Donahaye, E.J., Navarro, S., Bell, C., Jayas, D., Noyes, R., Phillips, T.W. [Eds.] (2007) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, Gold-Coast Australia. 8-13th August 2004. FTIC Ltd. Publishing, Israel. pp. 477-484

STUDIES OF PHOSPHINE AS A FUMIGANT FOR DRIED FRUIT UNDER TARPAULIN COVERS

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ABSTRACT

The purpose of the study was to evaluate the use of phosphine (FUMI-CEL™, a magnesium phosphide formulation) to control dried fig pests in stacks under tarpaulin covers. Three stacks built-up with perforated plastic boxes were prepared for about 50 tons of dried figs. The stacks were covered with tarps which were sealed with sand-snakes to the concrete floor. The stacks were dosed at 1, 2, and 3 g PH_3/tonne and the fumigations continued for 7 days at prevailing temperatures during the dried fig harvesting season in the Aegean region of Turkey. Trials were also repeated in the cold season. The fumigations were conducted at the dried fig processing and storage facility of TARIS to test their effectiveness against *Ephestia cautella* (eggs, larvae, and pupae), *Carpoglyphus lactis* (mixed stages) and *Oryzaephilus surinamensis* (eggs, larvae, pupae and adults). Test insects were retrieved from the stacks on a daily basis after 3 days of fumigations. During the trials, gas concentrations were monitored by an analyzer equipped with an electrochemical detector from different locations within the stacks and temperatures were recorded inside the stacks using T-type thermocouples (Hobo®). All insect bio-assays were retained for two weeks after removal from the stacks. Complete insect mortality of the test insects and mites was achieved after three days of exposure. The trials demonstrated that phosphine holds promise as a replacement for methyl bromide fumigations against the dried fruit pests.

INTRODUCTION

Turkish edible nuts and dried fruit production is high and dominates the world markets in this respect. Turkey is the most important dried fig producing and exporting country, with a production amounting to some 50.000 tonnes annually, comprising from 50 to 55% of the international market. Besides dried figs, Turkey is known as the largest exporter of hazelnuts, supplying about 85 percent of the world hazelnut trade. In addition, more than 50% of the world's dried apricot and raisin production are supplied by Turkey. Several species of moths, beetles and mites are very common pests of dried fruit. These species live on a variety of dried fruits ranging from dried figs, raisins, dried apricots and hazelnuts.

In spite of the advances recorded in many aspects of stored product pest control, fumigation being a nonresidual chemical treatment has remained the mainstay for control of stored product insects. The dried fruit industry in Turkey has used methyl bromide (MBr) for many years for the fumigation of processed or unprocessed dried fruits to control insect infestations. MBr was used extensively in the dried fruit industry mainly because of the short exposure time required. However, the use of MBr has been banned in the post harvest sector of Turkey since 2004. Today, the only chemical alternative to MBr available in Turkey is phosphine. Phosphine is a proven major tool used world-wide in the protection of food, seed and feed stocks against insect pests in storage, including commodities, structures, containers, chambers, and stacks under tarpaulins. Phosphine is characterised as a slow acting fumigant to which insects can develop resistance. However, fumigation studies, involving phosphine on dried fruits in Turkey have been limited so far. Thus, the aim of this study was to determine the exposure times needed to give complete control of the main pests of dried figs fumigated with FUMI-CEL^{TM}, a magnesium phosphide formulation in stacks under tarpaulin covers.

MATERIALS AND METHODS

The fumigation trials were carried out on dried figs in the Aegean region of Turkey. In the first trial, fumigation was carried out at the beginning of the harvesting and processing season (October), during which time, ambient temperatures were around 25-30°C. The second trial was carried out in the region during a relatively cold season of the year (November) when the ambient temperatures were around 20-25°C. In each season fumigations were repeated twice.

