Oxygenated Phosphine Fumigation for Control of Light Brown Apple Moth (Lepidoptera: Tortricidae) Eggs on Cut-Flowers

SAMUEL S. LIU,1 YONG-BIAO LIU,1,2 AND GREGORY S. SIMMONS3

ABSTRACT Light brown apple moth, *Epiphyas postvittana* (Walker), eggs were subjected to oxygenated phosphine fumigation treatments under 70% oxygen on cut flowers to determine efficacy and safety. Five cut flower species: roses, lilies, tulips, gerbera daisy, and pompon chrysanthemums, were fumigated in separate groups with 2,500 ppm phosphine for 72 h at 5°C. Egg mortalities of 99.7–100% were achieved among the cut flower species. The treatment was safe to all cut flowers except gerbera daisy. A 96-h fumigation treatment with 2,200 ppm phosphine of eggs on chrysanthemums cut flowers also did not achieve complete control of light brown apple moth eggs. A simulation of fumigation in hermetically sealed fumigation chambers with gerbera daisy showed significant accumulations of carbon dioxide and ethylene by the end of 72-h sealing. However, oxygenated phosphine fumigations with carbon dioxide and ethylene absorbents did not reduce the injury to gerbera daisy, indicating that it is likely that phosphine may directly cause the injury to gerbera daisy cut flowers. The study demonstrated that oxygenated phosphine fumigation is effective against light brown apple moth eggs. However, it may not be able to achieve the probit9 quarantine level of control and the treatment was safe to most of the cut flower species.

KEY WORDS phosphine fumigation, cut flower, light brown apple moth, phytosanitation, postharvest quality

Light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae), has a very limited distribution and a broad host spectrum, covering >500 plant species in >100 families including >250 nursery plant hosts (Johnson et al. 2007, Brockerhoff et al. 2011). Light brown apple moth can be a pest and cause significant yield losses of crop production (Danthanarayana 1975). Therefore, light brown apple moth is a quarantine pest in most countries. In recent years, light brown apple moth has established in California and could spread to other regions. Fresh products from infested areas are facing both domestic and international quarantine (Johnson et al. 2007, California Department of Food and Agriculture [CDFA] 2013). A postharvest treatment for light brown apple moth control is needed on affected fresh products for both domestic distributions and export to international markets. Most light brown apple moth infestations in California were found on nursery plants. Therefore, an effective postharvest treatment is needed to address the potential quarantine risk of nursery products such as seedlings, leafy and floral plants, and cut flowers to safeguard their domestic and international markets. As light brown apple moth adults lay egg masses mainly on upper leaf surfaces and stems (Mo et al. 2004), all life stages of the pests can occur on nursery products and need to be treated in a quarantine treatment.

Phosphine has been used to control pests on stored products for many decades, and it acts slowly and may take several days to achieve an effective control of a pest (Hove 1974, Hole et al. 1976). Phosphine is conventionally generated from metal phosphides mixed with a small quantity of ammonia as a by-product, which is phytotoxic to fresh commodities. In recent years, however, fumigation with cylindered pure phosphine at low temperature has been used successfully to control insects on some fresh fruits in Chile (Horn and Horn 2004, Horn et al. 2005), and research has been conducted in other countries to develop low-temperature phosphine fumigation treatments to control various pests on fresh commodities (Klementz et al. 2005; Liu 2005a, b). However, low-temperature phosphine fumigation is not very effective against light brown apple moth eggs, and no complete control of light brown apple moth eggs in 96-h fumigation with phosphine at high concentrations was achieved (Liu et al. 2013). Oxygenated phosphine fumigation, on the other hand, is more effective than regular phosphine fumigation against all insect species at different life stages (Liu 2011, 2012) and has a potential to control light brown apple moth eggs (Liu et al. 2013).
However, in large scale tests with lettuce, 72-h oxygenated phosphine fumigation killed 99.96% light brown apple moth eggs and no complete control was achieved (Liu et al. 2014).

