FUMIGATION OF WOOD WITH ALUMINIUM PHOSPHIDE FOR PROTECTION AGAINST FUNGI

H Pant & S Tripathi*

Forest Products Division, Forest Research Institute, Dehradun, India

Received May 2010

PANT H & TRIPATHI S. 2011. Fumigation of wood with aluminium phosphide for protection against fungi. The search for alternatives to the environmentally harmful fumigant methyl bromide has led to the evaluation of phosphine as preshipment and in-transit treatments for logs and sawn timber. The biological activity of aluminium phosphide against wood decaying fungi was determined using agar plate and soil block methods. Malt agar bioassay was carried out using five concentrations of aluminium phosphide against wood decaying white (*Trametes versicolor*) and brown rot (*Oligoporus placentus*) fungi. Minimum fungicidal concentration of fumigant was 1.0% for *T. versicolor* and 1.3% for *O. placentus*. Soil block bioassay was carried out on softwood (*Pinus roxburghii*) and hardwood (*Populus deltoides*). Wooden blocks of specific sizes were fumigated with five different concentrations of aluminium phosphide and subjected to the test fungi. Results revealed that 4.9% concentration at 91.76 g m^{-3} retention of aluminium phosphide gave more than 90% protection to the wood against white and brown rots. Treated specimens did not exhibit any change in dimensions after exposure to fungi but control specimens were badly affected.

Keywords: Brown rot, fumigate, hardwood, softwood, white rot

PANT H & TRIPATHI S. 2011. Perlindungan kayu daripada serangan kulat melalui pewasapan dengan aluminium fosfid. Pencarian alternatif kepada bahan wasap metil bromida yang tidak mesra alam membawa kepada penilaian fosfin sebagai rawatan balak dan kayu gergaji sebelum atau semasa pengangkutan. Aktiviti biologi aluminium fosfid terhadap kulat pereput kayu ditentukan menggunakan kaedah plat agar dan blok kayu. Bioasai agar malt dijalankan ke atas kulat pereput putih (*Trametes versicolor*) dan kulat pereput perang (*Oligoporus placentus*) menggunakan lima kepekatan aluminium fosfid. Kepekatan fungisid bahan wasap yang minimum ialah 1.0% bagi *T. versicolor* dan 1.3% bagi *O. placentus*. Bioasai blok tanah dijalankan ke atas kayu lampung (*Pinus roxburghii*) dan kayu keras (*Populus deltoides*). Blok kayu pelbagai saiz diwasap menggunakan lima kepekatan aluminium fosfid dan didedah kepada kulat. Keputusan menunjukkan bahawa kepekatan 4.9% pada penahanan aluminium fosfid sebanyak 91.76 g m^{-3} memberi 90% perlindungan kepada kayu terhadap kulat-kulat pereput putih dan perang. Spesimen yang dirawat tidak menunjukkan perubahan dimensi selepas pendedahan kepada kulat tetapi spesimen kawalan dipengaruhi dengan teruk.

INTRODUCTION

Fumigants have been widely used to reduce the threat of pests in wood. Though primarily directed at insects, certain fumigant chemicals have also been used to kill fungi and nematodes (Schmidt et al. 1997). Wood deterioration causes substantial economic losses and often there is no alternative to fumigant use. Presently, fumigants are applied mainly to utility poles, marine pilings and exposed laminated beams but their long-term effectiveness, coupled with the development of more easily handled formulations, suggests potential applications.

Phosphine is a colourless gas at room temperature and normal atmospheric pressure. It is odourless when pure at concentrations up to 282 mg m^{-3} (200 ppm), a highly toxic level. The 'garlicky' odour of technical phosphine depends on the presence of odoriferous impurities and is usually detectable at concentrations between 0.14 and 7 mg m^{-3}. The autoignition temperature of pure phosphine is 38 °C, but the presence of impurities, particularly diphosphine (PH_2–PH_2), often causes the technical product to ignite spontaneously at room temperature and it forms explosive mixtures with air at concentrations greater than 1.8%. Oxidation of phosphine yields water and phosphorus oxides or oxyacids.

