Potential of oxygenated phosphine fumigation for postharvest pest control

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Oxygenated phosphine fumigations (fumigations under superatmospheric oxygen levels) were found to be significantly more effective than fumigations under the normal oxygen level against different life stages of insect pests (Liu 2011). This new finding has a potential to be used to develop more effective and shorter fumigation treatments for postharvest pest control. Both advantages and disadvantages of oxygenated phosphine fumigation are discussed.

Phosphine emerges as an alternative to methyl bromide for postharvest pest control as methyl bromide is being phased out globally. However, phosphine acts slowly in killing insects and it may take over 10 days to kill tolerant ones. Phosphine is also less effective at lower temperatures and takes much longer to control pests as compared with treatments at higher temperatures. Therefore, more effective phosphine fumigations would be desirable to shorten treatment times and reduce fumigation costs. Carbon dioxide enhances phosphine toxicities to a limited extent. However, many fresh products such as lettuce are sensitive to CO_2 and therefore a phosphine-CO_2 mixture may not be a suitable fumigant for sensitive commodities, especially when fumigations may last for several days at low temperatures.

Oxygen is essential to the toxicity of phosphine against insects in the past (Bond 1963, Bond et al. 1967, Kashi 1981). However, there is no further research in enhancing phosphine toxicity with oxygen, probably due to the flammable nature of phosphine as it reacts with oxygen in the air when the phosphine level exceeds 1.8%. In our recent study, phosphine fumigations under superatmospheric oxygen levels (oxygenated phosphine fumigation) were found to be significantly more effective against all four insect species tested, and oxygenated phosphine fumigation seems to have a good potential to be developed into more effective fumigation treatments for postharvest pest control. Four insect species at different life stages were tested including larvae and adults of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), pupae of the leafminer, *Liriomyza langei* Frick (Diptera: Agromyzidae), eggs of grape mealybug, *Pseudococcus maritimus* (Ehrhorn) (Hemiptera:

Pseudococcidae), and eggs and pupae of Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), representing different insect orders. Eggs from Indian meal moth and grape mealybug and pupae from the leafminer and Indian meal moth were tested because, in general, eggs and pupae are more tolerant of phosphine than larvae and adults.

All insects were fumigated in 1.9 liter glass jars with a sample of diluted Vaporphos with 1.6% (v/v) pure phosphine balanced with nitrogen in a compressed cylinder (Cytec Canada, Inc., Niagara Falls, Ontario, Canada) under different oxygen levels ranging from the normal 20.9% to 80% at different temperatures for different durations. Indian meal moth eggs were fumigated under oxygen levels ranging from 10 to 80% to determine effects of both low and high oxygen levels on phosphine toxicity. The high oxygen levels in fumigation jars were established by flowing oxygen into the jars and monitoring oxygen levels at an outlet with an oxygen analyzer. The low oxygen levels were established by releasing nitrogen into the jars instead of oxygen.

Western flower thrips mortalities increased significantly from 79.5 to 97.7 and 99.3% when oxygen was increased from 20.9 to 40 and 80% in 5 h fumigations with 1000 ppm phosphine at 5°C. Leafminer pupal survivorship decreased significantly from 71.2% under 20.9% O_2 to 16.2 and 1.1% under 40 and 80% O_2 in 24 h fumigations with 500 ppm phosphine at 5°C. Complete control of leafminer pupae was achieved in 24 h fumigations with 1000 ppm phosphine at 5°C under 60% O_2 or higher. Survivorships of grape mealybug eggs also decreased significantly in 48 h fumigations with 1000 ppm phosphine at 2°C under 60% O_2 as compared with the fumigations under 20.9% O_2. Indian meal moth egg survivorships decreased significantly from 17.4 to 0.5% in responses to an oxygen level increase from 20.9 to 40% in 48 h fumigations with 1000 ppm phosphine at 10°C and reached 0.2% in fumigations under 80% O_2. When the oxygen level was reduced from 20.9 to 15 and 10% in fumigations, survivorships of Indian meal moth eggs increased significantly from 17.4 to 32.9 and 39.9%, respectively. Increased O_2 levels also resulted in significantly lower survival rates of Indian meal moth pupae in response to 24 h fumigations with 500 and 1000 ppm phosphine at 10°C and a complete control was achieved in the 1000 ppm phosphine fumigations under 60% O_2.

Oxygen enhanced phosphine toxicity significantly against all life stages tested. This has not been reported before, and the findings have a potential to be used to develop more effective phosphine fumigation treatments for pest control. The fact that the significant enhancements of phosphine toxicity existed in all tests against different life stages of all four insect species suggest that oxygenated phosphine fumigation is likely to increase phosphine toxicity against a broad range of insects. However, the magnitude of toxicity enhancement will likely vary depending insect species and their life stage based on results of the present study. From the current study, the magnitude of toxicity enhancements was less dramatic against eggs of both grape mealybug and Indian meal moth than against other life stages tested. The results also have practical implications for control of all the four insects used in this study.

However, the practical use of oxygenated phosphine fumigation may depend on our understanding of safety of the treatment. Phosphine will self-ignite when its concentration exceeds 1.8% in the air. The perception may be that increased oxygen levels will increase the risk of phosphine ignition during fumigation. Past research, on the other hand, has shown that the self-ignition concentration of phosphine is actually higher under increased oxygen levels and elevated oxygen levels have ignition suppressing effects (Bond and Miller 1988, Kondo et al. 1995). Therefore, oxygenated phosphine fumigation will unlikely increase fire risk as compared with conventional phosphine fumigation.

Insects vary greatly in susceptibility to phosphine. Insect responses to oxygenated phosphine fumigations are also expected to vary considerably. However, the enhancement of phosphine toxicity by oxygen will likely make some insect species which cannot be controlled with normal phosphine fumigations in a reasonable time frame to become sufficiently susceptible to oxygenated phosphine fumigations to be controlled effectively. Therefore, oxygenated phosphine fumigations have a potential to expand target pests for phosphine fumigation. Reduced phosphine uptake is associated insect resistance to phosphine even though the resistance mechanism may be complex. It is possible that increased oxygen levels in fumigation treatments will also result in increased uptake of oxygen by the resistant insects. Therefore, oxygenated phosphine fumigation may also have a potential to control phosphine resistant pests.

For the practical use of oxygenated phosphine fumigation, high oxygen levels need to be established first before releasing phosphine. Therefore, the procedures of oxygenated phosphine fumigations will be more complex than the normal phosphine fumigations. However, given the advantages of shorter treatment times as well as the potential to control resistant and tolerant pest species, oxygenated phosphine fumigation has a good potential to be more economical and effective for postharvest pest control. More research is warranted to develop oxygenated phosphine fumigation treatments for commercial use.

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