

The control of mites with fumigation

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Abstract

Phosphine is the most widely used chemical for controlling insects in stored grain. However, earlier laboratory trials and the perception of the industry suggests it is less suitable for mite control because the egg stage will survive even at high doses. In addition, mites tend to develop in cool, damp conditions, neither of which are likely to favour the efficacy of phosphine. This work set out to re-assess phosphine and methyl bromide against mites and, having shown that complete control of at least some species of store product mites could be obtained under certain conditions, to examine the dosage rates and exposure periods needed for successful, commercial treatments using phosphine.

Initial trials done on field population of mites in wheat at 16% moisture and about 10°C, showed that all stages of *Acarus siro*, including eggs, could be controlled by doses of 2.5g/m³ phosphine and exposure period of at least 8 days. Later, more refined testing showed that the minimum dose to give complete control in 6 days was 2g/m³ but there were some survivors when the dose was reduced to 1mg/m³. Similar results were obtained in both wheat and oilseed rape. Small numbers of *Glycyphagus destruor* and *Cheyletus eruditus* also present were controlled.

As result of these trials, it has been possible to draw up a dosage schedule using phosphine for commercial treatments against mites in a range of commodities.

Introduction

Stored products mites are the most common pests in farm-stored grain (Griffiths, et al., 1976; Prickett & Muggleton, 1991) and, when present in detectable numbers, are unacceptable to many end users such as millers or maltsters. There are three main genera of pest mites that are endemic in the UK, so all grain is at risk. Mites will also attack a wide range of other proteinaceous and farinaceous foods.

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These include, flour, biscuits, breakfast cereals, dried milk powder, cheese, nuts, cattle feed and pet food (Wilkin, 1982; Anon, 1996). The latter survey by the Ministry of Agriculture, Fisheries and Food showed that mites were found regularly in samples of domestic foodstuffs collected from retail outlets. Other surveys have found different species of the same group of mites infesting dried fruits (Fleurat-Lessard, 1975).

The presence of mites in food can cause direct damage such as the consumption of the material, the reduction in its food value (Wilkin, et al., 1987) and reduce the commercial value of commodities such as grain. However, another important problem associated with mite infestation is that many of the storage pests are powerful allergens and will trigger allergic reactions in man (Hansen & Nielsen, 1996).

The Astigmatid pest mites that attack grain and other stored foods are well adapted to the conditions found during storage particularly in temperate climates. Many species will increase in numbers provided the relative humidity is above 65% (equivalent to a grain moisture content of about 14.5%) and the temperature is above 5°C. However, optimum development occurs at higher humidities and about 25°C. Under these conditions they have the potential to increase by 5–7 times per week, depending on the species (Cunnington, 1965).

As a result of the widespread occurrence of mites, considerable effort has been made to develop effective control measures for use during storage. Reducing the moisture content of grain or other products so that the intergranular relative humidity is lower than 65% will arrest mite development. However, drying grain to this level is expensive, require the input of energy and, in any case, may not be practical for some other foodstuffs. Also, during the winter months the surface layers of a bulk of grain or even bagged goods can re-absorb water from the air and become sufficiently damp to support serious, local mite infestations. The application of pesticides can also be effective in controlling mites (Wilkin, 1974; Stables, 1980). However, work done in the UK has shown that all key pest species have developed high levels of resistance to all chemicals currently available to treat grain (Starzewski, 1991). The direct application of contact pesticides to most other foodstuffs is not permitted.

Fumigation, usually with phosphine, is commonly used to control insects infesting grain but laboratory tests by Amrao

(1959) and Bowley & Bell (1981) suggests that the eggs of mites are extremely tolerant to both methyl bromide and phosphine. As these are the only chemicals that are widely used for treating grain and foodstuffs, fumigation, particularly with phosphine is not regarded as an effective option against mites unless two fumigations are done sufficiently separated to allow all eggs to have hatched (Anon, 1993). However, there are no published data of field assessments to validate this theory.

Background to Experiments

This work was done with the aim of simulating practical conditions likely to be met in the UK as closely as possible and producing results that could be used to determine the commercial potential for using fumigation to control mites. Two main experiments were done. The first set out to establish if mites could be controlled under the most favorable gas concentrations achievable during a practical fumigation. This work was done with both phosphine and methyl bromide. A further experiment was then done to explore a range of doses but using only phosphine.

First Experiment

Materials and methods

Materials

A supply of wheat infested with a mixed population of mites was located at a farm grain store. The grain was checked in situ and found to contain several thousand mites/kg, principally *Acarus* sp but also some *Glycyphagus* sp and *Cheyletus* sp.

Cylindrical plastic bins, 87 litres capacity and with well-fitting lids were used as experimental containers. Twenty-kg lots of wheat were shovelled into each bin which occupied about one third of the available space. The filled bins were taken back to a test room that was maintained at about 10°C, placed on pallets and left to equilibrate for 7 days. An external band of sticky material was applied to each bin to minimize the risk of mites entering or leaving the grain.

Application of the fumigants

Phosphine was generated from Degesch, 0.6g aluminium phosphide pellets each of which releases 0.2g of phosphine. The pellets were introduced to the bins in small wooden containers, placed on a ledge well above the surface of the grain. Immediately after the pellets were added to each bin, the lid was replaced and sealed with plastic adhesive tape. The spent residues after the gas had been generated were retained in the container for removal at the end of the exposure period. Three dosage rates of 1, 2 and 4 pellets/bin were used giving theoretical doses of 2.5, 5 and 10g of phosphine/m³. Two exposure periods, 8 and 16 days, were used at each dosage rate.

