Efficacy of a Combination of Beta-Cyfluthrin and Imidacloprid and Beta-Cyfluthrin Alone for Control of Stored-Product Insects on Concrete

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ABSTRACT   The insecticidal effect of Temprid, a formulation that contains beta-cyfluthrin and imidacloprid, was tested on concrete for control of seven stored-product insect species: the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens); the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); the red flour beetle, *Tribolium castaneum* (Herbst); the confused flour beetle, *T. confusum* Jacquelin du Val; the hide beetle, *Dermestes maculatus* (DeGeer); and the psocids *Liposcelis bostrychophila* Badonnel and *L. paeta* Pearman. Temprid, which contains 10.5% beta-cyfluthrin and 21% imidacloprid, was tested at the rate of 17.2 ml of formulation/4.1 liters of water/100 m^2. Adults were exposed for 4, 8, 14, and 24 h, and then daily for 7 d, on untreated dishes or dishes treated with Temprid. In the untreated dishes, mortality of *C. ferrugineus* and *O. surinamensis* was lower when food was present, but food did not affect mortality of the other species. Presence of food did not affect mortality of any of the species tested in the treated dishes. *C. ferrugineus*, *O. surinamensis*, and the two psocid species were very susceptible to Temprid, with mortality of 97–100% after 7 d of exposure. In contrast, *D. maculatus*, *T. castaneum*, and *T. confusum* were tolerant to Temprid, as mortality did not exceed 57, 25, and 17%, respectively, at the 7-d exposure. A separate series of similar bioassays with Tempo, a formulation that contains 11.8% beta-cyfluthrin alone, which was applied at the same dose rate as Temprid, was conducted using *O. surinamensis* and *T. castaneum* as the target insect species, and results showed that Tempo was at least as effective as Temprid. Our results indicate that the simultaneous use of beta-cyfluthrin with imidacloprid is not more effective on concrete than beta-cyfluthrin alone, and efficacy of both formulations varies with the target species.

KEY WORDS   cyfluthrin, imidacloprid, binary combinations, surface treatment

The direct application of contact insecticides as grain protectants has been used extensively to deter infestation by stored-product insects (Arthur 1996). In addition, there are numerous insecticides that can be used on various types of surfaces, as well as in cracks and crevices, in stored-product facilities (Arthur 2012). There is increased interest in the evaluation of insecticides that could be used for this purpose, and many ingredients are registered for application with normal mechanical liquid sprayers (Arthur 2012). Most studies that have tested surface treatments for control of stored-product insects have focused on the evaluation of single compounds. However, data available indicate that a single active ingredient may not be able to control all of the species that are likely to exist in a given stored-product facility. This is particularly important given that several species coexist at various population densities (Subramanyam and Harein 1990, Athanassiou et al. 2009a). For example, 22 insect taxa were found during 1 yr of sampling in a horizontal store of wheat in Greece (Athanassiou et al. 2009a).

The use of binary combinations of active ingredients is considered one of the means available to expand the spectrum of target species for which a given application is effective. Athanassiou et al. (2009b) found that a combination of the organophosphate (OP) chlorpyrifos-methyl with the pyrethroid deltamethrin was superior to spinosad or natural pyrethrum for control of stored-grain psocids (Psocoptera). Daglish (2008) reported that the use of chlorpyriphos-methyl in combination with spinosad was, in many cases, more effective than the application of either insecticide alone for the control of several stored-grain insect species.

Given that some of the currently used insecticides for surface treatments, particularly OPs, have high mammalian toxicity, it is essential to evaluate newer,

