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ABSTRACT The residual effect of chlorfenapyr (Phantom) was evaluated for residual control of three stored-product psocid species: *Liposcelis bostrychophila* Badonnel, *Liposcelis entomophila* (Enderlein), and *Liposcelis paeta* Pearman (Psocoptera: Liposcelididae). Chlorfenapyr was applied to individual arenas with a concrete surface at rates of 0, 2.8, 13.8, 20.6, 27.5, 55, and 110 mg active ingredient (AI)/m^2. Adults were exposed on the treated arenas and mortality assessed after 1, 2, and 3 d. The procedures were repeated weekly on the same treated arenas for 3 wk to assess residual efficacy. At each week, mortality of all species was low after 1 d of exposure but notably increased after 2 or 3 d. *L. entomophila* was the most susceptible species, with 99–100% mortality at rates of 13.8 mg/m^2 or higher. Similarly, mortality of *L. paeta* after 3 d of exposure at the same concentration ranged from 92 to 100%. *L. bostrychophila* was the least susceptible species, with mortality of <60% during the third week after application at rates ≤27.5 mg/m^2. However, even for this species, mortality after 3 wk was 90% or higher at rates >27.5 mg/m^2. Complete mortality of all species occurred after 3 d exposure at the highest rate tested of 110 mg/m^2. Thus, our results show that chlorfenapyr is effective against major psocid species at the application rates evaluated in this study.

KEY WORDS chlorfenapyr, *Liposcelis*, surface treatment, Psocoptera

Psocids (Psocoptera) are serious pests of a wide variety of stored products, but mainly of amylaceous commodities such as cereals and their products (Nayak 2006, Throne et al. 2006, Opit and Throne 2008, Athanassiou et al. 2010). They complete their life cycle in ≈3 wk, and they can cause considerable quantitative and qualitative losses during grain storage (Opit et al. 2009a,b; Athanassiou et al. 2009, 2010). Several organophosphate and pyrethroid insecticides have been evaluated as surface treatments, but in general these insecticides give poor control of psocids (Collins et al. 2000; Nayak et al. 2002a,b; 2003). Recent studies showed that insecticides labeled for use as surface or spot and crack and crevice treatments in the United States will be effective against stored-product psocids belonging to the genus *Liposcelis.* Athanassiou et al. (2011) reported that the insect growth regulator pyriproxyfen was moderately effective against *Liposcelis bostrychophila* Badonnel, *Liposcelis decolor* (Pearman), and *Liposcelis paeta* Pearman (Psocoptera: Liposcelididae) at the label rate of 2.3 mg (AI)/m^2 in a 35-d exposure study on concrete. However, the authors suggested longer-term experiments to examine if pyriproxyfen is able to eliminate the psocid population. Athanassiou et al. (2013) showed that Temprid, a formulation that contains 10.5% β-cyfluthrin and 21% imidacloprid, caused >96% mortality of *L. bostrychophila* and *L. paeta* adults when applied at the maximum label rate of 16 ml of formulation/3.8 liters of water/94 m^2 on concrete.

Another insecticide that has been registered as a structural treatment for urban pests (i.e., termites, cockroaches, and ants) in the United States is chlorfenapyr (Arthur 2008, 2009), which is an insecticidal pyrrole that causes cell death by inhibiting ATP synthesis (Hunt 1996, Mascarenhas and Boethel 1997, McLeod et al. 2002). Previous studies have shown that chlorfenapyr is effective against *Tribolium castaneum* (Herbst) and *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) when it was applied on concrete, vinyl tile, and plywood surfaces (Arthur 2008, 2009).

The only available data on efficacy of chlorfenapyr against *L. bostrychophila* and *Liposcelis entomophila* (Enderlein) (Psocoptera: Liposcelididae) were re-

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ported by Guedes et al. (2008). In that study, the authors found that chlorfenapyr provided high, short-term efficacy for control of these two species at 24.7 μg (AI) / cm^2. However, there are no available data on the residual efficacy of chlorfenapyr against stored-product psocids. The objective of the current study was to evaluate the residual efficacy of chlorfenapyr for control of several psocid species at rates comparable with those that were effective against stored-product beetles.

