). Antagonism of fipronil toxicity by piperonyl butoxide and s,s,s-tributyl phosphorotrithioate in the German cockroach (Dictyoptera: Blattellidae). *Journal of Economic Entomology* **90**: 1254-1258.

Valles, S.M. & Yu, S.J. (1996). Detection and biochemical characterization of insecticide resistance in the German cockroach (Dictyoptera Blattellidae). *Journal of Economic Entomology* **89**: 21-26.

Wei, Y., Appel, A.G., Moar, W.J. & Liu, N. (2001). Pyrethroid resistance and cross-resistance in the German cockroach, *Blattella germanica* (L.). *Pest Managment Science* **57**: 1055-1059.

Wu, D., Scharf, M.E., Neal, J.J., Suiter, D.R. & Bennett, G.W. (1998). Mechanism of fenvalerate resistance in the German cockroach, *Blattella germanica* (L.). *Pesticide Biochemistry and Physiology* **61**: 53-62.

Zhai, J. & Robinson, W. (1991). Pyrethroid resistance in a field population of German cockroach, *Blattella germanica* (L.). *Japonis Journal of Sanitary Zoology* **42**: 241-244.