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Residual efficacy of deltamethrin applied on porous and non-porous surfaces against *Sitophilus granarius* (L.), *Plodia interpunctella* (Hübner) and *Blattella germanica* (L.)

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Abstract

Residual efficacy of the insecticide deltamethrin, EC formulation with 25 g/L AI + 225 g/L PBO (synergist piperonyl butoxide), against lab populations of *S. granarius* and *P. interpunctella* by applying product water solutions (12.5 mg AI/m^2) to porous surface, and against *B. germanica* by applying them to non-porous surface,

was investigated in laboratory (at 25±1°C and 55-60% r.h.). The mortality of cockroach adults on deposits aged 0, 14, 30 and 45 days was estimated after 30 minutes of their contact with the treated surfaces, and additional 24 h and 48 h of recovery, while the mortality of stored-product insects (adults or larvae) on 0, 7, 14 and 30 days old deposits was estimated after 2, 7 and 14 days of exposure to treated surfaces and additional 7 days of recovery. Mortality of cockroaches in all variants was 100%, except on 45 days old deposit and after 24 h of recovery, when it was 97%. Deltamethrin caused 0% weevil mortality after 2 days of exposure to deposits of all ages (0-30 days), while *P. interpunctella* larval mortality was 87-93%. However, mortality was 100% after 7 and 14 days of weevil/moth exposure in all variants of deposit ages and/or additional 7 days of recovery. The results show that deltamethrin applied to porous and non-porous surfaces is a highly effective insecticide for weevil/moth and cockroach control, and it showed a good residual activity for up to 30 and 45 days, respectively.

Keywords: *S. granarius*; *P. interpunctella*; *B. germanica*; Deltamethrin; Residual efficacy.

1. Introduction

The granary weevil *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) and Indian meal moth *Plodia interpunctella* (Hübner) (Lepidoptera: Phycitidae) are very important insect pests of stored plant products, which are able to cause major losses unless controlled. Also, the German cockroach *Blattella germanica* (L.) (Dictyoptera: Blattellidae) is a widespread urban pest which is frequently present in storages, stored-products and food processing facilities (Hill, 1990; Ebeling, 1991; Rees, 2004; Almaši, 2008; Stejskal et al., 2015).

The use of contact (residual) insecticides, besides sanitation of storage ambient and surfaces, is the most important step in prevention and control of pests (Kljajić, 2008; Arthur, 2012; Jankov et al., 2013; Rumbos et al., 2014). Several products, mostly in the class of organophosphate insecticides and synthetic pyrethroids, have been registered worldwide (Arthur and Subramanyam, 2012; MacBean, 2012) and in Serbia (Team of editors, 2016) as plant protection products (PPPs) and/or biocide products (BP) (WHO, 1999 and 2006).

The residual efficacy of contact insecticides on treated surfaces is known to depend on the type of insecticide, its formulation, type of surface (e.g. metal, wood or concrete), species of stored product insect or duration of exposure (Arthur, 1996; Athanassiou et al., 2013; Jankov et al., 2013; Rumbos et al., 2014). The present study therefore focused on examining the residual efficacy of deltamethrin (with piperonyl butoxide synergist), EC formulations, applied at the recommended rate against stored-product insect pests, represented by *S. granarius* and *P. interpunctella* on porous surface, and an urban pest, *B. germanica* on non-porous surface after different periods of contact with treated surface.

2. Materials and Methods

Test insects and insecticides

Laboratory populations of test insects were reared in an insectary at 25±1°C temperature and 60±5% relative humidity (r.h.). Adults of the *S. granarius* were reared in 2.5L glass jars containing whole grain soft wheat of 12% moisture content as described by Harein and Soderstrom (1966) and Davis and Bry (1985). Indian meal moths *P. interpunctella* were reared on a diet containing corn meal (flour), ground wheat flour, honey and glycerol as described by Boles and Marzke (1966). German cockroaches *B. germanica* were reared in 5.0 L glass jars with cardboards inside, mainly containing coarse wheat meal and/or pelleted food, as described by Morgan (1985).

Two-to-four weeks old *S. granarius* unsexed adults, third instars (L_3 stage) of *P. interpunctella* larvae and one week old *B. germanica* adults, were used in the bioassays.