Materials and Methods

Insects. Adults of *L. bostrychophila*, *L. entomophila*, and *L. paeta* that were <3-wk old were used in the tests. The psocids were reared on a mixture of 97% cracked wheat kernels, 2% Rice Krispies (Kellogs, Battle Creek, MI), and 1% brewer's yeast at 30°C and 70% relative humidity (RH; Opit and Throne 2008). The colonies had been reared in the laboratory for 6–7 yr, and they were initially collected from grain bins and elevators in Kansas. Voucher specimens of these species were deposited at the Kansas State University Museum for Entomological and Prairie Arthropod Research (*L. bostrychophila #202*, *L. entomophila #182*, and *L. paeta #207*).

Bioassays With Chlorfenapyr. All tests were conducted in petri dishes (9 cm diameter by 1.5 cm height) with a surface area of 62 cm^2. The formulation Phantom EC, which contains 21.45% chlorfenapyr [240 mg (AI)/ml], was obtained from BASF Corporation (Research Triangle Park, NC). Label directions specify creation of a 0.5% diluted concentration by mixing 89 ml of product in 3,784 ml of water (as the maximum rate for outside peripheral treatments). This dilution can be applied at a maximum of 35.4 ml per 1,858 cm^2 as an outside perimeter spray. Hence, the equivalent of this rate for the 62 cm^2 area of the concrete arena was 1.2 ml, which was 6.8 mg (AI) per petri dish or 1.1 g (AI)/m^2. For our study, the 0.5% dilution was formulated in 50-ml volumetric flasks, in proportion to the label directions for mixing the larger volume of 3,784 ml. Concrete treatment arenas were created in individual plastic petri dishes, using a driveway patching material (Rockite, Hartline Products Co. Inc., Cleveland, OH). The internal sides of all dishes were coated with Fluon (polytetrafluoroethylene, Northern Products, Woonsocket, RI) to prevent escape of psocids.

We first created dilute solutions of 0 (untreated control), 1, 5, 7.5, 10, 20, and 40% of the labeled application rate by mixing the appropriate amount of the formulation with distilled water: 0.12 ml of the formulation in 500 ml water, 0.12 ml of the formulation in 100 ml water, 0.18 ml of the formulation in 100 ml water, 0.12 ml of the formulation in 50 ml water, 0.12 ml of the formulation in 25 ml water, and 0.24 ml of the formulation in 25 ml water, respectively. The maximum volume of formulated spray as an outdoor perimeter treatment corresponds to 1.2 ml/62 cm^2 surface area of each dish. The volume of spray was 0.3 ml per area of the petri dish, which is a further dilution of 75%. Hence, the actual application rates were 2.8, 13.8, 20.6, 27.5, 55, and 110 mg (AI) / m^2, and hereafter will be referred to in this manner. A Badger 100 artists' airbrush (Badger Corporation, Franklin Park, IL) was used to spray the solution as a fine mist directly on the concrete surface of individual dishes. An additional series of dishes were prepared with distilled water and sprayed, as described above, and served as controls.

The dishes were left to dry for 24 h on a laboratory counter. Ten adults of one of the species were placed on each dish. Then, all dishes were placed in incubators set at 25°C and 65% RH during the entire experimental period. Adult mortality was determined by prodding with a brush to detect movement under a stereomicroscope after 1, 2, and 3 d of exposure. After the 3-d mortality counts, all (alive or dead) individuals were discarded, and the dishes were again placed in the incubators and held until the following week when the second week assessment was done, as described above, with the introduction of new adults in the dishes. The same procedure was followed for an additional 1 wk (third week). The entire procedure was replicated four times by preparing three new dishes each time for each rate (i.e., 12 dishes for each rate and species).

