Contact Toxicity and Residual Effects of Selected Insecticides Against the Adult *Paederus fuscipes* (Coleoptera: Staphylinidae)

LEE-JIN BONG,[1] KOK-BOON NEOH,[2] ZAIRI JAAL,[1] AND CHOW-YANG LEE[1,3]

J. Econ. Entomol. 106(6): 2530–2540 (2013); DOI: http://dx.doi.org/10.1603/EC13198

ABSTRACT The contact toxicity of four insecticide formulations (deltamethrin, fipronil, fenitrothion, and imidacloprid) applied on three different substrates (tile, plywood, and concrete) against the adult rove beetle, *Paederus fuscipes* Curtis, was evaluated. The relative order of speed of killing effects was as follows: deltamethrin > imidacloprid > fipronil > fenitrothion. Although deltamethrin showed the fastest action against *P. fuscipes*, the recovery rate of rove beetles at 48 h posttreatment was moderate (≈ 25%) on the tile surface to high (≈80%) on the plywood surface. Thus, it is likely that the insects did not pick up the lethal dose especially on porous surfaces. In contrast, fipronil demonstrated delayed toxicity that might promote maximal uptake by the insects. More than 80% mortality was registered for tile and plywood surfaces up to 4 wk after exposure. High mortality (almost 100%) was recorded for imidacloprid-exposed *P. fuscipes* at 48 h posttreatment, but only on the tile surface. Among the four insecticides tested, fenitrothion was the least effective against *P. fuscipes* because low percentage to no mortality was recorded in the fenitrothion treatment.

KEY WORDS insecticide toxicity, insecticide susceptibility, resistance, insecticide formulation

Rove beetles (*Paederus* spp.; Coleoptera: Staphylinidae) are pests that cause dermatitis linearis in urban and rural human living spaces (Couppie et al. 1992, Kim et al. 1995, Croft et al. 1996, Sendur et al. 1999, Banney et al. 2001, Gnanaraj et al. 2007, Rahmah and Norjaiza 2008, Davidson et al. 2009, Huang et al. 2009). *Paederus fuscipes* Curtis (Fig. 1) resides in moist areas such as marshes, edges of freshwater lakes, and rice fields because larvae are highly susceptible to desiccation (Bong et al. 2013b). From an ecological perspective, *P. fuscipes* is a beneficial insect that suppresses agricultural pest populations in agroecosystems (Frank and Kanamitsu 1987). However, because of anthropogenic and landscape disturbances, invasion of *P. fuscipes* into human settings and subsequent serious health impacts are on the rise (Bong et al. 2012, 2013a).

Spraying of insecticides in the *P. fuscipes* habitat, especially rice fields, to reduce the pest population is not practical. The species is an important biological control agent of insect pests in rice fields, thus reducing the population would conflict with agricultural interests. Thus, chemical treatment in infested human settings seems to be the best approach to dealing with rove beetle infestations.

In the 1960s, several trials of now banned pesticides (e.g., DDT, lindane, chlordane, malathion, diazinon, and dieldrin) against *P. fuscipes* were conducted (Frank and Kanamitsu 1987). However, information about the effectiveness of newer insecticides against rove beetles is lacking. Considering the wide geographical distribution of this pest and its health threat posed to the public, information on the management of *P. fuscipes* is clearly needed.

In the current study, we exposed *P. fuscipes* to four insecticide products (deltamethrin [Crackdown 10SC; Bayer CropScience, Petaling Jaya, Selangor, Malaysia], imidacloprid [Premise 200SC; Bayer CropScience], fipronil [Termidor 25EC; BASF Agro BV Amhen (NL), Waedenswll, Switzerland], and fenitrothion [Sumithion 20MC; Sumitomo Chemical, Tokyo, Japan]) that are commonly used in professional pest management programs and

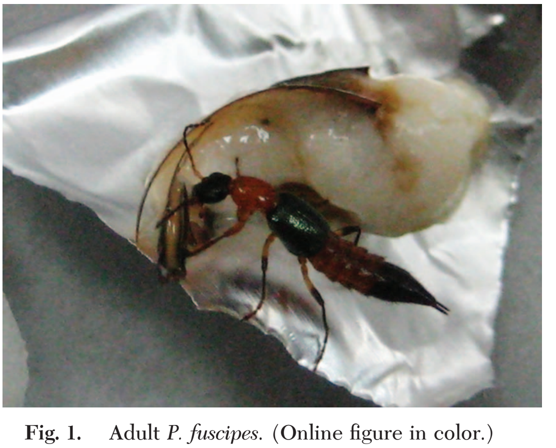

Fig. 1. Adult *P. fuscipes*. (Online figure in color.)

[1] Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia, 11800 Penang, Malaysia.
[2] Center for Southeast Asian Studies, Kyoto University, 46 Shimoadachi-cho, Yoshida, Sakyo-ku, Kyoto 606-8501, Japan.
[3] Corresponding author, e-mail: chowyang@usm.my.

evaluated their contact toxicity. We examined the toxic effect of these insecticides when applied on tile, wood, and concrete.

Materials and Methods

Insects. Adults of *P. fuscipes* were collected from residential areas at two localities in mainland Penang, Malaysia: Desa Wawasan (DW; 5° 21′21.38″ N, 100° 26′50.82″ E, 9 m elevation) and Sri Pinang (SP; 5° 26′52.89″ N, 100° 23′52.69″ E, 10 m elevation). The two locations are 11.31 km apart. DW is ≈1.89 km away from Permatang Pauh rice field, and SP is ≈0.57 km away from Sungai Dua rice field. These two strains were chosen because they exhibited different development time in the previous study, and this indicated the possibility of insecticide tolerance differences between the two strains (Bong et al. 2012).

The rove beetles were maintained in the insectarium of the Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia at 28.0 ± 0.2°C, 63.5 ± 2.0% relative humidity (RH), and a photoperiod of 12:12 (L:D) h. The rearing method was adopted from Bong et al. (2012). An open-bottom plastic container (11.0 cm in diameter by 10.0 cm in height) was filled with gypsum plaster (thickness ≈3.0 cm). The rearing container was stacked on a container (11.0 cm in diameter by 6.0 cm in height) provisioned with moist cotton to maintain the moisture for the gypsum plaster. The beetles were provided with freeze-killed lobster cockroaches (*Nauphoeta cinerea* (Olivier)) as food source, and a moist cotton ball was provided as a water source and a site for oviposition. New food was provided daily. Immature stages (i.e., eggs, larvae, and pupae) were reared using specimen tubes (15 mm in diameter by 50 mm in height; Samco, Woking, United Kingdom); the inner part of the tubes was layered with moist filter papers (3.5 cm in width by 5.0 cm in length). Eggs laid by the field-collected adults were kept individually in the rearing tubes. Once the larvae emerged, the first larval instar was supplied with ≈2.0 mg of freeze-killed adult mosquitoes (*Aedes aegypti* (L.)) and the second larval instar was given 4.0 mg of adult mosquitoes as a food source. The rearing tubes were covered with muslin cloth to prevent the larvae from escaping and to allow air ventilation. After the adults emerged, males and females were separated. The first filial generation of unmated male and female from the two field-collected populations were then provided with dry dog food (Purina, Rayong, Thailand) as the food source and a moist cotton ball as the water source before testing. For the experiments, 3- to 4-wk-old *P. fuscipes* were selected because the survivorship of the population leveled off at this period (Bong et al. 2012). The test insects were provided only moist cotton ball 24 h before testing, and acclimatized for 2 h under laboratory conditions of 26.4 ± 0.16°C, 63.2 ± 0.63% RH, and a photoperiod of 12:12 (L:D) h before testing.

