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Efficacy of dinotefuran (Alpine® spray and dust) on six species of stored product insects

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ABSTRACT

Dinotefuran, an agonist of insect nicotinic acetylcholine receptors, was evaluated both as a 0.5% active ingredient aerosol spray and a dust combined with diatomaceous earth (DE), 5 g/m^2 and 10 g/m^2, at 45% r.h. and 75% r.h. Target species were six adult stored product insect species: *Tribolium castaneum* (Herbst), *Rhyzopertha dominica* (F.), *Oryzaephilus surinamensis* (L.), *Tribolium confusum* Jacqueline du Val, *Dermestes maculatus* (DeGeer), and *Mezium affine* Boieldieu. Adults were continually exposed for 4 d on the dusts, and assessments were done after 8 h and after 1, 2, 3, and 4 d to determine knockdown and adult survival/mortality. Mortality of *T. castaneum*, *R. dominica*, and *O. surinamensis* generally increased with exposure interval, and was 90% or more after three days of exposure at both dust rates and r.h. levels. Mortality of *D. maculatus* and *T. confusum* after three days ranged between 60 and 70% and 50 and 60%, respectively. Mortality of *M. affine* was 5% or less even after 4 days of exposure. Mortality of all species except *M. affine* was generally lower when exposed to the spray rather than the dust. No late stage larvae of *T. castaneum*, *T. confusum*, *O. surinamensis*, exposed to either the spray or the dusts emerged as adults, and only 3% of exposed *D. maculatus* emerged as adults. Results show that dinotefuran could be incorporated into management plans for control of stored product insects.

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1. Introduction

There are many species of insects that can be pests of stored products (Rees, 2004). Sanitation and other cultural control methods, such as product rotation, in-bound inspection and insect monitoring are all components of management programs for stored product insects, but in many cases the use of an insecticide may be required (Arthur, 2008). Low risk insecticides such as neonicotinoids can be used to eliminate infestations of traditional urban insect pests in homes and retail stores. The efficacy of the neonicotinoids thiamethoxam and imidacloprid (Yue et al., 2003; Arthur et al., 2004) has already been evaluated against a few insect pests of stored products. Dinotefuran is a third-generation neonicotinoid belonging to the furanicotinyl group (Wakita et al., 2003). The mode of action of this group is to disrupt synapses in the central nervous system, functioning as an agonist of the nicotinic acetylcholine receptor (Tomizawa and Yamamoto, 1993). This chemical has a wide spectrum of insecticidal activity and low mammalian and avian toxicity (Wakita et al., 2003). Insect species from several orders have been examined for their susceptibility to this new neonicotinoid, including *Nephotettix cincticeps* (Uhler), the green rice leafhopper; *Laodelphax striatellus* (Fallén), the small brown planthopper; *Spodoptera litura* (F.), the common cutworm (Wakita et al., 2003); *Anoplophora glabripennis* (Motschulsky), the Asian long-horn beetle (Wang et al., 2005); the mosquitoes *Anopheles gambiae* (Giles), *Culex quinqufasciatus* (Say), *Aedes aegypti* (L.), (Corbel et al., 2004); and *Periplaneta americana* (L.), the American cockroach (Kiriyama and Nishimura, 2002). However; there are no published reports in the scientific literature regarding susceptibility of stored product insects to dinotefuran.

Diatomaceous earth (DE) is a natural product consisting of the fossilized cell walls of diatoms. Commercial formulations are sold world-wide for use as insecticides either on raw grains or as a surface treatment in interior structures. There are many research publications and recent reviews on the characteristics of different DE products worldwide, and efficacy often varies widely depending on the biological and environmental factors, the target insect species, and the specific DE product (Arthur, 2000; Jeschke and Nauen, 2008; Athanassiou et al., 2009a; Iatrou et al., 2010; Wakil et al., 2010; Kavallieratos et al., 2012).

There is a commercial product in the United States that contains both products, dinotefuran and DE, sold under the trade name

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Alpine® (BASF, Research Triangle Park, NC, USA), as a spray containing 0.5% active ingredient [a.i.] dinotefuran, and as a dust containing 0.25% a.i. dinotefuran combined with Diasource® DE (Boise, ID, USA). The dust formulation has low and high label rates of 5 g/m^2 and 10 g/m^2, respectively. The objectives of this test were to: 1) determine effectiveness of the spray and dust formulations on a range of stored product insect species, 2) evaluate how quickly the insecticide kills adult insects, and 3) evaluate effects of relative humidity (r.h.) on product efficacy.

2. Materials and methods

The following insects were used as the test species: *Tribolium castaneum* (Herbst), the red flour beetle, *Tribolium confusum* Jacqueline du Val, the confused flour beetle, *Rhyzopertha dominica* (F.), the lesser grain borer, and *Oryzaephilus surinamensis* (L.), the sawtoothed grain beetle. *Dermestes maculatus* (DeGeer), the hide beetle, infests a variety of dried animal products, but can also be present in processing plants (Olsen et al., 1987). The final insect species selected was *Mezium affine* (Boieldieu), the American spider beetle. This species is distributed throughout the USA and Canada, and is considered a minor pest (Rees, 2004). However, it is present in flour mills and warehouses and there are no data concerning susceptibility of *M. affine* to insecticides relative to other stored product insects.