Low-temperature phosphine fumigation has also been tested on cut flowers, and there are significant variations among different cut flower species in sensitivity to phosphine fumigation (Karunarathne et al. 1997, Weller and van Graver 1998, Zhang et al. 2013). Fumigations with phosphine generated from aluminum phosphide tablets at 1 g/m² concentration for 5 h at 13 to 18°C are phytotoxic to some cut flowers and not effective against target insects (Weller and van Graver 1998). Fumigations at a low temperature of 2°C with phosphine gas generated from aluminum phosphide tablets free of ammonia for 8 d are safe to all cut flowers. When treatment time is extended to 12 d, injuries occur on some cut flower varieties (Zhang et al. 2013).

Oxygenated phosphine fumigation has not been tested on cut flowers. In the present study, five varieties of cut flowers were subjected to oxygenated phosphine fumigation treatments for control of light brown apple moth to determine treatment effects on cut flower quality and vase life and to verify their efficacy against light brown apple moth eggs.

Materials and Methods

**Insect.** *E. postvittana* was collected from Santa Cruz County in California in 2007 and reared on artificial pink bollworm diet (Miller et al. 1996) at the U.S. Department of Agriculture–Animal and Plant Health Inspection Services–Plant Protection and Quarantine–Center for Plant Health Science and Technology (USDA-APHIS-PPQ-CPHST) laboratory in Salinas, California. Moths were held in cages and fed with 10% sucrose solution supplied in saturated cotton rods. Corrugated wax papers were lined along the walls of the cages as substrates to collect eggs. Egg sheets were collected within 24 h and used for fumigation experiments immediately. They were cut into pieces containing 100–200 eggs each based on visual estimation, and pieces were individually placed in plastic vials (3 cm in diameter and 7 cm in height). A piece of yellow sticky card was also suspended in each vial to catch neonates after they hatched from surviving eggs.

**Chemicals.** A fumigant sample with 1.6% pure phosphine gas balanced with nitrogen in a compressed cylinder from Cytec Canada, Inc. (Niagara Falls, Ontario) was used. Commercial grade oxygen (>99.9% purity) in a compressed cylinder from a commercial source was used in this study. Helium and hydrogen for gas chromatography were purchased commercially. Carbon dioxide absorbent soda lime (SodaSorb, W.R. Grace, Cambridge, MA) and ethylene absorbent potassium permanganate (Power Pellets, Ethylene Control, Selma, CA) were bought commercially.

**Cut-Flowers.** Five species of cut flowers belonging to four families were obtained from a commercial source and they were roses, *Rosa* cv. *hybrid* L., lilies, *Lilium* cv. *Hybrid*, tulips, *Tulipa* cvs., gerbera daisy, *Bellis perennis*, and pompon chrysanthemums, *Chrysanthemum morifolium*. All cut flowers were obtained within 3 d after harvest and kept standing in water at 2°C overnight in a walk-in cooler before being used in fumigation experiments.

**Fumigation Procedures.** All fumigation treatments of cut flowers and light brown apple moth eggs were conducted in 11-liter acrylic drums (15.2 cm in diameter and 61.0 cm in height). The acrylic drums have sealable lids for loading and two ports with valves near the top and the bottom of the wall. In each fumigation test, cut flowers from different species were set up in different drums and fumigated separately. Uniform and healthy cut flowers were selected from delivered commercial cut flowers, and re-cut flower stems to about 35 cm long under water to avoid air embolism using a scissor sterilized with 95% (v/v) ethanol. A wet paper towel soaked with 100 ml water was used to warp each bunch of cut flowers of each species and the wet paper towel with flower stems were contained in a plastic bag with its opening sealed to the flower stems. The cut flower bunch for each species was then placed in each drum at a standing position. A piece of egg sheet with light brown apple moth eggs in an unzipped plastic bag was also placed in each drum. Each drum was then sealed with a rubber cap secured with a metal bracket and a tape on the wall across the cap.