Insecticides. Four commercial insecticide formulations from different chemical classes were tested: 1) pyrethroid: deltamethrin 10 g/liter SC (Crackdown 10 SC); 2) organophosphate: fenitrothion 200 g/liter MC (Sumithion 20 MC); 3) phenylpyrozole: fipronil 25 g/liter EC (Termidor 25 EC); and 4) neonicotinoid: imidacloprid 200 g/liter SC (Premise 200 SC). All insecticides were diluted with distilled water in compliance with the recommended application rates: deltamethrin (15 mg a.i. [active ingredient]/m^2), fenitrothion (250 mg a.i./m^2), imidacloprid (5 mg a.i./m^2), and fipronil (10 mg a.i./m^2).

Surface Contact Toxicity. Experiments were carried out in the laboratory under the conditions as mentioned in Insects section. The following three surfaces measuring 20.0 cm in length by 20.0 cm in width were used for the contact toxicity tests: tile (second-grade glazed floor tile), plywood (0.1-inch construction-grade plywood), and concrete (cement: sand ratio = 1:2). Each insecticide dilution was spread on each surface. For the controls, each surface was treated with distilled water. The treated surfaces were air-dried at room temperature for 24 h before testing. A polyethylene ring (4.5 cm in diameter by 2.5 cm in height) coated with fluon on the inner wall was placed on each treated surface and covered to prevent the test insects from escaping. For each strain, 10 insects were exposed onto a treated surface (e.g., deltamethrin-treated tile). The test was replicated three times per each sex.

For the fast-acting insecticides, data were observed every 5 min up to ≈1 h for deltamethrin and 2 h for imidacloprid. All individuals were then transferred into clean plastic containers (4.5 cm in diameter by 2.5 cm in height) and were provided with food and a moist cotton ball. For slow-acting insecticides, fipronil and fenitrothion, data were observed for up to 24 h before the specimens were transferred into clean containers. The recovery and mortality of the test insects were observed at 48 h posttreatment. A test insect was considered dead if it was unable to right itself to a normal position when being gently probed.

Residual Toxicity. The same treated materials that were tested on day 1 were kept at room temperature and were used for the 7-, 14-, 21-, and 28-d residual toxicity tests. The method described above was used for each test using new batches of insects.

Data Analysis. The data obtained were subjected to probit analysis to determine the time required for 50% dead (LT_{50}) and 90% dead (LT_{95}). The overlapping fiducial limit generated in probit analysis indicated the insignificant differences of responses to insecticides, and vice versa. Probit analysis was not performed if the percentage of dead was <50%. Percentage of mortality was subjected to arcsine square-root transformation. For each strain, as no significant differences in 48-h mortality were shown between adult male and female in Student's *t*-test at $\alpha = 0.05$ (see Results), mortality data for male and female were pooled for each insecticide. The toxicity of insecticides on different surfaces throughout the 28-d period was examined with analysis of variance (ANOVA) using the general linear model (GLM) with factorial design of 5 by 3 by 5. The independent variables were type of insecticides, with five levels; type of surfaces, with three levels; and days, with five levels. The values were then separated using Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$. All analyses were performed using SPSS analysis version 11.0 (SPSS Inc., Chicago, IL).

Results

Insecticidal Activity, Strain, and Gender. Because significant differences were detected for the different surfaces tested (see LT_{50} and LT_{95} in Tables 1 and 2), only data for the insecticides tested on tile (a nonporous surface) were used for comparisons of insecticidal activity, gender, and strain.

Among the four insecticides tested, deltamethrin killed insects the fastest (LT_{50} 0.25–0.46 h for the SP strain and 0.32–0.43 h for the DW strain). For imidacloprid, the LT_{50} of adults occurred within 0.41–3.98 h for the SP strain and 0.13–1.73 h for the DW strain. Toxicity of fipronil was delayed, with significantly higher LT_{50} (4.92–28.07 h for the SP strain and 5.49–14.19 h for the DW strain) compared with deltamethrin and imidacloprid. For fenitrothion, it took >14.7 h to kill 50% of the test insects, and it was effective for no longer than 14 d.

The LT_{50} and LT_{95} values (Tables 1 and 2) revealed strain differences in the response to insecticides, as shown by the nonoverlapping fiducial limits. In general, deltamethrin and fipronil were less toxic against the DW strain compared with the SP strain, whereas fenitrothion and imidacloprid were more effective against the DW strain.

Table 1. The LT_{50} and LT_{95} of the SP strain of *P. fuscipes* exposed to four insecticides on three types of substrate at 1, 7, 14, 21, and 28 d

Surface (20 by 20 cm)	Insecticide (application rate, mg a.i./m^2)	Day	Gender	LT_{50} (h; 95% FL)	LT_{95} (h; 95% FL)	Slope (±SE)	χ^2 (df)
Tile	Deltamethrin (15)	1	F	0.27 (0.26–0.28)	0.44 (0.40–0.48)	7.85 (0.77)	3.70 (12)
			M	0.25 (0.24–0.26)	0.37 (0.35–0.41)	9.54 (0.96)	5.45 (9)
		7	F	0.27 (0.26–0.28)	0.39 (0.36–0.44)	10.71 (1.31)	2.88 (7)
			M	0.29 (0.28–0.30)	0.41 (0.39–0.44)	10.47 (0.92)	4.12 (11)
		14	F	0.33 (0.30–0.36)	0.52 (0.44–0.72)	8.35 (0.90)	27.89 (10)
			M	6.13 (0.48)	3.53 (19)		
		21	F	0.39 (0.37–0.41)	0.71 (0.66–0.79)	6.36 (0.46)	8.14 (17)
			M	0.36 (0.35–0.38)	0.65 (0.60–0.72)	6.50 (0.46)	6.71 (18)
		28	F	0.46 (0.43–0.48)	0.81 (0.74–0.91)	6.58 (0.56)	6.20 (14)
			M	0.41 (0.40–0.42)	10.25 (0.80)	3.56 (15)	
	Fipronil (10)	1	F	10.78 (10.18–11.39)	20.36 (18.44–23.30)	5.96 (0.52)	3.58 (12)
			M	8.32 (7.76–8.87)	15.39 (13.73–18.18)	6.16 (0.66)	3.04 (8)
		7	F	4.92 (4.44–5.42)	16.59 (13.85–21.13)	3.12 (0.26)	4.53 (14)
			M	5.11 (4.70–5.55)	3.90 (0.32)	4.98 (14)	
		14	F	10.12 (8.70–12.11)	71.71 (47.99–128.75)	1.93 (0.19)	6.19 (15)
			M	11.57 (10.69–12.54)	30.67 (25.57–40.06)	3.89 (0.40)	1.87 (12)
		21	F	28.07 (24.38–35.27)	73.42 (52.26–138.29)	3.94 (0.63)	1.03 (6)
			M	9.77 (8.76–10.97)	37.27 (28.96–32.64)	2.83 (0.28)	4.83 (12)
		28	F	11.27 (9.75–13.23)	80.90 (55.75–138.20)	1.92 (0.186)	2.46 (15)
			M	16.76 (14.56–19.93)	87.21 (58.10–171.86)	2.30 (0.305)	2.56 (10)
	Fenitrothion (250)	1	F	21.10 (19.70–23.24)	42.46 (35.00–58.86)	5.42 (0.732)	3.27 (10)
			M	(43.33%)[a]	NA	NA	NA
		7	F	(13.33%)[a]	NA	NA	NA
			M	(23.33%)[a]	NA	NA	NA
		14	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Imidacloprid (5)	1	F	1.05 (0.97–1.13)	3.29 (2.78–4.11)	3.31 (0.27)	1.03 (20)
			M	0.41 (0.35–0.46)	2.39 (1.77–3.70)	2.13 (0.22)	6.98 (14)
		7	F	1.04 (0.80–1.34)	25.01 (13.82–59.94)	1.19 (0.12)	9.24 (12)
			M	0.84 (0.54–1.32)	232.52 (75.18–1361.67)	0.67 (0.08)	11.399 (12)
		14	F	1.01 (0.62–1.52)	204.75 (77.29–940.42)	0.71 (0.09)	1.86 (12)
			M	0.99 (0.77–1.26)	28.14 (16.66–57.12)	1.13 (0.09)	3.42 (16)
		21	F	0.89 (0.50–1.61)	115.70 (30.43–1580.21)	0.78 (0.09)	24.77 (13)
			M	1.10 (0.83–1.43)	39.59 (23.89–76.51)	1.06 (0.08)	16.95 (16)
		28	F	3.98 (3.02–5.45)	211.11 (95.86–685.14)	0.95 (0.10)	4.30 (16)
			M	1.03 (0.73–1.55)	77.18 (28.91–374.45)	0.88 (0.11)	6.63 (11)
Plywood	Deltamethrin (15)	1	F	0.72 (0.68–0.75)	1.41 (1.28–1.60)	5.60 (0.43)	6.42 (19)
			M	0.61 (0.59–0.64)	0.97 (0.90–1.08)	8.17 (0.69)	7.58 (14)
		7	F	0.69 (0.66–0.72)	1.32 (1.19–1.50)	5.88 (0.47)	6.61 (17)
			M	0.62 (0.59–0.66)	1.40 (1.25–1.63)	4.67 (0.35)	4.28 (19)
		14	F	0.77 (0.71–0.82)	2.01 (1.70–2.56)	3.92 (0.38)	7.07 (15)
			M	0.55 (0.52–0.58)	1.10 (0.98–1.27)	5.51 (0.47)	2.71 (14)
		21	F	0.94 (0.88–1.01)	2.25 (1.94–2.77)	4.34 (0.41)	13.06 (13)
			M	1.15 (1.05–1.31)	5.90 (0.49)	6.33 (15)	
		28	F	0.82 (0.77–0.87)	1.74 (1.53–2.10)	5.02 (0.48)	5.35 (12)
			M	0.97 (0.87–1.13)	6.22 (0.67)	1.67 (10)	

