

# Effect of fumigation temperature on the efficacy of phosphine against strongly resistant psocids *Liposcelis bostrychophila* (Psocoptera: Liposcelididae)

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## Abstract

Species of *Liposcelis* psocids have emerged as major pests of stored grain in Australia in recent years. Several populations have been detected with high resistance to phosphine, the major chemical treatment. Highest resistance has been detected in the cosmopolitan species *Liposcelis bostrychophila*. As part of a national resistance management strategy to maintain the viability of phosphine, we are developing minimum effective dosage regimes (concentration × time) required to control all life stages of resistant *L. bostrychophila* at a range of grain temperatures. Four concentrations of phosphine, 0.1, 0.17, 0.3 and 1 mg/L, were evaluated for their effectiveness against strongly resistant *L. bostrychophila* at a series of fumigation temperatures: 20, 25, 30 and 35°C. Results were recorded as the least number of days taken to achieve population extinction. We found that, at any fixed concentration of phosphine, time to population extinction decreased as fumigation temperature increased from 20 to 30°C. For example, at 0.1 mg/L, it took more than 14 days at 20°C to completely control these insects, whereas at 30°C it took only seven days. Increase in fumigation temperature from 25°C to 30°C dramatically reduced the exposure period needed to achieve population extinction of resistant psocids. For example, a dose of 0.17 mg/L over six days at 30°C completely controlled strongly resistant *L. bostrychophila* populations that can survive at 1 mg/L and 25°C over the same exposure period. Findings from our study will be used to formulate recommendations for registered dosage rates and fumigation periods for use in Australia.

## Introduction

In Australia, phosphine is used to disinfest up to 80% of stored grain. A national resistance management strategy has been adopted by the grain industry to protect and enhance the longevity of this important fumigant (Collins, 1998; Collins et al., 2000). Over the past decade, several species of liposcelidid psocids have established themselves as major pests in Australian stored-produce ecosystems and recently we have detected resistance to phosphine in these pests (Nayak et al., 2002). Numerous populations of the cosmopolitan species *Liposcelis bostrychophila* Bandonnel, collected both from farms and from central storages in different parts of Australia, have been shown to have the

strongest level of resistance to phosphine of any psocid species (Nayak et al., 2002). We found that resistance in this psocid pest was stronger than that detected earlier in the major beetle pest *Rhyzopertha dominica* (F. Collins, 1998; Nayak et al., 2002; Collins et al., 2000).

A number of studies have demonstrated that, in the range of normal fumigating temperatures from 10 to 35°C, the concentration of phosphine required to kill a given stage of an insect species decreases inversely with temperature (Lindgren and Vincent, 1966; Barker, 1969; Hole et al., 1976; Price and Mills, 1988; Hyne and Winks, 1997; Phillips et al., 1999). This work involved mostly beetle pests and there are no reports available on the effect of fumigation temperature on the efficacy of phosphine against resistant psocids. In view of the development of strong resistance to phosphine by *L. bostrychophila*, it was considered important to evaluate the effect of fumigation temperatures on the efficacy of phosphine so as to develop new and effective control protocols (concentration × time) against these insects. These protocols will be recommended for registration and use in management of psocid infestations in stored grain in Australia.

## Materials and methods

### Insects

Strain SLB3 of *L. bostrychophila* was collected from a central storage at Kārkoö, South Australia, in 1997. It has not been selected with phosphine in the laboratory. To date, SLB3 is the strongest phosphine-resistant strain of *L. bostrychophila* detected in Australia (Nayak et al., 2002).