**Author for correspondence. E-mail: tripathis@icfre.org*

Phosphine producing materials have become the predominant fumigants used for treatment of bulk-stored grain throughout the world. It is available in solid formulation of aluminium phosphide or magnesium phosphide. This fumigant produces toxic gases when released. These gases readily penetrate into infested kernels and eliminate all insect life stages.

In China, transportation of logs with pupae of *Hyphantria cunea* in the bark caused the spread of the pest. Fumigation of logs wrapped in plastic with phosphine at 15–20 g m^{-3} for three days at 25–29 °C produced 100% pupal mortality (Shu & Yu 1984).

Phosphine fumigation at 2.0 g m^{-3} and 25 °C applied for short periods (48 hours) is unlikely to be an effective quarantine treatment for forest insect pests (Oogita et al. 1997). Poplar timber infested with larvae and pupae of Asian longhorn beetle (*Anoplophora nobilis*) and larvae of two other pests were treated with phosphine (Wang et al. 2003). Insects were 100% controlled at 15.5 °C using concentrations of 112 to 183 mg/hour/litre in a 120-hour treatment.

According to the US manual for ECO2FUME (CYTEC 2009), a 10-day treatment is required for treating wood and wood products. For best results, a dose of 750–1000 ppm phosphine is recommended. High concentrations can counter the solubility of phosphine in water or moisture present in the wood or wood product.

Rapid depletion of phosphine was reported by New Zealand log exporters (Primaxa 2002). A similar observation was reported by Leesch et al. (1989) when monitoring in-transit disinfestation of wood chips using aluminium phosphide to control pine wood nematode. Phosphine concentrations were generally 100–1500 ppm after a day but had dropped to 2.5–40 ppm after seven days.

Zhang (2004) reported phosphine depletion and decline during in-transit fumigation of logs. Penetration of phosphine through *Pinus radiata* and hardwood (kwila) timber using both seasoned (dry) and unseasoned (wet) blocks was studied (Annis & Dowsett 2001). They concluded that a significant amount of gas was absorbed by the wood, both across and along the grain. Phosphine penetrated the wood grain of both seasoned and unseasoned hardwood and softwood. The effects of bark and soil contaminants on the rate of depletion of phosphine in green logs were studied in a simulated in-transit fumigation trial (Zhang & Brash 2007). The presence of bark enhanced phosphine depletion.

Primaxa (2002) investigated the effect of moist wood (63.2% moisture content) on phosphine depletion. Baker et al. (2003a, b) carried out two crude trials using infested billets of pine logs (200–300 mm diameter) in 230 l plastic barrels. All insects in the controls were found alive but all treated insects, dead.

Two trials involving the exposure of naturally infested radiata pine logs within a custom designed fumigation chamber were carried out (Frontline Biosecurity 2003). At the conclusion of the trial, no insect survived.

Hosking and Goss (2005) simulated in-hold fumigation in two sealed 2 m^3 chambers. In a trial similar to an earlier study (Frontline Biosecurity 2003), they compared two phosphine treatments —the current protocol of 2.0 g phosphine/m^3 as aluminium phosphide with a top up of 1.5 g phosphine/m^3 on day 5 and a single application of 4 g phosphine/m^3. No individual was alive in either treatment.

Zhang and van Epenhuijsen (2005) carried out two trials together to test the efficacy of phosphine for the control of two major quarantine insect pests. Direct exposure to 200 ppm phosphine for 10 days fully disinfested nymphs of drywood termites and *Prionoplus reticularis* eggs. In the second trial, 200 ppm phosphine fumigation for 10 days was the minimum requirement to ensure full disinfestations of *Arhopalus tristis* eggs. Zhang et al. (2007) used higher rates of phosphine (3–4 g m^{-3}) for longer durations (72–120 hours) at 15 °C. All treatments gave 100% control of burnt pine longhorn eggs and golden haired bark beetle or black pine bark beetle larvae.

Glassey (2009) tested phosphine for in-transit fumigation of *Pinus radiata* pine logs from New Zeland. The current specification of 200 ppm for 10 days was shown to be effective for all life stages of cerambycids (*Prionoplus reticularis*), bark beetles (*Hylastes ater, Hylurgus ligniperda*) and drywood termites (*Kalotermes brouni*).