Methyl bromide was applied as a cold liquid (taken from a freezer at -16°C) using a syringe. An evaporator containing a pre-heated metal heat sink, was placed on the ledge in the bin, the lid replaced and sealed with tape. The required amount of methyl bromide was then dribbled onto the evaporator through a tube inserted in the lid of the bin. This tube was then sealed. A single dose of 20 g/m³ was used with an exposure period of 48 hours. Each treated bin was equipped with a small, battery powered fan mounted on a perforated tube pushed into the grain to aid gas circulation.

Three replicate bins, selected at random, were used for each fumigant/dose/exposure period combination, together with six, untreated control bins.

Measurement of gas concentrations

Two gas sampling lines were installed in selected bins. One line was placed in the head-space and the other below the surface of the grain. Each line was protected by a dust filter. Six bins treated with phosphine and one bin treated with methyl bromide were monitored for gas concentrations. The gas concentration in one control bin from both fumigations was also monitored.

Gas samples were drawn through one sampling line by pump via the measuring cell and then returned to the bin via the second line. In the case of phosphine a CITICELL, electro-chemical sensor with an accuracy of $\pm 2\%$ of FSD and a response time of less than 15 seconds was used. For methyl bromide a GOW-MAC 30S-4, thermal conductivity cell was used with an accuracy of $\pm 0.01\%$ and a response time of less than 15 seconds.

Conditions of exposure

The temperature in the room was monitored at three positions almost every day using remote sensors. The temperature in the grain in three bins treated with phosphine, one bin treated with methyl bromide and two control bins was checked in the same way.

The moisture content of the grain in each bin was measured before treatment and at the end of the exposure period, by testing samples in a Sinar 6060 moisture meter.

Assessment of mite populations

Mite populations were monitored using the method described by Wilkin and Hope (1979). Three 250g samples of grain were collected from each bin using a volumetric scoop. The samples were sieved over a 0.7mm mesh and the sievings examined using a low-power (X20) binocular microscope. The number of live mites in each sample was counted and identified to genus. Selected individuals from each genus were mounted on slides and identified to species.

An assessment of the mite population was done before treatment, at the end of each of the exposure periods and then 14 and 21 days after the end of the exposure period. These post-exposure periods were calculated using data from Cunnington (1985) to predict the maximum duration of the

egg stage at 10°C.

Results

Both fumigants were applied without difficulty. The sealing of the bins appeared good as no gas could be detected in the room or in the control bins.

Assessment of gas concentrations-Methyl bromide

The measured gas concentration over time in the grain (bottom) and the head-space (top) of the bins are given in

Fig. 1. The Concentration Time Products (CTPs) calculated from these concentrations are shown in Table 1. The initial aim had been to achieve a CT of about 600g h/m³, as suggested by Anon (1993) to give complete control of eggs, but a range of between 500 to 750g h/m³ was measured. The differences between replicates can be attributed to the difficulty of measuring the small volume of liquid methyl bromide needed to dose each bin. After 48 hours, the lids were removed from the bins to allow airing. The lids were replaced when no further methyl bromide could be detected.

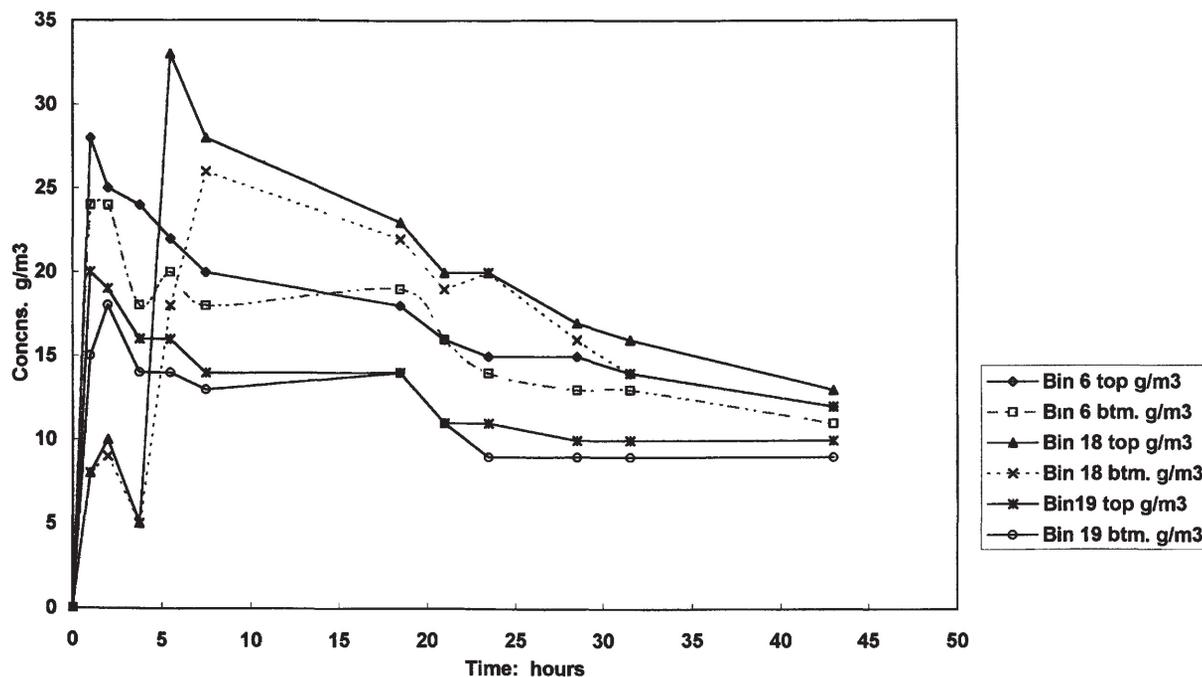


Fig. 1. CT curves: Methyl bromide; 23.5g/m³ dosage, 48 hrs exposure in bins of wheat

Table 1. CTPs obtained on the surface and at the bottom of 20kg of wheat, fumigated with MeBr for 48hrs at 20g/m³.