Data Analysis. The data for treated and untreated dishes were analyzed separately for each species by the multivariate analysis of variance (MANOVA) repeated measures with Wilks' Lambda estimate using the JMP version 9 software (SAS Institute Inc. 2010, SAS Institute, Cary, NC). Means were separated by the Tukey–Kramer honestly significant difference (HSD) at $\alpha = 0.05$ (Sokal and Rohlf 1995).

Results

Mortality of *L. bostrychophila*. Between and within exposure intervals, all main effects and associated interactions were significant (Table 1). As rate increased, mortality generally increased (Table 2). During the first week of the test, mortality did not exceed 74% after 1 d of exposure. However, after 2 d of exposure, mortality was >91% at rates of 55 and 110 mg/ m^2, whereas after 3 d exposure complete mortality occurred at the highest rate of 110 mg/m^2. Similar trends were noted during the second week of the test. During the third week of the test, mortality was notably reduced in all cases with the exception of the highest rate, where it was 100% after 3 d of exposure. At the lowest rate of 2.8 mg/ m^2, survival of the exposed adults was 100%.

Mortality of *L. entomophila*. Between and within exposure intervals, all main effects and associated interactions were significant (Table 1). Chlorfenapyr was very effective against *L. entomophila* during all 3 wk of the test (Table 3). For rates >20.6 mg/m^2, mortality was ≥90% after 1 d of exposure during the first week of the test. After 2 and 3 d of exposure, mortality exceeded 94% even at the lowest rate. All *L. entomophila* adults were dead for rates >2.8 mg/m^2 after 3 d of exposure. During the second week of the test, mortality after 2 d of exposure was 99.2% for rates

Table 1. Repeated measures MANOVA parameters for main effects and associated interactions for mortality levels of *L. bostrychophila*, *L. entomophila*, and *L. paeta* adults during a 3-wk period (error df = 77 for all species)

Insect species	df	*F*	*P*	df	*F*	*P*
	First week					
	All between variables					
	Intercept			Rate		
L. bostrychophila	1	1,208.0	<0.01	6	78.2	<0.01
L. entomophila	1	13,195.6	<0.01	6	355.6	<0.01
L. paeta	1	4,414.1	<0.01	6	124.5	<0.01
	All within variables					
	Exposure			Exposure x rate		
L. bostrychophila	2	128.8	<0.01	12	7.5	<0.01
L. entomophila	2	43.7	<0.01	12	6.6	<0.01
L. paeta	2	19.0	<0.01	12	3.5	0.01
	Second week					
	All between variables					
	Intercept			Rate		
L. bostrychophila	1	1,041.9	<0.01	6	83.3	<0.01
L. entomophila	1	3,246.8	<0.01	6	106.1	<0.01
L. paeta	1	1,073.3	<0.01	6	58.3	<0.01
	All within variables					
	Exposure			Exposure x rate		
L. bostrychophila	2	59.2	<0.01	12	5.1	<0.01
L. entomophila	2	62.1	<0.01	12	6.9	<0.01
L. paeta	2	56.4	<0.01	12	5.7	<0.01
	Third week					
	All between variables					
	Intercept			Rate		
L. bostrychophila	1	413.9	<0.01	6	55.0	<0.01
L. entomophila	1	11,907.0	<0.01	6	335.3	<0.01
L. paeta	1	3,592.2	<0.01	6	170.5	<0.01
	All within variables					
	Exposure			Exposure x rate		
L. bostrychophila	2	71.2	<0.01	12	7.2	<0.01
L. entomophila	2	30.9	<0.01	12	7.0	<0.01
L. paeta	2	31.3	<0.01	12	4.0	<0.01

20.6, 27.5, and 55 mg/m^2, but complete mortality occurred only at the highest rate of 110 mg/m^2. Complete mortality was noted for rates >13.8 mg/m^2 after 3 d of exposure. During the third week of the test, mortality was 99.2% at 55 and 110 mg/m^2 after 1 d of exposure. All *L. entomophila* adults were dead at rates >20.6 and >2.8 mg/m^2 after 2 and 3 d of exposure, respectively.