Most of the work which is reported on aluminium phosphide toxicity is on insects. No work has been reported on wood decaying fungi. The industries are keen on expanding the application of this fumigant. In the present study, aluminium phosphide was tested against wood decaying fungi, i.e. white rot (*Trametes versicolor*) and brown rot (*Oligoporus placentus*) fungi. The objective of this research was to determine the effective concentrations of aluminium phosphide for

protection of hardwood and softwood against *T. versicolor* and *O. placentus*.

MATERIALS AND METHODS

Malt agar bioassay

Malt agar medium (4%) was prepared by adding 20 g malt and 20 g agar powder and dissolved in 1 litre of distilled water which was heated until boil. The medium was sterilised in an autoclave at 15 lb pressure and 120 °C for 20 min (Datar 1995). After autoclaving, 30 ml of the medium were poured into each sterilised Petri plates (9 cm diameter) in the culture room. These Petri dishes were allowed to cool for one hour until the medium solidified. Six replicates were set up for each concentration of fumigant along with the control (fumigant free).

Fumigation of malt agar medium and antifungal activity test

Petri dishes with malt agar medium were placed in desiccators connected with a conical flask with the help of connecting glass tube having stop cock-1. On the other side the desiccator was also connected with a vacuum pump also having stop cock-2 in between. The fumigant was placed in the conical flask which was heated on hot plate at 25 °C. Before heating, partial vacuum (60 mm Hg) was created in the desiccator for 5–10 min to replace the air by opening stop cock-2. During this period, stop cock-1 was kept closed. After creating vacuum, the fumigant was heated and the fume was allowed to pass into the desiccator through glass tube by opening stop cock-1 while stop cock-2 was closed. Five different concentrations of aluminium phosphide, i.e. 0.1, 0.3, 0.5, 0.7 and 1.0% (w/v) were used for the study. One higher concentration i.e. 1.3% was also used against *O. placentus*. The heating process was carried out for one hour and the Petri dishes were left in the desiccator for 24 hours. The Petri dishes containing the medium with or without fumigant were inoculated with an inoculum disc of actively growing 14–16-day-old culture of the test fungi. The plates were incubated in the incubation chamber which was maintained at 25 ± 2 °C and 70 ± 4% relative humidity. Results were recorded after 15 days in terms of per cent surface coverage by the test fungi over malt agar medium and shown as total per cent growth inhibition (Kapse 1996, Wedge et al. 2000).

The total growth of fungus was rated as in Table 1 (Goyal & Dev 1982). Inhibition in growth of test fungi was statistically analysed using SPSS 10.0.

Determination of nature of antifungal activity

To determine the nature of antifungal activity, the inoculum discs of the test fungi, in which growth was completely suppressed by the fumigant, were transferred to fresh fumigant free malt agar medium. The plates were incubated for 15 days and results were recorded. If the growth is resumed immediately, it is categorised as fungistatic and if no growth takes place again then the activity is termed as fungicidal (Iqbal et al. 2004). For each concentration and control, three replicates were conducted.

Soil block bioassay

On the basis of preliminary screening tests of aluminium phosphide as fumigants by malt agar bioassay, further testing of this fumigant by soil block bioassay was conducted at five different concentrations, i.e. 0.9, 1.9, 2.9, 3.9 and 4.9% (w/v) against both the test fungi, i.e. *T. versicolor* and *O. placentus* (Cartwright & Findlay 1958, Da

Table 1 Grading of surface coverage of test fungi on malt agar medium

Growth type	Surface coverage of mycelium on the medium (%)
None	0
Sporadic	0–5
Little	5–25
Moderate	25–50
Considerable	50–75
Complete	> 75

Costa & Rudman 1958, IS 2008). Aluminium phosphide (56%, trade name Fumino™) was procured locally.

Fungal strains

The test fungi used were *T. versicolor* (for non-conifers *Populus deltoides*) collected from oak stem, Senji forest area, Mussorie Forest Research Institute Herbarium No. 7437 and *O. placentus* (for conifers *Pinus roxburghii*) received from FPRL Princess Risbourgh England, No. 304–A. (ASTM 1980, IS 2008). Fungi were maintained at 25 ± 2 °C on 2% (w/v) malt agar until inoculation.