An insecticide (EC formulation) based on deltamethrin 25 g/L AI, with the synergist piperonyl butoxide 225 g/L, (Kontakt, Galenika-Fitofarmacija a.d., Serbia) was tested.

Bioassay

For stored-product insects, the residual efficacy tests were performed using a methodology described in PP 1/202 (1) and PP 1/204 (1) (OEPP/EPPO, 2004). Porous surface, made by plates of burned bricks (33 x 33 cm) of around 1 m^2, was cleaned, washed and dried before treatment. Water solutions of the insecticide deltamethrin were made immediately before treatment (49.5 mL water and 0.5 mL product). After stirring, the 1 m^2 plate surfaces were treated with 50 mL of water solutions of deltamethrin (12.5 mg AI/m^2) using a low-pressure sprayer. The procedure was repeated (two treatments) with fresh water solutions of the same insecticide. Untreated control surface was sprayed with water only (50 mL/m^2) following the same procedure. Temperature in the facility was 25±1°C and 60±5% r.h. throghout the experiment.

After deposits were dried (0 days deposit age), three glass rings (h=25 mm, R=55 mm) were placed to represent each treatment, each species and each duration of exposure. About 0.25 g of coarse wheat meal was placed into each ring and spread over ring area before 20 adults of *S. granarius* and 10 larvae of *P. interpunctella* were inserted (3 x 2 repetitions per each test species and each exposure). Ring edges were coated with paraffin after insect insertion and the rings lidded with plastic sieves to prevent insects escape. Insect mortality on deposits of different age (0, 7, 14 and 30 days) was estimated after 2, 7 and 14 days of insect exposure to treated porous surface and 7 days of recovery on untreated coarse wheat meal in the laboratory.

For cockroaches, according to principles described by Busvine (1971) and WHO (1999),

tests were performed on non-porous surface made of tile plates (33 x 33 cm) of around 1 m^2, previously cleaned, washed and dried. The plates were treated with 50 mL of water solutions of deltamethrin (12.5 mg AI/m^2) using a low-pressure sprayer. The procedure was repeated (two treatments) with fresh water solutions of the same insecticide. Untreated control surface was sprayed with water only (50 mL/m^2). After deposits were dried (0 days deposit age), 10 adults of *B. germanica* were put on treated surface and covered with three glass Petri dishes (h=2 cm, R=15 cm) (3 x 2 repetitions). Insect mortality on deposits of different age (0, 14, 30 and 45 days) was estimated after 30 minutes (non-choice exposure), and 24 and 48 hours of lab recovery with addition of coarse wheat meal.

Data analysis

Mortality data were initially corrected as suggested by Abbott (1925) and then analyzed using one-way ANOVA. Means were separated by Fisher's LSD test at P=0.05 (Sokal & Rohlf, 1995). Before analysis, mortality percentages were transformed using *arcsine*. However, untransformed means and standard deviations are shown in tables.

3. Results

Sitophilus granarius

The residual efficacy of deltamethrin after 2 days of adult exposure to porous surface was 0%, on deposits of all ages (0-30 days) (Table 1). After 7 and 14 days of exposure, deltamethrin efficacy was 100%, also on deposits of all ages (0-30 days). After seven days of recovery on untreated wheat in the laboratory, the mortality of adults in all treatment variants was 100%, including the variant of 2 days of exposure.

Plodia interpunctella

After 2 days of larval exposure to treated porous surface, deltamethrin achieved the highest efficacy (100%) on the 0-day deposit, while on 30 days old deposit it was 90%, with statistically significant differences (Table 2). After 7 and 14 days of larval exposure to deltamethrin deposits, residual efficacy were 100% in all treatament variants.

Tab. 1 Residual efficacy of deltamethrin (12.5 mg AI/m²) against *S. granarius* after 2, 7 and 14 days of adult exposure to treated porous surface. For each exposure period separately, means within columns followed by the same letter are not significantly different, Fisher's LSD test at *P*>0.05. Where no letters exist, no significant differences were recorded.