Mortality of *L. paeta*. Between and within exposure intervals, all main effects and associated interactions were significant (Table 1). Chlorfenapyr was very effective even against *L. paeta* during the 3 wk of the residual experiment, with increased mortality at increasing rates (Table 4). During the first week of the experiment, mortality after 1 d of exposure exceeded 94% for rates >20.6 mg/m^2 and was 100% at the highest rate. After 2 and 3 d of exposure, mortality exceeded 98% for rates >2.8 mg/m^2. During the second week, mortality was 100% after 3 d only on dishes treated with the highest rate. During the third week, mortality was ≥90% for rates >2.8 mg/m^2 and 100% for rates >27.5 mg/m^2 after 2 and 3 d of exposure.

Discussion

Recent studies showed that stored-product psocids were very tolerant to most of the insecticides that were effective against other major stored-product insect species, such as beetles and moths. In grains, Athanassiou et al. (2009) reported that spinosad or natural pyrethrum were unable to totally control *L. bostrychophila*, *L. entomophila*, and *L. paeta*. Moreover, on concrete, Athanassiou et al. (2011) found that the insect growth regulator pyriproxyfen did not control *L. paeta* and only partially controlled *L. bostrychophila* and *L. decolor*. Guedes et al. (2008) found that chlorfenapyr was more effective than pyrethrins for the control of *L. bostrychophila* and *L. entomophila*. Our results show efficacy of chlorfenapyr against these major stored-product psocids. Among the species tested, *L. entomophila* was the most susceptible to chlorfenapyr, given that efficacy during the entire 3 wk of the bioassays was 99–100%, even on dishes treated with the lowest rate of 13.8 mg /m^2, at the 3-d exposure interval. Similarly, for the same rate and

Table 2. Mean mortality (% ± SE) of *L. bostrychophila* adults exposed on concrete for 1, 2, and 3 d in dishes treated with chlorfenapyr at 0 (untreated control), 2.8, 13.8, 20.6, 27.5, 55, and 110 mg (AI)/m² during a 3-wk period

Exposure	Rate [mg (AI)/m²]							F	P
	0	2.8	13.8	20.6	27.5	55	110		
First week									
1 d	0.0 ± 0.0C	5.0 ± 1.5Ca	14.2 ± 3.1BCb	19.2 ± 4.7BCb	25.0 ± 5.8Bc	54.2 ± 7.3Ab	73.3 ± 5.3Ab	33.8	<0.01
2 d	0.0 ± 0.0D	20.8 ± 6.7Da	44.2 ± 6.7Ca	72.5 ± 6.6Ba	71.7 ± 6.6Bb	91.7 ± 3.4ABa	99.2 ± 0.8Aa	50.2	<0.01
3 d	0.0 ± 0.0D	25.0 ± 7.9Ca	50.0 ± 7.5Ba	84.2 ± 4.5Aa	94.2 ± 3.1Aa	98.3 ± 1.1Aa	100.0 ± 0.0Aa	74.5	<0.01
F	–	3.0	10.0	41.7	42.6	25.4	24.2		
P	–	0.06	<0.01	<0.01	<0.01	<0.01	<0.01		
Second week									
1 d	0.0 ± 0.0D	1.7 ± 1.1Da	16.7 ± 3.1CDb	33.3 ± 6.0BCb	45.0 ± 7.7Bb	76.7 ± 6.3Ab	90.8 ± 6.6Aa	46.8	<0.01
2 d	0.0 ± 0.0E	5.0 ± 2.9Ea	40.0 ± 6.9Dab	71.7 ± 7.1Ca	76.7 ± 8.6BCa	95.0 ± 2.9ABa	99.2 ± 0.8Aa	62.6	<0.01
3 d	0.0 ± 0.0C	10.0 ± 7.5Ca	51.7 ± 10.0Ba	90.0 ± 3.5Aa	90.8 ± 5.3Aa	99.2 ± 0.8Aa	100.0 ± 0.0Aa	65.8	<0.01
F	–	0.8	6.1	25.8	10.3	8.8	1.8		
P	–	0.46	<0.01	<0.01	<0.01	<0.01	0.19		
Third week									
1 d	0.0 ± 0.0C	0.0 ± 0.0Ca	4.2 ± 2.6BCb	9.2 ± 5.0BCb	8.3 ± 3.2BCb	25.8 ± 7.8Bb	66.7 ± 9.2Ab	21.3	<0.01
2 d	0.0 ± 0.0C	0.0 ± 0.0Ca	17.5 ± 5.5BCab	25.0 ± 7.5Bb	35.8 ± 8.2Ba	74.2 ± 7.8Aa	95.8 ± 1.9Aa	43.0	<0.01
3 d	0.0 ± 0.0C	0.0 ± 0.0Ca	39.2 ± 9.8Ba	52.5 ± 6.4Ba	58.3 ± 8.4Ba	90.0 ± 5.9Aa	100.0 ± 0.0Aa	44.5	<0.01
F	–	–	7.0	11.7	12.7	21.3	11.3		
P	–	–	<0.01	<0.01	<0.01	<0.01	<0.01		