Preparation of test blocks

Sapwood of chir pine (*P. roxburghii*) and poplar (*P. deltoides*) from seasoned planks, free from knots, mould, stain and other defects were taken. It was converted into dimensions of 19 × 19 × 19 mm with a 0.32 mm central hole on the tangential face along the length of the grain and weighed (W_1). The test blocks were about 17% moisture content under laboratory conditions. They were divided into weight groups of 0.1 g intervals. The sample could be separated into density groups because of the accurate cutting of the blocks. Earlier studies have shown that using blocks of closely related densities made it possible for the concentration of the treating solution be adjusted so as to result in a series of blocks with evenly spaced gradient retentions. These blocks were then subjected to 103 ± 2 °C in an oven and the weight was recorded until constant weight (W_2). Moisture content of the wood was calculated from initial weight (W_1) and conditioned weight (W_2) of the test blocks. The moisture content of the wood blocks used for soil block bioassay test was 4%. For each concentration of aluminium phosphide in each wood against each fungus as well as control, six replicates were used.

$$\text{Moisture content of wood (\%)} = \frac{W_1 - W_2}{W_2} \times 100$$

Sensitisation and fumigation of test blocks

The test blocks were steamed at 100 °C for about 20 min at atmospheric pressure in an autoclave in tightly fitted bottles (IS 2008). The sanitised test blocks were placed on wire rack inside desiccators, connected with a vacuum pump. A partial vacuum of 60 mm Hg was created in desiccators for 30 min to expel air from desiccator. A known amount of fumigant was heated in a conical flask on hot plate (25 °C), which was connected to the desiccators with the help of a glass tube through which fumes passed from conical flask to the desiccator. The heating process was carried out for 3 hours and the blocks were left in the desiccator for 72 hours. The blocks were then taken out and weighed immediately (W_3).

Preparation of soil culture bottles

Sieved, air-dried garden soil amounting to 125 g with pH between 5 and 7 was filled (compacted by tapping) in screw capped bottles. Sample of the air-dried soil was taken. The pH of the soil was potentiometrically measured in the supernatant suspension of a 1:5 soil: liquid (v/v) mixture. Distilled water (44 ml) was added to the bottles so as to obtain 130% of water holding capacity of soil. Feeder blocks of dimensions 4 × 19 × 35 mm were prepared from sapwood of *Bombax ceiba,* a highly perishable wood and used for providing nutrients to the growing culture/ mycelium in culture bottles. Two feeder blocks were placed directly on the surface of the soil. The prepared bottles with caps loosened were sterilised and autoclaved for 30 min.

Preparation of test culture

Fungal inocula from freshly grown culture measuring 10 × 10 mm pieces were taken from the outer edge of mycelium of two-week-old fungal colonies and placed on the edge of feeder blocks in sterilised culture bottles. The inoculated bottles with slightly loosened lids were incubated in BOD (biochemical oxygen demand) for a controlled condition of temperature and humidity. The incubator was maintained at 25 ± 2 °C and 70 ± 4% relative humidity for three weeks until the mycelia mat had covered the feeder blocks.

Introduction and incubation of test blocks in culture bottles

Two blocks with cross-sections faced down were placed on feeder blocks in contact with mycelium in each culture bottle. The bottles containing test blocks were incubated for 14 weeks in an

incubator maintained at 25 ± 2 °C and relative humidity of 70 ± 4% (IS 2008).

At the end of the incubation period, the fumigated and control blocks were removed from the culture bottles. The adhering mycelia were cleaned off, taking care not to remove the splinters of the wood. The blocks were dried at room temperature for three to four days in an oven and weighed till constant weight. The extent of fungal attack was determined by weight loss.

$$\text{Weight loss } (\%) = \frac{W_3 - W_4}{W_3} \times 100$$

where

W_3 = conditioned weight of the blocks before test (after fumigation)
W_4 = conditioned weight of the blocks after test

Weight loss caused by test fungi was statistically analysed using SPSS 10.0 package. Critical difference (CD) was calculated at 0.05 significance level to determine whether a pair of means was significantly different from each other.

