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# Aerosol insecticide distribution inside a flour mill: Assessment using droplet measurements and bioassays

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ABSTRACT

The distribution of aerosol applications of pyrethrin + methoprene, generated from a mechanical fogger, and pyrethrin + pyriproxyfen, dispensed from a pressurized cylinder, were characterized inside a pilot-scale flour mill using measurements of particle size and concentration and effects on adult confused flour beetles, *Tribolium confusum* Jacqueline duVal, in bioassay arenas. Particle measurements were made using TSI Aerodynamic Particle Sizer (APS) units placed in an open straight line at distances of 4.3, 8.9, and 13.5 m from the aerosol release point (open configuration). Measurements were also made using a second configuration (termed obstructed), which was done by moving the APS unit at 8.9 m underneath a piece of equipment, and moving the APS unit at 13.5 m behind a support beam. Actual concentration and calculated deposition were about 4× greater for the pyrethrin + methoprene aerosol compared to the pyrethrin + pyriproxyfen aerosol. However, efficacy was similar since bioassays using adult *T. confusum* showed no difference in recovery after exposure to either insecticide. Concentration and calculated deposition of both aerosols decreased with increasing distance from the spray release point and when the APS units were in the obstructed configuration, and recovery of bioassay insects after exposure increased with increasing distance from the spray release point. Results from this field trial show how efficacy of aerosol applications is impacted by distance and obstacles, and how use of equipment that measures droplet size and concentration can help quantify the dispersion and spread of insecticidal aerosols. Results also provide guidance to develop relationships between aerosol deposition and efficacy and thus improve pest management programs for structural management of stored product insects.



## 1. Introduction

Published research with insecticidal aerosols in relation to insect pest management has historically focused on aerosols applied outdoors for mosquito control (Bonds, 2012). Estimates of spray droplet size distribution for optimum efficacy range from 5 to 25 μm, depending on the specific application techniques, as droplets in this size range are most likely to impinge on the body of flying mosquitoes (Haile et al., 1982; Mount, 1998). However, when insecticidal aerosols are used inside buildings for control of stored product insects, spray particles are expected to disperse throughout the structure and not only land on the body of exposed insects, but also provide good coverage of surfaces throughout the facility (e.g., floor, walls, machinery, duct work, pipes, and pallets). Aerosols could come into contact with flying or walking adults, but since most of the insect populations are in hidden areas at any given point in time most likely insect control is through insect exposure to surfaces that have a residual deposition of those aerosol particles.

Aerosol insecticides are widely used in the food industry to suppress insect activity inside facilities such as mills, processing plants, and warehouses. Bernhard and Bennett (1981) examined aerosol deposition in relation to control of confused flour beetle, *Tribolium confusum* Jacquelin duVal, and rice weevil, *Sitophilus oryzae* (L.). However, they did not make any estimates of actual particle size. Arthur et al. (2014) conducted a study to determine efficacy of an aerosol applied at different particle sizes to control

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adult *T. confusum*. This study examined differences between particles of 1% active ingredient [AI] pyrethrin (Entech Systems, Kenner, LA, USA) dispensed at 2 μm versus 16 μm, using different post-exposure techniques and adults of *T. confusum* as the target species and life stage. The smaller particle size was largely ineffective even though the actual concentration of insecticide was equal to or greater than the concentration dispensed at 16 μm. Thus, particle size and not concentration was the determining factor in conferring efficacy. Similarly, Campbell et al. (2014) assessed aerosol distribution inside a flour mill, using bioassay arenas containing adult *T. confusum*, and showed that aerosols of pyrethrin + methoprene and pyrethrin + pyriproxyfen did not disperse evenly, but instead there were areas within the mill that experienced greater recovery of exposed adults, presumably from differential aerosol distribution.

Characterization of aerosol droplet size, distribution, and concentration in outdoor applications for mosquitoes is typically assessed by collecting droplets on Teflon-coated microscope slides mounted on a rotating impactor (Farooq et al., 2009; Clayson et al., 2010). These droplet samplers can vary in terms of their ability to collect smaller particles (Bonds et al., 2009). Also, actual deposition is affected by wind speed and other meteorological factors (Faraji et al., 2016). Thus, there is a need to investigate more precise methods for assessing aerosol deposition for structural applications in flour mills, food production facilities, and food storage centers where environmental conditions may be more stable compared to outdoor environments.

