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Dispersion, efficacy, and persistence of dichlorvos aerosol against two flour beetle life stages in a mill

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ABSTRACT

The dispersion, efficacy, and persistence of dichlorvos applied as an aerosol inside the Kansas State University pilot flour mill was evaluated based on responses of adults of the confused flour beetle, *Tribolium confusum*, and pupae of the red flour beetle, *Tribolium castaneum*, during and after application. Dichlorvos was applied at the highest labeled rate of 0.35 g/m^3. Concrete arenas with or without different life stages of the two species were placed in open, obstructed, and concealed mill locations during aerosol application. Knockdown and mortality of *T. confusum* adults was 99–100% and mortality of *T. castaneum* pupae was 97–100% in open and obstructed mill locations, indicating uniform dispersion of dichlorvos. In concealed locations, knockdown and mortality of *T. confusum* adults and mortality of *T. castaneum* pupae was 85–94%, indicating effective dispersion of dichlorvos into pieces of equipment. Holding insects directly exposed to dichlorvos for an additional 24 h in the same arenas did not increase knockdown or mortality. Exposure to dichlorvos residues aged for an additional 24 h on concrete resulted in moderate to poor knockdown and/or mortality of *Tribolium* spp. suggesting lack of residual activity. Results show dichlorvos will give immediate kill of exposed insects but will not offer effective residual control.

1. Introduction

The use of methyl bromide for structural fumigation has been discontinued in the United States, except for certain critical uses, as per the agreement reached under the Montreal Protocol (Fields and White, 2002; Anonymous, 2004). Alternative fumigants such as phosphine ($ECO_2FUME^{®}$) and sulfuryl fluoride (ProFume™), currently available for insect pest management in flour mills, have certain limitations. Phosphine reacts with exposed metals and electrical equipment causing corrosion (Bond et al., 1984) and some strains of stored-product insects have developed resistance to it (Arthur et al., 1988; Zettler, 1990). Eggs of stored-product insects are hard to kill at labeled rates of sulfuryl fluoride rendering it less economical (Bell and Saviddou, 1999; Small, 2007; Baltaci et al., 2009; Hartzer et al., 2010; Athanassiou et al., 2012). In addition, during fumigation food-processing facilities should not be in operation and must be sealed relatively air-tight. Structural heat treatments are viable alternatives to fumigants but can be expensive and may not be suitable for use in all facilities (Subramanyam et al., 2011).

In recent years, use of aerosols for managing insects in food-storage and food-processing facilities is becoming popular as an alternative to fumigants and heat treatments (Jenson et al., 2010a, b; Sutton et al., 2011; Boina and Subramanyam, 2012). This technique is also known as space spray, fogging, or ultra-low volume (ULV) application depending on the equipment and insecticide formulation used and particle sizes dispersed. In a typical aerosol application, the formulated insecticide is dispensed as fine particles of 5–50 μm through an atomizer (Peckman and Arthur, 2006).

In the present study, dispersion, efficacy and residual activity of a new formulation of dichlorvos, Vap-20® with carbon dioxide (Chem-Tech Ltd., Des Moines, IA, USA), applied as aerosol at the high labeled rate of 0.35 g/m^3 (0.07 g(AI)/m^3), was evaluated for control of adults of the confused flour beetle, *Tribolium confusum* (Jacquelin du Val), and pupae of the red flour beetle, *Tribolium castaneum* (Herbst), in a pilot flour mill. These two species are commonly associated with flour mills (Good, 1937; Salmond, 1956; Buchelos, 1981; Campbell and Arbogast, 2004).

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2. Materials and methods

2.1. Insects

Adults of *T. confusum* and pupae of *T. castaneum* used in the experiments were obtained from cultures maintained on 95% white wheat flour plus 5% brewer's yeast (by weight) at 28 °C and 65% r.h. in the Stored-Product Insects Research and Education Laboratory (SPIREL), Department of Grain Science and Industry, Kansas State University, Manhattan, KS, USA. These insects have been in rearing since 1999 without insecticide exposure and are hence assumed to be insecticide-susceptible. Unsexed adults of mixed ages of *T. confusum* were collected directly from 0.94-L culture jars after sifting the bleached wheat flour plus 5% by weight of brewer's yeast diet using an 841-μm opening sieve (Seedburo Equipment Company, Chicago, IL. USA). To collect 1–2 day old pupae of *T. castaneum*, 50 unsexed adults of mixed ages were introduced into 150-ml plastic containers containing 30 g of bleached flour previously sifted through a 250-μm opening sieve. After 2 d at 28 °C and 65% r.h., the flour was sifted through an 841-μm opening sieve to remove adults. The flour with eggs in containers was held at the rearing conditions for 24 d before sifting the flour through a 250-μm sieve to collect pupae (Brijwani et al., 2012).