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safer, and environmentally friendly compounds as surface treatments. One of these compounds is the pyrethroid cyfluthrin, which has been proved effective for control of the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), on concrete (Arthur 1998, 1999a). Athanassiou et al. (2004) found that the isomer beta-cyfluthrin was superior to the pyrethroids deltamethrin and alpha-cypermethrin on wheat for control of the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae). However, cyfluthrin is considered moderately effective for control of other species, such as the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), and the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) (Arthur 1999b,c). One possible solution to overcome this problem is the simultaneous use of cyfluthrin with other novel compounds with a different mode of action. One promising compound with low mammalian toxicity is the neonicotinoid imidacloprid, which acts on the nicotinic acetylcholine receptors and is registered globally for control of a wide range of pests. Imidacloprid is globally one of the most commonly used insecticides for seed coating (Yue et al. 2003). In addition, Daglish and Nayak (2012) found that imidacloprid was effective on wheat against *R. dominica* but ineffective against *S. oryzae.* Recently, imidacloprid was formulated with beta-cyfluthrin in a single commercial formulation under the trade name Temprid (Bayer Crop Science, Research Triangle Park, NC), which is registered for crack and crevice treatments for control of stored-product and urban pests. This is considered as an enhanced formulation of an older one, Tempo (Bayer Crop Science), which contains only beta-cyfluthrin. Given that there are no data available for the combined use of imidacloprid with beta-cyfluthrin for control of stored-product insect pests, the purpose of this work was to examine the efficacy of Temprid on concrete for control of several of these pests.

Materials and Methods

Insects. Adults of *T. castaneum, T. confusum;* the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae); the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae); the hide beetle, *Dermestes maculatus* (De Geer) (Coleoptera: Dermestidae); *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelididae); and *L. paeta* Pearman were used in the tests. The beetles were reared at 27.5°C and 75% relative humidity (RH), and the psocids were reared at 30°C and 75% RH. *T. castaneum* and *T. confusum* were reared on wheat flour plus 5% brewer's yeast, while *O. surinamensis* and *C. ferrugineus* were reared on rolled oats plus 5% brewer's yeast. *D. maculatus* was reared on dog food (Purina Lamb and Rice Dog Food, Purina, St. Louis, MO), at 30°C and 70% RH. The psocids were reared on a mixture of 97% cracked wheat kernels, 2% rice flakes, and 1% brewer's yeast at 30°C and 70% RH (Opit and Throne 2008). All beetle species have been reared in

the laboratory for several decades, with the exception of *D. maculatus,* which was collected from a pet food plant in Missouri, and has been reared in the laboratory since then. Both psocid species were collected from the grain elevators of the Center for Grain and Animal Health Research (formerly, the Grain Marketing and Production Research Center) in Manhattan, KS, in 2006, and have been reared in the laboratory since then. Beetle and psocid adults that were used in the tests were <4-wk and <2-wk old, respectively.

Bioassays with Temprid. The formulation Temprid SC, which contains 10.5% beta-cyfluthrin and 21% imidacloprid, was tested at the rate of 17.2 ml of formulation/4.1 liters of water/100 m^2 (corresponding to the highest label rate of 16 ml/gallon/1,000 feet^2 in the United States). The experiment was carried out in a completely randomized block design, with three subreplicates and three replicates. All tests were conducted in petri dishes (9 cm diameter × 1.5 cm high), with a surface area of 62 cm^2. One day before the tests, the bottoms of the dishes were covered with driveway patching material (Rockite, Hartline Products Co., Inc., Cleveland, OH) to create the concrete surface. The internal sides of all dishes were coated with Fluon (polytetrafluoroethylene, Northern Products, Woonsocket, RI) to prevent escape of psocids. To obtain the label rate, solutions of 25 ml, that contained 0.1 ml of Temprid, were prepared with distilled water, and each dish was sprayed with 0.25 ml of the solution. 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. Ten adults of each species were placed on an individual dish immediately after it was sprayed. Half of the dishes contained food, which was placed on the concrete after spraying; there were 10 cracked wheat kernels in dishes containing psocids, *O. surinamensis,* and *C. ferrugineus,* 0.5 g of wheat flour for *T. confusum* and *T. castaneum,* and 1 g of dog food for *D. maculatus.* The other half of the dishes did not contain food. An additional series of dishes, with or without food, were prepared and sprayed, as described above, with distilled water, and served as controls. Adult mortality was determined by prodding with a brush to detect movement under a stereomicroscope after 4, 8, 14, and 24 h of exposure, and then daily for 7 d. The entire procedure was replicated three times by preparing three new dishes each time for each combination (three replicates with three subreplicates = 9 dishes for each combination).