Each drum chamber was then flushed with oxygen through an inlet and an outlet to establish an oxygen-enriched atmosphere with 81% O₂. An oxygen analyzer (Series 810, Illinois Instruments, Inc., Johnsburg, IL) was used to monitor oxygen levels in the drums. About 1 h after establishing the high oxygen level, a fumigant sample was then injected into each drum through one of the ports using a 500 ml airtight syringe (Vici Precision Sampling, Baton Rouge, LA). The volumes of 1,735.9 and 1,527.6 ml phosphine samples were injected for the 2,500 and 2,200 ppm phosphine fumigation treatments, respectively. The pressure inside chambers was balanced against normal pressure with a 30- by 60-cm empty foil bag connected to the acrylic cylinders. The phosphine samples diluted the oxygen concentration in each chamber to about 70%. After injection, the acrylic cylinders were kept for 72 h at 5°C in a walk-in cooler to complete the fumigation treatment. At the beginning and the end of the experiment, phosphine concentration was monitored by a Hewlett Packard 6890N gas chromatograph (Agilent Technologies, Santa Clara, CA) with a flame photometric detector as described previously (Liu 2012). At the end of fumigation, the drum chambers were ventilated for at least 30 min in a fumage hood to terminate the fumigation treatments.

**Egg Mortality Evaluation.** After fumigation, eggs from treatments and the control were placed in separate plastic cups with screened lids. A piece of yellow sticky card was suspended in each cup to catch neonates from surviving eggs. The plastic cups were held at 22°C and 90–95% relative humidity (RH) for over 2 wks to allow all surviving eggs to hatch and neonates
Caught on the sticky cards. Both neonates on the cards and unhatched eggs were then counted to determine survivorship of the light brown apple moth eggs.

**Cut Flower Quality Evaluation.** After fumigation, cut flowers were stored in a walk-in cooler at 2 °C for 7 d, and then evaluated for vase life. Stems of cut flowers from treatments and the control were cut off about 2 cm under water. Cut flowers from both the treatment and the control for each species were placed in a separate plastic container with water and held at 20 °C, 65% RH, and a photoperiod of 12:12 (L:D) h in a growth chamber. Visual quality was evaluated at 3, 4, 5, 7, and 8 d. Visual appearances were observed to identify any symptoms including wilting, curl, abscission, loose turgidity, or discolorations of leaves, sepals, petals, or bracts, leaf dry, and discolorations of flower leaves, sepals, or petals. Visual quality score range of 1 (extremely poor), 3 (fair), and 5 (excellent) with 2 and 4 in between the grades was used.

**Responses of Cut Flower Varieties and Light Brown Apple Moth Eggs to Phosphine Fumigation.** Cut flowers from different species with light brown apple moth eggs were fumigated separately with 2,500 ppm phosphine under 70% oxygen for 72 h at 5°C to determine efficacy in controlling light brown apple moth eggs and compare responses of different cut flower species to oxygenated phosphine fumigation. All five species of cut flowers: roses, lilies, tulips, gerbera daisy, pompon chrysanthemums were bundled and fumigated separately in separate acrylic drum chambers under 70% oxygen. Nonfumigated cut flowers of each species were also stored at 5°C to serve as controls. A piece of egg sheet with about 500 light brown apple moth eggs in an unsealed plastic bag was added in each acrylic drum chamber to be fumigated together with cut flowers. A piece of untreated egg sheet was stored at the treatment temperature as the control. Egg survivorship and cut flower vase life were measured after fumigation using the procedures described above. The treatment for each cut flower species was replicated three times. Over 3,000 and 800 eggs were used in each treatment and control, respectively. Egg survivorship was determined after fumigation using the procedures described above.

**Effects of Phosphine Fumigation with CO2 and Ethylene Absorbents on Gerbera Daisy Cut Flowers.** Gerbera daisy cut flowers were found injured by phosphine fumigation in the above experiment. In an effort to determine whether carbon dioxide or ethylene was a potential cause, an oxygenated phosphine fumigation experiment with gerbera daisy cut flowers was conducted with and without hydrated soda lime and ethylene absorber separately to compare their impact on flower quality. Cut flowers were fumigated with 2,500 ppm phosphine under 70% O2 for 72 h at 5°C. Five treatments were included in each test, phosphine alone, phosphine + CO2 absorbent, phosphine + ethylene absorbent, control in 70% O2, and control in ambient air. In each test, 10–12 stems of gerbera daisy were bundled and set up in each drum chamber.