All species used in the study were obtained from cultures reared at the USDA-ARS Center for Grain and Animal Health Research (CGAHR), Manhattan, KS, USA. The colonies of *T. castaneum* and *T. confusum* had been maintained for about 30 years, and were reared on a mixture of 95% unbleached-white wheat flour and 5% brewer's yeast. The cultures of *R. dominica* and *O. surinamensis* culture have also been maintained for about 20 years at CGAHR, and were reared on whole wheat and rolled oats, respectively. The *D. maculatus* colony originated from individuals collected in 2009 from a processing plant in the state of Missouri, and it was reared and maintained on ground commercial dog food. The colony of *M. affine* was received at CGAHR in 2000 from the Ohio State University, and was reared on the same media as the flour beetles. Cultures of all species were maintained at 27 °C–60% r.h. in continual darkness.

Individual test arenas were created using the bottom portion of a plastic Petri dish, which was 14 cm diameter × 1.25 cm in height, and about 62 cm^2 in area. Arenas were created using a driveway patching material (Rockite®, Hartline Products, Cleveland, OH, USA). This powder was mixed with tap water in an approximate ratio of 0.5 g/1 ml of water to create a slurry, which then was used to fill the arena to a depth of about 0.5 cm. A total of 192 arenas were created, which were allowed to cure in open air for 2 d. The sides of the arenas to be used for *O. surinamensis*, *D. maculatus*, and *M. affine* were lined with Fluon® (Northern Products, Woonsocket, RI, USA) to minimize escape of adults. A replicate consisted of 48 arenas, for the six species, four treatments (untreated controls, the dinotefuran spray, and the low and high label rates for the dust), and two r.h. levels of 45% and 75%. The replicates were conducted separately as individual blocks (Randomized Complete Block) at 27 ± 1 °C.

For each replicate, the dust was applied in proportion to the label rates using a flour sifter (1.18 mm diameter mesh openings) to dispense 77 mg per arena for the low rate (5 g/m^2) and 154 mg per arena for the high rate (10 g/m^2). The spray was a 0.5% active ingredient product packaged in a pressurized 557 g aerosol can. The insecticide was dispensed by attaching a plastic extension tube to the nozzle, and applying to the surface area of the arena for about 2 s, as specified on the product label. The next day after the treatments were applied, 25 one to two-week old adults of each of the six species were placed on an individual arena, eight arenas for each species. After treatment these arenas were placed in an incubator set at 27 °C and 45% r.h. Another set of four control arenas of each species were placed in second incubator also set at 27 °C and 75% r.h. Arenas in both incubators were maintained in complete darkness. At 8 h and at 1, 2, 3, and 4 d post-treatment, each arena was removed from the incubator, and adults classified as having "survived" exposure (upright and capable of normal motor movement), knocked down (on their backs and incapable of upright movement), or dead (no movement when touched with a probe). Whenever mortality was complete, no further counts were made on that arena. After each post-treatment assessment, arenas were immediately returned to the incubator. After the assessments at 96 h (4 d) the insects and arenas were discarded.

Tests were also conducted against late-stage larvae but procedures were modified. Tests were not done with larvae of *R. dominica*, as this is an internal feeder of bulk grains, hence the total number of arenas created for this portion of the study was 160, 40 for each of four replicates. For each of the five species, 25 late-instars were placed on the treated arenas, along with 2 g of the media used for the colonies of each species, as previously described. After one week, adult emergence was monitored every 2–3 days in the arenas, and one week after adult emergence was completed in the untreated controls, the individuals in the treatment arenas were classified as live larvae, dead larvae, live pupae, dead pupae, live adults, and dead adults. The majority of dead adults were those that completed eclosion to the adult stage but died after emergence.

For the adult study, data for adult survival, knockdown, and mortality at the exposure intervals of 8 h and 1, 2, 3, and 4 d post-treatment (date) were analyzed using the General Linear Models Procedure (GLM) of the Statistical Analysis System (SAS, SAS Institute, v 9.1, Cary, NC, USA) with species, treatment, r.h., exposure interval, and date as main effects. Associated two-way interactions were also estimated. Because all observations at the daily intervals were done on the same individual units, this initial data analysis was done with date (8 h and 1–4 d post-treatment) as a repeated measure. After this initial analysis, data were then analyzed with treatment and r.h. as main effects, again with date (1–4 d post-treatment) as a repeated measure. The error term used in the repeated measure was the replicate by species by treatment by r.h. error term, with a denominator df value of 36, instead of the overall error denominator df value of 469, which gave a more conservative measure of main effects and interactions. One-way ANOVA analysis was then done using the GLM Procedure in SAS to determine treatment effects within exposure intervals for each species for survival and mortality, and also differences in both of these variables between the r.h. levels. Both survival and mortality were used because they are not the inverse of each other, as individual adult beetles were also classified as knocked down.

For the larval study, observations were recorded at approximately 3 weeks after adult emergence was completed in untreated controls. Data were recorded as live and dead larvae, live and dead pupae, and live and dead adults (those individuals able to emerge as adults but died within 24–48 h). Because of excessive control mortality in larvae of *M. affine*, this species was eliminated from the analysis. Adult emergence was analyzed using the Waller–Duncan option under the GLM Procedure to determine differences between treatments and between treatments and untreated controls. As only one measurement was made, the test was not analyzed as a repeated measure in this case. The order of species susceptibility was determined by adding the percentage knockdown with the percentage of non-responsive insects at the conclusion of the test to create the variable percentage affected for each of the three treatments.