Bin no	CTPs: Top g h/m ³	CTPs: Bottom g h/m ³
6	743	721
18	837	744
19	640	495

The theoretical CT for the empty 87 litre bins, given a dose of 20g/m³, is 860g h/m³. However, taking the volume occupied by the 20kg of grain into account reduces the free-space so that the theoretical CT rises to 1025g h/m³. The

apparent loss of methyl bromide suggested by the measured gas concentrations may be attributable to sorption of the gas onto the grain. In practice, doses are usually calculated on the basis of the Tables issued in EPPO Bulletins (Anon, 1993a). These take into account the amount and type of commodity and its density.

Phosphine

When the exposure period was completed, the bins were aired by opening the lids and the spent residues of the aluminium phosphide were removed.

The results from the bins in which concentration of gas was measured are shown in Fig. 2. The CTPs calculated from these concentrations in bins treated with 1 or 4 pellets are shown in Table 2.

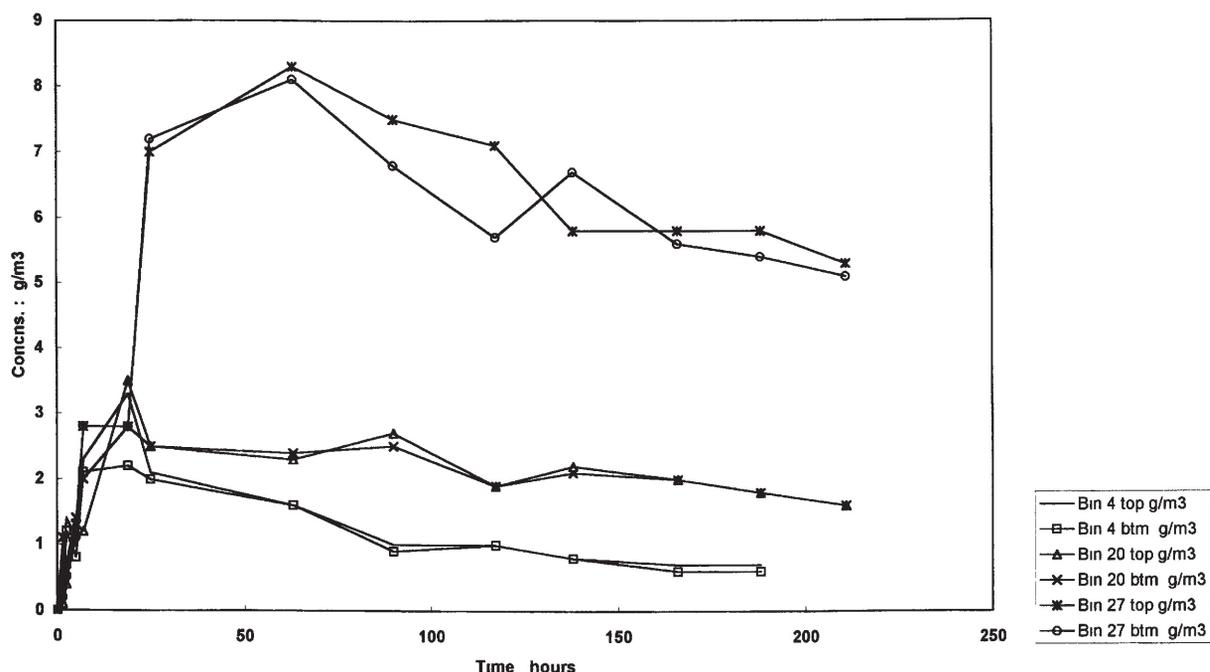


Fig.2. CT Curves: Phosphine: 8 days exposure in bins of wheat

Table 2. CTPs obtained in wheat fumigated with phosphine at different doses and exposure periods

Dose: Pellets	Exp. time(days)	CTPs: g h/m ³
4	16	1206
4	8	1300
2	16	600
2	16	664
2	8	450
1	16	334
1	8	240

The theoretical gas concentrations in the bins should have reached a maximum of 2.74, 5.48 and 10.96 g/m³, assuming that each pellet released 0.2 g of phosphine. In practice, only 43 to 62% of the theoretical CTPs were achieved, with the longer exposure giving the lower percentages. This was probably caused by phosphine being adsorbed onto the damp grain. There will also have been some breakdown of phosphine because of the high relative humidity in the intergranular spaces (>75%).

Temperatures and moisture contents

The mean temperature for the room and the grain treated with methyl bromide and phosphine, are shown graphically in Fig. 3. The temperature of the grain remained close to 10°C throughout the period when the grain was exposed to the fumigants. However, it rose a little during the post-fumigation period for the grain treated with phosphine.

The moisture content of the grain at the start of the trial was about 16.5% with extremes of 16.1 – 17.4%. The

mean and range remained largely unchanged throughout the experiment and the lowest value recorded of 15.9% was still well above the minimum moisture content required for mite development in wheat at about 10°C.

Assessment of mites

All pre-treatment samples contained live mites with a range of about 1500 to 5000 mites/kg. The variation is not surprising because of the random way the grain was collected from a large bulk at a farm grain store. The most common species was *Acarus siro* with smaller numbers of *Glycyphagus destructor*. There were also a few individuals of the predatory mite *Cheyletus* sp, Gamasids and *Tydeus* sp.

Following the treatment with methyl bromide immediately after the 48hr exposure period, no live (moving) mites could be found. Assessments done 14 and 21 days after the end of the exposure period also yielded no live mites. The dead, motile stages shrivelled and became almost unrecognisable. However, a few eggs still appeared normal even at the last assessment.

Numbers of live mites in the control samples remained largely the same as the pre-treatment assessment, although by the end of the 21 days post-treatment period, many larvae and nymphs were apparent.