Three stacks of dried figs, in perforated plastic boxes, were constructed at the dried fig processing and storage facility of TARIS. Stack contained approximately 55 tonnes of dried figs. Each stack was built in a similar way, but fumigations were carried out at dosages of 1, 2 and 3 g PH3/tonne for 7 days of exposure. Before dosing, test insects (Table 1) in plastic vials were placed in a perforated plastic box of naturally infested dried fig samples (25-30 kg). There were 5 boxes containing test insects for each stack. These boxes were placed 2 m away from each other at the opposite site of the fumigant introduction location. The stacks were covered with tarpaulins. Before use, the covers were checked against daylight for pinhole damage, and other defects. Any holes if present were sealed with adhesive tape. The tarpaulin covers were pressed to the concrete floor with sand-snakes. Nylon tubing, 3 mm i.d., was inserted into each stack through small holes in one side of the sheeting at points close to the location of the test insect boxes. The tubing was plugged with plastic stopcocks. The required amounts of fumigant plate (FUMI-CELTM) were weighed and inserted in a gap between the boxes for each stack. Immediately afterwards , the tarp covers were sealed with sand-snakes. Gas concentrations in the stacks were monitored during the 7 days of fumigation using a Bedfont phosphine monitor (measuring range 0–2000 ppm).

At the end of 3, 4, 5, 6 and 7 days of exposure, each stack's tarpaulin cover was carefully opened and the test insects contained in the plastic box were retrieved. After retrieval of the dried fig box, the tarp cover was closed with sand-snakes. All laboratory insects (active stages) in the perforated plastic vials were retained for two weeks under laboratory conditions, while eggs and pupae were retained for 10 days and then checked for mortality. In addition, a perforated plastic box of dried figs (25-30 kg) for each exposure period and concentration was completely wrapped using shrink-film to protect it from the risk of outside infestation. These boxes were kept for two weeks for observations on adult emergence of natural insect survivors inside the boxes. If any live insects were found among the test insects or in the naturally infested dried-fig boxes, the fumigation at this exposure period was regarded as having failed.

TABLE 1

The number and age of test insect species at the stages used for testing their mortality rates

Species	**Stage**	**Age (d) ***	**Number per replicate**
Ephestia cautella (1) *Oryzaephilus surinamensis* (2)	Eggs	0-3	100
	Larvae	18-20 (1) 14-16 (2)	100
	Pupae	0-3	50
	Adults	1-2 (1) 7-14 (2)	50
Carpophylus hemipterus *Carpoglyphus lactis*	Mixed	Mixed	Uncounted

* age for larvae from egg stage; adults from emergence

RESULTS AND DISCUSSION

Upon exposure to air, FUMI-CEL^{TM}, a magnesium phosphide formulation, begins to react with atmospheric moisture to produce phosphine gas. This reaction starts slowly, gradually accelerates and then tapers off again as the magnesium phosphide is spent. Rates of decomposition will vary depending upon moisture and temperature conditions. Magnesium phosphide formulations release phosphine more completely and more rapidly at temperatures below 20ºC as compared to aluminium phosphide. Average phosphine concentrations recorded in the stacks are given in Figures 1 and 2. The temperatures during the first fumigation trials at the beginning of the harvesting and processing season (October) ranged from 25 to 30ºC. The second trial was carried out at a relatively cold season of the year (November) in the region, when ambient temperatures were around 20-25ºC. The recorded gas concentration values were plotted against the exposure period for both periods. Regardless of phosphine dosage it can be seen in the first fumigation trials that concentrations built up to a maximum within 24 h of the treatment as the gas evolved from the solid formulation (Figure 1). Due to the high moisture content of the dried-figs (~20-23%) at the beginning of the harvesting and processing season, the peak concentration was noticed at the end of the first day of exposure. However, in the second fumigation trials concentrations built up to a maximum within 72 h of the treatment as gas evolved from the solid formulation regardless of phosphine dosage (Figure 2). It has been established that the evolution of phosphine from aluminium phosphide tablet preparations is dependent on temperature and humidity in the enclosure or the moisture content of the commodity (Banks, 1991; Ducom and Bourges, 1993). Rajendran and Muralidharan (2001) stated that retention of phosphine during bag-stack treatment of paddy rice is influenced by the moisture contents of the product. In our tests, distribution of phosphine gas was generally not a problem in the stack treatments.

The decay in phosphine concentration in the stacks was slow and this trend is clearly seen in the graphs (Figure 1 and 2). The retention of phosphine gas during fumigation of dried-figs in the stack was high enough for effective fumigation. In fumigation of stored products, the decay in gas concentration has been attributed predominantly to (i) sorption of the fumigant by the commodity and (ii) leakage of the gas. Degree of sorption is determined by the chemical composition of the commodity, water activity and particle size (Banks, 1993; Annis, 1990). In the present study gas loss can be attributed predominantly to sorption of the fumigant by the commodity, but further research is needed to study sorption of dried fruits.