Qualitative determination of aluminium phosphide in fumigated wood blocks

Qualitative testing of fumigant on the surface was done just after fumigation. Fumigated wooden blocks were brush coated with aqueous solution of ammonium molybdate. Blue coloration of phosphomolybdous acid complex was formed on the surface of wood samples (Fiske & Subbarow 1925).

Quantitative determination of aluminium phosphide in fumigated wood blocks

Phosphorus was estimated using ammonium molybdate, phenophthaline, HNO_3 and NaOH by volumetric method (Scott 1918). From the amount of phosphorus obtained from above, the retention of aluminium phosphide was calculated. For calculating retention, six replicates were used.

RESULTS

Trametes versicolor exhibited 100% mean growth inhibition at 1%, whereas for *O. placentus,* a higher concentration of 1.3% was needed (Table 2). At other concentrations, i.e. 0.7, 0.5 and 0.3%, mean growth inhibition values for *T. versicolor* were 68.0, 53.1 and 13.9% respectively, whereas 100% surface coverage was found in control and at 0.1% concentration. Thus, at lower concentrations, aluminium phosphide had less antifungal activity. The nature of antifungal (fungistatic or fungicidal) activity was also determined and it was found that 1.0% of aluminium phosphide showed fungicidal activity against white rot.

Similarly, aluminium phosphide at 1.3% concentration had completely inhibited the growth of *O. placentus* compared with 100% growth in the control. Aluminium phosphide at this concentration also revealed fungicidal activity against *O. placentus*. Petri dishes fumigated with 1.0% aluminium phosphide recorded 79.4% mean growth inhibition of test fungus. Mean growth inhibition values of 69.4, 62.6 and

Table 2 Mean growth inhibition of fungi in Petri plates fumigated with different concentrations of aluminium phosphide

Fumigant	Concentration (% w/v)	Inhibition (%)		Mean (%)
		T. versicolor	*O. placentus*	
Aluminium phosphide	Control	0	0	0 c
	C1	0	36.85 (37.36)	18.42 (18.68) d
	C2	13.88(21.85)	62.59 (52.27)	38.23 (37.06) e
	C3	53.14(46.78)	69.42 (56.42)	61.28 (51.6) f
	C4	68.00 (55.53)	79.44 (63.02)	73.72 (59.27) g
	C5	100.00(89.96)	100.00 (89.96)	100.00 (89.96) h
Mean		39.17 (35.69) a	58.05 (49.84) b	

Values in parentheses are arsine values. Different alphabets denote significant difference.
$CD_{(0.05)}$ fungi = 0.36, concentrations = 0.63
For *T. versicolor* C1 = 0.1%, C2 = 0.3%, C3 = 0.5%, C4 = 0.7% and C5 = 1.0%
For *O. placentus* C1 = 0.3%, C2 = 0.5%, C3 = 0.7%, C4 = 1.0% and C5 = 1.3%

36.9% of the test fungus were recorded in Petri dishes exposed to 0.7, 0.5 and 0.3% aluminium phosphide respectively. Statistical analysis revealed that all concentrations of aluminium phosphide tested against wood decaying fungi were significantly different from one another ($p \leq 0.05$). Significant difference was observed between the per cent growth inhibition caused by aluminium phosphide against *T. versicolor* and *O. placentus* at ($p \leq 0.05$).

Figure 1a shows control (non-fumigated) block brush coated with ammonium molybdate solution. Three blocks were split from the centre and again coated with ammonium molybdate solution to see the penetration of aluminium phosphide. Uneven coloration suggested uneven impregnation of fumigant (Figure 1c).

The assay was based on the reaction of PO_4^{3-} with excess molibdic acid (generated by combining sulphuric acid with ammonium molybdate) which produced the colourless phosphomolybdic acid complex which was reduced to intensely blue coloured phosphomolybdous acid complex. The colour generated was quite stable (Fiske & Subbarow 1925)