Continued on following page

Table 1. Continued

Surface (20 by 20 cm)	Insecticide (application rate, mg a.i./m^2)	Day	Gender	LT_{50} (h; 95% FL)	LT_{95} (h; 95% FL)	Slope (±SE)	χ^2 (df)
	Fipronil (10)	1	F	10.84 (10.18–11.43)	22.75 (20.20–26.70)	5.11 (0.430)	6.03 (13)
			M	10.92 (10.32–11.50)	19.20 (17.33–22.31)	6.71 (0.72)	9.70 (9)
		7	F	9.42 (8.32–10.69)	41.40 (31.77–60.33)	2.56 (0.25)	8.02 (12)
			M	5.63 (5.16–6.16)	13.24 (11.16–17.03)	4.43 (0.47)	4.16 (8)
		14	F	4.49 (4.10–4.92)	12.40 (10.40–15.83)	3.73 (0.34)	7.75 (11)
			M	5.17 (4.71–5.65)	13.69 (11.59–17.33)	3.89 (0.38)	4.61 (10)
		21	F	4.10 (3.69–4.48)	10.48 (8.89–13.38)	4.03 (0.45)	3.33 (9)
			M	8.54 (7.91–9.24)	18.58 (15.93–23.35)	4.88 (0.53)	1.55 (8)
		28	F	8.85 (8.07–9.72)	23.90 (19.56–32.38)	3.81 (0.43)	3.68 (9)
			M	8.22 (7.67–8.77)	16.89 (15.16–19.49)	5.26 (0.43)	5.89 (12)
	Fenitrothion (250)	1	F	(0%)[a]	NA	NA	NA
			M	(13.33%)[a]	NA	NA	NA
		7	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Imidacloprid (5)	1	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		7	F	NA	NA	NA	NA
			M	NA	NA	NA	
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
Concrete	Deltamethrin (15)	1	F	0.29 (0.28–0.31)	0.49 (0.45–0.55)	7.50 (0.70)	3.09 (11)
			M	0.20 (0.19–0.21)	0.32 (0.29–0.35)	8.14 (0.76)	4.04 (10)
		7	F	0.43 (0.41–0.45)	0.74 (0.67–0.86)	6.95 (0.56)	23.75 (16)
			M	0.29 (0.28–0.30)	0.47 (0.44–0.52)	7.76 (0.71)	8.57 (11)
		14	F	0.81 (0.77–0.85)	1.70 (1.53–1.96)	5.11 (0.39)	4.68 (20)
			M	0.51 (0.49–0.53)	0.90 (0.83–1.02)	6.58 (0.59)	3.14 (15)
		21	F	0.84 (0.80–0.89)	1.69 (1.52–1.94)	5.45 (0.46)	2.04 (15)
			M	0.77 (0.72–0.82)	1.77 (1.56–2.10)	4.56 (0.37)	4.48 (16)
		28	F	1.58 (1.45–1.72)	5.06 (4.56–6.96)	3.25 (0.32)	2.81 (16)
			M	3.70 (3.12–4.70)	3.81 (0.35)	3.24 (14)	
	Fipronil (10)	1	F	23.46 (21.95–27.05)	43.12 (33.86–83.09)	6.22 (1.48)	0.49 (7)
			M	27.80 (25.60–33.13)	45.13 (36.49–73.86)	7.82 (1.61)	1.13 (7)
		7	F	(10.00%)[a]	NA	NA	NA
			M	(3.33%)[a]	NA	NA	NA
		14	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Fenitrothion (250)	1	F	14.98 (12.85–18.24)	53.71 (36.38–115.67)	2.97 (0.52)	2.86 (7)
			M	13.99 (13.00–15.16)	36.83 (30.31–49.48)	3.91 (0.43)	2.26 (13)
		7	F	(13.33%)[a]	NA	NA	NA
			M	24.61 (20.11–35.03)	2.28 (0.39)	0.89 (10)	
		14	F	(0%)[a]	NA	NA	NA
			M	(23.33%)[a]	NA	NA	NA
		21	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Imidacloprid (5)	1	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		7	F	NA	NA	NA	NA
			M	NA	NA	NA	
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA

[a] Not available; percentage of dead after 24 h (in brackets).
NA, not applicable; FL, fiducial limits.