No live mites were found in any of the grain treated with phosphine at any dose at the end of either exposure period. When the grain was re-assessed 14 and 21 days later, no signs of live mites were found with one exception. One live *Acarus* larva was found in a sample 21 days after the end of the exposure period in the lowest dose exposed for 8 days.

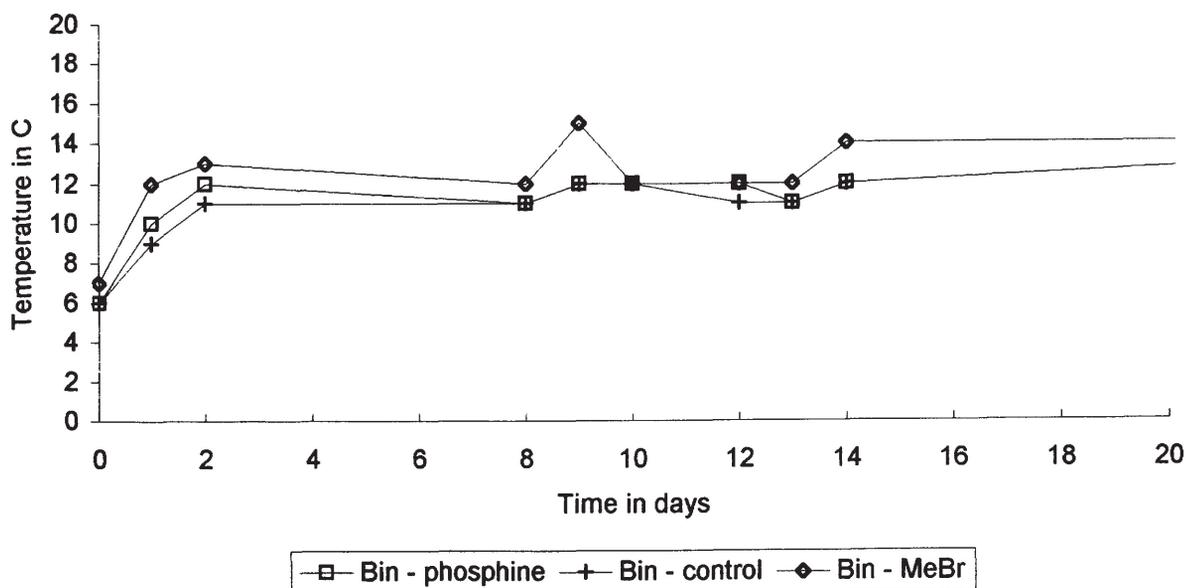


Fig. 3. Temperatures in selected bins measured during the trial

The numbers of live mites in the controls remained about the same at the pre-treatment level. As an additional check, grain treated with phosphine at the lowest dose was re-examined after a further 14 days. No live mites of any stage were found and no eggs of normal appearance could be seen. However, the numbers of live mites in the controls still remained high.

Second Experiment

About a year after the first experiments had been completed, a further trial was done but using phosphine only. This work was intended to produce a dose response and provide data to allow a commercial treatment schedule to be drawn up with confidence. Much of the experimental detail remained the same as the first experiment but efforts were made to collect more information, make some minor improvements to the methodology and to reduce work load where this could be done without compromising the work.

Materials and methods

These trials largely followed the materials and methods as set out in the first experiment given in 3 above. The same bins and exposure room were used and the work was done at about 10°C. The main differences were in the method of generating phosphine and the monitoring of gas concentrations in all bins. Mite-infested wheat from the same farm store but from the next harvest was used and a supply of infested oilseed rape (OSR) was also collected from the same store.

The phosphine was generated from Degesch aluminium

phosphide pellets that were first ground in a pestle and mortar and then the ground powder was weighed out using an electronic balance accurate to 0.001g. The weighed aliquots of aluminium phosphide powder were placed in small paper cups that were transferred rapidly to the bins. Immediately, after the aluminium phosphide was placed in the bin, the lid was sealed with plastic adhesive tape. The whole operation was carried out with speed to minimise the generation of phosphine before the bins were sealed.

Three dosage rates were used for the cereal grain: 1, 2 and 3g/m³ and doses of 2 and 3g/m³ were used to treat the OSR. In addition, three empty bins were treated with phosphine at 2g/m³. Three bins of OSR and three of wheat were left untreated to act as controls.

Three exposure periods were used for the wheat: 2, 6 and 12 days. The OSR and empty bins were exposed for 12 days.

During the first attempt to set up this experiment problems were encountered with the equipment used to monitor phosphine. These were sufficiently serious to cause the abandonment of the trial. However, it was possible to make use of the data for the 2-day exposures.

Following the failure of the gas monitoring equipment after 2 days, the trial was abandoned. The bins of grain were returned to the grain store, emptied and then refilled from the same point in the grain bulk as used in the first attempt. The bins of oilseed were also emptied and refilled. This grain was allowed to stand for 8 days before being assessed for live mites and then re-treated with aluminium phosphide powder as described earlier. However, as the biological results from the 2-day exposure were available, it was not considered necessary to repeat this exposure period.

Experience gained during the first attempt, resulted in modifications to the method of gas monitoring. A system was developed to purge the gas sampling line without loss of gas and minimising the exposure of the sensor cell to phosphine. In addition, gas concentration were measured only at the bottom of each bin as earlier data had shown little difference in gas concentrations between the free space above the grain and samples drawn from the intergranular space.