About 15 g of soda lime in a cup was hydrated and placed in the treatment chamber. One gram of soda lime can absorb 150 ml (0.29 g) CO2 at 20°C (Sodasorb manual of CO2 absorption). About 5 g of potassium permanganate in a plastic vial (5 cm in diameter and 8.5 cm in height) was placed in the chamber for the phosphine + ethylene absorbent treatment. One gram of potassium permanganate can absorb over 900 μl ethylene at 25°C (Peiser and Suslow 1998). About 1,000 light brown apple moth eggs were included in each fumigation treatment and the control with ambient air in each test. The rest of procedures of treatments were the same as described above. The amounts of CO2 and ethylene absorbents placed in the respective treatment chambers were sufficient as indicated by no color change for either soda lime or potassium permanganate at the end of 72-h sealing. Each treatment was replicated three times. After fumigation, egg survivorship and cut flower quality were evaluated every day from day 1 to day 6 using the procedures described above.

**Data Analyses.** Insect egg mortalities from fumigation treatments of different cut flowers were corrected for the control mortality using Abbott's method (Abbott 1925) and then compared using one-way ANOVA and Tukey's HSD multiple range test of JMP statistical discovery software (SAS Institute 2012). Postharvest quality scores among treatments for all five tested cut flowers at different posttreatment times were also compared statistically using one-way ANOVA (SAS Institute 2012).

**Results**

The relative mortalities of light brown apple moth eggs in responses to 72-h fumigation treatments with 2,500 ppm phosphine for all five tested cut flowers ranged from 99.71 to 100%, and there were no significant differences among the cut flower species ($F = 0.840$, df = 4, 20; $P = 0.5162$). Mortality in the control was 13.21% (Table 1). The extended 96-h fumigation of chrysanthemum cut flowers with 2,200 ppm phosphine under 70% O2 at 5°C resulted in 99.98%
Table 1. Effects of oxygenated phosphine fumigation treatments under 70% oxygen on mortality of *E. postvittana* eggs on five cut flowers at 5°C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cut flower</th>
<th>Number of eggs</th>
<th>% Mortality (± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH$_3$ (ppm)</td>
<td>Time (h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,500</td>
<td>72</td>
<td>Tulip</td>
<td>3.747</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rose</td>
<td>3.577</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lily</td>
<td>3.760</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chrysanthemum</td>
<td>4.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daisy</td>
<td>3.728</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>3.748</td>
</tr>
<tr>
<td>2,200</td>
<td>96</td>
<td>Chrysanthemum</td>
<td>11.143</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>2.463</td>
</tr>
</tbody>
</table>

Controls were stored under the normal atmosphere at the same temperature.

Mortalities for controls were absolute mortalities and mortalities for treatments were relative mortalities calculated using Abbott’s method (Abbott 1925) to correct for control mortalities. Mortality values followed by the same letter were not significantly different based on Tukey’s multiple range test (*P* > 0.05, SAS Institute 2012).

Table 2. Response of *E. postvittana* eggs to 72-h fumigation treatments of gerbera daisy cut flowers with 2,500 ppm phosphine under 70% oxygen in the presence and absence of CO$_2$ or ethylene absorbent at 5°C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of eggs</th>
<th>% Mortality (± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH$_3$</td>
<td>3.571</td>
<td>99.08 ± 0.92a</td>
</tr>
<tr>
<td>PH$_3$ + CO$_2$ absorbent</td>
<td>3.546</td>
<td>98.69 ± 1.23a</td>
</tr>
<tr>
<td>PH$_3$ + ethylene absorbent</td>
<td>4.715</td>
<td>99.87 ± 0.09a</td>
</tr>
<tr>
<td>Control</td>
<td>3.715</td>
<td>23.02 ± 8.06</td>
</tr>
</tbody>
</table>

Controls were stored under the normal atmosphere at the same temperature.

* The mortality for the control was absolute mortality and mortalities for treatments were relative mortalities calculated using Abbott’s method (Abbott 1925) to correct for control mortalities. Mortality values followed by the same letter were not significantly different based on Tukey’s multiple range test (*P* > 0.05, SAS Institute 2012).

There were significant increases in CO$_2$ and ethylene levels in hermetically sealed drum chambers with gerbera daisy cut flowers under 70% O$_2$ by the end of 72-h treatment. In each drum with 10 stems of gerbera daisy, the average CO$_2$ level increased from the ambient level to 4.02 ± 0.31% and the average ethylene level increased to undetectable ambient level to 0.27 ± 0.11 ppm at the end of 72-h sealing. Oxygen levels, on the other hand, declined by 2.4 ± 0.5% from the original 70% at the end of 72-h sealing.