Table 2. The LT_{50} and LT_{95} of the DW strain of *P. fuscipes* exposed to four insecticides on three types of substrate at 1, 7, 14, 21, and 28 d

Surface (20 by 20 cm)	Insecticide (application rate, mg a.i./m^2)	Day	Gender	LT_{50} (h; 95% FL)	LT_{95} (h; 95% FL)	Slope (±SE)	χ^2 (df)
Tile	Deltamethrin (15)	1	F	0.37 (0.35–0.39)	0.58 (0.53–0.68)	8.48 (1.06)	8.77 (7)
			M	0.36 (0.34–0.37)	0.56 (0.51–0.64)	8.58 (1.01)	5.18 (10)
		7	F	0.33 (0.31–0.35)	0.59 (0.53–0.68)	6.59 (0.65)	3.28 (11)
			M	0.35 (0.33–0.36)	0.60 (0.54–0.69)	6.90 (0.70)	2.51 (10)
		14	F	0.41 (0.39–0.43)	0.64 (0.58–0.75)	8.34 (0.96)	10.98 (9)
			M	6.74 (0.69)	3.22 (9)		
		21	F	0.43 (0.41–0.46)	0.80 (0.71–0.95)	6.16 (0.68)	3.00 (10)
			M	0.37 (0.35–0.38)	0.57 (0.53–0.63)	8.59 (0.92)	3.97 (10)
		28	F	0.42 (0.40–0.44)	0.76 (0.70–0.85)	6.46 (0.56)	3.23 (14)
			M	0.36 (0.35–0.38)	5.44 (0.46)	4.11 (16)	
	Fipronil (10)	1	F	11.15 (10.49–11.80)	21.05 (19.13–23.92)	5.96 (0.51)	3.33 (13)
			M	8.56 (8.07–9.03)	14.59 (13.35–16.50)	7.09 (0.67)	2.31 (9)
		7	F	11.68 (10.26–13.34)	49.54 (36.13–82.67)	2.62 (0.34)	5.74 (10)
			M	5.49 (4.85–6.21)	2.79 (0.25)	2.16 (12)	
		14	F	(34.48%)[a]	NA	NA	NA
			M	13.18 (10.66–17.13)	132.46 (73.91–353.23)	1.64 (0.22)	2.02 (10)
		21	F	(34.48%)[a]	NA	NA	NA
			M	14.19 (12.54–16.38)	61.66 (44.71–100.91)	2.58 (0.29)	2.20 (13)
		28	F	(40.74%)[a]	NA	NA	NA
			M	7.60 (6.38–8.89)	35.11 (25.64–58.08)	2.48 (0.32)	2.73 (8)
	Fenitrothion (250)	1	F	(46.67%)[a]	NA	NA	NA
			M	(36.67%)[a]	NA	NA	NA
		7	F	21.25 (17.48–30.65)	126.98 (66.50–532.37)	2.12 (0.41)	1.45 (9)
			M	14.70 (12.42–20.08)	68.91 (38.77–285.29)	2.45 (0.54)	1.0 (10)
		14	F	16.42 (13.25–23.27)	155.49 (73.52–804.86)	1.69 (0.33)	1.59 (8)
			M	(38.46%)[a]	NA	NA	NA
		21	F	(30.00%)[a]	NA	NA	NA
			M	(44.44%)[a]	NA	NA	NA
		28	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
	Imidacloprid (5)	1	F	1.33 (1.18–1.50)	5.65 (4.44–7.89)	2.61 (0.24)	5.22 (14)
			M	0.55 (0.48–0.62)	2.30 (1.82–3.15)	2.64 (0.23)	6.34 (14)
		7	F	1.64 (1.25–2.30)	43.93 (21.21–131.74)	1.15 (0.13)	4.44 (13)
			M	0.16 (0.13–0.19)	0.91 (0.65–1.54)	2.16 (0.25)	7.53 (10)
		14	F	0.96 (0.80–1.16)	16.15 (9.93–32.34)	1.34 (0.13)	2.65 (21)
			M	0.13 (0.11–0.14)	0.45 (0.36–0.63)	3.02 (0.36)	6.58 (11)
		21	F	0.99 (0.64–1.63)	272.69 (84.54–1600.80)	0.67 (0.07)	9.45 (14)
			M	0.20 (0.16–0.25)	1.79 (1.17–3.53)	1.75 (0.22)	5.78 (10)
		28	F	1.73 (1.18–2.73)	2.60 (1.78–4.40)	0.84 (0.09)	2.26 (13)
			M	0.26 (0.22–0.32)	2.60 (1.77–4.40)	1.66 (0.15)	5.41 (13)
Plywood	Deltamethrin (15)	1	F	0.37 (0.35–0.39)	0.71 (0.63–0.84)	5.75 (0.55)	3.48 (11)
			M	0.40 (0.39–0.42)	0.62 (0.57–0.70)	8.60 (0.87)	6.54 (11)
		7	F	0.38 (0.36–0.40)	0.58 (0.54–0.66)	8.80 (0.86)	2.98 (9)
			M	0.31 (0.29–0.32)	0.49 (0.45–0.56)	8.18 (0.88)	4.83 (9)
		14	F	0.33 (0.31–0.35)	0.58 (0.52–0.67)	6.78 (0.75)	5.23 (10)
			M	0.39 (0.38–0.40)	0.50 (0.48–0.53)	15.50 (1.52)	1.21 (10)
		21	F	0.39 (0.36–0.42)	0.82 (0.72–1.00)	5.10 (0.54)	3.22 (11)
			M	0.57 (0.53–0.62)	11.01 (1.13)	2.66 (8)	
		28	F	0.38 (0.36–0.39)	0.56 (0.53–0.62)	9.45 (0.89)	3.84 (11)
			M	0.55 (0.51–0.60)	10.24 (1.08)	2.06 (8)	
	Fipronil (10)	1	F	19.01 (17.77–21.08)	34.90 (28.75–50.73)	6.24 (1.04)	6.06 (7)
			M	18.82 (17.67–20.45)	35.67 (29.91–48.64)	5.92 (0.87)	11.82 (8)
		7	F	6.96 (6.23–7.71)	24.08 (20.12–30.61)	3.05 (0.26)	5.65 (13)
			M	10.29 (8.56–12.30)	40.99 (28.94–76.10)	2.74 (0.30)	19.88 (12)
		14	F	8.36 (7.55–9.18)	24.13 (20.60–29.80)	3.57 (0.30)	9.30 (12)
			M	8.22 (6.55–10.23)	26.69 (18.70–54.18)	3.22 (0.31)	36.96 (12)
		21	F	11.79 (9.80–14.16)	33.04 (23.84–67.59)	3.68 (0.38)	37.49 (12)
			M	12.61 (11.35–14.05)	52.48 (40.08–78.59)	2.66 (0.28)	12.98 (16)
		28	F	11.70 (10.71–12.67)	27.38 (23.57–34.07)	4.46 (0.48)	2.40 (10)
			M	7.54 (6.59–8.58)	30.82 (23.82–44.88)	2.69 (0.28)	5.51 (11)
	Fenitrothion (250)	1	F	(46.67%)[a]	NA	NA	NA
			M	(48.15%)[a]	NA	NA	NA
		7	F	(30.00%)[a]	NA	NA	NA
			M	(14.81%)[a]	NA	NA	
		14	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Imidacloprid (5)	1	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		7	F	NA	NA	NA	NA
			M	NA	NA	NA	
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA

