Mortality of stored grain insects exposed to cylinderized phosphine in wheat bins

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Abstract

A cylinderized formulation of phosphine dissolved in liquid carbon dioxide was evaluated and compared with aluminum phosphide pellets for killing stored grain insects in steel bins containing 4.2 metric tons of hard red winter wheat. Bins treated with cylinderized phosphine were dosed at 200 ppm and re-dosed periodically to maintain gas levels at 160 - 240 ppm. Bins treated with aluminum phosphide pellets received 34 pellets. Test insects included Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum and Plodia interpunctella. Insects were placed in ventilated vials in bioassay chambers. Samples were collected daily for seven days.

One day of exposure to either fumigant was sufficient to kill most adults and pupae of Rhyzopertha dominica, Sitophilus oryzae, and Tribolium castaneum, and larvae and pupae of Plodia interpunctella. Eggs of Rhyzopertha dominica survived one day, but were killed by the second day. Tribolium castaneum eggs were killed within one day with either fumigation. Results with Sitophilus oryzae eggs were inconclusive. Plodia interpunctella eggs succumbed to both treatments at levels ranging from 59.7 - 99.7% relative to control survival.

Bins treated with cylinderized phosphine received 3.6g of PH3 while bins treated with aluminum phosphide pellets received 6.8g. Therefore, the cylinderized formulation elicited mortality comparable to that of the pellet formulation, but utilized nearly half as much active ingredient.

Introduction

Current formulations of phosphine available for use in the United States are pellets or tablets of the metallic salts aluminum phosphide and magnesium phosphide that evolve phosphine gas (PH3) when exposed to air and moisture. Despite the relative ease and safety in applying pellets to a grain mass there are disadvantages to the pellets that may influence efficacy. Following application of pellets, PH3 increases in concentration over several hours or days until all the material is reacted. The rate at which the concentration increases is dependent on temperature and relative humidity. Precise dosing of PH3 and assurance of appropriate exposure times are difficult to achieve because of the dynamic release characteristics of the gas from pellet formulations and inherent structural leaks.

Products and methods have recently been developed for applying phosphine directly as a gas for fumigations. In Australia, a pressurized distribution system for fumigating with phosphine was successfully implemented on a commercial scale in 1988 following three years of testing (Winks 1993). In England, the potential use of a cylinder-based formulation of phosphine in liquid carbon dioxide was first examined in 1987 in a pilot-scale study in the laboratory (Chakrabarti & Wontert-Smth 1987). Field trials in steel grain bins and in floor-stored grain demonstrated that a cylinder-based formulation of phosphine in liquid carbon dioxide was effective in controlling insect populations (Chakrabarti et al. 1991, Bell et al. 1993).

A new product (ECOzFUME™ Fumigant Gas, BOC Gases, U.S.A.) is being tested in the United States. This product is a cylinderized formulation of phosphine dissolved in liquid carbon dioxide at approximately 2% PH3 and 98% CO2. There are several advantages to applying phosphine directly as a gas. Phosphine gas released from a cylinder is not flammable, can rapidly reach a target dose in a structure, is not dependent on air temperature or relative humidity, leaves no dusty residue as with pellet formulations, and can be precisely metered by adding required amounts of gas when needed.

The objective of this research was to evaluate the efficacy of cylinderized phosphine for killing various species and life
stages of stored product insects in stored wheat. Additionally, we compared the mortality from cylinderized phosphine with that achieved by a conventional formulation of aluminum phosphide pellets and we compared the amounts of PH₃ utilized by each method.

**Materials and Methods**

Experiments were conducted in corrugated steel grain bins, 1.8 m dia by 2.7 m high, each containing approximately 4.2 metric tons of hard red winter wheat. Five bins were assigned for treatment with cylinderized phosphine, five bins were assigned for treatment with aluminum phosphide pellets, and one bin was untreated and used for holding control insects for mortality studies. Bins treated with cylinderized phosphine were administered an initial dose of 200 ppm phosphine gas and then re-dosed periodically to maintain gas levels at 160 - 240 ppm. Bins treated with aluminum phosphide pellets received 34 pellets probed into the center of the grain mass; this treatment represented a minimum dose as recommended by the manufacturer. Phosphine gas levels (PortaSens Gas Detector; Analytical Technology, Inc., Oaks, Pennsylvania) and temperatures (Fluke 51 Digital Thermometer; Fluke Corporation, Everett, Washington) were monitored in all bins throughout the course of the seven-day experiment.

Three life stages of each of four species of pest insects were assessed for their mortality in response to fumigants applied to wheat in experimental grain bins. Test insects and their life stages included *Rhyzopertha dominica*, the lesser grain borer (eggs, pupae and adults); *Sitophilus oryzae*, the rice weevil (eggs, pupae and adults); *Tribolium castaneum*, the red flour beetle (eggs, pupae and adults); and *Plodia interpunctella*, the Indianmeal moth (eggs, 5th instar larvae and pupae). Ten adults of each species, 10 *T. castaneum* pupae, 8 pupae and approximately 258 eggs of *P. interpunctella*, and infested wheat/media of the other species/life stages were placed in small, ventilated vials and deployed in each treatment bin and in the control (unfumigated) bin. Each treatment bin was equipped with a bioassay chamber that was a ventilated plastic pipe, 2 m by 5 cm, positioned horizontally across the top of each bin, 15 cm below the surface of the grain mass. The distal end of the bioassay chamber was capped and the proximal end extended through the bin wall to the exterior to accommodate two ball valves that were 60 cm apart. The space between the valves served as a gas lock through which insect vials connected by string could be pulled from the bioassay tube and recovered with minimal loss of gas from the bin. Vials with untreated control insects were placed in plastic pipe sections and placed 15 cm below the surface of the grain in the control bin, from which they were removed via the top hatch. Equal sub-samples of treated and control insects were removed from bins daily for seven days and held in the laboratory to evaluate mortality.