Bioassays with Tempo. An additional series of bioassays was conducted with Tempo SC Ultra, a formulation that contains 11.8% beta-cyfluthrin, to determine possible differences in efficacy between the two formulations. This series of bioassays and the analysis were carried out using the same protocol as above. Given that the highest label rate of Tempo was the same as for Temprid, the preparation of solutions and application was done as described previously. Temprid and Tempo have different concentrations of beta-cyfluthrin, so they are not directly comparable in their

Table 1. Repeated measures MANOVA parameters for main effects and associated interactions for mortality levels of *C. ferrugineus*, *O. surinamensis*, *T. castaneum*, *T. confusum*, *D. maculatus*, *L. paeta*, and *L. bostrychophila* adults (error df = 44 for all species)

| Insect species | All between variables | | | | | |
| | Intercept | | | Treatment | | |
	df	F	P	df	F	P
C. ferrugineus	1	705.4	<0.01	3	125.6	<0.01
O. surinamensis	1	27.3	<0.01	3	17.7	<0.01
T. castaneum	1	11.7	<0.01	3	4.3	<0.01
T. confusum	1	9.4	<0.01	3	2.7	0.05
D. maculatus	1	75.6	<0.01	3	3.8	0.02
L. paeta	1	783.5	<0.01	3	217.1	<0.01
L. bostrychophila	1	1,255.5	<0.01	3	334.9	<0.01

| Insect species | All within variables | | | | | |
| | Exposure | | | Exposure × treatment | | |
	df	F	P	df	F	P
C. ferrugineus	9	123.3	<0.01	27	9.0	<0.01
O. surinamensis	9	345.4	<0.01	27	15.4	<0.01
T. castaneum	9	2.7	0.02	27	1.5	0.09
T. confusum	9	3.5	0.03	27	2.2	<0.01
D. maculatus	9	12.8	<0.01	27	1.6	0.06
L. paeta	9	323.4	<0.01	27	15.1	<0.01
L. bostrychophila	9	458.7	<0.01	27	17.8	<0.01

efficacy; hence, we used only two species for these tests, *O. surinamensis* and *T. castaneum*, because preliminary trials indicated that they were susceptible and tolerant to beta-cyfluthrin, respectively.

Data Analysis. The data for treated and untreated dishes were analyzed separately for each species with the Multivariate Analysis of Variance (MANOVA) Repeated Measures and Wilks' Lambda estimate, by using the JMP software (Sall et al. 2001). Means were separated by the Tukey–Kramer honestly significant difference (HSD) at $\alpha = 0.05$ (Sokal and Rohlf 1995).

Results

Insecticidal Effect of Temprid. Exposure and treatment had a significant effect on mortality for all species, except for *T. confusum* where treatment was not significant (Table 1). For *C. ferrugineus*, control mortality was not affected by the presence of food until the seventh day when mortality in dishes that contained food was significantly lower than that in dishes without food (13 and 38%, respectively) (Table 2). In contrast, the presence of food did not affect mortality on treated dishes regardless of the exposure interval. Mortality was 97 and 99% in dishes with or without food, respectively, after 7 d of exposure.

Food significantly affected mortality of *O. surinamensis* in the control dishes after 5 d (Table 3). After 7 d, ca. one-third of the *O. surinamensis* adults were dead in dishes without food, but mortality was negligible (3%) in dishes with food. Mortality in control dishes with or without food was similar during the first 4 d. The presence of food had no effect on mortality in the treated dishes, which reached 99–100% after 7 d.

For *T. castaneum*, almost all of the adults in the control dishes were alive after 7 d, regardless of the

Table 2. Mean mortality (% ± SE) of *C. ferrugineus* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