In the first, aborted trial, the post-treatment counts were minimised because of the limitations of the gas monitoring. Only the upper and lower doses applied to wheat were assessed for live mites at the end of the 2-day exposure period. However, all bins of wheat from this exposure period were retained for a post treatment assessment that was done after a further 23 days

Results

During the aborted test, initial measurements showed that phosphine concentrations appeared to follow the theoretical rate of gas production. Unfortunately, by the second day, the readings obtained with the meter became erratic. The decision was therefore taken to abandon the trial. However, the effect on the mite population of the 2-day exposure was assessed. Samples from the high and low doses were assessed for mites in the normal manner. These results and the moisture content of the grain are given in Table 3. The heavy, pre-treatment infestation was reduced to a very low level after 2 days exposure to phosphine but a small numbers of survivors (better than 99% control), consisting of all motile stages were found. Only the low and high doses were counted but there was no clear indication of a dose response. Counts done 23 days after the end of the exposure period showed that the mite population had recovered to about 15% of the original level but that the majority of the mites were larvae.

The replacement grain used in the second experiment was also heavily infested with mites and when assessed 2 days before treatment, the mean level of infestation was about 5000/kg, with maximum of about 17,000/kg and a minimum of about 3000/kg. Almost all the mites were *Acarus* sp with a few individuals of *Glycyphagus* and *Cheyletus* spp. The moisture content of the wheat was about 15.6%.

When the mites were assessed at the end of the 6 and 12-day exposure period, all motile stages were dead in all three doses so that 100% control was achieved. The infestation in the control bins remained at about the same level as before treatment. Counts done 21 days after the end of the 6-day exposure period revealed no live mites in the wheat treated at 2 or 3g/m³. However, very small numbers of larvae (< 20 mites/kg) were in wheat treated at 1g/m³. Counts done 21 days after the end of the 12-day exposure period produced

no live mites at any of the doses. The control infestation was, in general higher at the end of the trial than in the pre-treatment counts.

Table 3. Mite/kg in samples of wheat collected from bins treated with 1, 2 or 3g/cu m phosphine and exposed for 48 hours. Each result is the mean of 3 samples taken from each of three replicate bins.

Time in days	Dose g/cu m	Number of live mites/kg	Moisture content %
	1	6847	15.9
- 2	2	9784	15.9
	3	6954	16
2	1	21	15.6
(end of exposure period)	2	*	*
	3	13	15.3
25	1	1088	15.6
(23 days after end of exposure period)	2	1077	15.7
	3	466	15.9

* Assessment not done

Before treatment the oilseed was infested with a mean number of mites of about 5000/kg and had a mean moisture content of about 8.6%, as determined with an electric moisture meter. The infestation was composed of the same species as found in the wheat. After 12 days exposure to phosphine, all motile mites were dead but the mites in the controls remained at about the pre-treatment levels. A further assessment, 21 days after the end of the exposure period, showed no live mites except for one bin treated at 2g/m³ in which a number of larvae were found. The gas concentrations in this bin were much lower than the other two replicates treated at that dose.

The temperatures in one bin of wheat, one bin of oilseed and in the room, during the second phase of the experiment are given in Fig. 4. These show that the temperature fluctuated because of outside variations but remained close to 10°C. The grain or oilseed had a buffering effect on temperature so that there was less fluctuation in the bins.

The gas concentrations measured in the bins are given graphically in Figs. 5, 6 & 7. The final CTPs achieved are given in Table 4. The results of the gas monitoring show that, in some cases, there was variation between the three replicates of each dose/time/commodity combination. This variation generally took the form of one bin giving lower gas concentrations than the other two. Obviously, these lower

gas concentrations were also reflected in lower final CTPs. However, the replicates of wheat treated at 1 and 2 g/m³ exposed for 6 days, and the low dose exposed for 12 days, together with the empty bins, showed little variation.

Table 4. Final CTPS obtained in bins of wheat, OSR or empty bins fumigated with phosphine.

Bin no	Commodity	Exposure	Dosage	CTPS
46	wheat	6 days	low (1g/m ³)	82 g h/m ³
19	wheat	6 days	low (1g/m ³)	60 g h/m ³
33	wheat	6 days	low (1g/m ³)	81 g h/m ³
11	wheat	6 days	med (2g/m ³)	159 g h/m ³
52	wheat	6 days	med (2g/m ³)	150 g h/m ³
8	wheat	6 days	med (2g/m ³)	169 g h/m ³
22	wheat	6 days	high (3 g/m ³)	187 g h/m ³
15	wheat	6 days	high (3 g/m ³)	246 g h/m ³
2	wheat	6 days	high (3 g/m ³)	267 g h/m ³
20	wheat	12 days	low (1g/m ³)	132 g h/m ³
36	wheat	12 days	low (1g/m ³)	144 g h/m ³
1	wheat	12 days	low (1g/m ³)	120 g h/m ³
27	wheat	12 days	med (2g/m ³)	163 g h/m ³
48	wheat	12 days	med (2g/m ³)	212 g h/m ³
23	wheat	12 days	med (2g/m ³)	256 g h/m ³
6	wheat	12 days	high (3g/m ³)	404 g h/m ³
3	wheat	12 days	high (3g/m ³)	399 g h/m ³
39	wheat	12 days	high (3g/m ³)	286 g h/m ³
49	OSR	12 days	med (2g/m ³)	200 g h/m ³
55	OSR	12 days	med (2g/m ³)	207 g h/m ³
28	OSR	12 days	med (2g/m ³)	89 g h/m ³
50	OSR	12 days	high (3g/m ³)	210 g h/m ³
26	OSR	12 days	high (3g/m ³)	286 g h/m ³
29	OSR	12 days	high (3g/m ³)	312 g h/m ³
I	empty	12 days	med (2g/m ³)	237 g h/m ³
II	empty	12 days	med (2g/m ³)	271 g h/m ³
III	empty	12 days	med (2g/m ³)	241 g h/m ³

