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Influence of temperature and artificially-created physical barriers on the efficacy of synergized pyrethrin aerosol

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ABSTRACT

The dispersal of aerosol insecticides within a flour mill may be hampered by barriers created from machinery and other equipment that block dispersion. Additionally, seasonal temperature variations may influence aerosol dispersion and subsequent effectiveness against stored product insects. The influence of barriers and temperatures on the efficacy of synergized pyrethrin aerosol against adults and pupae of the confused flour beetle, *Tribolium confusum* (Jacquelin du Val), was evaluated in experimental sheds. Insects were exposed to the aerosol at target temperatures of 22, 27, and 32 °C. Wooden boxes 1 m in length, 20 cm in width, and 5, 10, or 20 cm in height were used for creating different open and concealed areas for exposing insects. Results showed that exposing adults of *T. confusum* in open areas produced more moribund adults (those knocked down and unable to move except for reflex twitching or unable to respond when touched with a probe) at all temperatures, while survival increased with increasing distance from the front to the back of the boxes. Given the decreased survival, it would appear that more aerosol dispersed under the box height of 20 cm compared to 5 and 10 cm box heights because survival was generally less under the 20 cm box compared to the other two. Less than 2% of the pupae exposed in the open emerged as adults, but as the distance increased from the front to the back of the box adult emergence from these exposed pupae increased. Synergized pyrethrin aerosol can provide good control of *T. confusum* pupae and adults and may not be affected by seasonal temperature variations, but aerosol dispersion into obstructed or concealed areas may affect control.

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1. Introduction

The confused flour beetle, *Tribolium confusum* Jacquelin du Val, along with the related species *Tribolium castaneum* (Herbst), are important pests of flour mills in the United States of America (USA) (Arthur, 2008; Arthur and Campbell, 2008). The constant availability of flour patches and the structural complexity created by different types of processing equipment can create areas inside of flour mills that are conducive for growth and development of both species (Good, 1937; Cotton, 1958; Campbell and Runnion, 2003). Also, *T. castaneum* adults can fly whereas *T. confusum* adults do not appear to fly (Rees, 2004).

Historically fumigation with methyl bromide as a whole-plant treatment was the primary strategy used to control insect infestations inside flour mills in the USA. Options for whole-plant treatment of mills include alternative fumigants such as sulfuryl fluoride, cylinderized phosphine, or heat treatments. However, heat treatment may not be suitable for many older facilities and can be cost-intensive, while fumigants require facility shutdown, and phosphine could cause potential damage to equipment and structural components (Fields and White, 2002; Brijwani et al., 2009; Subramanyam et al., 2011).

Synergized pyrethrin has the potential to be a technically and economically feasible alternative to fumigants or heat. Aerosols can be used to target a portion of a facility, which makes them a cost effective and desirable option for many commercial operations (Boina and Subramanyam, 2012). However, dispersal of aerosol inside a flour mill may be limited by barriers such as milling equipment and structural components. Movement underneath concealed and obstructed areas and resulting particle deposition may be reduced compared to more open areas (Boina and Subramanyam, 2012).

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Bernhard and Bennett (1981) reported lower dispersion of synergized pyrethrin aerosol in open and partly open cabinets, and in closed areas compared to completely exposed areas. Similarly, Toews et al. (2010) reported less than 75% mortality in all life stages of *T. castaneum* exposed under wooden pallets as opposed to at least 80% mortality when these life stages were exposed in open areas without obstructions. Campbell et al. (2014) conducted a study whereby *T. confusum* were exposed within a flour mill in areas that would be open or obstructed to the aerosol, such as underneath equipment, along walls and corners, and beside structural beams. There was variation in efficacy for two formulations of aerosol pyrethrin, which led to greater recovery in obstructed sites and along the walls and in corners compared to the more open areas. However, mortality of adults was almost 100% when exposed to the organophosphate dichlorvos (Campbell et al., 2014; Subramanyam et al., in press).

Additionally, ambient temperature inside a facility during aerosol application may influence insecticidal efficacy. Campbell et al. (2010) conducted a study in which they monitored temperature within a flour mill and in a wheat-processing facility. They reported average daily temperature inside the facilities to be about 24 and 30 °C during cool and warm seasons, respectively. Although pyrethrin insecticide has a negative temperature coefficient, the addition of the synergist piperonyl butoxide increases its toxicity at higher temperatures (Blum and Kearns, 1956). Higher temperatures may also facilitate dispersion of aerosols into hidden and obstructed areas. In general, there is a lack of published data regarding the distribution and efficacy of synergized pyrethrin aerosol at different temperatures. The only recent results are described in Campbell et al. (2014), in which the evaluations described in the preceding paragraph were conducted at target temperatures of 27 and 40 °C (low and high, respectively). There was greater 24 h knockdown of adult *T. confusum* exposed to the pyrethrin aerosols at the high versus low temperature, but after 2 weeks the reverse had occurred, indicating a greater recovery of at the high versus low temperatures.

