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# Residual efficacy of deltamethrin as assessed by rapidity of knockdown of *Tribolium castaneum* on a treated surface: Temperature and seasonal effects in field and laboratory settings

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ABSTRACT

Concrete arenas were treated with the pyrethroid deltamethrin at rates of 8, 16, and 24 mg active ingredient [AI]/$m^2$, and held either in a chamber set at 27 °C, inside a non-climate controlled interior building, or the floor of an empty grain bin. Bioassays of the arenas were conducted post-treatment by exposing mixed-sex adult *Tribolium castaneum* Herbst and assessing knockdown every 30 min for 3 h. Four separate trials were conducted, two during Autumn of 2015 and 2016 and two during Summer of 2016 and 2017. Knockdown did not increase with increasing application rate. Equations were fit to the combined rate data at each residual bioassay week for each location, and mean data were also compared to determine differences in knockdown at different times among the arenas held in the different locations. During Summer, knockdown was generally slower after two weeks on arenas held inside the grain bin compared to arenas held inside the building or inside the chamber. The arenas inside the bin experienced more hours of temperature above 32.2 °C during Summer compared to arenas inside the building or chamber. These extra hours of high temperature accumulation could have contributed to increased degradation of the residues, resulting in slower knockdown. During Autumn rapidity of knockdown was generally similar on arenas held in all three locations. In all trials, the total hours of temperature accumulation were far greater in the chamber compared to the building or the grain bin, but this had little effect on efficacy. Managers can use this information to more precisely apply deltamethrin, either as a pre-binning treatment inside a grain bin or elevator silo or as a residual treatment inside a milling or production facility.



## 1. Introduction

Grain storage facilities are often cleaned and the flooring surface treated with a residual contact insecticide before newly-harvested grains are stored. Among the insecticides registered in the United States (US) for this purpose is the pyrethroid deltamethrin, which is also registered as a residual treatment for direct application to raw grains going into storage. In addition, deltamethrin can be applied to flooring surfaces inside mills, warehouses, and food production facilities as a general treatment. Temperatures inside grain bins and inside mills and warehouses often fluctuate, and high temperatures can affect residual control by contributing to rapid degradation of the residues from the insecticide application. Degradation of organophosphate insecticides generally increases as temperatures increase (Arthur et al., 1992; Fleurat-Lessard et al., 1998), while pyrethroids are more stable compared to organophosphates, and are not as affected by elevated temperatures (Noble et al., 1982; Afridi et al., 2001).

One of the most common stored product insects in the US is *Tribolium castaneum* (Herbst), the red flour beetle. When adults of this species are exposed on grains or a surface treated with a residual contact insecticide, they are initially knocked down or incapacitated from exposure. This knockdown response to insecticide exposure can be defined as being on their backs with differing degrees of movement. Agrafioti et al. (2015) developed an index that related various levels of knockdown to eventual mortality under conditions of continual exposure. However, adult *T. castaneum* that are knocked down can still recover if they are removed from a treated surface and placed on an untreated surface, especially if they are provided with a food source (Arthur, 2013; Sehgal et al., 2014).

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Studies with residual efficacy of insecticides, treated surfaces, and stored product insects generally focus on mortality as the evaluation criterion (Valki et al., 2014), and the speed or rapidity of knockdown is rarely examined. Arthur et al. (2015) conducted a study whereby concrete exposure arenas were held inside milling facilities, and rapidity of knockdown was used to assess impacts of residual milling debris on residual efficacy of the pyrethroid cyfluthrin. This study showed the feasibility of using rapidity of knockdown as an assessment criterion. Since deltamethrin can be used in different environments, residual efficacy, as assessed by rapidity of knockdown, may be affected by temperature conditions in those environments. Also, since deltamethrin can be applied at a range of label rates, it is also necessary to examine residue efficacy at multiple rates within that label specification, as increasing the rate should have some beneficial effect on residual efficacy. Therefore, the objectives of this study were to determine: 1) residual efficacy of deltamethrin in simulated field environments compared to constant temperature inside a chamber, 2) if residual efficacy varied with different times of the year, and 3) if residual efficacy varied with application rate.

## 2. Materials and methods

This study was conducted at the USDA-ARS Center for Grain and Animal Health Research (CGAHR), in Manhattan, KS, USA, using a commercial formulation of deltamethrin (Centynyal®, 4.75% Active Ingredient [AI]/L (50 mg AI/L), provided by Central Life Sciences, Schaumberg, IL, USA). The label specifies application of the product at a range of 7.5–45 ml of formulation in 3.8 L of water to cover 92 $m^2$ (4–24 mg AI/$m^2$). The rates used in this study were 8, 16, and 24 mg [AI]/$m^2$, hereby designated as low, medium, and high rates, respectively.

Individual exposure arenas were created by filling the bottom of a plastic Petri dish (8.9 cm diameter, 62 $cm^2$ area) with a water-based concrete slurry (Rockite®, Hartline Products, Cleveland, OH, USA). This process involves mixing the dry concrete powder with water to create a liquid slurry, and filling an individual Petri dish (hereby termed "arenas") to a depth of ~1.25 cm. A total of 60 arenas were created, 45 were used for insecticide treatments and 15 were used for untreated controls. These arenas were dried on a laboratory counter for a week before being used for the experiment.