| Exposure | Control | | Temprid | | F | P |
	Food	No food	Food	No food		
4 h	0.0 ± 0.0a	0.0 ± 0.0a	1.7 ± 1.1a	1.7 ± 1.1a	1.5	0.24
8 h	1.7 ± 1.1a	0.0 ± 0.0a	3.3 ± 1.9a	5.8 ± 2.3a	2.5	0.08
16 h	2.5 ± 1.8b	0.0 ± 0.0b	5.8 ± 2.6ab	12.5 ± 4.1a	4.4	<0.01
1 d	5.0 ± 2.3b	3.3 ± 1.4b	34.2 ± 4.5a	45.8 ± 6.8a	24.4	<0.01
2 d	6.7 ± 2.8b	5.8 ± 1.9b	67.5 ± 8.2a	80.0 ± 5.8a	55.2	<0.01
3 d	9.2 ± 4.0b	7.5 ± 2.5b	79.2 ± 6.6a	87.5 ± 4.9a	84.2	<0.01
4 d	10.8 ± 4.2b	12.5 ± 3.5b	86.7 ± 4.7a	93.3 ± 3.1a	134.7	<0.01
5 d	12.5 ± 4.5b	19.2 ± 3.6b	87.5 ± 4.3a	97.5 ± 1.8a	146.1	<0.01
6 d	13.3 ± 4.3b	25.8 ± 4.2b	95.0 ± 2.9a	99.2 ± 0.8a	180.2	<0.01
7 d	13.3 ± 4.3c	37.5 ± 4.6b	96.7 ± 1.9a	99.2 ± 0.8a	167.0	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

presence of food (Table 4). On the treated dishes, mortality was low, and was not affected significantly by the presence of food. After 7 d, mortality of *T. castaneum* was 14 and 25% for dishes with or without food, respectively. Results were similar for *T. confusum*. Control mortality was low, while mortality in the treated dishes did not exceed 17% (Table 5).

Mortality of *D. maculatus* was not affected by the presence of food in the control or treated dishes (Table 6). Control mortality was generally high and exceeded 12% even after 1 d of exposure, reaching 17–23% after 7 d. Mortality was 18–23% after 1 d of exposure in the treated dishes, but did not exceed 57% during the 7-d exposure period.

Both psocid species were very susceptible to Temprid. Mortality of *L. paeta* was not affected by the presence of food (Table 7), and mortality in the control dishes with or without food was 11 and 2%, respectively, after 7 d while mortality levels in the treated dishes was >98% after 4 d of exposure. For *L. bostrychophila*, control mortality was generally higher on dishes that contained food (Table 8). In the treated dishes, there was no effect of food, and all adults were dead after 7 and 5 d on dishes with or without food, respectively.

Insecticidal Effect of Tempo. Treatment, exposure, and their interaction were significant for both species

Table 3. Mean mortality (% ± SE) of *O. surinamensis* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