In the present trials, no live stages of test insects were detected for the all exposure periods at the beginning of the harvesting and processing season (Table 2). In addition to the test insects, no active insects were found in the samples of dried figs after fumigation. Thus, complete mortality of insects was observed at the end of 3 days of exposure in the stacks at the three phosphine gas concentrations. On the other hand, live stages of test insects were detected after 3 and 4 days of exposure periods during the relatively cold season of the year. Consequently, for the late season, complete control of insects was only realized in fumigations with 5, 6, and 7 days of exposure periods at the three gas concentrations (Table 2). In addition to the test insects, no active insects were found in the samples of dried figs after fumigations at 5, 6, and 7 days exposure periods.

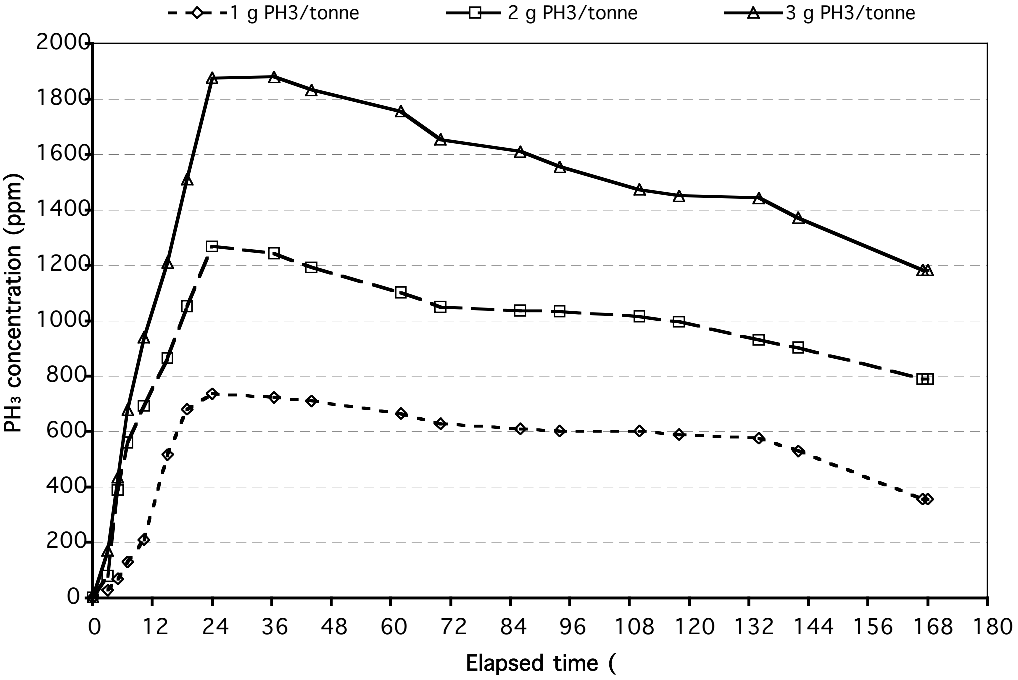

Figure 1. Phosphine concentration during 7 days of stack fumigation of dried figs under tarpaulin, carried out during the harvesting and processing season (October) in which ambient temperatures were around 25-30°C