**Results**

One day of exposure to either cylinderized phosphine or aluminum phosphide pellets was sufficient to kill 93.4 - 100% of *R. dominica* and *S. oryzae* adults, the three life stages of *T. castaneum*, and larvae of *P. interpunctella* (Table 1). All of these life stages were dead on days 2 - 7.

**Table 1. Mean mortality (%) of test insects after one day of exposure to fumigants. There was 100% mortality of all these life stages on days 2 - 7.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Life Stage</th>
<th>Cylinderized Phosphine</th>
<th>Aluminum Phosphide</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhyzopertha dominica</em></td>
<td>Adults</td>
<td>100</td>
<td>93.7</td>
</tr>
<tr>
<td><em>Sitophilus oryzae</em></td>
<td>Adults</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><em>Tribolium castaneum</em></td>
<td>Eggs</td>
<td>100</td>
<td>93.4</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Pupae</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><em>Plodia interpunctella</em></td>
<td>Larvae</td>
<td>100</td>
<td>98.0</td>
</tr>
<tr>
<td></td>
<td>Pupae</td>
<td>87.2</td>
<td>74.4</td>
</tr>
</tbody>
</table>

Mortality of *R. dominica* pupae ranged from 94.7 - 99.4% after 1 - 3 days of exposure (Fig. 1). Data for days 4 - 7 were not available. Some pupae of *S. oryzae* survived one day of exposure to fumigants, none survived 2 and 3 day exposure, and a few survived after 4 - 7 days of exposure (Fig. 2). Mortality of *P. interpunctella* pupae was only 87.2 and 74.4% after one day of exposure to cylinderized phosphine and aluminum phosphide pellets, respectively, with 100% mortality for the rest of the study. Eggs of *R. dominica* survived one day of exposure to test fumigants but were killed on the second and third days of treatment (Fig. 3). However, some eggs of *R. dominica* survived exposure on days 4 - 7. Results with *S. oryzae* eggs were inconclusive because of poor survival of control insects. Eggs of *P. interpunctella* succumbed to treatment by both cylinderized phosphine and aluminum phosphide pellets at levels ranging from 59.7 - 99.7% relative to control survival (Fig. 4). The highest mortality of *P. interpunctella* eggs occurred at the beginning and end of the 7-day trial and the highest survival was in those exposed for four days.

Phosphine gas concentrations in the bins treated with cylinderized phosphine were able to reach the desired level of 200 ppm quicker than bins treated with aluminum phosphide pellets (Fig. 5). With the ability to safely re-dose bins with cylinderized phosphine, the desired concentration...
was maintained. The mean phosphine concentration in the bins treated with aluminum phosphide pellets reached a peak concentration after 30 hours and then declined throughout the duration of the study.

The mean grain temperature near the bioassay chamber during the seven-day experiment was 31.9°C.

![Diagram](image)

**Fig. 1.** Mean mortality of *R. dominica* pupae.

![Diagram](image)

**Fig. 2.** Mean mortality of *S. oryzae* pupae.
Fig. 3. Mean mortality of *R. dominica* eggs.

Fig. 4. Mean mortality of *P. interpunctella* eggs.
Cylinderized phosphine was effective for killing various species and life stages of stored product insects in wheat stored in steel grain bins. Overall, insect mortality was as high or higher using cylinderized phosphine when compared with aluminum phosphide pellets.

The high survival of *P. interpunctella* eggs at four days, combined with the high mortality of eggs at the beginning and end of the 7-day trial, suggests that some form of phosphine-induced tolerance was experienced by eggs exposed for four days with either fumigant.

In this experiment, each bin treated with cylinderized phosphine received a total of approximately 3.6 g of PH₃ while bins treated with aluminum phosphide pellets received about 6.8 g of PH₃ (an amount equivalent to the lowest label rate of 150 pellets/28.3 m³). Therefore, the cylinderized formulation elicited mortality against stored-product insects comparable to that elicited by the traditional pellet formulation, but utilized nearly half as much active ingredient. Minimizing the amount of chemical applied to a commodity, yet maintaining or improving insect control, is a significant and desired attribute of cylinderized phosphine.

**Discussion**

Cylinderized phosphine was effective for killing various species and life stages of stored product insects in wheat stored in steel grain bins. Overall, insect mortality was as high or higher using cylinderized phosphine when compared with aluminum phosphide pellets.

The high survival of *P. interpunctella* eggs at four days, combined with the high mortality of eggs at the beginning and end of the 7-day trial, suggests that some form of phosphine-induced tolerance was experienced by eggs exposed for four days with either fumigant.

In this experiment, each bin treated with cylinderized phosphine received a total of approximately 3.6 g of PH₃ while bins treated with aluminum phosphide pellets received about 6.8 g of PH₃ (an amount equivalent to the lowest label rate of 150 pellets/28.3 m³). Therefore, the cylinderized formulation elicited mortality against stored-product insects comparable to that elicited by the traditional pellet formulation, but utilized nearly half as much active ingredient. Minimizing the amount of chemical applied to a commodity, yet maintaining or improving insect control, is a significant and desired attribute of cylinderized phosphine.

**References**