| Exposure | Control | | Temprid | | F | P |
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	1.7 ± 1.1a	0.0 ± 0.0a	0.8 ± 0.8a	0.8 ± 0.8a	0.7	0.56
16 h	1.7 ± 1.1a	0.0 ± 0.0a	3.3 ± 1.4a	1.7 ± 1.1a	1.6	0.20
1 d	2.5 ± 1.3b	1.7 ± 1.1b	13.3 ± 2.6a	11.7 ± 3.0a	8.0	<0.01
2 d	2.5 ± 1.3b	2.5 ± 1.8b	42.5 ± 6.8a	35.0 ± 4.0a	26.9	<0.01
3 d	2.5 ± 1.3b	4.2 ± 2.3b	63.3 ± 7.1a	56.7 ± 5.6a	48.9	<0.01
4 d	3.3 ± 1.4b	7.5 ± 2.5b	85.8 ± 3.8a	75.0 ± 5.2a	154.5	<0.01
5 d	3.3 ± 1.4c	13.3 ± 2.2b	90.0 ± 2.8a	88.3 ± 3.7a	313.3	<0.01
6 d	3.3 ± 1.4c	23.3 ± 2.8b	98.3 ± 1.1a	95.8 ± 1.9a	637.8	<0.01
7 d	3.3 ± 1.4c	30.0 ± 4.3b	99.2 ± 0.8a	100.0 ± 0.0a	461.4	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Table 4. Mean mortality (% ± SE) of *T. castaneum* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
16 h	0.0 ± 0.0a	0.0 ± 0.0a	0.8 ± 0.8a	0.0 ± 0.0a	1.0	0.40
1 d	0.0 ± 0.0a	0.0 ± 0.0a	2.5 ± 1.3a	0.8 ± 0.8a	2.3	0.09
2 d	0.0 ± 0.0b	0.0 ± 0.0b	2.5 ± 1.3ab	6.7 ± 3.3a	3.1	0.04
3 d	0.0 ± 0.0b	0.0 ± 0.0b	4.2 ± 1.9ab	8.3 ± 3.7a	3.7	0.02
4 d	0.0 ± 0.0b	0.0 ± 0.0b	5.0 ± 2.0ab	13.3 ± 6.4a	3.5	0.02
5 d	0.0 ± 0.0b	0.0 ± 0.0b	8.3 ± 3.7ab	14.2 ± 6.3a	3.6	0.02
6 d	0.0 ± 0.0b	0.8 ± 0.8ab	10.8 ± 4.7a	17.5 ± 7.9a	3.3	0.03
7 d	0.0 ± 0.0b	0.8 ± 0.8b	14.2 ± 5.6a	25.0 ± 8.4a	5.6	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Table 6. Mean mortality (% ± SE) of *D. maculatus* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0a	0.0 ± 0.0a	0.8 ± 0.8a	0.8 ± 0.8a	0.7	0.58
8 h	0.0 ± 0.0a	0.0 ± 0.0a	1.7 ± 1.7a	1.7 ± 1.7a	0.7	0.58
16 h	3.3 ± 1.9a	4.2 ± 1.9a	5.8 ± 2.9a	5.0 ± 2.6a	0.2	0.89
1 d	12.5 ± 4.6a	15.0 ± 4.2a	22.5 ± 6.1a	18.3 ± 5.9a	0.7	0.57
2 d	15.2 ± 4.5a	15.8 ± 4.2a	30.0 ± 6.6a	25.8 ± 6.7a	1.9	0.15
3 d	15.0 ± 4.4b	16.7 ± 4.1b	35.0 ± 6.8a	32.5 ± 7.4a	3.2	0.03
4 d	15.8 ± 4.2b	20.0 ± 5.5ab	42.5 ± 7.9a	37.5 ± 8.8ab	3.6	0.02
5 d	16.6 ± 4.0b	20.8 ± 6.0ab	47.5 ± 8.1a	42.5 ± 10.5ab	4.2	0.01
6 d	16.7 ± 4.0b	22.5 ± 6.9ab	51.7 ± 7.4a	46.7 ± 11.3a	4.9	<0.01
7 d	17.5 ± 4.6c	23.3 ± 7.4bc	56.7 ± 7.0a	52.5 ± 10.9ab	6.5	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

tested (Table 9). For *O. surinamensis,* as in the previous series of bioassays, control mortality was higher in dishes that did not contain food (Table 10). Mortality was high in treated dishes and reached 99–100% after 6 d of exposure. For this species, food had no effect on mortality in the treated dishes.

As in the previous tests, mortality of *T. castaneum* adults was low in the controls and was not affected by the presence of food (Table 11). In the treated dishes, mortality was significantly higher in the absence of food, but only for some exposure intervals. At the 7 d exposure, mortality ranged between 33 and 53%, which was higher in comparison with the respective figures for Temprid in the previous series of bioassays.

Discussion

The presence of food in the concrete arenas was critical for survival of some of the species tested. Adults of *C. ferrugineus* and *O. surinamensis* were able to survive on concrete without food for three and 4 d, respectively, but the absence of food caused rapid mortality after this interval. As underlined by previous studies, adult mortality in untreated dishes that contain no food is because of starvation (Edde and Phillips 2006). Nevertheless, food may not be essential for some short intervals for these species, which can sur-

vive in refugia such as cracks and crevices without the need for food. Despite the fact that sanitation and appropriate hygienic conditions in a given facility are directly related to insect presence, it seems that some species can tolerate the absence of food and remain in untreated areas without food for a short time. For the rest of the species tested, the presence of food in the untreated dishes was not an important factor, at least for the 7-d interval examined here. Hence, the absence of food is more crucial for some of the species tested than for others. Paradoxically, mortality of *L. bostrychophila* after 7 d in the controls was higher when food was present, but still did not exceed 10%.