Deposit age	**Residual efficacy (% ± SE)**	
(days)	**Before recovery**	**After 7 days of recovery**
After 2 days of exposure		
0	0.0 ± 0.0	100.0 ± 0.0
7	0.0 ± 0.0	100.0 ± 0.0
14	0.0 ± 0.0	100.0 ± 0.0
30	0.0 ± 0.0	100.0 ± 0.0
After 7 days of exposure		
0	100.0 ± 0.0	100.0 ± 0.0
7	100.0 ± 0.0	100.0 ± 0.0
14	100.0 ± 0.0	100.0 ± 0.0
30	100.0 ± 0.0	100.0 ± 0.0
After 14 days of exposure		
0	100.0 ± 0.0	100.0 ± 0.0
7	100.0 ± 0.0	100.0 ± 0.0
14	100.0 ± 0.0	100.0 ± 0.0
30	100.0 ± 0.0	100.0 ± 0.0

Tab. 2 Residual efficacy of deltamethrin (12.5 mg AI/m²) against *P. interpunctella* after 2, 7 and 14 days of larval exposure to treated porous surface. For each exposure period separately, means within columns followed by the same letter are not significantly different, Fisher's LSD test at *P*>0.05. Where no letters exist, no significant differences were recorded.

Deposit age	**Residual efficacy (% ± SE)**	
(days)	**Before recovery**	**After 7 days of recovery**
After 2 days of exposure		
0	100 ± 0.0 a	100.0 ± 0.0
7	96.7 ± 0.3 ab	100.0 ± 0.0
14	98.3 ± 0.3 a	100.0 ± 0.0
30	90.0 ± 0.3 b	100.0 ± 0.0
After 7 days of exposure		
0	100.0 ± 0.0	100.0 ± 0.0
7	100.0 ± 0.0	100.0 ± 0.0
14	100.0 ± 0.0	100.0 ± 0.0
30	100.0 ± 0.0	100.0 ± 0.0
After 14 days of exposure		
0	100.0 ± 0.0	100.0 ± 0.0
7	100.0 ± 0.0	100.0 ± 0.0
14	100.0 ± 0.0	100.0 ± 0.0
30	100.0 ± 0.0	100.0 ± 0.0

Blattella germanica

After 30 minutes of cockroach exposure to treated non-porous surfaces, deltamethrin achieved the highest paralysis (100%) on 0-45 days old deposits (Table 3). After 24 and 48 h of cockroaches recovery, deltamethhrin caused 100% adult mortality in all treatament variants, except in the variant of 24 h of recovery from exposure to 45 days old deposit when it was significantly lower, 97%.

Tab. 3 Paralysis/mortality (%) of *B. germanica* after 30 minutes of adult exposure to non-porous surface treated with deltamethrin (12.5 mg AI/m^2) and 24 h and 48 h recovery. For each exposure period separately, means within columns followed by the same letter are not significantly different, Fisher's LSD test at $P>0.05$. Where no letters exist, no significant differences were recorded.

Deposit age	Paralysis/mortality (% ± SE) after		
(days)	30 min exposure	24 h recovery	48 h recovery
0	100.0 ± 0.0	100.0 ± 0.0 a	100.0 ± 0.0
14	100.0 ± 0.0	100.0 ± 0.0 a	100.0 ± 0.0
30	100.0 ± 0.0	100.0 ± 0.0 a	100.0 ± 0.0
45	100.0 ± 0.0	97.5 ± 0.5 b	100.0 ± 0.0

4. Discussion

In reviewing analysis by Arthur (2012) we concluded that aerosols and contact insecticides are becoming good alternatives to the fumigant methyl bromide in flour mills, food production facilities and food warehouses. A number of later studies showed good potential of various contact insecticides after application on different surfaces in control of stored-product insect pests: e.g. malathion, pirimiphos-methyl and lambda-cyhalothrin against rice wevil *Sitophilus oryzae* (L.) (Jankov et al., 2013), spinetoram against stored-product beetle species (Vassilakos et al., 2014), cypermethrin and pirimiphos-methyl against *S. granarius* and *P. interpunctella* (Andrić et al., 2014) and two formulations of pirimiphos-methyl (EC and CS) against *S. granarius,* lesser grain borer *Rhyzopertha dominica* (F.) and confused flour beetle *Tribolium confusum* (Jacquelin duVal) (Rumbos et al., 2014).