In previous tests conducted inside small-scale experimental sheds, larvae and adults of *T. confusum* were more tolerant to a commercial formulation of pyrethrin aerosol compared to pupae and (Kharel et al., 2014ab). Therefore, *T. confusum* pupae and adults were selected for the present study to represent tolerant immobile and an active stage, respectively. The objectives were to evaluate the efficacy of synergized pyrethrin aerosol at temperatures of 22, 27, and 32 °C against *T. confusum* adults and pupae, and to observe effects of dispersion of the insecticide underneath a barrier.

2. Materials and methods

This study was conducted in six experimental sheds at the USDA-ARS Center for Grain and Animal Health Research (CGAHR), Manhattan, KS, USA. The experimental sheds were 6 m long, 2.9 m wide and 2.6 m high, and each was equipped with a heating/air conditioning unit that could be set at different temperatures. The target temperatures for the study were 22, 27, and 32 °C. A treatment and control shed was designated for each temperature, and the thermostats were set to the desired temperatures. Temperatures were monitored with HOBO data loggers (Onset Computer Corporation, Bourne, MA, USA). Colonies of *T. confusum* were obtained from CGAHR that were reared at 27 °C and 70% r.h on a diet of wheat flour supplemented with 5% (w/w) brewer's yeast. Pupae that were 5 weeks from the time of egg hatch and 1–2-week old unsexed adults were used for the study.

The formulation of synergized pyrethrin insecticide used in this test was Entech Fog 10 (EPA Reg. No. 40391-10). The formulation comprised 1.0% pyrethrins, 2.0% piperonyl butoxide (technical), 3.33% N-octyl bicycloheptane dicarboximide, and 93.67% other ingredients (Entech Systems Corporation, Kenner, LA, USA).

Inside each shed three 1 m by 0.20 m areas were marked on the floor at a distance of 0.30 m from one another. These areas were about 0.60 m from the end wall and 0.85 m from the side walls. Three wooden boxes of 1 m length, 20 cm width, and 5, 10, or 20 cm height were placed randomly in each of the three marked areas. The boxes were open in the front and closed in the back. A line (P1 = open position) was marked outside each box 7.6 cm from the front opening, along with four lines (P2, P3, P4, and P5 = concealed positions) inside the boxes at about 7.6, 35.5, 63.5, and 91.4 cm, respectively, from the open front end. These boxes were of the same design as those used in Campbell et al. (2014). Exposure arenas were prepared using glass Petri dishes (62 cm^2 in area) that contained 1 g of wheat flour. Each dish was placed at the positions described above, and contained either 20 adults or 10 pupae of *T. confusum* (Fig. 1). A total of 30 Petri dishes containing *T. confusum* adults or pupae were exposed per shed (2 life stages × 5 exposure positions × 3 boxes heights = 30 total). A line was marked as the aerosol spray position, which was about 2.8 m from the open exposure position.

The required amount of aerosol insecticide per shed (47 ml) was calculated on the basis of the labeled rate of Entech Fog 10 (1.04 ml/m^3). The insecticide was delivered using a hand-held aerosol applicator, a Fogmaster Jr. 5330 (The Fogmaster Corporation, Deerfield Beach, FL, USA), set to deliver 20.8 ml of Entech Fog 10 formulation per min. The total time required to deliver 47 ml of insecticide was 2 min and 16 s. The aerosol was applied by a person standing at the aerosol spray position and holding the Fogmaster spray unit at about 3 m above the floor and pivoting the unit slowly from side to side. Three sprays were done for each of 6 replications, conducted on 14, 15, 21, 22, 28, and 29 of August 2012. Preliminary testing had showed that the sheds could be cooled to 22 and 27 °C but not heated effectively to 32 °C. Consequently, the aerosol was applied at about 0800 h inside the shed used for the target temperature of 22 °C, at about 1100 h inside the shed used for the target temperature of 27 °C, and at about 1500 h in the shed used for the target temperature 32 °C. The individual Petri dishes containing either pupae or adults were held in both the treated and control sheds for 2 h after the aerosol was applied, then all dishes were removed from the sheds and placed in an incubator set at 27 °C and 70% r.h. This entire process was repeated for each of the six replications. Temperatures during time blocks of 0800–1100 h, 1300–1600 h, and 1500–1800 h, were averaged over the replications for the target temperatures of 22, 27, and 32 °C, respectively.

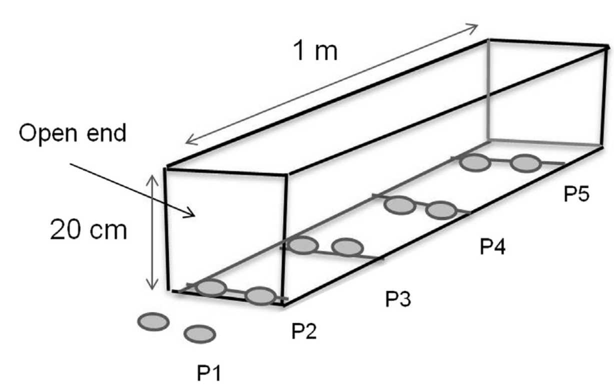

Fig. 1. Exposure of *T. confusum* adults and pupae held in Petri dishes at open and concealed positions in and outside of the box (open position = P1, concealed positions = P2, P3, P4, and P5). The exposure boxes used in the test were 1 m long, 20 cm wide with heights 5, 10 and 20 cm.