In contrast with the control dishes, the presence of food did not impact efficacy of Temprid for any of the species tested. This is probably because of the fact that adults were immobilized right after their first contact with the treated surface, so contact with the food that was available in this area was restricted. Despite the fact that no quantitative data were recorded, we observed that adults of all species were knocked down, even at the shorter (4 h) exposure period. However, we would expect recovery of some of these surviving adults, especially in the case of the least susceptible species, would be likely to occur if these individuals had been removed from the treated surface. Arthur (2009) exposed adults of *T. castaneum* for 2–8 h on

Table 5. Mean mortality (% ± SE) of *T. confusum* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
16 h	0.0 ± 0.0a	0.0 ± 0.0a	1.7 ± 1.1a	0.8 ± 0.8a	1.3	0.29
1 d	0.0 ± 0.0a	0.8 ± 0.8a	3.3 ± 1.9a	2.5 ± 1.8a	1.2	0.31
2 d	0.0 ± 0.0a	0.8 ± 0.8a	3.3 ± 1.9a	2.5 ± 1.8a	1.2	0.31
3 d	0.0 ± 0.0a	0.0 ± 0.0a	5.8 ± 3.6a	4.2 ± 2.3a	1.6	0.20
4 d	0.0 ± 0.0a	0.8 ± 0.8a	5.8 ± 3.6a	5.0 ± 2.9a	1.6	0.21
5 d	0.0 ± 0.0a	0.8 ± 0.8a	9.2 ± 4.7a	5.8 ± 3.1a	2.3	0.09
6 d	0.0 ± 0.0a	0.8 ± 0.8a	10.8 ± 5.3a	6.7 ± 3.1a	2.7	0.06
7 d	0.0 ± 0.0b	0.8 ± 0.8b	16.7 ± 5.0a	6.7 ± 3.1ab	6.7	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Table 7. Mean mortality (% ± SE) of *L. paeta* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.8 ± 0.8a	0.0 ± 0.0a	2.5 ± 1.3a	2.5 ± 2.5a	1.5	0.22
8 h	1.7 ± 1.7a	0.0 ± 0.0a	5.0 ± 2.3a	4.2 ± 2.3a	1.6	0.21
16 h	2.5 ± 2.5a	0.0 ± 0.0a	6.7 ± 3.3a	4.2 ± 2.3a	1.4	0.26
1 d	2.5 ± 2.5b	0.0 ± 0.0b	25.0 ± 6.8a	23.3 ± 7.8a	6.2	<0.01
2 d	3.3 ± 2.6b	0.0 ± 0.0b	68.3 ± 7.2a	59.2 ± 9.4a	35.5	<0.01
3 d	3.3 ± 2.6b	0.8 ± 0.8b	90.0 ± 3.9a	85.0 ± 5.4a	187.6	<0.01
4 d	6.7 ± 4.0b	0.8 ± 0.8b	98.3 ± 1.1a	98.3 ± 1.1a	633.1	<0.01
5 d	9.2 ± 5.4b	0.8 ± 0.8b	99.2 ± 0.8a	98.3 ± 1.1a	366.1	<0.01
6 d	9.2 ± 5.4b	0.8 ± 0.8b	99.2 ± 0.8a	99.2 ± 0.8a	376.0	<0.01
7 d	10.8 ± 5.4b	1.7 ± 1.1b	99.2 ± 0.8a	99.2 ± 0.8a	360.0	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Table 8. Mean mortality (% ± SE) of *L. bostrychophila* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Temprid, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a	0.8 ± 0.8a	1.0	0.40
16 h	0.0 ± 0.0a	0.0 ± 0.0a	0.8 ± 0.8a	1.7 ± 1.7a	0.7	0.54
1 d	6.7 ± 2.8ab	0.8 ± 0.8b	23.3 ± 6.3a	19.2 ± 6.3a	5.0	<0.01
2 d	8.3 ± 3.0b	0.8 ± 0.8b	60.8 ± 9.4a	73.3 ± 7.5a	34.6	<0.01
3 d	8.3 ± 3.0b	0.8 ± 0.8b	91.7 ± 3.9a	94.2 ± 3.4a	292.3	<0.01
4 d	8.3 ± 3.0b	0.8 ± 0.8c	96.7 ± 1.9a	99.2 ± 0.8a	847.0	<0.01
5 d	8.3 ± 3.0b	1.7 ± 1.1b	96.7 ± 1.9a	100.0 ± 0.0a	854.5	<0.01
6 d	8.3 ± 3.0b	1.7 ± 1.1b	98.3 ± 1.7a	100.0 ± 0.0a	920.5	<0.01
7 d	10.0 ± 3.0b	2.5 ± 1.3c	100.0 ± 0.0a	100.0 ± 0.0a	1,089.0	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Table 10. Mean mortality (% ± SE) of *O. surinamensis* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Tempo, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
16 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
1 d	0.0 ± 0.0a	0.0 ± 0.0a	3.3 ± 1.9a	4.2 ± 1.9a	2.7	0.06
2 d	0.0 ± 0.0b	0.0 ± 0.0b	36.7 ± 7.4a	39.2 ± 4.3a	26.0	<0.01
3 d	0.8 ± 0.8b	1.7 ± 1.1b	75.8 ± 4.8a	80.0 ± 4.8a	163.2	<0.01
4 d	0.8 ± 0.8b	5.8 ± 2.9b	90.0 ± 2.8a	96.7 ± 1.3a	584.4	<0.01
5 d	0.8 ± 0.8c	18.3 ± 3.5b	97.5 ± 1.3a	97.5 ± 1.3a	658.0	<0.01
6 d	0.8 ± 0.8c	27.5 ± 3.5b	99.2 ± 0.8a	100.0 ± 0.0a	744.7	<0.01
7 d	2.5 ± 1.8c	43.3 ± 5.6b	99.2 ± 0.8a	100.0 ± 0.0a	257.7	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