The pyrethroid deltamethrin has been classified as a highly applicable insecticide, and is used for control of many arthropods, including cockroaches that are important in public health (Baur, 1991; WHO, 1984 i 2006; Mac Bean, 2012; Team of editors, 2016). Also, international research (Arthur 1997a,b; Kavallieratos et al., 2016) and studies in Serbia (Kljajić and Perić, 2006; Andrić et al., 2010; Pražić Golić et al., 2015) on the effects of different formulations of deltamethrin have shown that it is a highly effective insecticide in control of different stored-products species and cockroaches having notable residual efficacy (Arthur, 1997a,b and 2018; Kljajić and Perić 2009; Sims et al., 2010; Paudyal et al., 2016).

In our tests with laboratory populations of the stored-product insect pests *S. granarius* and *P. interpunctella*, deltamethrin applied to porous surface at a rate of 12.5 mg AI/m^2 reached its highest efficacy (100%) on up to 30 days old deposits after 7 and 14 days of adult and larval exposure before and after 7 days of recovery, including the 2 days exposure, only after 7 days of recovery. Also, in tests with *B. germanica*, in all treatament variants after 30 minutes of adults exposure to treated non-porous surface, deltamethrin achieved the highest paralysis of 100% on up to 45 days old deposits, and 100% adult mortality after 24 h and 48 h of recovery, except in the variant of 24 h of recovery after exposure to 45 days old deposit (97%). The results of our study showed that the pyrethroid deltamethrin with synergist piperonyl butoxide has high residual efficacy against the stored-product insects *S. granarius* and *P. interpunctella* after application on porous surface, and against the urban pest *B. germanica* on non-porous surface. These findings contribute significantly to the existing IPM programmes, showing that deltamethrin can be used simultaneously as a PPP and BP insecticide.

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Insecticidal efficacy of abamectin against red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae): influence of dose, exposure interval, relative humidity and temperature

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In this communication, the insecticidal efficacy of Abamectin against *Tribolium castaneum* adults were evaluated in two sets of bioassays: In the 1st series of experiment, the effect of temperature was assessed on wheat treated at 0.01, 0.10, 0.25, 0.50, 0.75, 1.00 and 1.50 mg kg-1 at 20°C and 30°C, and 65%rh. The moisture content of the wheat ranged between 11.8 and 12.1%. Spraying was performed using a Badger 100 artists' airbrush (Franklin Park, IL, USA) on a stainless-steel tray in which 1 kg of wheat containing 5% (weight:weight) broken kernel was treated with 5 mL of an aqueous solution containing the appropriate volume of the EC formulation corresponding to each dose. Treated and untreated grains were kept into incubators at 30°C for 6 h to remove the excess moisture. After that, the grains were kept at 20 and 30°C and 65% rh in temperature-controlled incubators (Binder Model: KB 720) for 24 h for acclimatization to experimental conditions. For the experiment, eight samples of 60 g were obtained from each treated or untreated lots for each temperature and put into a cylindrical plastic vial (7 cm long × 5 cm diameter). Sixty (1-2 wk old) adults were placed in each vial containing treated wheat. There were 8 replicates for each exposure period and control. Adult mortality were recorded on 7th, 14th, and 21st d after treatment by reintroducing alive adults in the same vial while discarding the dead ones. At the end of the 21th d of exposure, all dead and alive adults were discarded, and the vials containing wheat only was returned to corresponding temperature-control.

The effectiveness of Spinetoram against red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae)

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The data were analyzed, after arcsine transformation, with GLM-repeated measures (ANOVA) at a significance level of P less than 0.05 using Statistica version 7, and the means were compared with Tukey's HSD test. Arcsine transformed means were back transformed for presentation. Mortality was proportional to dose rate and exposure period. At 1 ppm dose rate, mortality at the end of 7th day was recorded as 34,44% and increased to 52.59% after 15 day of exposure. Mortality response was more pronounced at/above 1 ppm. Thus at 15th day of exposure, mortality rates were calculated as