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Efficacy of alpha-cypermethrin and thiamethoxam against *Trogoderma granarium* Everts (Coleoptera: Dermestidae) and *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) on concrete

Christos G. Athanassiou [a], Nickolas G. Kavallieratos [b, c, *], Maria C. Boukouvala [b, c, d], Marios E. Mavroforos [c], Demetrius C. Kontodimas [c]

[a] Laboratory of Entomology and Agricultural Zoology, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Phytokou str., Nea Ionia 38446, Magnissia, Greece
[b] Laboratory of Agricultural Zoology and Entomology, Department of Crop Science, Agricultural University of Athens, 75 Iera Odos str., 11855 Athens, Attica, Greece
[c] Laboratory of Agricultural Entomology, Department of Entomology and Agricultural Zoology, Benaki Phytopathological Institute, 8 Stefanou Delta str., 14561 Kifissia, Attica, Greece
[d] Laboratory of Organic Chemistry, Department of Chemistry, University of Ioannina, Panepistimioupolis, 45110 Ioannina, Greece

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ABSTRACT

Laboratory bioassays were conducted to evaluate alpha-cypermethrin and thiamethoxam for the control of adults, small larvae and large larvae of the khapra beetle *Trogoderma granarium*, and the yellow mealworm beetle *Tenebrio molitor*, on concrete. Factors such as dose (0.025 and 0.1 mg alpha-cypermethrin or thiamethoxam/cm^2), exposure interval (1, 3 and 7 d), and formulation (alpha-cypermethrin SC and thiamethoxam WG) were evaluated. Apart from immediate assessment at end of exposure, an assessment of delayed mortality was performed with the survivors of the 7-d exposure by removing them from the treated substrate and keeping them on untreated surfaces for 7 more days. After the 7-d exposure, more *T. granarium* adults were dead on dishes treated with alpha-cypermethrin than with thiamethoxam. Small larvae were generally less susceptible than adults. After 7 d, small larval mortality reached 64.4% for alpha-cypermethrin, while for thiamethoxam it was <6%. Large *T. granarium* larvae were more tolerant than the small ones. Delayed mortality of *T. granarium* adults was generally high for both insecticides and doses, and ranged between 43.3 and 63.3% of those that were still alive immediately after the 7-d treatment. For both larval categories, delayed mortality was higher for larvae that had been previously exposed to alpha-cypermethrin, than with thiamethoxam. For *T. molitor*, after the 7-d exposure, significantly more adults were dead on dishes treated with alpha-cypermethrin than with thiamethoxam. For small larvae mortality was 38.9% at the lowest thiamethoxam dose, but in the other cases ranged between 88.9 and 95.6%. In the case of large larvae, the overall mortality was low in all tested combinations. Regarding delayed mortality of this species, it remained at low levels, for both adults and small larvae. Our results indicate that *T. molitor* was more susceptible than *T. granarium* in both insecticides tested, but alpha-cypermethrin was more effective than thiamethoxam.

1. Introduction

The khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is one of the most important quarantine insect species globally, and the most important quarantine species of stored products (Hill, 1990; Bell and Wilson, 1995). Its diapause can last for years, while there is always a "reservoir" of the population of *T. granarium* in diapause, especially due to conditions of reduced food availability and/or conditions that are not favorable for population development (Bell et al., 1984; Hill, 1990). At the same time the diapausing larvae are particularly tolerant to insecticides (Bell et al., 1984; Bell and Wilson, 1995; Edde et al., 2012). *T. granarium*, especially at the larval stage, is easily transferred

* Corresponding author. Laboratory of Agricultural Zoology and Entomology, Department of Crop Science, Agricultural University of Athens, 75 Iera Odos str., 11855 Athens, Attica, Greece.
E-mail address: nick_kaval@hotmail.com (N.G. Kavallieratos).

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through international trade and this is why it is often intercepted in many parts of the world, making this species one of the most important "alien" or "invasive" species globally (Banks, 1977; Bell et al., 1984; Peacock, 1993; Bell and Wilson, 1995; Myers and Hagstrum, 2012; EPPO, 2013). For instance, Myers and Hagstrum (2012) noted that in US entry ports *T. granarium* was intercepted 559 times from 1985 to 2010, but newer data suggest that this number has remarkably increased since 2010 (Myers, personal communication). Previous studies have already pointed out the potential for establishment of *T. granarium* in different geographical regions (Howe and Lindgren, 1957; Banks, 1977; Viljoen, 1990). It is well established that *T. granarium* is resistant to phosphine (Bell et al., 1984; Bell and Wilson, 1995). Also, other insecticides that are effective for the control of other major stored product species are not effective for the control of *T. granarium*. These insecticides include deltamethrin, dichlorvos, malathion and pirimiphos methyl (Kumar et al., 2010; Pretheep Kumar et al., 2010).

Another species of major importance is the yellow mealworm beetle *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) (Aitken, 1975; Guo et al., 2014). Despite the fact that this species is very common in warehouses and food processing facilities, the data for the efficacy of insecticides against *T. molitor* are disproportionally few. Still, there are cases where common insecticides were not effective for the control of this species. For instance, larvae of *T. molitor* were not affected by diatomaceous earth (DE) (Mewis and Ulrichs, 2001).