2.2. Dichlorvos application

The aerosol treatments were made in the Hal Ross pilot flour mill at Kansas State University, Manhattan, KS, USA, which has five floors occupying a total volume of 9628 m^3. The layout of the mill has been described in detail by Brijwani et al. (2012). The air-handling system was shut down during the aerosol treatment. The dichlorvos formulation (Vap-20®, 20% dichlorvos plus 80% carbon dioxide by weight) was applied as an aerosol at the highest labeled rate of 0.35 g/m^3 by dispensing 614, 684, 717, 642, and 773 g of dichlorvos in the first (floor volume, 1756.4 m^3), second (2088.7 m^3), third (1946.3 m^3), fourth (1946.3 m^3) and fifth (2231.1 m^3) mill floors, respectively. The mill temperature was 27 °C and 42% r.h.

2.3. Bioassay methods (treatments)

Ready-mix concrete (Rockite, Hartline Products Co. Inc., Cleveland, OH, USA) was mixed with water to make a slurry. The slurry was poured into Petri dishes (90-mm diam. and 15 mm high) to approximately half the height of the dish. The concrete was allowed to dry for several days in the laboratory at room conditions. These concrete arenas were used for insect exposure in the mill. The arenas had either no insects or 10 unsexed adults of mixed ages of *T. confusum* or 10 pupae of *T. castaneum*. Adults of *T. castaneum* were not used for direct aerosol exposure because of their tendency to fly. On each floor, arenas were placed at three open locations where they were not obstructed by equipment or mill structural components, three obstructed locations where aerosol deposition was partially obstructed by equipment or structural components, and three concealed locations where aerosol deposition was hindered because arenas were placed inside pieces of mill equipment. The obstructed and concealed locations on each floor are identified in Table 1. On each mill floor and location, four bioassay methods or insect exposure treatments were evaluated by placing two arenas with *T. confusum* adults and two arenas with *T. castaneum* pupae and four arenas without insects. There were a total of eight arenas per location and 72 arenas per floor and 360 arenas in the entire mill. Arenas without lids were placed in the mill 1 h prior to aerosol application. The four bioassay methods or treatments evaluated were: T1, direct exposure of arenas with insects to dichlorvos during fogging and until the facility was cleared 24 h later; T2, direct exposure of insects to dichlorvos during fogging and until the facility was cleared plus an additional 24 h exposure in the same arenas that were held in a laboratory growth chamber at 28 °C and 65% r.h. (48 h); T3, exposure of insects for 24 h in the laboratory at 28 °C and 65% r.h. to dichlorvos residues in arenas that were exposed to dichlorvos aerosol in the mill without insects; and T4, which was same as T3, except that arenas were held at 28 °C and 65% r.h. for 24 h before exposing insects for another 24 h at controlled conditions. After aerosol application, arenas were collected the following day (24 h) after the mill was ventilated. Adults of *T. confusum* or pupae of *T. castaneum* were added (10 insects/arena) immediately after bringing dishes to the laboratory (T3) or after aging residues for 24 h (T4). For each of the treatments T1–T4, a set of nine untreated arenas (3 each corresponding to open, obstructed, and concealed locations) with 10 adults of *T. confusum* or nine arenas with 10 pupae of *T. castaneum* per dish, held at 28 °C and 65% r.h. in a laboratory growth chamber, served as the control treatment.

After the exposure periods mentioned above, all arenas including untreated controls, were examined to assess insect knockdown and/or mortality. Adults of *T. confusum* that could not walk or right themselves when gently stimulated with a camel's hair brush were considered knocked down. After this assessment, all adults of *T. confusum* and pupae of *T. castaneum* in treatments T1–T4 were transferred to untreated arenas with 3 g of bleached flour plus 5% by weight of brewer's yeast diet. These arenas were incubated at 28 °C and 65% r.h. for 7 d to assess mortality. Adults of

Table 1
Obstructed and concealed locations of concrete dishes among the five floors of the Hal Ross pilot flour mill.[a]

Floor	Placement of concrete arenas	Location number within a floor	Location description
First	Obstructed	1	Beneath the roller mill
		2	Beneath the semolina bag station
		3	Beneath the air-lock hoppers
	Concealed	1	Inside the roller mill
		2	Inside the roller mill
		3	Inside the roller mill
Second	Obstructed	1	Beneath flour transport screw conveyers
		2	Beneath scourer/aspirator
		3	Beneath patent/clears scales
	Concealed	1	Inside the precision grader
		2	Inside the color sorter
		3	Inside the hopper
Third	Obstructed	1	Beneath the polisher
		2	Beneath the cylinder separator
		3	Beneath the spouting
	Concealed	1	Inside the pneumatic piping
		2	Inside the cylinder separator
		3	Inside the disc separator
Fourth	Obstructed	1	Beneath the hand add station
		2	Beneath the flour bin
		3	Beneath the cyclones
	Concealed	1	Inside the sifting station
		2	Inside the combi-cleaner
		3	Inside the sifter
Fifth	Obstructed	1	Beneath the first break scale
		2	Beneath bin-vent filter
		3	Beneath the cyclones
	Concealed	1	Inside the cyclones
		2	Inside the micro ingredient feeders
		3	Inside the Carter Day screen separator

[a] Open locations where concrete arenas were placed included mill areas free of obstruction or concealment from any pieces of equipment or structures.