Pinus roxburghii and *P. deltoides* blocks fumigated with 0.9, 1.9, 2.9, 3.9 and 4.9% aluminium phosphide exhibited 16.9, 35.6, 54.3, 73.0 and 91.8 g m^{-3} retentions respectively (Table 3). Control blocks of *P. roxburghii* and *P. deltoides* of both sets exposed to *T. versicolor* and *O. placentus* had more than 50% weight loss. All concentrations of aluminium phosphide caused weight losses below 20 and 30% subjected against *T. versicolor* and *O. placentus* respectively. *Pinus roxburghii* blocks fumigated with 0.9, 1.9, 2.9, 3.9 and 4.9% aluminium phosphide and subjected to *T. versicolor* recorded mean weight losses of 16.9, 14.0, 12.7, 10.4 and 7.4% respectively. Mean weight loss of 50.7% was observed in control blocks (Table 3). In the case of brown rot, blocks fumigated with 0.9% aluminium phosphide showed 25.1% mean weight loss. Blocks fumigated with 1.9, 2.9, 3.9 and 4.9% aluminium phosphide recorded weight losses of 17.0 12.9, 10.2 and 7.9% respectively, compared with 51.4% mean weight loss in control blocks.

Populus deltoides blocks fumigated with 4.9% aluminium phosphide subjected to *T. versicolor* showed weight loss of 7.5%, while weight losses of 12.1, 14.2, 16.50 and 20.0% were recorded in test blocks fumigated with 3.9, 2.9, 1.9 and 0.9% aluminium phosphide respectively. In control blocks, 53.4% weight loss was recorded. Fumigated blocks of *P. deltoides* with 0.9, 1.9, 2.9, 3.9 and 4.9% aluminium phosphide subjected to *O. placentus* recorded weight losses of 28.8, 20.2, 16.6, 13.8 and 9.5% respectively. In control blocks, 54.8% weight loss was observed (Table 3).

The extent of deterioration caused by *T. versicolor* and *O. placentus* in both wood species was significantly different ($p \leq 0.05$). *Oligoporus placentus* caused more weight loss compared with *T. versicolor* (Table 3). Surface testing for the presence of fumigant was done qualitatively. It was observed that blue colour developed completely and evenly on the outer surface of wooden blocks. Blocks were cut from the centre and the colour suggested uneven distribution of fumigant. The study exhibited good penetration of fumigant inside the wood.

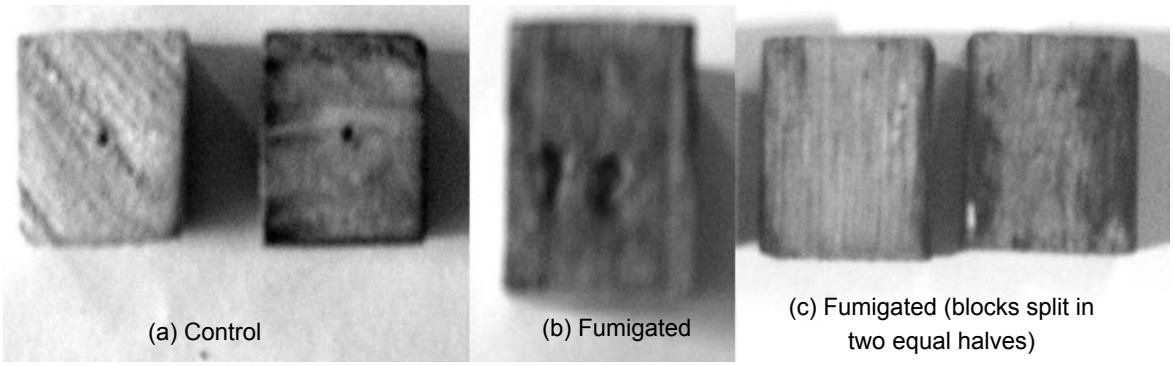

Figure 1 Qualitative determination of phosphorus in wood blocks fumigated with aluminium phosphide

Table 3 Mean weight loss (%) of wood fumigated with aluminium phosphide due to decay fungi