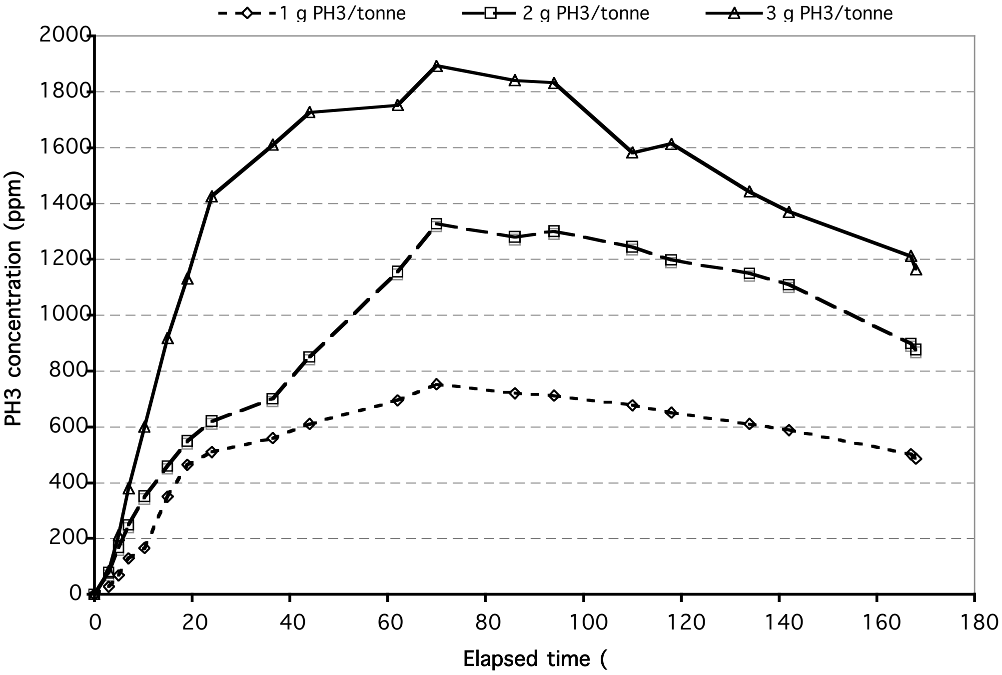

Figure 2. Phosphine concentration during 7 days of stack fumigation of dried figs under tarpaulin, carried out in the relatively cold season of the year (November) when the ambient temperatures were around 20-25°C.

From our fumigation trials, we found that an application rate of 1 g PH_3/ton during 3 days exposure at the beginning of the harvesting and processing season was sufficient to control dried fruit pests in the Aegean region of Turkey. Several published reports document an increased mortality of stored-product beetles when exposed to fumigants at high temperatures. Because the gaseous fumigants are mainly absorbed by the exposed insects through their respiratory systems, factors that influence their respiratory activity, for example changes in temperature, could also affect the uptake of a fumigant (May, 1989). The toxicity of phosphine to insects has been shown to increase with a rise in temperature (Sato *et al.*, 1973), probably due to an increase in metabolic rate and oxygen consumption that also stimulates uptake of the fumigant. Thus, a decrease in respiration rate at low temperatures, and a consequent decrease in the uptake of a fumigant, could jeopardize the effectiveness of a fumigation operation. So, we found that three days of exposure were not sufficient to control the dried fruit pests during the relatively cold season of the year and at least five days exposure were needed to obtain complete control. Storage of grain in bag-stacks fumigated with phosphine under gas-proof covers or sheets is commonly practiced in the tropics (Taylor and Gudrups, 1996; van S. Graver, 1990). Phosphine fumigation of dried fruit under tarpaulins may also be the easiest way for processors to control stored-product insects in the Aegean region of Turkey. Because phosphine is characterised as a slow acting fumigant, the duration of a lethal concentration is the most important factor. Consequently, longer exposure periods should result in better control of the stored-product pests.

TABLE 2
Mortality records of test individuals over different exposure periods.

		Complete mortality (C) Fumigation failed (F)				
		Exposure time (d)				
	Concentration (g PH_3/tonne)	**3**	**4**	**5**	**6**	**7**
First trial (in harvesting and processing season (October) in which ambient temperature was around 25-30°C)	1	C	C	C	C	C
	2	C	C	C	C	C
	3	C	C	C	C	C
Second trial (in relatively cold season of the year (November) in the region where the ambient temperature was around 20-25°C)	1	F	F	C	C	C
	2	F	F	C	C	C
	3	F	F	C	C	C

ACKNOWLEDGEMENTS

This study was partially supported through the projects entitled entitled “Project to Phase-Out Methyl Bromide in the Dried Fig Sector in Turkey (TTGV-P2/30m)” funded by the World Bank through the Multilateral Funds for the Implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer; and by “Reduction of MBr emission on the fumigation of dried fruits and development of an alternative fumigation method (TUBITAK-TARP 2274)” funded by The Scientific and Technical Research Council of Turkey (TUBITAK).

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