Continued on following page

Table 2. Continued

Surface (20 by 20 cm)	Insecticide (application rate, mg a.i./m²)	Day	Gender	LT_{50} (h; 95% FL)	LT_{95} (h; 95% FL)	Slope (±SE)	χ^2 (df)
Concrete	Deltamethrin (15)	1	F	0.25 (0.24–0.26)	0.39 (0.37–0.44)	8.40 (0.92)	10.13 (8)
			M	0.21 (0.20–0.23)	0.36 (0.32–0.43)	7.22 (0.68)	15.43 (10)
		7	F	0.38 (0.36–0.40)	0.81 (0.72–0.96)	4.92 (0.41)	2.47 (16)
			M	0.36 (0.34–0.37)	0.63 (0.57–0.72)	6.62 (0.58)	4.27 (14)
		14	F	0.59 (0.57–0.61)	0.97 (0.89–1.09)	7.61 (0.70)	6.23 (13)
			M	0.46 (0.43–0.48)	0.85 (0.76–1.02)	6.06 (0.65)	9.73 (12)
		21	F	0.67 (0.64–0.71)	1.24 (1.12–1.43)	6.13 (0.52)	5.69 (12)
			M	0.72 (0.67–0.78)	1.73 (1.46–2.22)	4.31 (0.43)	3.25 (13)
		28	F	1.33 (1.24–1.42)	3.50 (2.99–4.32)	3.90 (0.32)	1.74 (19)
			M	2.12 (1.80–2.68)	4.42 (0.43)	3.24 (12)	
	Fipronil (10)	1	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		7	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Fenitrothion (250)	1	F	(48.15%)[a]	NA	NA	NA
			M	10.32 (9.27–11.42)	35.17 (28.25–48.63)	3.09 (0.33)	6.03 (13)
		7	F	(37.04%)[a]	NA	NA	NA
			M	16.40 (12.93–23.89)	1.92 (0.33)	3.21 (7)	
		14	F	(14.81%)[a]	NA	NA	NA
			M	(18.52%)[a]	NA	NA	NA
		21	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
	Imidacloprid (5)	1	F	(0%)[a]	NA	NA	NA
			M	(7.41%)[a]	NA	NA	NA
		7	F	(0%)[a]	NA	NA	NA
			M	(0%)[a]	NA	NA	
		14	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		21	F	NA	NA	NA	NA
			M	NA	NA	NA	NA
		28	F	NA	NA	NA	NA
			M	NA	NA	NA	NA

[a] Not available; percentage of dead after 24 h (in brackets).
NA, not applicable; FL, fiducial limits.

The lethal times for adult males and females exposed to deltamethrin did not differ significantly. In contrast, adult males were more susceptible to fipronil and imidacloprid than adult females in both strains.

Residual Efficacy. No significant differences in the 48-h mortality were found between males and females (SP strain: deltamethrin [P = 0.228], fipronil [P = 0.282], fenitrothion [P = 0.862], and imidacloprid [P = 0.107]; DW strain: deltamethrin [P = 0.861], fenitrothion [P = 0.875], and imidacloprid [P = 0.185]). Thus, mortality data for male and female specimens were pooled for each strain. Overall, the interactions between surfaces, insecticides, and residual efficacy for both the SP strain (F = 5.552; df = 22.6, 158.3; $P < 0.001$) and the DW strain (F = 5.122; df = 19.9, 149.2; $P < 0.001$) were significantly different.

Fipronil and imidacloprid were persistent on tile; >90% mortality of test insects of the SP strain was recorded for up to 1 mo posttreatment. The mortality of *P. fuscipes* exposed to tile treated with deltamethrin reached 90% at days 1 and 7 posttreatment. However, the residual effect of deltamethrin was significantly declined (F = 7.993; df = 4, 25; $P < 0.001$) at 14 d posttreatment and onwards, with mortality <80%. Fenitrothion caused ≈70% mortality at day 1, but mortality was significantly lower compared with values for the fipronil, imidacloprid, and deltamethrin treatments (F = 56.624; df = 4, 25; $P < 0.001$). On the 7-d-old treated surface, mortality in the fenitrothion treatment dropped to 20% and was statistically similar to that of the control treatment. Unlike the other insecticides tested, fenitrothion-treated tile lost its efficacy at day 14 posttreatment (Fig. 2).

For the DW strain (Fig. 3), fipronil and imidacloprid were persistent on tile throughout the 4-wk period, with mortality ranging from 80 to 100%. Although the residual effectiveness of imidacloprid significantly declined over time (F = 5.037; df = 4, 25; P = 0.004), mortality remained high after 28 d. The residual effect of deltamethrin was slightly lower compared with that of fipronil and imidacloprid, but it was persistent, with 70–92% mortality throughout the experiment. Fenitrothion achieved ≈48–65% mortality when adults were exposed to tiles for up to 21 d.

Generally, the activities of the insecticides tested on plywood were poor. The exception was fipronil, which caused 100% mortality for both strains throughout the experimental period. The residual effect of deltamethrin on treated plywood was inconsistent for the SP strain. The mortality recorded

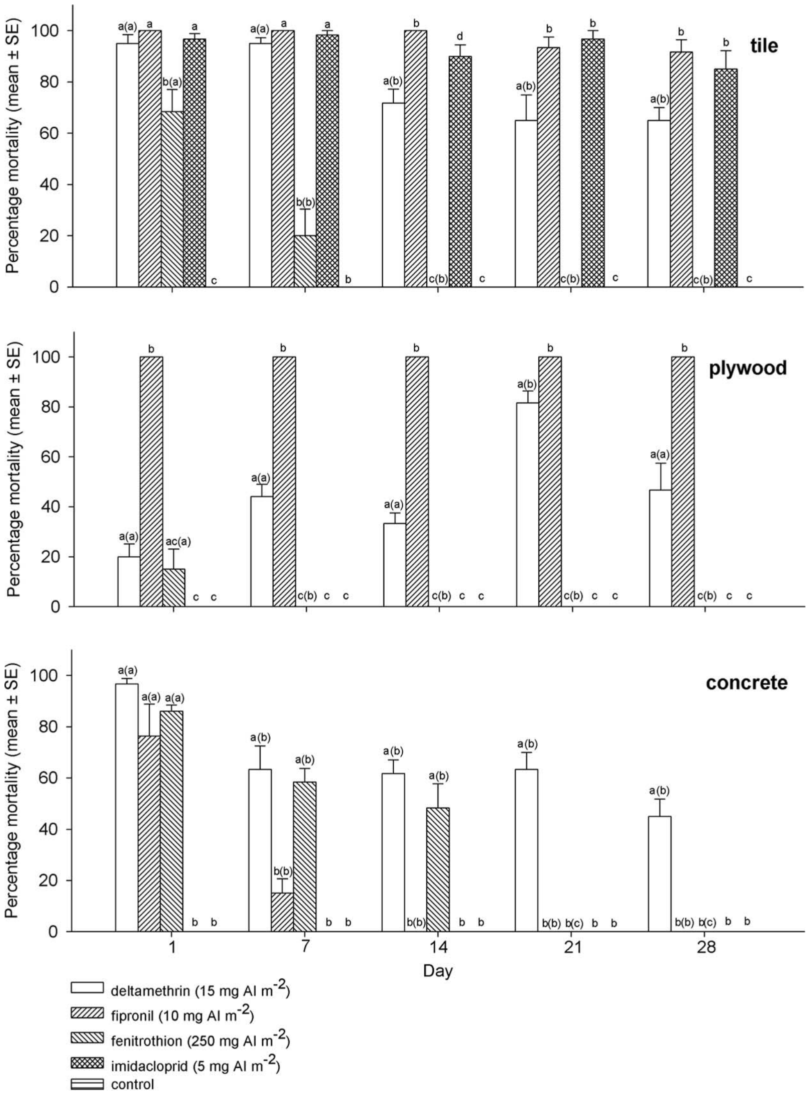

Fig. 2. Percentage mortality of *P. fuscipes* (SP strain) at 48 h posttreatment with deltamethrin, fipronil, fenitrothion, and imidacloprid after exposure to 1-, 7-, 14-, 21-, and 28-d-old substrates. The letter above each bar refers to the comparison between insecticides within a time period, whereas the letter in parentheses refers to the comparison between time periods for a given insecticide. Scale bars labeled with same letters are not significantly different (Tukey's HSD; $P > 0.05$; $n = 6$).

for the 1-d-old surface was low (20% mortality), but it increased up to 80% for the 21-d-old surface. In contrast, 46–53% mortality was recorded for the DW strain throughout the experiment. Mortality values for the DW strain for the 1- and 7-d-old fenitrothion-treated plywood were ≈60 and 50%, respectively, but the treated plywood had no effect at 14 d for either strain. No mortality was observed for the imidacloprid-treated plywood throughout the experiment (Figs. 2 and 3).