Concentration (% w/v)	Retention (g m^{-3})	Wood				Mean
		P. roxburghii		*P. deltoides*		
		T. versicolor	*O. placentus*	*T. versicolor*	*O. placentus*	
Control	0.00	50.69 (45.38)	51.44 (45.80)	53.42 (46.94)	54.80 (47.73)	52.58 (47.46) e
0.9	16.85	16.86 (24.23)	25.14 (30.08)	20.04 (26.58)	28.82 (32.45)	22.71 (28.33) f
1.9	35.58	14.00 (21.96)	16.95 (24.30)	16.50 (23.96)	20.22 (26.70)	16.91 (23.29) g
2.9	54.31	12.70 (20.87)	12.91 (21.04)	14.15 (22.08)	16.61 (24.04)	24.23 (22.00) h
3.9	73.04	10.36 (18.77)	10.17 (18.58)	12.14 (20.38)	13.82 (21.81)	11.62 (19.88) i
4.9	91.76	7.35 (15.72)	7.88 (16.28)	7.46 (15.83)	9.53 (17.97)	8.05 (16.45) j
Mean (Wood)		19.70 (25.25) c		22.29 (27.21) d		
Mean (Fungi)		19.64 (25.22) a		22.36 (27.23) b		

Values in parentheses are arsine values. Different alphabets (e–j) denote significant difference.
$CD_{(0.05)}$ wood = 0.15, fungi = 0.15, concentrations = 0.26
a = *T. versicolor,* b = *O. placentus*, c = *P. roxburghii,* d = *P. deltoides*

DISCUSSION

Trametes versicolor caused less weight loss in softwood compared with hardwood. This is in conformity with the findings of Melecion and Morrell (2009). This is probably due to the inability of the fungus to cause substantial degradation of coniferous components and the tendency of this fungus to be more active on hardwood materials. *Oligoporus placentus* caused more deterioration in wood. These fungi are unique in that they are the only known microbes that can degrade cellulose in wood without first removing lignin. They degrade cellulose causing rapid decrease in depolymerisation at low weight loss.

Earlier studies on decay by *T. versicolor* suggested that the faster decay of hardwood compared with softwood might be due to the effect of different amounts and different types of lignin in the wood. The lignin of most softwood is composed almost entirely of guaiacylpropyl (G) units. Lignin in hardwood, in addition to G units, often has numerous syringylpropyl (S) units. A study on the influence of lignin type on decay by *T. versicolor* was conducted using a number of wood with a wide range of S:G (S: syringyl-like lignin structures; G: guaiacyl-like lignin structures) ratios and different lignin type distributions. The results of the study were consistent with the fact that lignin content and lignin type affected the decay resistance of wood (Llewellyn et al. 1994).

CONCLUSIONS

Preliminary screening of aluminium phosphide against wood decaying fungi *T. versicolor* and *O. placentus* through malt agar bioassay showed fungicidal activity at 1.0 and 1.3% concentrations respectively. Aluminium phosphide gave protection to softwood and hardwood blocks against *T. versicolor* and *O. placentus* at all concentrations tested. Aluminium phosphide at the highest concentration (4.9%) provided more than 90% protection to softwood and hardwood blocks compared with the controls which were destroyed up to 55% by both the test fungi. The presence of aluminium phosphide on the surface or inside the wood may be quantified after different time intervals.

ACKNOWLEDGEMENTS

The authors are thankful to SS Negi, the Director of the Forest Research Institute (FRI), Dehradun, India for providing facilities for the study. They are also thankful to the staff of the Wood Preservation Discipline, FRI, Dehradun for help during experimental work.

REFERENCES

Annis P, Dowsett H. 2001. Phosphine penetration through timber: a report of some laboratory studies. Cytec Australia Ltd. (Unpublished report)

ASTM. 1980. *Standard Method of Testing Wood Preservatives by Laboratory Soil Block Cultures. Standard D 1413–61.* ASTM, Philadelphia.

Baker RT, Keall JB, Crockett FA & Fraser AM. 2003a. Fumigation of pine logs (*P. radiata*) with phosphine. (Unpublished)

Baker RT, Keall JB, Crockett FA, Fraser AM. 2003b. Fumigation of pine logs (*P. radiata*) with phosphine, trial two. (Unpublished report)

Cartwright KSG & Findlay WPK. 1958. *Decay of Timber and its Prevention.* His Majesty's Stationery Office, London.

CYTEC. 2009. www.cytec.com /specialtychemicals / PDFs/ PhosphineGas/ECO%20US%20 Manual. Accessed on 17 February 2009.

DaCosta EWB & Rudman P. 1958. The causes of natural durability in timber—I. The role of toxic extractives in the resistance of tallow wood (*Eucalyptus microcorys* F. Muell). *Australian Journal of Biological Science* 11: 45–57.