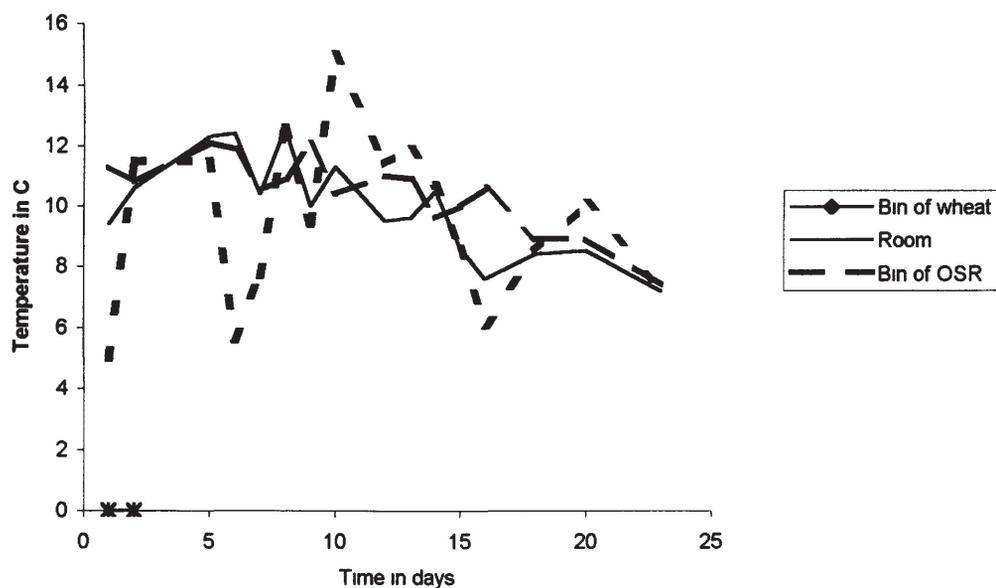


Fig. 4. Temperature in bins of wheat or OSR and exposure room.