concrete dishes treated with the pyrrole chlorfenapyr, and he found that survival was high when food was available in the postexposure period. For the same insecticide, Arthur and Fontenot (2012) noted that presence of food significantly affected the susceptibility of immature *T. castaneum*, even in partially treated arenas. Similarly, Toews et al. (2010) reported that the presence of food affected mortality of *T. confusum* individuals after exposure to aerosols. Nevertheless, in a recent study, Athanassiou et al. (2011) found that there was no clear effect of the presence of food on the efficacy of the insect growth regulator (IGR) pyriproxyfen on concrete for control of *L. bostrychophila*, *L. paeta*, and *L. decolor* (Pearman). Hence, knocked down individuals are not affected by the presence of food, and food plays a role only if these individuals are removed from the treated surface.

Our results demonstrate that the combined use of cyfluthrin with imidacloprid, formulated as Temprid, differs in its efficacy among the species tested. Psocids were found highly susceptible, given that mortality was 100% or close to 100% even before the termination of the 7-d interval. This is particularly important given that many psocid species are tolerant to a broad spectrum of insecticides with various modes of action (Nayak et al. 1998, 2005; Athanassiou et al. 2009b, 2010,

2011). Guedes et al. (2008) found that *L. bostrychophila* and *L. entomophila* (Enderlein) were susceptible to beta-cyfluthrin on concrete surfaces, with *L. bostrychophila* being more tolerant than *L. entomophila.* Similarly, *C. ferrugineus* and *O. surinamensis* were susceptible to Temprid. Our results stand in accordance with previous reports for the application of pyrethroids for control of *O. surinamensis* (Collins and Wilson 1987, Watson and Barson 1996). Conversely, *T. castaneum*, *T. confusum*, and *D. maculatus* were tolerant to Temprid. In previous studies with cyfluthrin for control of *T. castaneum*, survival was high after removal of the insects from the treated substrate despite the fact that cyfluthrin could cause rapid knockdown (Arthur 1998, 1999a; Toews et al. 2010). In contrast, there are not many published reports on the efficacy of pyrethroids for control of *D. maculatus.* Golob and Kilminster (1987) found that dried fish that were dipped in several pyrethroids with piperonyl butoxide were protected from infestation by *D. maculatus*, and among these pyrethroids, deltamethrin provided adequate protection for 6 mo. In laboratory tests, Cloud and Collison (1986) found that OPs and carbamates were generally more effective than pyrethroids for control of this species. Our results show that Temprid was not effective for control of *D. maculatus*, and higher dose rates or exposures are needed for its control.