Datar VV. 1995. Antifungal activity of neem (*Azadirachta indica)* leaves against some phytopathogenic fungi. Pp 49–51 in Mariappan V (Ed) *Neem for the Management of Crop Diseases.* Associated Publishing Co., New Delhi.

Fiske CH & Subbarow Y. 1925. Analysis of organic phosphate bonds. *Journal of Biological Chemistry* 66: 375.

Frontline Biosecurity. 2003a. Phosphine efficacy trial No.1 log exposure. (Unpublished report)

Glassey KL. 2009. Phosphine as an alternative to methyl bromide for the fumigation of pine logs and swan timbers. *IUFRO International Forest Biosecurity Conference, Incorporating the Sixth International Forest Vegetation Management Conference.* 16–20 March 2009, Rotorua.

Goyal P & Dev I. 1982. Effect of extractives on durability of sal (*Shorea robusta*) wood. *Journal of Timber Development Association of India* 28: 12–16.

Hosking GP & Goss M. 2005. Phosphine fumigation of logs. Frontline Biosecurity. (Unpublished report)

Iqbal MCM, Jayasinghe ULB, Herath HMTB, Wijesekara KB & Fujimoto Y. 2004. A fungistatic chromene from *Ageratum conyzoides. Phytopathology and Mycology* 32: 119–126.

IS. 2008. *IS 4873 Methods of Laboratory Testing of Wood Preservatives Against Fungi—Part 1.* Second revision. Bureau of Indian Standards, New Delhi.

Kapse NK. 1996. Formulation of biofungicidal preparation to control fungal decay of stored bamboos with particular emphasis on *Trichoderma* species. PhD thesis, Deemed University, Dehradun.

Leesch JG, Davis R, Simonaitia A & Dwinell LD. 1989. In-transit shipboard fumigation of pine woodchips to control *Bursaphelenchus xylophilus. OEPP/EPPO Bulletin* 19: 173–181.

Llewellyn GC, Dashek WV & Rear OCE. 1994. *Biodeterioration Research 4: Mycotoxins, Wood Decay, Plant Stress, and General Biodeterioration.* Plenum Press, New York.

Melencion N & Morrell JJ. 2009. Effect of fungal attack on maximum load capacity of simulated wall assemblies. *Wood and Fiber Science* 41: 22–27.

Oogita T, Soma Y, Mizobuchi M, Oda Y, Matsuoka I & Kawakami F. 1997. Mortality tests for forest insect pests by phosphine fumigation. *Yokohama Plant Protection Station Research Bulletin* 38: 17–20.

Primaxa. 2002. Preliminary investigation into phosphine fumigation of logs. (Unpublished report)

Schmidt EL, Juzwik J & Schneider B. 1997. Sulfuryl fluoride fumigation of red oak logs eradicates the oak wilt fungus. *European Journal of Wood and Wood Products* 55: 315–318.

Scott WW. 1918. *Standard Methods of Chemical Analysis.* D Van Nostrand Company, New York.

Shu CR & Yu CY. 1984. A preliminary report on quarantine and experimental control of *Hyphantria cunea* at the pupal stage. *Forest Science and Technology* 9: 21–22.

Wang Y, Zhan G, Wang X, Xu L, Liu W, Wu N, Yang Y, Shi L & Sun C. 2003. Primary study on the phosphine fumigation of poplar timber infested with *Anoplophora nobilis. Plant Quarantine* 17: 129–132.

Wedge DE, Galindo JCG & Macias FA. 2000. Fungicidal activity of natural and synthetic sesquiterpene lactone analogs. *Phytochemistry* 53: 747–757.

Zhang Z. 2004. Review of phosphine sorption and depletion during fumigation. (Unpublished report)

Zhang Z & Brash DW. 2007. What causes phosphine depletion during log fumigation? Crop & Food Research Confidential Report No. 1976.

Zhang Z & van Epenhuijsen CW. 2005. Phosphine as a fumigant to control pests in export logs. (Unpublished report)

Zhang Z, van Epenhuijsen CW, Brash D, Hedderley D & McLachlan A. 2007. In transit phosphine fumigation for export logs and timber without top up. Crop & Food Research Confidential Report No. 1940.