Within each row, means followed by the same upper-case letter are not significantly different, in all cases df = 6, 83; within each column, means followed by the same lower-case letter are not significantly different, in all cases df = 2, 35; HSD test at 0.05.

exposure interval, mortality of *L. paeta* was >81%. Conversely, *L. bostrychophila* was the least susceptible to chlorfenapyr, because, at the conditions mentioned above, mortality did not exceed 52%. Guedes et al. (2008) also noted that *L. bostrychophila* was more tolerant than *L. entomophila* to both β-cyfluthrin and chlorfenapyr on concrete.

Most of the studies available for the efficacy of contact insecticides on concrete and other surfaces focus on immediate mortality after an application, and there are comparatively few data on residual efficacy. Contact insecticides are used as part of pest management programs in flour mills and food warehouses, and therefore residual efficacy is highly desirable because long-term control reduces the need to repeat the applications at short intervals. In light of our findings, chlorfenapyr, at rates of 13.8 mg/m² or more, provided adequate control of *L. entomophila* and *L. paeta* for 3 wk. In contrast, the efficacy of chlorfenapyr against *L. bostrychophila* was notably reduced during the third week of the experiments, and was 100% after 3 d only on dishes treated with 110 mg/m² of the label rate. Adequate identification of the species that are present in a storage facility is essential because knowledge of the target species may give an accurate prediction of the residual efficacy of the insecticide to be used, or even indicate the selection of the insecticide. It is generally expected that insecticide degradation will occur faster on concrete in comparison with other surfaces, such as galvanized steel, due to the fact that

Table 3. Mean mortality (% ± SE) of *L. entomophila* adults exposed on concrete for 1, 2, and 3 d in dishes treated with chlorfenapyr at 0 (untreated control), 2.8, 13.8, 20.6, 27.5, 55, and 110 mg (AI)/m² during a 3-wk period