There were significant differences among the five cut flower species in susceptibility to oxygenated phosphine fumigation. Most cut flower species (four out of five) tolerated the 72-h fumigation treatment and only gerbera daisy cut flowers were sensitive to phosphine fumigation (Fig. 1). All cut flowers except pompon chrysanthemum showed declines of postharvest quality in vase over time. There was no difference between the treatment and the control at any time for tulip and lily. However, lily cut flowers from the treatment bloomed 2–3 d earlier than those from the control.

Fig. 1. Postharvest qualities of five cut flower varieties at different time intervals after 72-h oxygenated phosphine (2,500 ppm) fumigation treatments under 70% oxygen at 5°C for controlling light brown apple moth eggs. Legends: open circle: control in ambient air; filled circle: oxygenated phosphine fumigation treatment; open triangle: control under 70% oxygen. For the four flower species with two treatments, the * sign indicates significant difference between the fumigation treatment and the control at *P* ≤ 0.05. For Gerbera daisy, letters were used to indicate the significance of the differences among the three treatments. Treatments labeled with the same letter were not significantly different (*P* > 0.05, SAS Institute 2012).
The quality scores of rose from both treatment and the control showed rapid decline over time and reached the lowest score of 1 by day 8. However, the quality scores for the treatment were significantly higher than those for the control at day 3, 4, and 5. Roses from the control showed browning around the petal edges after they were placed in the growth chamber and roses from the treatment, however, did not show such symptoms. Pompon chrysanthemum cut flowers showed only slight but statistically significant declines in quality after day 6 in vase as compared with the control. The fumigation treatment, however, caused injuries to gerbera daisy cut flowers and resulted in a dramatic decline of quality scores at the start of vase life observation. The control had a quality score of about 4.5 and the treatment had a score of 1.5 at day 3. The control under 70% O₂ also showed slightly lower quality scores as compared with the control under the normal atmosphere and the difference was significant at day 5 (Fig. 1). For fumigated gerbera daisy cut flowers, the stems showed severe necrosis in a form of water-soaked, darkened, and flimsy dead tissues and the dead stem sections often collapsed and bended by the weight of flowers (Fig. 2). The necrosis was about 10–15 cm long and dried in 2–3 d in the growth chamber.

In the fumigation experiment with gerbera daisy, the control in the ambient air had the highest quality scores and quality showed slight decline from day 1 to day 6 in the vase. The quality for the control under 70% O₂ was not significantly different from the quality of the control in the ambient air initially but declined over time and was significantly lower than the quality for the control in the ambient air at day 5 and day 6 even though the quality scores were all above 4. The fumigation treatments with and without CO₂ or ethylene absorbent all had very low quality scores of ≤1.5 immediately after fumigation and there were no significant differences among them (Fig. 3).

Discussion

Cut flowers varied by species in response to oxygenated phosphine fumigation treatments for control of light brown apple moth eggs. Four out of five cut flower species tolerated well to the 72-h fumigation with 2,500 ppm phosphine as indicated by almost identical postharvest quality scores between the treatment and the control in most cases. However, the impact on quality of gerbera daisy by the fumigation treatment was very severe and made the cut flowers unsalable. These results suggest that oxygenated phosphine fumigation is safe to most tested cut flowers. However, fumigation tests need to be performed to identify susceptible species before the treatment can be used commercially.

The impact of the fumigation treatment on gerbera daisy cut flowers does not seem to be caused by either CO₂ or ethylene accumulation because adding the absorbent for either of them did not have any effect in lessening the injury. It is likely that phosphine caused the injuries to gerbera daisy cut flowers. Phytotoxicity...
of traditionally produced phosphine from metal phosphides is considered to be caused by ammonia which is coreleased with phosphine to modulate phosphine-releasing chemical reaction of metal phosphides (Bond 1984). The new low-temperature fumigation with pure cylindered phosphine is considered safe to fresh commodities because of the absence of ammonia and fumigation is conducted at low temperatures. However, the testing of pure phosphine on fresh commodities is still very limited as indicated by a few publications, and low-temperature fumigation with pure phosphine still has only been used in recent years on limited fresh products (Weller and van Graver 1998; Klementz et al. 2005; Liu 2008a, 2012; Liu et al. 2013, 2014; Zhang et al. 2013). The results of severe injuries to gerbera daisy cut flowers by phosphine fumigation in the present study suggest that pure phosphine can also be phytotoxic to certain fresh products.