Apart from direct applications of insecticidal measures in the grain, as in the case of fumigants and residual grain protectants, control of stored product insect species is reliant upon the use of insecticides that are applied on surfaces, empty warehouses or in targeted crack and crevice treatments (Kavallieratos et al., 2011; Arthur, 2012; Kharel et al., 2014). One major category of insecticides that are used for this purpose are aerosols, which are based on organophosphates, synergized pyrethrins, pyrethroid compounds or insect growth regulators (IGRs) (Arthur and Campbell, 2008; Sutton et al., 2011; Kharel et al., 2014). Aerosols have been shown to be very effective against a wide range of species on different types of commodities (Arthur, 2012). However, the application of pyrethroids to surfaces was ineffective against several key insect species. For example, Guedes et al. (2008) noted that for the control of the psocids *Liposcelis bostrychophila* Badonnel and *Liposcelis entomophila* (Enderlein) (Psocoptera: Liposcelididae) on concrete, natural pyrethrins were not effective. Moreover, pyrethrins were not able to control these two species, and also *Liposcelis paeta* Pearman (Psocoptera: Liposcelididae) on maize, rice, and wheat, (Athanassiou et al., 2009). In a recent study, beta-cyfluthrin was not effective for the control of the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), on concrete (Athanassiou et al., 2013). Novel categories of insecticides are now being considered for use in the control of species which are not susceptible to pyrethroids. Among these, neonicotinoids have a different mode of action as compared with the traditional neurotoxic compounds and therefore can play a role as alternatives to pyrethroids, or can be used in combination with pyrethroids. For example, a combination of beta-cyfluthrin with the neonicotinoid imidacloprid was effective on concrete for the control of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae), *L. bostrychophila*, and *L. paeta* (Athanassiou et al., 2013). The neonicotinoid insecticide thiamethoxam was effective for the control of the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) and *O. surinamensis* on maize, the rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) on wheat and *T. castaneum* on maize and wheat (Arthur et al., 2004). Yue et al. (2003) reported that maize treated with thiamethoxam or imidacloprid and sorghum treated with thiamethoxam were protected from infestation by the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). However, there are no recent studies in the scientific literature evaluating the effect of surfaces treated with pyrethroids against *T. granarium* and *T. molitor*. Also, there are no data available on the insecticidal efficacy of the neonicotinoid thiamethoxam against these two species. Thus, the objective of the present study was to test in the laboratory these two insecticides for the control of *T. granarium* and *T. molitor* on concrete, by evaluating both immediate and delayed mortality.

2. Materials and methods

2.1. Insects

The insects used in the tests were reared at the Laboratory of Agricultural Entomology, Benaki Phytopathological Institute, Kifissia. The cultures, initially collected from Greek storage facilities, have been kept at Benaki Phytopathological Institute for more than two years in the case of *T. molitor* and since 2013 in the case of *T. granarium*. *T. granarium* was reared on whole wheat at 25 °C and 65% relative humidity (r.h.) in continuous darkness. *T. molitor* was reared on wheat bran at 30 °C and 65% r.h., also in darkness. In the experiments, small or large larvae and unsexed adults were used for both species. For *T. granarium*, we defined that the small larvae were <3 mm (usually 2 mm), and large larvae were >3 mm (usually close to 4 mm). Similarly, for *T. molitor*, we defined that the small larvae were <14 mm (usually <10 mm), and large larvae were >14 mm (usually >15 mm). All *T. granarium* adults used were <24 h old whereas all *T. molitor* adults were <2 weeks old.

2.2. Formulations

The alpha-cypermethrin formulation Power SC (containing 62.4 g/l alpha-cypermethrin, provided by Hybrid Hellas, Metamorphossis, Greece) and the thiamethoxam formulation Actara WG (containing 250 g/kg thiamethoxam, provided by Syngenta Hellas, Athoussa, Greece) were used for experimentation.

2.3. Bioassays

Both formulations were tested at the doses of 0.025 and 0.1 mg active ingredient (a.i.)/cm^2. The experiment was carried out in a completely randomized block design, with three subreplicates and three replicates. All tests were conducted in petri dishes (8 cm diameter by 1.5 cm high), with a surface area of 50.27 cm^2. One day before the tests, the bottoms of the dishes were covered with the CEM I 52.5 N material (Durostick, Aspropyrgos, Greece) to create the concrete surface. The concrete material was powder with apparent specific mass 2.7–3.2 g/cm^3, specific mass 0.8–1.3 g/cm^3, pH 12, able to withstand temperatures from −20 to 100 °C and contained 0.01% chlorine ions. The internal sides of all dishes were coated with Fluon (polytetrafluoroethylene, Northern Products, Woonsocket, RI) to prevent escape of insects. The concrete surface of individual dishes was sprayed with 1 ml of an aqueous solution, as a fine mist, that contained the appropriate volume of alpha-cypermethrin or thiamethoxam corresponding to each dose. Spraying was carried out using an AG-4 airbrush (Mecafer S.A., Valence, France). Then, 10 adults of each species were placed on each dish. The same procedure was followed for each of the groups of larvae. The dishes contained food, which was placed on the concrete after spraying; there were 1 g wheat kernels in dishes containing *T. granarium*, and 1 g of wheat bran in dishes containing