Exposure	Rate [mg (AI)/m²]							F	P
	0	2.8	13.8	20.6	27.5	55	110		
First week									
1 d	0.8 ± 0.8Da	46.7 ± 7.5Cb	74.2 ± 7.1Bb	80.8 ± 6.1ABb	90.0 ± 3.5ABb	92.5 ± 3.1ABb	95.8 ± 2.9Aa	46.9	<0.01
2 d	3.3 ± 1.9Ca	94.2 ± 2.9Ba	100.0 ± 0.0Aa	99.2 ± 0.8ABa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	733.0	<0.01
3 d	3.3 ± 1.9Ba	99.2 ± 0.8Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	2203.0	<0.01
F	0.8	38.4	1.2	9.3	8.3	6.1	2.1		
P	0.46	<0.01	<0.01	<0.01	<0.01	<0.01	0.14		
Second week									
1 d	0.8 ± 0.8Da	31.7 ± 6.8Cb	59.2 ± 7.4Bb	78.3 ± 4.4ABb	83.3 ± 4.7Ab	94.2 ± 2.6Ab	94.2 ± 3.6Aa	53.2	<0.01
2 d	0.8 ± 0.8Ca	60.8 ± 9.3Ba	90.8 ± 5.3Aa	99.2 ± 0.8Aa	99.2 ± 0.8Aa	99.2 ± 0.8Aab	100.0 ± 0.0Aa	82.7	<0.01
3 d	0.8 ± 0.8Ca	75.8 ± 8.5Ba	99.2 ± 0.8Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	130.8	<0.01
F	0.0	7.4	15.9	22.4	11.8	4.0	2.7		
P	1.00	<0.01	<0.01	<0.01	<0.01	0.03	0.09		
Third week									
1 d	0.0 ± 0.0Ca	51.7 ± 7.2Bb	70.0 ± 8.3Bb	91.7 ± 3.2Ab	96.7 ± 1.4Ab	99.2 ± 0.8Aa	99.2 ± 0.8Aa	70.7	<0.01
2 d	2.5 ± 1.3Ca	85.0 ± 3.6Ba	96.7 ± 1.9Aa	99.2 ± 0.8Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	483.6	<0.01
3 d	2.5 ± 1.3Ca	94.2 ± 1.9Ba	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	1722.3	<0.01
F	1.8	22.1	11.3	5.7	5.5	1.0	1.0		
P	0.18	<0.01	<0.01	<0.01	<0.01	0.38	0.38		

Within each row, means followed by the same upper-case letter are not significantly different, in all cases df = 6, 83; within each column, means followed by the same lower-case letter are not significantly different, in all cases df = 2, 35; HSD test at 0.05.

Table 4. Mean mortality (% ± SE) of *L. paeta* adults exposed on concrete for 1, 2, and 3 d in dishes treated with chlorfenapyr at 0 (untreated control), 2.8, 13.8, 20.6, 27.5, 55, and 110 mg of (AI)/m² during a 3-wk period

Exposure	Rate [mg (AI)/m²]							F	P
	0	2.8	13.8	20.6	27.5	55	110		
First week									
1 d	2.5 ± 1.8Ca	49.2 ± 7.5Bb	85.0 ± 5.4Ab	85.8 ± 5.4Ab	94.2 ± 3.4Aa	97.5 ± 1.3Ab	100.0 ± 0.0A	67.4	<0.01
2 d	3.3 ± 1.9Ca	70.8 ± 8.9Bab	98.3 ± 1.7Aa	99.2 ± 0.8Aa	98.3 ± 1.7Aa	100.0 ± 0.0Aa	100.0 ± 0.0A	101.8	<0.01
3 d	5.8 ± 9.0Ca	79.2 ± 29.1Ba	99.2 ± 0.8Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	100.0 ± 0.0A	110.7	<0.01
F	0.7	3.5	5.7	6.3	1.9	3.7	–		
P	0.52	0.04	<0.01	<0.01	0.16	0.04	–		
Second week									
1 d	2.5 ± 1.3Ca	11.7 ± 3.2Ca	44.2 ± 8.7Bb	65.8 ± 7.6Ba	64.2 ± 5.8Bb	89.2 ± 3.1Ab	94.2 ± 2.3Ab	45.4	<0.01
2 d	4.2 ± 1.9Ca	14.2 ± 4.5Ca	63.3 ± 11.1Bab	80.0 ± 7.5ABa	81.7 ± 5.2ABa	95.8 ± 1.9Aab	99.2 ± 0.8Aa	44.1	<0.01
3 d	4.2 ± 1.9Ba	15.8 ± 4.4Ba	81.7 ± 7.4Aa	87.5 ± 8.2Aa	90.0 ± 3.5Aa	97.5 ± 1.8Aa	100.0 ± 0.0Aa	71.4	<0.01
F	0.3	0.3	4.2	2.0	7.1	3.5	5.0		
P	0.74	0.77	0.02	0.15	<0.01	0.04	0.01		
Third week									
1 d	0.0 ± 0.0C	9.2 ± 2.3Cc	64.2 ± 9.8Bb	80.8 ± 7.3ABa	73.3 ± 7.0ABb	94.2 ± 3.4Aa	94.2 ± 4.2Aa	46.1	<0.01
2 d	0.0 ± 0.0C	23.3 ± 3.8Bb	90.0 ± 3.0Aa	91.7 ± 5.1Aa	87.5 ± 5.2Aab	100.0 ± 0.0Aa	100.0 ± 0.0Aa	153.9	<0.01
3 d	0.0 ± 0.0C	40.8 ± 3.6Ba	95.0 ± 2.0Aa	95.8 ± 2.3Aa	99.2 ± 0.8Aa	100.0 ± 0.0Aa	100.0 ± 0.0Aa	489.5	<0.01
F	–	23.5	7.5	2.2	6.5	3.0	2.0		
P	–	<0.01	<0.01	0.13	<0.01	0.06	0.16		

