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Comparison of spinetoram, imidacloprid, thiamethoxam and chlorantraniliprole against life stages of *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) on concrete

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ABSTRACT

Spinetoram, imidacloprid, thiamethoxam and chlorantraniliprole are new insecticides with novel mode of actions, low mammalian toxicity and low impact to environment. In the present study, the efficacy of these insecticides was tested against *Tribolium confusum* Jacquelin du Val on concrete. Among the tested insecticides, spinetoram proved to be more effective, providing complete control of *T. confusum* adults and young larvae after 14 days of exposure. For the young larvae, thiamethoxam at the highest dose and chlorantraniliprole at both doses were equally effective with spinetoram. On the other hand, none of the tested insecticides were able to control *T. confusum* pupae. Moreover, none of the insecticides had ovicidal effect, with the exception of chlorantraniliprole in some combinations. From the mobile life stages, the most tolerant life stages were old larvae and the most susceptible young larvae. The presence of food (flour) moderated *T. confusum* mortality. From the results of the present study, we can conclude that spinetoram, thiamethoxam and chlorantraniliprole showed potential and need be further evaluated for surface treatments in stored product facilities. Our work underlined the need for good cleaning and sanitation procedures in warehouses and food processing facilities.

1. Introduction

Tribolium confusum Jacquelin du Val (Coleoptera: Tenebrionidae), a secondary colonizer, is a serious pest in cereal processing facilities and a major pest in flour mills (Trematerra and Süss, 2006). *T. confusum* infestation is directly related to serious product loses and qualitative degradations (Aitken, 1975). Chemical control is the main strategy for *T. confusum* and other stored product pests in food processing facilities and silos. For instance, phosphine fumigation is the most common method for disinfestation of these facilities, but this method cannot provide long term protection as reinfestation can quickly occur (Campbell et al., 2010). Resistance has been reported to phosphine and also to contact insecticides such as malathion, chlorpyriphos-methyl and dichlorvos in some strains of *T. confusum* (Zettler, 1991). Alternatives to phosphine are heat treatment and controlled atmospheres which are effective in controlling *Tribolium* species (Chiappini et al., 2009; Mahroof et al., 2003), but both methods are expensive and cannot provide protection for a long period. Heat treatment with temperatures above 50 °C can control the adults of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), but cannot totally control all the life stages of the insects, and reinfestation is likely to occur one month after treatment (Opit et al., 2011).

Residual insecticides have also been used against *Tribolium* species in mills and food processing facilities, but resistance has been reported for some of them, such as organophosphates and pyrethroids (Subramanyam et al., 1989; Collins, 1990). One insecticide with a novel mode of action is spinetoram, a mixture of two synthetically modified spinosyns (spinosyn J and spinosyn L) which are metabolites of the bacterium *Saccharopolyspora spinosa* Mertz and Yao (Bacteria: Actinobacteridae). Spinetoram has a neurotoxic mode of action on insects, through contact or ingestion, and it was introduced as a novel insecticide with greater potency and faster speed of action in comparison with the older spinosyn-based relative spinosad (Dripps et al., 2008; Sparks et al., 2008). Spinetoram is ineffective against *T. confusum* when applied directly on wheat, *Triticum aestivum* L. (Vassilakos et al., 2012). However, the efficacy of spinetoram against *T. confusum* has not been examined so far as a surface application.

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Imidacloprid and thiamethoxam are new insecticides that belong to neonicotinoids with neurotoxic mode of action. Imidacloprid has been extensively used us a seed coat treatment with satisfactory results against a wide range of pests (Pons and Albajes, 2002; Zhang et al., 2011). Recently, Daglish and Nayak (2012) reported that imidacloprid was ineffective against *T. castaneum* on wheat. Thiamethoxam efficacy against *T. castaneum* on treated wheat and maize, *Zea mays* L., depended on the dose, time of exposure and temperature, but mortality was generally low (Arthur et al., 2004). Chlorantraniliprole is a new anthranilic diamide insecticide, with a novel mode of action that interrupts the normal muscle contraction. Chlorantraniliprole is very effective against several fruit and vegetable pests (Ioriatti et al., 2009; Teixeira et al., 2009; Jiang et al., 2012). However, there are no published data to date on the efficacy of chlorantraniliprole against stored product insect species. In the present study, we investigated the efficacy of spinetoram, imidacloprid, thiamethoxam and chlorantraniliprole against *T. confusum* on concrete.

2. Materials and methods

2.1. Test insects

T. confusum was reared on wheat flour at 1-lt glass jars (8.6 cm in diameter, 17.5 cm in height) in incubators set at 65% RH and 25 °C, under continuous darkness. The experiments were conducted with eggs (0–48 h old), young larvae and old larvae (1–3rd and 4–7th instar, respectively), pupae (1–5 days old) and adults (10–20 days old). Eggs were separated from the flour by using a sieve with 48 mesh and young larvae were separated from the other life stages using a sieve with 1 mm openings.

2.2. Insecticides and formulations

The insecticides used in this study were spinetoram SC-NC (11.7% active ingredient (AI) obtained from Dow AgroSciences, UK), imidacloprid (Gaucho, 59.9% (AI) obtained from Bayer), thiamethoxam (Cruiser, 60% (AI) obtained from Syngenta) and chlorantraniliprole (Altacor, 3.5% (AI) obtained from DuPont). For each insecticide the application rates of 0.05 mg (AI)/cm^2 and 0.1 mg (AI)/cm^2 were used. The insecticide application was made by using Mecafer AG4 artist's airbrush (Mecafer Co., France).