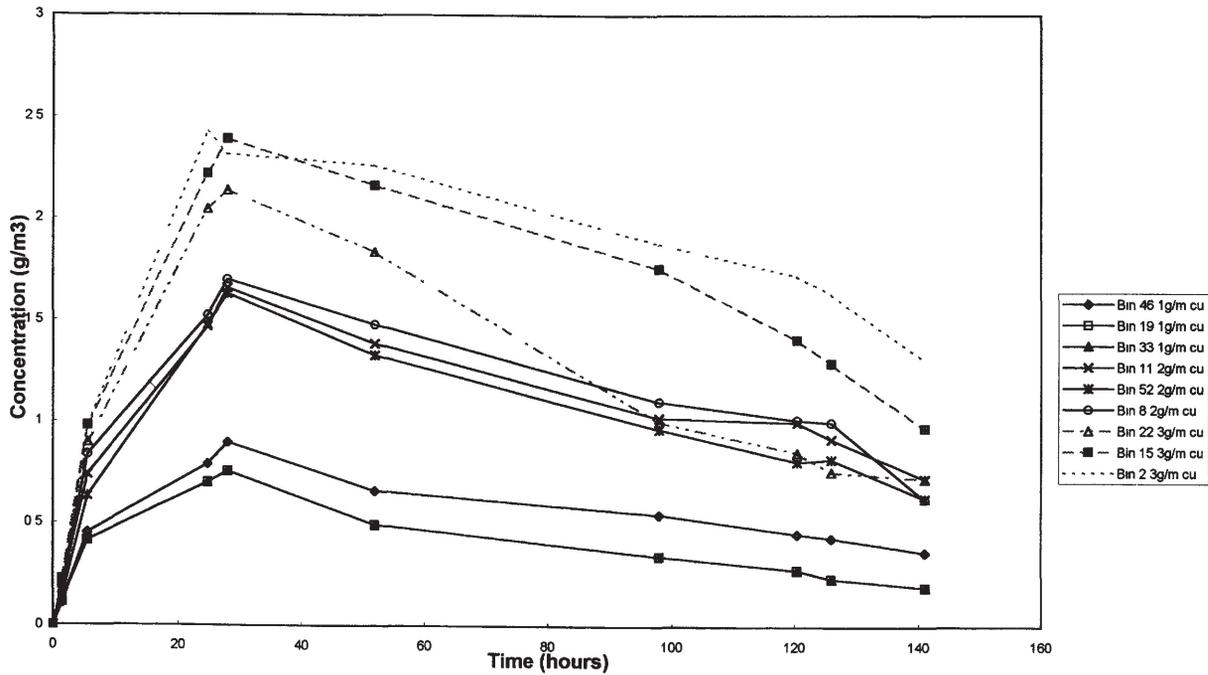


Fig. 5. Concentrations of phosphine in bins of wheat during 6 days exposure

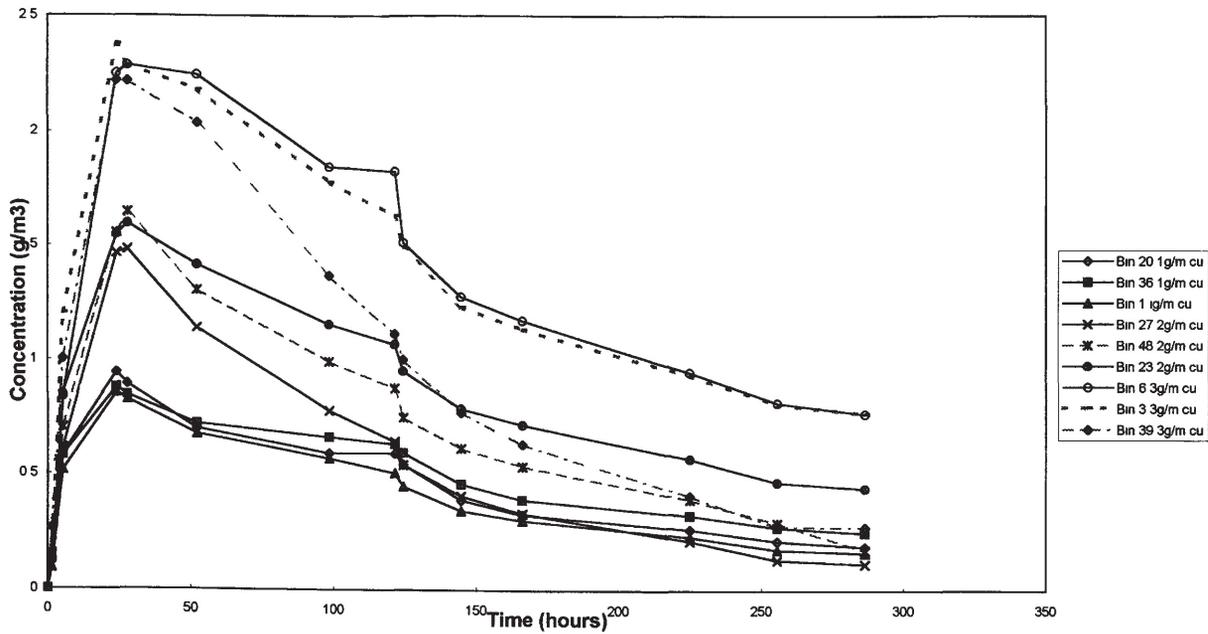


Fig. 6. Concentrations of phosphine in bins of wheat during 12 days exposure

Discussion and Conclusions

The first trials showed that high doses of phosphine or methyl bromide, coupled with correspondingly high CTPs, would give complete control of mites infesting wheat. The control of motile stages was not unexpected, as this had been achieved by other workers (Amaro, 1959; Bowley & Bell, 1981). However, no live mites were found 21 days

and, in one case, 37 days after the end of the exposure period. All information on mite biology suggests that this period far exceeded the maximum duration of the egg stage at 10°C.

The main limitation of the first trials was that, whilst the doses used were not excessive or impossible to achieve, they were several times greater than doses normally used under commercial conditions. In addition, the work gave no indication of a dose response. These limitations were

addressed in the second experiment but work with methyl bromide was not continued

During the second experiment, the rate at which phosphine was evolved at the start of the exposure period of the main trial was consistent with the predicted rate but

peak concentrations occurred after about 24 hours. This is rather more rapid than might be expected at 10°C under practical conditions and is probably a consequence of using finely ground aluminium phosphide with a very large surface area exposed to the moist air.

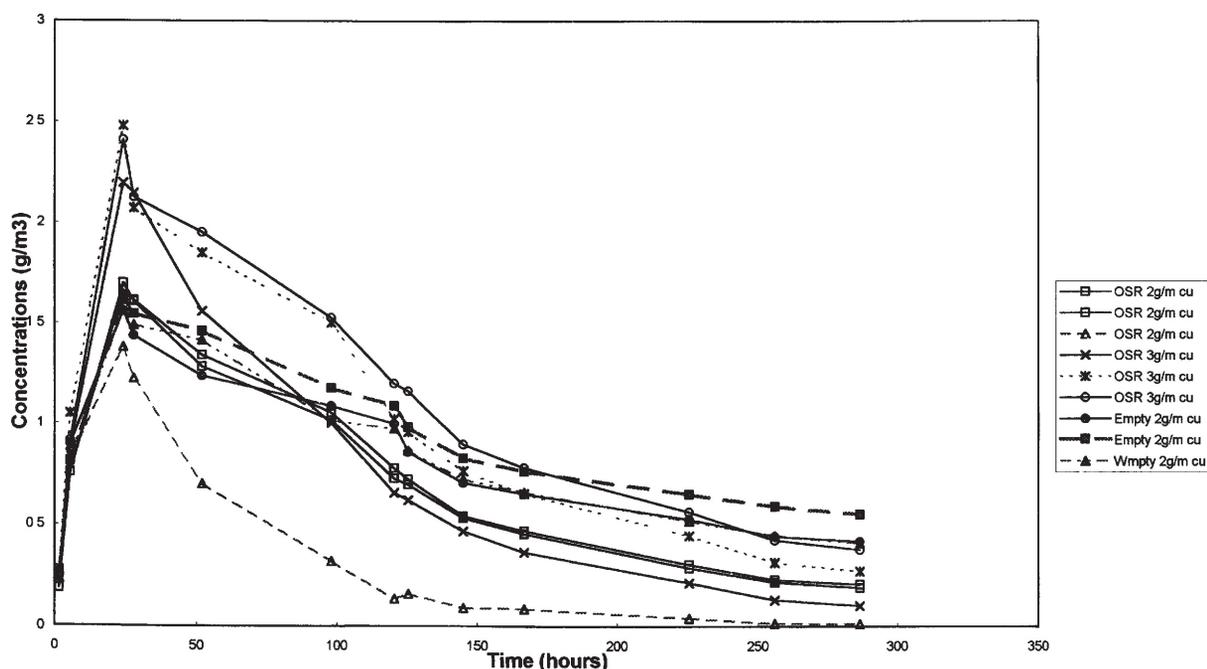


Fig. 7. Concentration of phosphine in bins of OSR and empty bins during 12 days exposure

Some differences between replicates were apparent and in several cases, differences of 30% or more between one replicate and the other two were found. In every case, this variability between replicates took the form of one bin with a lower concentration. No obvious explanation was found for this and there was no detectable leakage of phosphine from any of the bins (by smell or checking with a personal phosphine monitor). However, it is possible that some of the gas sample lines had developed minute leaks at stress points so that some air was drawn in together with the phosphine when the gas sample was sucked to the meter. Another possibility is that there was some variation in the consistency of the aluminium phosphide powder produced by grinding the pellets. In almost every case, no biological consequence of the lower gas concentrations was detected. The exception was one bin of OSR where mites survived the treatment in the bin with the lowest dose.