### Time to population extinction assays

Response to phosphine was measured by exposing mixed-age cultures of psocids to fixed concentrations of phosphine as described previously (Nayak et al., 2002) using a continuous flow application of fumigant mixed with air, essentially as described by Hyne and Winks (1997). Cultures of *L. bostrychophila* were specially prepared so that they contained all life stages living in a wheat-based culture medium (Nayak and Collins, 2001). Approximately 25 g of mixed-age culture were taken in plastic soufflé cups (30-mL capacity) and three replicates were arranged in each of six stainless-steel chambers for each treatment. Phosphine and

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air were allowed to flow through each chamber in one direction, controlled by mass flow controllers. The experiments were undertaken in rooms that maintained a constant temperature to within  $\pm 1^\circ\text{C}$ . Moisture content of the culture medium with insects was maintained at 13% (equivalent to 70% r.h.) by passing the phosphine-air mixture through a water bath set at an appropriate temperature.

Insects were removed from the fumigation after a predetermined exposure period. The criterion of population extinction was the absence of live psocids when the treated mixed-age cultures were inspected four weeks after fumigation (Nayak et al., 2002). In this way, the time taken, in days, to completely control all life stages was determined at each test concentration. The results were recorded simply as the least number of whole days taken to achieve population extinction. Due to limitations of space, in some cases population extinction could not be achieved at  $20^\circ\text{C}$  as expected within the experimental period. In those cases the results were presented as greater than (>) the longest observation period. Such experiments will be repeated later to obtain definitive results.

The influence of fumigation temperature was examined at 20, 25, 30 and  $35^\circ\text{C}$  using the methodology described above. Phosphine concentrations considered for this study were 0.1, 0.17, 0.3 and 1 mg/L, doses currently registered in Australia. Phosphine concentration was monitored throughout these experiments using a gas chromatograph (Varian Star 3600X<sup>®</sup>) fitted with a pulsed-flame photometric detector.

## Results

At the lowest experimental temperature of  $20^\circ\text{C}$ , time to population extinction was more than 14 days at concentrations of 0.1, 0.17 and 0.3 mg/L and more than 8 days at 1 mg/L (Table 1). At  $25^\circ\text{C}$ , population extinction was achieved on day 11 and day 8 at 0.1 and 1 mg/L of phosphine, respectively. At 0.17 and 0.3 mg/L, however, some insects in the population sample survived 11 days exposure. Identical results were obtained at all concentrations of phosphine at both 30 and  $35^\circ\text{C}$  (Table 1). At these temperatures, population extinction was completed in seven days at 0.1 mg/L, and in six days at higher concentrations.

**Table 1.** Effect of fumigation temperature on time to population extinction (days) of strong resistant *L. bostrychophila* (SLB3) at different doses of phosphine

Phosphine concentration (mg/L)	Temperature ( $^\circ\text{C}$ )			
	20	25	30	35
0.1	>14	11	7	7
0.17	>14	>11	6	6
0.3	>14	>11	6	6
1	>8	8	6	6

## Discussion

In general, time taken to population extinction of *L. bostrychophila* tended to decrease with increasing temperature in the range  $20\text{--}30^\circ\text{C}$  at all application rates of phosphine (Table 1). Increasing temperature beyond  $30^\circ\text{C}$ , however, did not reduce the fumigation period needed. There was a

dramatic increase in effectiveness of phosphine with increase in temperature from 25 to 30 or  $35^\circ\text{C}$ , where phosphine was most effective against resistant *L. bostrychophila*. Phosphine was least effective at  $20^\circ\text{C}$ , taking more than double the time required at  $30^\circ\text{C}$  for population extinction. Our results agree with earlier observations in experiments with beetle pests, that effectiveness of phosphine increases with increase in fumigation temperature (Lindgren and Vincent, 1966; Hole et al., 1976; Price and Mills, 1988; Hyne and Winks, 1997).

We conclude that strongly resistant *L. bostrychophila* populations can be controlled with a significantly reduced fumigation period if we increase fumigation temperature from  $25^\circ\text{C}$  to  $30^\circ\text{C}$ . For example, a dose of 0.17 mg/L over six days at  $30^\circ\text{C}$  completely controlled these insects, which can survive at 1 mg/L and  $25^\circ\text{C}$  over the same exposure period. The current findings will be recommended for integration into the national resistance management strategy.

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