There are considerable variations among cut flower species in sensitivity to ethylene (Mańcnez et al. 2010, van Doorn and Han 2011, Almasi et al. 2013). Ethylene can cause senescence and reduced vase life (van Doorn and Han 2011, Reid and Jiang 2012). Ethylene exposures were found to enhance flowering in Tritelia laxa lilies (Han et al. 1990), but to reduce flower opening in cut lily flowers (Elgar et al. 1999). It is not clear whether ethylene played a role in the observed 2–3 d earlier blooming of lilies from the fumigation treatment than those from the control in the present study. The ethylene level of about 0.27 ppm found in this study was much lower than a lower range of 2–10 ppm levels reported in other studies which may and may not affect cut flowers (van Doorn and Han 2011). However, ethylene at 0.3 ppm was also reported to have significant effects on bud openings of oriental lily ‘Stargazer’ (Han and Miller 2003). Given that ethylene was detected in the hermetically sealed chambers with gerbera daisy cut flowers, some cut flowers that are very sensitive to ethylene could be injured in a 3-d long phosphine fumigation treatment for control of light brown apple moth eggs. Therefore, it will likely to be beneficial to remove ethylene during phosphine fumigation with an absorbent especially when loading factor is high.

The increase of CO₂ level to about 4% by the end of 72-h hermetical sealing of gerbera daisy cut flowers in the drum chambers is relatively low in comparison to CO₂ levels used in modified atmosphere packaging of cut flowers to extend cut flower vase life (De Pascale et al. 2005, Tshwenyane et al. 2012). CO₂ levels of up to 10% in modified atmosphere packaging extend postharvest vase life of cut flowers (De Pascale et al. 2005). Atmospheres with 10% CO₂ also reduce Botrytis without damage to rose cut flowers (Tshwenyane et al. 2012). Therefore, an accumulation of about 4% CO₂ in the 72-h phosphine fumigation treatment for control of light brown apple moth eggs is not expected to cause negative impact on cut flower vase life.

In an earlier study, complete control of light brown apple moth eggs was achieved in a 72-h fumigation treatment with 2,000 ppm phosphine under 60% O₂ (Liu 2013). It was further suggested that phosphine had an optimal concentration of 1,500–2,000 ppm against light brown apple moth eggs and phosphine at 3,000 ppm actually became less effective (Liu 2013). In the present study, phosphine concentration in the 96-h treatment of chrysanthemum cut flowers was 2,200 ppm which is in or close to its optimal concentration range against light brown apple moth eggs. However, light brown apple moth egg mortality was 99.98%, and there were still a few eggs that survived the treatment. In another study, a 72-h fumigation treatment of lettuce and light brown apple moth eggs with 1,700 ppm phosphine under 60% O₂ also did not achieve 100% egg mortality (Liu et al. 2014). Phosphine concentrations in the earlier study and in the present study are likely in or close to an optimal concentration range. All these results suggest that even though oxygenated phosphine fumigation is more effective than regular phosphine fumigation against light brown apple moth eggs, it may not be able to achieve a probit9 level control of light brown apple moth eggs in practical fumigation treatments.

In summary, oxygenated phosphine fumigation was effective against light brown apple moth eggs on cut flowers and achieved >98% mortalities in all treatments. Cut flowers differed considerably by species in sensitivity to phosphine fumigation treatments. Four out of five species tolerated the 72-h oxygenated phosphine fumigation. The injuries to gerbera daisy cut flowers were likely due to direct effects of phosphine and were not linked to carbon dioxide or ethylene accumulation in the treatment chamber. The study indicated that oxygenated phosphine fumigation is safe to control light brown apple moth eggs on most cut flower species, but may not achieve the probit9 quarantine control level.
Acknowledgments

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