Table 9. Repeated measures MANOVA parameters for main effects and associated interactions for mortality levels of *O. surinamensis* and *T. castaneum* adults (error df = 44 for both species)

Insect species	All between variables					
	Intercept			Treatment		
	df	F	P	df	F	P
O. surinamensis	1	3055.6	<0.01	3	694.0	<0.01
T. castaneum	1	78.4	<0.01	3	25.1	<0.01
	All within variables					
	Exposure			Exposure × treatment		
	df	F	P	df	F	P
O. surinamensis	9	447.1	<0.01	27	23.1	<0.01
T. castaneum	9	16.6	<0.01	27	3.4	<0.01

Table 11. Mean mortality (% ± SE) of *T. castaneum* adults exposed with or without food on concrete for 4 h to 7 d in untreated dishes or dishes treated with Tempo, applied at the rate of 17.2 ml of formulation/4.1 liters of water/100 m²

Exposure	Control		Temprid		F	P
	Food	No food	Food	No food		
4 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
8 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
16 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	—	—
1 d	0.0 ± 0.0a	0.8 ± 0.8a	0.8 ± 0.8a	0.8 ± 0.8a	0.3	0.80
2 d	0.0 ± 0.0a	0.8 ± 0.8a	1.7 ± 1.1a	2.5 ± 1.3a	1.3	0.30
3 d	0.0 ± 0.0b	1.7 ± 1.1b	3.3 ± 1.9ab	7.5 ± 2.2a	4.4	<0.01
4 d	0.0 ± 0.0b	1.7 ± 1.1b	5.0 ± 2.0b	15.0 ± 4.5a	7.1	<0.01
5 d	0.0 ± 0.0b	1.7 ± 1.1b	10.0 ± 2.8ab	19.2 ± 4.8a	9.6	<0.01
6 d	0.0 ± 0.0b	1.7 ± 1.1b	20.8 ± 5.0a	35.8 ± 6.1a	18.3	<0.01
7 d	0.0 ± 0.0c	2.5 ± 1.3c	33.3 ± 5.6b	52.5 ± 5.2a	42.8	<0.01

Within each row, means followed by the same letter are not significantly different (df = 3, 47; HSD test at 0.05).

Imidacloprid has been evaluated as a grain protectant by Daglish and Nayak (2012) for control of a wide range of stored-product beetle species. In that study, the authors reported that imidacloprid was effective for control of *O. surinamensis*, *C. ferrugineus*, *T. castaneum*, and *R. dominica*, on wheat, and progeny production was completely suppressed at 10 ppm, which is considered a high rate in comparison with the dose rates of the most commonly used registered grain protectants. However, even 10 ppm of imidacloprid was not effective for control of *S. oryzae.* Yue et al. (2003) showed that imidacloprid was unable to control late-instar *P. interpunctella* on maize, even at doses as high as 312.5 ppm. Arthur et al. (2004) reported that thiamethoxam, another neonicotinoid with a similar mode of action, was effective for control of the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae), *S. oryzae*, *R. dominica*, and *O. surinamensis*, but not for *T. castaneum.* Our results for the combined use of beta-cyfluthrin with imidacloprid are in accordance with the above findings for the reduced susceptibility of *T. castaneum.* However, there are no data available so far for the efficacy of imidacloprid alone on concrete for control of stored-product insects.

The application of beta-cyfluthrin (Tempo) alone was as effective as Temprid for the two species that we tested. In fact, Tempo was more effective than Temprid for control of *T. castaneum*, given that mortality after the 7-d exposure was two times higher. Similarly, Tempo acted faster than Temprid for control of *O. surinamensis* adults given that mortality caused by Tempo was higher than that caused by Temprid after 3 d of exposure. Consequently, at least for these two species, the addition of imidacloprid did not increase the efficacy of beta-cyfluthrin, and to some extent, might have caused a slight detrimental effect which can partially explain the differences in efficacy for control of *O. surinamensis* and *T. castaneum.*

In summary, our results show that Temprid was effective for control of *C. ferrugineus*, *O. surinamensis*, *L. bostrychophila*, and *L. paeta*, but not for control of *T. castaneum*, *T. confusum*, and *D. maculatus*. In addition, the use of beta-cyfluthrin alone is likely to provide similar efficacy levels, without the simultaneous presence of imidacloprid. Additional combinations of cyfluthrin with other ingredients should be evaluated to identify treatments capable of controlling a broader spectrum of pest species.

Acknowledgments

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