The volumetric spray rate used to apply the insecticide to an individual arena was also in proportion to the label spray rate, which was calculated as approximately 0.3 ml per individual arena. Fifteen of the 60 arenas described above were first treated with 0.3 ml each of distilled water, using a Badger 100 Artist's airbrush (Franklin Park, IL, USA) to mist the water on the surface of the individual exposure arena. These water-treated arenas were the untreated controls. Next, low, medium, and high insecticide rates were formulated in separate 25-ml flasks, in proportion to the label rate described above, which was 0.1, 0.2, 0.3 ml of formulation in each 25-ml flask for the three rates, respectively. Each rate was used to treat fifteen arenas, 0.3 ml of solution per arena.

After all arenas were treated, one arena from each of the three treated replicates, along with an untreated control, were placed in one of fifteen metal "arena holders" fabricated in the shop at the CGAHR, as shown in Fig. 1. Five of these holders were placed in an incubator set at 27 °C and 60% r.h. in continual darkness, five were placed in the mezzanine of an exterior building at the CGAHR, and five were placed on the floor of an empty grain bin at CGAHR. At each location, a Hobo Pendant Logger (Onset Computer, Bourne, MA, USA) was placed to record temperature and light intensity every hour.

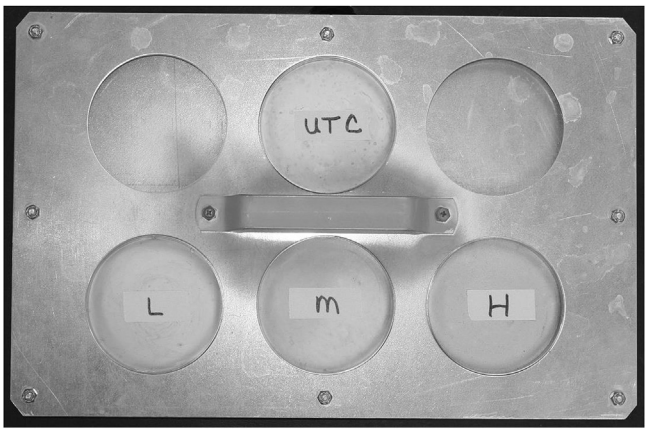


**Fig. 1.** Photo of metal arena showing placement of untreated arena (UTC), and arenas treated with the low (L), medium (M), and high (H) rates of deltamethrin, 8, 16, and 24 mg active ingredient [AI]/$m^2$, respectively. Holders were 41 cm L by 25 cm W.

One day later (hereby termed week 0), all holders and arenas were removed from their respective locations and held in an interior laboratory at the CGAHR. Ten 1-2-week-old adult *T. castaneum*, obtained from pesticide-susceptible colonies maintained at the CGAHR, were placed in each arena. This colony had been in culture at the CGAHR for more 35 years, and was reared on a diet of 95% organic whole-wheat flour and 5% Brewer's yeast, at 27 °C 60% r.h. in continual darkness. Every 30 min until 3 h, arenas were examined and adults classified as running or knocked down (on their backs unable to right themselves, or only able to walk normally without flipping over on their backs). After three hours, the adults were discarded, and the arenas were returned to their same locations. The exposure process was repeated every two weeks for ten weeks, and then the arenas were discarded.

The first test was done on 15 October 2015 and was termed Autumn 2015. The entire test was repeated on three more occasions, following all procedures described above, with actual treatments done on 17 May 2016 (Summer, 2016), 4 October 2016 (Autumn, 2016), and 4 May 2017 (Summer, 2017). Because of different temperature conditions for these tests, each of the four trials was analyzed as a separate trial. Light intensity values were 0 for the chamber and inside the grain bin, and light recordings only occurred during limited afternoon hours in the interior building when the western sun shined through the window, thus these data were eliminated from analysis. Values for knockdown were converted to a percentage of the total in each arena, as occasionally there was an escapee from the arena or the total was 9 or 11 instead of 10. Data were analyzed using the Mixed Procedure of the Statistical Analysis System (SAS, Version 9.2, Cary, NC, USA), with main effects exposure time, bioassay week, location, and application rate. Since all observations for knockdown were made on the same arena, this was considered a Repeated Measure, and analyzed using the Repeated option under the Mixed Procedure. Means and standard errors for data were obtained using the Means Procedure of SAS.

For the initial analyses at each of the four trials, treatment level (three deltamethrin rates) was significant at $P < 0.001$. However, when data were examined in more detail, there was no pattern of increasing knockdown with increasing deltamethrin rate, i.e. results were mixed with no consistency. Therefore, data for treatment levels were combined for the final analyses. Data for knockdown with respect to time was done as an ordered sequence, therefore instead of doing mean separation tests for knockdown with respect to exposure time, curves were fit to the