Within each row, means followed by the same upper-case letter are not significantly different, in all cases df = 6, 83; within each column, means followed by the same lower-case letter are not significantly different, in all cases df = 2, 35; HSD test at 0.05.

concrete is porous and highly alkaline (White and Leesch 1996, Arthur et al. 2009, Arthur 2012). Wijayaratne et al. (2012) exposed *T. castaneum* larvae and flour on varnished wood and concrete treated with methoprene, and showed that the emergence of adults was consistently greater on concrete than on varnished wood. However, paradoxically, Arthur (2008) reported that chlorfenapyr was more effective on concrete than on tile or plywood for control of adult *T. castaneum.* Additional testing is needed for longer periods and a wider range of species to determine the stability of chlorfenapyr over time.

In an earlier study with chlorfenapyr, Arthur (2009) reported that adult recovery of *T. castaneum* after exposure on concrete treated with chlorfenapyr was high after the removal of the exposed adults from the treated substrate, especially when there was access to food (flour). In our study, although quantitative observations were not obtained, we noted that, especially during the third week and at the lower chlorfenapyr concentrations, many individuals were fully recovered. Hence, under real-world conditions, these individuals will eventually escape from the treated area to reproduce. The scenario of partially treated areas or areas treated with low rates is realistic, and is likely to occur even in optimized structural applications. Consequently, the fact that some areas receive less or no insecticide may cause increased survival of the exposed insects. Athanassiou et al. (2009) noted that for grains partially treated with spinosad, survival of adults of the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), was high when the adults were on the untreated part of the grain. Similarly, Arthur (2008) noted that the recovery of adults of *T. confusum* and *T. castaneum* after exposure on chlorfenapyr was high, with *T. confusum* being more susceptible than *T. castaneum.* In our study, it is estimated that adults that were immobilized would be dead if they had been continually exposed to the treated surface, while mobile adults would be fully recovered. Despite the fact that for other species, in comparison with other insecticides, chlorfenapyr is relatively slow-acting (Guedes et al. 2008), high mortality was noted even after 2 d of exposure. These levels are comparable with the efficacy of other insecticides, such as cyfluthrin + imidacloprid, which provide high levels of mortality after 2 or 3 d for *Liposcelis* spp. (Athanassiou et al. 2013). In summary, our results show that chlorfenapyr is an effective alternative to pyrethroids and ogranophosphates for control of psocids on concrete, providing effective control for at least 3 wk and even at very low rates. More experimentation is required to estimate recovery patterns of the exposed individuals to chlorfenapyr.

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