High mortality of the SP strain was observed at day 1 for the deltamethrin- (≈100%), fipronil- (≈ 80%), and fenitrothion- (≈ 90%) treated concretes, but mortality declined significantly at day 7 posttreatment (deltamethrin [$F = 10.006$; df = 4, 25; $P < 0.001$]; fipronil [$F = 20.113$; df = 4, 25; $P < 0.001$]; and fenitrothion [$F = 48.365$; df = 4, 23; $P < 0.001$]). The mortality of test insects exposed to 7-d-old fipronil-treated concrete was <20%, which was statistically similar to that of the control. Approximately 60% of tested insects were killed when exposed to 7-d-old deltamethrin- and fenitrothion-treated concrete. However, fenitrothion-treated concrete lost its effectiveness after 21 d. In contrast, the residual effect of deltamethrin persisted for 4 wk, with an average of 60% mortality of the test insects. No mortality occurred for the imidacloprid-treated concrete at this time point (Fig. 2).

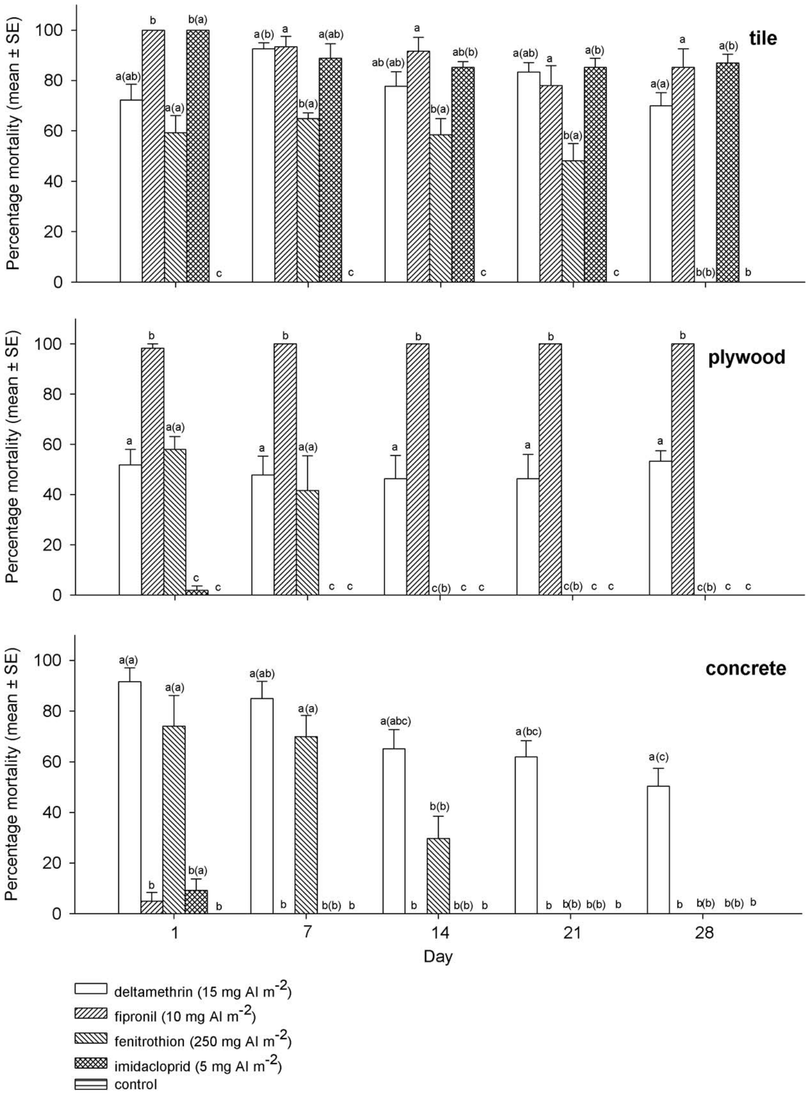

Fig. 3. Percentage mortality of adult *P. fuscipes* (DW strain) at 48 h posttreatment with deltamethrin, fipronil, fenitrothion, and imidacloprid after exposure to 1-, 7-, 14-, 21-, and 28-d-old substrates. The letter above each bar refers to the comparison between insecticides within a time period, whereas the letter in parentheses refers to the comparison between time periods for a given insecticide. Scale bars labeled with same letters are not significantly different (Tukey's HSD; $P > 0.05$; $n = 6$).

For the DW strain (Fig. 3), the effect of deltamethrin-treated concrete significantly declined over time ($F = 6.129$; df = 4, 25; $P = 0.001$). High mortality (≈90%) was recorded at days 1 and 7 after insecticide exposure, but it decreased significantly to 70% for the 14-d-old surface and persisted for the following 2 wk. Approximately 70% mortality was observed for the 1- and 7-d-old fenitrothion-treated concrete, but it lost its residual effect at 14 d (≈ 30% mortality) posttreatment and onwards. Both fipronil- and imidacloprid-treated concrete was ineffective against the test insects regardless of the age of the treated surfaces.

Discussion

The LT_{50} and LT_{95} values (Tables 1 and 2) revealed distinct differences between the DW and SP strains in response to the insecticides tested. These differences likely indicate that the two strains have different tolerances to the insecticides. The DW strain was previously exposed to pyrethroids such as Pesguard FG 161 (d-tetramethrin 4.4% wt:wt and cyphenothrin 13.2% w/s), which was frequently applied during a management program in that particular residential area (information provided by Seberang Perai Municipal Council, Penang, Malaysia). In contrast, the SP strain was regularly exposed to organophosphates (chlorpyrifos and phenthoate), carbamates (e.g., isoprocarb, fenobucarb, and propoxur), and neonicotinoids (imidacloprid and thiamethoxam), which were used to manage agricultural pests of the paddy field at the study site (information provided by Plant Protection and Plant Quarantine Unit of Penang). Thus, it is possible that insecticide resistance in these strains could explain the observed discrepancy between the DW and SP strains in response to deltamethrin, fenitrothion, and imidacloprid. This phenomenon is widespread among Coleoptera. For example, the Colorado potato beetle is resistant to imidacloprid (Grafius and Bishop 1996, Olson et al. 2000, Zhao et al. 2000), pyrethroids, and organophosphates (Jiang et al. 2010); *Tribolium castaneum* (Herbst) (Collins 1990), *Listronotus maculicollis* Kirby (Ramoutar et al. 2009), and *Sitophilus zeamais* Motschulsky (Ribeiro et al. 2003) are resistant to pyrethroids; and *Rhyzopertha dominica* (F.) is resistant to organophosphates (Guedes et al. 1997). All of these insects had been highly exposed to insecticides, and their mean generation times are relatively short, as is also true for *P. fuscipes* (Bong et al. 2012). Nevertheless, this occurrence of resistance in *P. fuscipes* will require further investigation.