If the obvious outliers are ignored, certain inferences can be drawn from the gas concentrations and final CTPs. The effects of changes in dose and exposure period follow the predicted pattern but the OSR tends to yield slightly lower final CTPs than those for wheat. The final CTPs for the empty bins were slightly higher than those obtained with wheat or OSR and the gas concentration at the end of 12 days exposure were higher than with either commodity.

This would suggest that the presence of wheat or OSR influences the CTPs achieved, presumably because of sorption or enhanced breakdown of phosphine, or a combination of both. This effect is likely to be much greater in field-scale trials where the amount of commodity will be much greater in relation to the volume under gas. Dose applied during commercial treatments will have to allow for this effect.

Two days exposure to all three doses of phosphine gave almost complete kill of all motile stages of mites. However, a few mites of all stages were still alive. This must be regarded as a failure but, in commercial terms, did give extremely good control. For example, if grain is to be sold but is contaminated by mites, obtaining 99% control could be regarded as acceptable by both buyer and seller. The limitations of this short exposure was apparent when the grain was re-examined 24 days after the end of exposure, by which time a moderate mite infestation had developed. This was composed largely of larvae, suggesting that eggs were the most common stage to survive the fumigation. However, when the grain had been checked at the end of 2 days exposure, there were a few live individuals of all motile stages. There was no clear indication of a dose response either at the end of the 2-day exposure period or 24 days after the end of the exposure. Therefore, it seems unlikely

that an increase in dose would improve the effectiveness of very short exposures.

Six days exposure to 2 or 3g/m³ phosphine gave complete control of the mites in wheat. Survivors occurred with 6 days exposure to 1g/m³ in wheat and, in one bin of OSR after 12 days exposure to 2g/m³. By examining the gas concentration curves in bins where mites survived, it would seem that the initial peak concentration is of less importance than the final CTP. Therefore, if final CTPs are used as a guide of efficacy, a figure of more than 100 and preferably about 130, is needed to control mites. Once again, applying practical considerations to these results, it would seem wise to aim for a CTP of 200+ during a commercial fumigation to control mites.

The experimental technique used worked extremely well and has the advantage that the results can be extrapolated to commercial conditions. The trials showed that mite infestations in wheat or OSR can be controlled by fumigation with methyl bromide or phosphine, provided certain parameters are met. However, the bins used in these trials were extremely gas-tight and will not be representative of conditions found in grain stores, for example. Another important point when considering the commercial exploitation of these results is that the bins used were small so that gas distribution was even throughout the grain. Data from commercial fumigations in bulk grain using phosphine show clearly that distribution can be very uneven (Bell, et al., 1991). Therefore, some method of achieving even distribution is likely to be an essential component of a successful commercial fumigation against mites. Further difficulties can be expected when controlling mite in UK-stored grain because of the low temperatures commonly encountered during winter. Low temperatures generally reduce the efficacy of fumigants but control was achieved in these trials despite the test temperatures of around 10°C.

Acknowledgement

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References

- Amaro, J. J. P. 1959. Toxicity of fumigants to mites Pest Infestation Research 1959, pp33–34.
- Anon 1993 Quarantine Procedures, EPPO Bul. 23 (18), 212–214
- Anon 1963a. Quarantine Procedures, EPPO Bul. 23 (12), 207–208.
- Anon 1996 Storage mites in foodstuffs. Food Safety Information Bulletin, 78 MAFF, London.
- Bell, C. H., Chakrabarti, B. & Mills, K. A. 1993. New application methods for the use of phosphine to disinfest bulk grain Project Report No. 41. Home-grown Cereals Authority, London, UK.
- Bowley, C. R. & Bell, C. H. 1981. The toxicity of twelve fumigants to three species of mites infesting grain. J. stored Prod. Res., 17, 83–87.
- Cunnington, A. M. 1965. Physical limits for complete development of the grain mite, *Acarus siro* in relation to its world distribution. J. appl. Ecol. 2, 295–306
- Cunnington, A. M. 1985 Factors affecting oviposition and fecundity in the grain mite *Acarus siro* especially temperature and relative humidity Experimental & Applied Acarology, 1, 327–344
- Fleurat-Lessard, F. 1975. Mise au point sur les Acariens des pruneaux Conditions de developpment et de propagation de *Carpoglyphus lactis* Revue de Zoologie Agricole et de Pathologie Vegetale 74, 121–138.
- Griffiths, D. A., Wilkin, D. R., Southgate, B. J. & LYNCH, S. M. 1976 A survey of mites in bulk grain stored on farms in England and Wales. Ann. appl. Biol. 82, 1975–201.
- Hansen, L. S. & Nielsen, P. S. 1996. Health aspects due to stored product pests and possibilities of alternative methods of stored product protection. Proc. International forum Stored Product Protection pp 143–147, Council of Europe Publishing, Strasbourg.
- Prickett, A. J. & Muggleton, J. 1991. Commercial grain stores 1988/89, England and Wales Pest incidence and storage practice HGCA Project Report N. 29 Home-Grown Cereals Authority, London.
- Stables, L. M. 1980. The effectiveness of some recently developed pesticides against stored-product mites. J. stored Prod. Res. 16, 143–146
- Starzewski, J. C. 1991. The incidence of resistance to pirimiphos-methyl in stored product mites collected from commercial grain stores in the United Kingdom In Prickett & Muggleton (1991), HGCA Report No. 29.
- Wilkin, D. R. 1974 The effects of mechanical handling and the admixture of acaricides on mites in farm-stored barley. J. stored Prod. Res. 11, 87–95.
- Wilkin, D. R. & Hope, J. A. 1973 Evaluation of pesticides against stored product mites. J. stored prod. Res. 8, 323–327.