2.3. Bioassays

The bioassays were carried out in concrete surfaced plastic Petri dishes (9 cm in diameter). The fast-setting cement Rapicret© (Isomat S.A., Greece) was used to create the concrete surfaces at the bottom of each dish. The concrete surfaces were made by mixing cement with water at a 4:1 ratio. After this application, the Petri dishes were left for at least one day for drying. The Petri dishes were sprayed with 1 ml of the appropriate solution of each dose of insecticide. A separate series of dishes was sprayed with 1 ml of distilled water, and served as a control. In half of the sprayed dishes, 0.5 g of wheat flour was added. After the application, the sprayed dishes were left for 1 day and 20 individuals of each life stage were then placed into each dish (separate dishes for each life stage), and all dishes were placed at the conditions mentioned above. Mortality of the exposed *T. confusum* larvae and adults was assessed on a daily basis for 7 days. After 14 days of exposure, mortality was measured again. Egg hatching and pupal emergence was also measured on a daily basis for 14 days. Three dishes were used for each insecticide/dose/life stage combination in each replicate. The entire experiment was repeated three times, by spraying new dishes each time (3 sub-replicates × 3 replicates = 9 dishes for each combination).

2.4. Data analysis

Mortality for adults and larvae, egg hatching and pupal emergence was analyzed separately including control data by using the MANOVA Fit Repeated Measures Procedure with random effects with Wilk's lambda estimate of JMP software (Sall et al., 2001), with insecticide, dose rate and commodity (presence or absence of food) as main effects, and time-mortality or hatching/emergence as the repeated variable (Table 1). Adult and larval mortality was also analyzed for each dose and commodity using a one-way ANOVA with insecticide as the fixed effect (Table 2). Egg hatching and pupal emergence were also analyzed for each insecticide and commodity using a one-way ANOVA with insecticide rate as the fixed effect

Table 1
Repeated-measures ANOVA statistics for *T. confusum* life stages, mortality for adult and larvae, egg hatching and pupal emergence (error df = 192).

Effect	DF[a]	Adults		Old larvae		Young larvae		DF[b]	Pupae		Eggs	
		F	P	F	P	F	P		F	P	F	P
All Between	23	75.8	<0.01	69.2	<0.0001	111.1	<0.0001	23	14.6	<0.0001	8.6	<0.0001
Intercept	1	4556.4	<0.0001	2702.5	<0.0001	8845.6	<0.0001	1	39,614.2	<0.0001	8806.2	<0.0001
Insecticide	3	195.4	<0.0001	248.7	<0.0001	288.6	<0.0001	3	46.3	<0.0001	53.6	<0.0001
Dose	2	320.8	<0.0001	166.4	<0.0001	430.8	<0.0001	2	47.9	<0.0001	3.6	0.0278
Commodity	1	26.0	<0.0001	45.2	<0.0001	260.3	<0.0001	1	3.3	0.0710	2.6	0.1089
Insecticide*Dose	6	63.5	<0.0001	58.1	<0.0001	76.2	<0.0001	6	12.6	<0.0001	3.3	0.0042
Insecticide*Commodity	3	1.6	0.1947	9.3	<0.0001	5.7	0.0009	3	0.9	0.4227	0.02	0.9964
Dose*Commodity	2	48.7	<0.0001	18.7	<0.0001	29.5	<0.0001	2	3.8	0.0250	0.2	0.8310
Insecticide*Dose*Commodity	6	1.1	0.3735	9.1	<0.0001	5.6	<0.0001	6	2.0	0.0696	1.01	0.4185
All Within Interactions	161	9.9	<0.0001	8.9	<0.0001	12.4	<0.0001	299	2.2	<0.0001	1.3	0.0004
Time	7	1742.0	<0.0001	722.4	<0.0001	3562.3	<0.0001	13	5044.4	<0.0001	644.7	<0.0001
Time*Insecticide	21	28.3	<0.0001	41.1	<0.0001	39.9	<0.0001	39	7.7	<0.0001	6.2	<0.0001
Time*Dose	14	49.4	<0.0001	37.8	<0.0001	57.8	<0.0001	26	9.4	<0.0001	0.6	0.9069
Time*Commodity	7	30.5	<0.0001	19.3	<0.0001	72.2	<0.0001	13	1.1	0.3574	2.5	0.0031
Time*Insecticide*Dose	42	10.9	<0.0001	10.4	<0.0001	9.3	<0.0001	78	2.5	<0.0001	1.0	0.5297
Time*Insecticide*Commodity	21	1.5	0.0707	3.5	<0.0001	5.3	<0.0001	39	1.1	0.3400	0.6	0.9473
Time*Dose*Commodity	14	27.9	<0.0001	3.2	<0.0001	22.0	<0.0001	26	3.1	<0.0001	0.2	1.0000
Time*Insecticide*Dose*Commodity	42	1.1	0.3231	2.3	<0.0001	2.6	<0.0001	78	0.8	0.8307	0.5	0.9997

[a] Degree of freedom for adults, old larvae and young larvae.
[b] Degree of freedom for pupae and eggs.