The LT_{50} values for the tile surface experiment (Tables 1 and 2) show the order of the speed of kill to be as follows: deltamethrin > imidacloprid > fipronil > fenitrothion. Among the insecticides tested, deltamethrin had the fastest action against adult *P. fuscipes.* Nevertheless, the recovery rate at 48 h posttreatment was moderate (≈25%) on the tile surface and high on the plywood surface (≈80%). Arthur (1997) reported a similar observation for the confused flour beetle *Tribolium confusum* J. duVal. They observed a recovery rate >70% after the test insects were exposed to 0.05% deltamethrin dust-treated plywood, concrete, and tile. Furthermore, the toxic effects of deltamethrin on plywood and concrete were inconsistent, and mortality at 48 h posttreatment was usually lower than that on the treated tiles. One possible explanation that may account for this issue is that porous surfaces, particularly plywood and concrete, may to certain degree, reduce the uptake of the insecticide by the insects (Chadwick 1985). The reduction in insecticide toxicity on porous surfaces might be because of rapid absorption of insecticide into the porous substrate. In addition, the alkaline nature of concrete likely slows down the effect of an insecticide (White 1982, 1988; Laskowski 2002; De Arias et al. 2003). Both Collins et al. (2000) and Nayak et al. (2002), who studied the liposcelid psocid, reported that pyrethroids had much higher long-term toxicity effects (up to 38 wk) when applied to galvanized steel (a nonporous surface) compared with concrete (a porous surface).

Although lower mortality was found in the deltamethrin-treated porous substrates compared with tile, deltamethrin was still effective against *P. fuscipes* on all substrates tested. This has also been shown for many other pyrethroids tested on other insects (Williams et al. 1983, Jain and Yadav 1989, Nayak et al. 2002, Campos and Phillips 2010). For example, cypermethrin and permethrin were found to have long-term toxic effects for up to 33 wk against *T. castaneum* on plywood (Watters et al. 1983). De Arias et al. (2003) showed that deltamethrin applied to wood blocks to kill *Triatoma infestans* (Klug) had toxic effects for up to 3 mo. However, *P. fuscipes* may avoid insecticide-treated surfaces or may not be confined and continuously exposed to the treated surfaces (Zettler and Arthur 2000). In such cases, the exposure time of rove beetles to deltamethrin would be short. The repellent nature of deltamethrin to *P. fuscipes* was not tested in this experiment but should be evaluated in future studies.

High mortality (almost 100%) was recorded for imidacloprid-exposed *P. fuscipes* at 48 h posttreatment on the tile surface. This indicates that this insecticide was highly toxic to the insects. Similarly, in *Atheta coriaria* (Kraatz) (Coleoptera: Staphylinidae), high mortality was observed in all stages when specimens were exposed to 0.01 and 0.1% imidacloprid applied using the Potter spray tower method (Jandricic et al. 2006). De Graaf et al. (2003) demonstrated that imidacloprid effectively reduced the population of the rove beetle *Neosorius brevipennis* Fagel on turfgrass. However, no toxic effects were seen for imidacloprid-treated plywood and imidacloprid-treated concrete (i.e., the more porous substrates) in the current study.

Fipronil had a delayed toxic response against *P. fuscipes,* as it took at least 4 h of exposure before 50% of test insects were killed but registered high mortality at 48 h posttreatment on tile and plywood surfaces only. The ineffectiveness of fipronil against *P. fuscipes* on concrete might be because of the insecticide formulation (emulsifiable concentrates) used in this study. Unlike deltamethrin, rove beetles may not be able to detect the presence of fipronil on treated surfaces. In the current study, fipronil was diluted to rate of 0.02%. Although no study of fipronil repellent effect on rove beetles was ever carried out, previous study on *Coptotermes formosanus* Shiraki indicated that fipronil at rates of 0.01 to 0.06% showed no repellent effect on the termites (Ibrahim et al. 2003). Another study on *Ixodes ricinus* L. indicated that fipronil at rate of 9.7% showed less repellent effect when compared with permethrin (Endris et al. 2000). Together with its slow-acting effects, rove beetles may therefore continuously pick up the lethal dose before they die (Barson 1991). This premise was further supported by the high mortality recorded at 48 h posttreatment. Intoxicated *P. fuscipes* always undergo muscle contraction, which leads to defecation and vomiting before death. It is also noteworthy that *P. fuscipes* is cannibalistic and necrophagous. Thus, it is likely that the toxicant is transferred via ingesting the intoxicated carcasses and by contact with excretions containing secondary fipronil metabolites (phenyl pyrozoles) that are highly toxic to the test insects (Buczkowski and Schal 2001). It was particularly true when the LT_{50} of adult *P. fuscipes* on day 7 and onwards was shorter compared with the first day of insecticide exposure (Tables 1 and 2). The possibility of this secondary horizontal transmission deserves further investigation. However, the results contrasted with those of a field study conducted by De Graaf et al. (2003). They found that fipronil treatment did not successfully reduce the abundance of staphylinids or damage caused by them on turfgrass. Among the four insecticides tested, the slow action and no to low mortality in the fenitrothion treatments indicated that this pesticide was the least effective at killing *P. fuscipes.*

In conclusion, deltamethrin and fipronil at the recommended application rates were effective against adult *P. fuscipes* on all the three surfaces. Although deltamethrin might repel the insects, its fast-acting and residual effects on both porous and nonporous surfaces showed that deltamethrin might serve as a preventive measure in insect infestation control program in residential areas. Alternatively, fipronil might be of good candidate, as its nonrepellent effect against the insects and slow-acting effect allow the insects to have sufficient time to pick up the lethal dose before they die. Although no toxic effect was seen for fipronil-treated concrete, this can be improved with suspended concentrate formulation.

Acknowledgments

We thank Mohd. Azwa Shah (Plant Protection and Plant Quarantine Unit of Penang) for providing information about insecticide applications in rice fields in Penang and M. Raju (Seberang Perai Municipal Council, Penang) and Wilson Ong and Seow-Hui Ooi (Universiti Sains Malaysia) for their valuable technical assistance. L.-J.B. was supported by a MyPhD scholarship from the Ministry of Higher Education, Malaysia. K.-B.N. was supported by a postdoctoral fellowship from Southeast Asian Studies for Sustainable Humanosphere, Kyoto University.

References Cited

Arthur, F. H. 1997. Differential effectiveness of deltamethrin dust on plywood, concrete, and tile surfaces against three stored-product beetles. J. Stored Prod. Res. 33: 167–173.

Banney, L. A., D. J. Wood, and G. D. Francis. 2001. Whiplash rove beetle dermatitis in Central Queensland. Australas. J. Dermatol. 41: 162–167.

Barson, G. 1991. Laboratory assessment of the residual toxicity of commercial formulations of insecticides to adult *Oryzaephilus surinamensis* (Coleoptera: Silvanidae) exposed for short time intervals. J. Stored Prod. Res. 27: 205–211.

Bong, L. J., K. B. Neoh, Z. Jaal, and C. Y. Lee. 2012. Life table of *Paederus fuscipes* (Coleoptera: Staphylinidae). J. Med. Entomol. 49: 451–460.

Bong, L. J., K. B. Neoh, Z. Jaal, and C. Y. Lee. 2013a. Dispersal pattern of *Paederus fuscipes* (Coleoptera: Staphylinidae: Paederinae) in relation to environmental factors and the annual rice crop cycle. Environ. Entomol. 42: 1013–1019.

Bong, L. J., K. B. Neoh, Z. Jaal, and C. Y. Lee. 2013b. Influence of temperature on survival and water relations of *Paederus fuscipes* (Coleoptera: Staphylinidae). J. Med. Entomol. 50: 1003–1013.

Buczkowski, G., and C. Schal. 2001. Emetophagy: fipronil-induced regurgitation of bait and its dissemination from german cockroach adults to nymps. Pestic. Biochem. Physiol. 71: 147–155.

Campos, M., and T. W. Phillips. 2010. Contact toxicity of insecticides for attract- and-kill applications against adult *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). Pest Manage. Sci. 66: 752–761.

Chadwick, P. R. 1985. Surfaces and other factors modifying the effectiveness of pyrethroids against insects in public health. Pestic. Sci. 16: 383–391.