There are instruments for sampling and characterizing fine particles or droplets. For example, the Aerodynamic Particle Sizer (APS, model 3321, TSI Incorporated, Shoreview, MN, USA) counts particles and measures their sizes from 0.5 to 20 μm. The APS unit draws an air sample of the aerosol cloud using a specific airflow. The sampled droplets are directed through a pair of laser beams. The time-of-flight of individual droplets is determined with high-speed electronic timing circuits (Armendariez and Leith, 2002). The flight-time measurements and the droplet density are related to the diameter of individual particles. Additional electronics tabulate the distribution of particles during a sampling period, such as 20 s. After the sampling period, the counters are reset and sampling and counting is repeated. Some of the parameters and distributions measured include the total count of particles per diameter and per sampling time interval, the geometric mean diameter (GMD), and the mass concentration of the aerosol (in units of $mg/m^3$) per sampling period. Current APS units and earlier models (APS 3320) have been used to assess particle distributions in a variety of research and industrial settings (Peters and Leith, 2003). However, in the scientific literature they have not been used to assess aerosol insecticide concentrations and depositions inside food facility environments such as flour mills. Thus, the objectives of this study were to: 1) determine feasibility and utility for using the APS units to characterize droplet size distribution from two different commercial aerosol formulations, 2) determine particle size distribution and deposition at selected distances from where the spray was dispensed, 3) evaluate effects of obstructions on aerosol dispersal, and 4) characterize insecticidal efficacy against adult *T. confusum* in relation to aerosol particle size distribution and deposition.

## 2. Materials and methods

### 2.1. General description

This study was conducted in the Hal Ross Flour Mill at Kansas State University in Manhattan, KS. A complete description of the mill and aerosoal application protocol has been previously published (Campbell et al., 2014). This study was done on the 4th floor and a schematic diagram of the 4th floor is shown in Fig. 1. The total volume of this room is ~1500 $m^3$. Prior to initiation of the experiment, doors were sealed by taping plastic sheeting around the door except for the main entrance. Also, any openings between the 4th and adjacent floors were sealed to minimize escape of the aerosol. Two aerosol insecticides formulations were used in this study, as described below, and they were both applied from a point ~1.8 m from the south wall and midway between the east and west walls, about 1 m in height from the floor surface (Fig. 1). The aerosol spray treatment was applied by a licensed applicator, who recorded the time applications started and stopped. The time required to dispense the insecticide ranged from 5 to 8 min, depending on the specific insecticide/sprayer used. After the 1-h test period, residual air-borne particles were exhausted with the mill's ventilation fans prior to re-entry.

The first insecticide was natural pyrethrin (BP 100, active ingredients (AI) are 1% pyrethrin and 5% Piperonyl Butoxide (PBO) synergist, MGK, Minneapolis, MN, USA), combined with the insect growth regulator methoprene (Diacon® II, now Diacon IGR®, 33% AI methoprene, Central Life Sciences, Schaumberg, IL, USA). A model 7401 Aerojet Fogger (Fogmaster, Deerfield Beach, FL, USA) was used to apply this formulation. The amount of formulation needed for an individual treatment was calculated according to label rates for treating the total air volume of the room. This was a liquid formulation combined in a ratio of 100:1 pyrethrin:methoprene, as specified by the label directions for application of both products as a space spray. The second insecticide was pyrethrin combined with the insect growth regulator pyriproxyfen (NyGuard, TurboCide PY-75w/IGR). This mixture was dispensed from a pressurized cylinder. In this formulation, the AI of the pyrethrin was 0.7%. It was a pre-mixed formulation with 0.2% AI pyriproxyfen, 5% PBO (Chem-Tech, Des Moines, IA, USA) with a $CO_2$ carrier.

Three APS units were used to assess particle sizes (APS1, APS2, and APS3) and two patterns of APS placement were evaluated. For the first pattern, the three APS units were positioned in a straight line from the application point at distances of 4.3 (APS1), 8.9 (APS2), and 13.5 (APS3) m. This pattern was termed “open”, because there were no obstructions between the APS units and the application point. The second position pattern was termed “obstructed”, and for this pattern, APS1 remained in the same spot, while APS2 was moved ~1 m toward the West so that it was underneath a flour sifter. The bottom of the sifter was ~0.5 m above the floor, and the gap between the collection tube of the APS unit and the bottom of the sifter was about 7.5 cm. APS3 was located behind a support column by moving it ~2 m backwards away from the sprayer and ~1 m toward the East wall.

The study was composed of a total of eight individual trials; two insecticides/sprayer systems, open and obstructed configurations, and two replicates of each combination. In addition to the APS units, for each of the trials, insect bioassay arenas were used. Bioassay dishes consisted of plastic Petri dishes (30 mm) holding five adult *T. confusum* and ~50 mg of flour (hereafter termed arenas). For each trial, a total of 15 arenas, three around each APS unit, in a circular pattern about 0.5 m from the unit, were used on the fourth floor where the aerosol was applied and a companion set of arenas was also placed on the first floor to serve as untreated controls. When the APS2 and APS3 units were moved to the obstructed positions, the bioassay arenas were moved so that the dishes were in the same relative positions with the APS units and also obstructed.

The APS units were set to tabulate particle count data for sampling periods of 20 s. Aerosol data was collected for over 90 min per trial, including ~10 min for pre-spray (background data), ~60 min for spray and aerosol settling, and ~20 min of exhaust and