Problems and New Approaches for the Use of Phosphine as a Grain Fumigant in the U.K.

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Introduction

Grain is stored in the U.K. in diverse structures, including galvanised steel bins and concrete silos, and on the floor in purpose-built stores, converted aircraft hangars, and other buildings. This diversity, coupled with the prevailing cool, damp weather conditions, creates difficulty in devising a general set of recommendations for the use of phosphine. From a biological viewpoint, further complexities arise because of the very wide differences in tolerance between stages of the same species of stored product pests, between different strains and species, and because of the effect of temperature on the concentration and exposure time ranges over which phosphine acts efficiently.

After harvest, grain is dried by flat-bed aeration or by use of grain dryers, and is then cooled, usually down to 4°–10°C. Nevertheless, localised problems often occur within large bulks, and infestations may reach noticeable proportions. Fumigation by phosphine is the only control method that is currently available for treating the while bulk in situ. Use of liquid fumigant mixtures is now precluded with the lowering of the permitted maximum residue level (MRL) for carbon tetrachloride in the U.K. to 0.1 ppm from 1 January 1989. This paper describes some new results relating to the toxicity of phosphine under marginal conditions and some developments leading to increased fumigation efficacy.

The Effect of Temperature on the Minimum of Exposure for Control

Recent tests on diapausing larvae of *Ephestia elutella* show that, for concentrations over 2 mg/L, the time required to achieve 99% kill at 25°C stabilises around 30 hours. This compares with about 23 hours for 99% kill at similar concentrations at 15°C (Table 1). Thus, the minimum time for achieving 99% kill increases with increasing temperature, indicating an active defence mechanism at work.

Experiments involving larvae in diapause demonstrate the toxic effect of phosphine in the absence of development. For many species, the minimum exposure period required for control is governed by the developmental rate of eggs or pupae. Phases of high natural tolerance are bridged by longer exposures as development continues in the presence of phosphine. Where such developmental effects control fumigation efficacy, lowering the temperature increases the exposure period required for kill, until cold itself becomes lethal.

Table 1. Effect of temperature on the minimum effective exposure period of phosphine at high concentration against diapausing larvae of *Ephestia elutella*.

	15°C				25°C		
Concn (mg/L)	LD_{99} (mg hours/L)	b±SE	Lt_{99} (hours)	Concn (mg/L)	LD_{99} (mg hours/L)	b±SE (hours)	LT_{99}
–	–	–	–	0.18	12.5	6.90±1.41	70.2
0.60	31.1	3.44±0.43	51.8	0.5	23.0	4.45±0.80	46.0
1.02	37.2	3.46±0.42	36.5	1.2	65.4	2.98±0.5	52.7
1.48	49.7	3.51±0.43	33.6	–	–	–	–
1.95	43.3	3.25±0.47	22.2	2.22	68.9	3.58±0.66	31.0
3.04	74.8	3.84±0.68	24.3	2.70	70.7	3.52±0.4	26.2
4.10	92.3	2.64±0.51	22.5	3.71	121.9	3.15±0.70	32.9

Mean Lt_{99} for 1.95 – 4.10 mg/L : 23 hours   Mean Lt_{99} for 2.22 – 3.71 mg/L : 30 hours

Effect of Changing Concentration Levels on the Toxicity of Phosphine

In tests on all stages of a resistant strain of *Cryptolestes ferrugineus*, the level of kill obtained was related to the concentration remaining at the end of the exposure period rather than the total Ct product. A 10–day exposure with Ct product 65±10 mg hours/L was chosen (Table 2). Also evident was the advantage of concentration levels falling later rather than earlier in the exposure period in terms of enhancing the level of kill obtained. In most cases survival was attributable to pupae or prepupae. Kills of other stages of this resistant strain exceeded 99% in all tests.

Dosing Methods for the Use of Phosphine

Results at low and changing concentration levels of phosphine highlight the need to delay the fall of concentrations to as late as possible in the exposure period. In practical terms this implies either a high degree of sealing, which can be expensive,

Table 2. Effect of different concentration profiles of phosphine on the toxicity of a 10-day exposure to pupae of *Cryptolestes ferrugineus*

Concentration profile	Ct product (mg hour/L)	% mortality	Concentration at end of 10-day exposure (mg/L)
Rising to 1.7 mg/L then 75% leakage per day	66.5	75.7	0.001
Rising to 0.94 mg/L then 50% leakage per day	58.4	96.6	0.01
Rising to 0.39 mg/L then 10% leakage per day	61.5	96.7	0.12
Level concentration (<2% leakage per day)	55.9	97.1	0.23
Rising to 1.4 mg/L in first day then falling to 0.11 mg/L after 4 days	73.6	82.0	0.10
Rising to 1.4 mg/L in first day then falling to 0.09 mg/L after 7 days	74.1	96.9	0.08

or a system of repeated or continuous introduction of gas. Formulations containing aluminium phosphide supply phosphine gas over a 1–3 day period, depending on temperature and availability of moisture. Under leaky conditions these generation times are too short to provide an effective exposure and insufficient to distribute gas throughout the bulk. Repeated application is unlikely to solve the problem of excessive leakage unless performed almost daily.

Promising results have been obtained in wheat–filled bins up to 175 tonnes capacity using a 2–3% mixture of phosphine in carbon dioxide, supplied from gas cylinders. After sheeting the grain surface, 5 g phosphine per tonne was applied within half an hour to the base of each bin via a copper pipe inserted into the aeration system. The gas was evenly distributed within 12 hours. Twenty–four hours later, concentrations in the bins had fallen to below 0.2 mg/L. Thereafter, concentrations above 0.3 mg/L could be maintained at most points by a very low top-up rate of 30 litres of 3% (by volume) phosphine in carbon dioxide per hour. This method of dosing has considerable potential for wider use in the U.K.