Collins, P. J. 1990. A new resistance to pyrethroids in *Tribolium castaneum* (Herbst). Pestic. Sci. 28: 101–115.

Collins, P. J., M. K. Nayak, and R. A. Kopittke. 2000. Residual efficacy of four organophosphates on concrete and galvanized steel surfaces against three liposcelid species (Psocoptera: Liposcelidae) infesting stored products. J. Econ. Entomol. 93: 1357–1363.

Couppie, P., F. Beau, and E. Grosshans. 1992. *Paederus* dermatitis: apropos of an outbreak in Conakry (Guinea) in November 1989. Ann. Dermatol. Venereol. 119: 191–195.

Croft, A., H. Smith, and I. Creamer. 1996. A pseudo-outbreak of skin disease in British troops. J. R. Soc. Med. 89: 552–556.

Davidson, S. A., S. A. Norton, M. C. Carder, and M. Debboun. 2009. Outbreak of dermatitis linearis caused by *Paederus ilsae* and *Paederus iliensis* (Coleoptera: Staphylinidae) at a military base in Iraq. U.S. Army Med. Dep. J. Jul-Sep: 6–15.

De Arias, A. R., M. J. Lehane, C. J. Schofield, and A. Fournet. 2003. Comparative evaluation of pyrethroid insecticide formulations against *Triatoma infestans* (Klug): residual efficacy on four substrates. Mem. Inst. Oswaldo Cruz 98: 975–980.

De Graaf, J., A. S. Schoeman, and R. L. Brandenburg. 2003. Ecology and control of *Neosorius brevipennis* (Coleoptera: Staphylinidae) on turf grass in south Africa. Fla. Entomol. 86: 370–372.

Endris, R. G., M. D. Matthewson, D. Cooke, and D. Amodie. 2000. Repellency and efficacy of 65% permethrin and 9.7% fipronil against *Ixodes ricinus.* Vet. Ther. 1: 159–168.

Frank, J. H., and K. Kanamitsu. 1987. *Paederus,* sensu lato (Coleoptera: Staphylinidae): natural history and medical importance. J. Med. Entomol. 24: 155–191.

Gnanaraj, P., V. Venugopal, M. K. Mozhi, and C. N. Pandurangan. 2007. An outbreak of *Paederus* dermatitis in a suburban hospital in South India: a report of 123 cases and review of literature. J. Am. Acad. Dermatol. 57: 297–300.

Grafius, E. J., and B. A. Bishop. 1996. Resistance to imidacloprid in Colorado potato beetles from Michigan. Resistant Pest Manage. Newsl. 8: 12–16.

Guedes, R.N.C., S. Kambhampati, B. A. Dover, and K. Y. Zhu. 1997. Biochemical mechanisms of organophosphate resistance in *Rhyzopertha dominica* (Coleoptera: Bostrichidae) populations from the United States and Brazil. Bull. Entomol. Res. 87: 581–586.

Huang, C. Z., Y. Q. Liu, J. Yang, J. Tian, L. Y. Yang, J. Zhang, Y. Q. Li, J. W. Li, C. S. Wang, Y. T. Tu, et al. 2009. An outbreak of 268 cases of *Paederus* dermatitis in a toy-building factory in Central China. Int. J. Dermatol. 48: 128–131.

Ibrahim, S. A., G. Henderson, and H. X. Fei. 2003. Toxicity, repellency, and horizontal transmission of fipronil in the formosan subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol. 96: 461–467.

Jain, S., and T. D. Yadav. 1989. Persistence of deltamethrin, etrimfos and malathion on different storage surfaces. Pesticides 23: 21–24.

Jandricic, S., C. D. Scott-Dupree, A. B. Broadbent, C. R. Harris, and G. Murphy. 2006. Compatibility of *Atheta* *coriaria* with other biological control agents and reduced-risk insecticides used in greenhouse floriculture integrated pest management programs for fungus gnats. Can. Entomol. 138: 712–722.

Jiang, W. H., Z. T. Wang, M. H. Xiong, W. P. Lu, P. Liu, W. C. Guo, and G. Q. Li. 2010. Insecticide resistance status of Colorado potato beetle (Coleoptera: Chrysomelidae) adults in northern Xinjiang Uygur autonomous region. J. Econ. Entomol. 103: 1365–1371.

Kim, J. O., S. W. Kim, D. S. Kim, and S. H. Pyun. 1995. Epidemiologic study of *Paederus* dermatitis prevailing in the midwest area of Kyungpuk province. Korean J. Dermatol. 33: 821–829.

Laskowski, D. A. 2002. Physical and chemical properties of pyrethroids. Rev. Environ. Contam. Toxicol. 174: 49–170.

Nayak, M. K., P. J. Collins, and R. A. Kopittke. 2002. Comparative residual toxicities of carbaryl, deltamethrin and permethrin as structural treatments against three liposcelidid psocid species (Psocoptera: Liposcelididae) infesting stored commodities. J. Stored Prod. Res. 38: 247–258.

Olson, E. R., G. P. Dively, and J. O. Nelson. 2000. Baseline susceptibility to imidacloprid and cross resistance patterns in Colorado potato beetle (Coleoptera: Chrysomelidae). J. Econ. Entomol. 93: 447–458.

Rahmah, E., and M. J. Norjaiza. 2008. An outbreak of *Paederus* dermatitis in a primary school, Terengganu, Malaysia. Malays. J. Pathol. 30: 53–56.

Ramoutar, D., S. R. Alm, and R. S. Cowles. 2009. Pyrethroid resistance in populations of *Listronotus maculicollis* (Coleoptera: Curculionidae) from southern New England golf courses. J. Econ. Entomol. 102: 388–392.

Ribeiro, B. M., R.N.C. Guedes, E. E. Oliveira, and J. P. Santos. 2003. Insecticide resistance and synergism in Brazilian populations of *Sitophilus zeamais* (Coleoptera: Curculionidae). J. Stored Prod. Res. 39: 21–31.

Sendur, N., E. Savk, and G. Karaman. 1999. *Paederus* dermatitis: a report of 46 cases in Audin, Turkey. Dermatology 199: 353–355.

Watters, F. L., N.D.G. White, and D. Coté. 1983. Effect of temperature on toxicity and persistence of three pyrethroid insecticides applied to fir plywood for the control of the red flour beetle (Coleoptera: Tenebrionidae). J. Econ. Entomol. 76: 11–16.

White, N.D.G. 1982. Effectiveness of malathion and pirimiphos methyl applied to plywood and concrete to control *Prostephanus truncatus* (Coleoptera: Bostrichidae). Proc. Entomol. Soc. Ontaria 113: 65–69.

White, N.D.G. 1988. Residual activity of insecticides on freshly harvested and previously stored wheat, and on various carriers exposed to concrete surfaces. Proc. Entomol. Soc. Ontaria 119: 35–41.

Williams, P., R. L. Semple, and T. G. Amos. 1983. Relative toxicity and persistence of three pyrethroid insecticides on concrete, wood and iron surfaces for control of grain insects. Gen. App. Entomol. 15: 7–10.

Zettler, J. L., and F. H. Arthur. 2000. Chemical control of stored product insects with fumigants and residual treatments. Crop Prot. 19: 577–582.

Zhao, J. Z., B. A. Bishop, and E. J. Grafius. 2000. Inheritance and synergism of resistance to imidacloprid in the Colorado potato beetle (Coleoptera: Chrysomelidae). J. Econ. Entomol. 93: 1508–1514.

Received 26 April 2013; accepted 18 September 2013.