J. Amer. Soc. Hort. Sci. 112(3):469–473. 1987.

# Floral and Foliar Quality of Potted Easter Lilies after STS or Phenidone Application, Refrigerated Storage, and Simulated Shipment

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*Additional index words.* *Lilium longiflorum*, potted flowering plants, senescence, postharvest handling, ethylene

*Abstract.* **The poststorage and post-shipping quality of *Lilium longiflorum* Thunb. 'Nellie White' plants sprayed with silver thiosulfate (STS) complex or phenidone was observed in a simulated interior environment. Bud abortion and foliar chlorosis increased while floral longevity declined with increasing storage period from 0 to 4 weeks in the dark at 2°C. One to 3 days of simulated, boxed shipment at 23° subsequent to 3 weeks storage at 2° further increased foliar chlorosis but did not influence bud abortion or floral longevity. Whole plant STS sprays (0.5 to 2.0 mM Ag) prior to harvest reduced storage-induced bud abortion and increased floral longevity, but did not reduce foliar chlorosis. Ethephon application to plants that had been stored for 3 weeks at 2° induced bud abortion and abnormal floral development. STS application (1.0 mM Ag) prior to storage reduced ethephon-induced disorders. Preharvest whole plant sprays of phenidone decreased bud abortion on stored and nonstored plants but did not influence floral longevity. Uptake of phenidone and STS through cut petioles enhanced ethylene production during opening of excised lily buds. Ethylene production increased while respiration declined during senescence of excised buds. STS did not reduce but did delay the peak of ethylene production during senescence of lily flowers. Chemical names used: 1-phenyl-3-pyrazolidone (phenidone); (2-chlorethyl)phosphonic acid (ethephon).**

Easter lily storage studies have been limited, and the resulting commercial storage recommendations are vague (17). Potted 'Georgia' lilies stored satisfactorily at 0° to 2°C in vented boxes for up to 4 weeks, although keeping quality of the plants was not studied (8). Non-boxed 'Nellie White' lilies were held successfully for up to 25 days in the dark at 1.5°, if the plants were examined for disease and watered periodically (6). In contrast, only 1 to 2 weeks of boxed storage at 0.5° to 6.0° caused a 25–35% loss in plant longevity of 'Ace' and 'Nellie White' (15). Foliar chlorosis in a simulated interior environment was the primary factor causing loss of longevity (15).

Application of α·cyclopropyl-α-(4-methoxyphenyl)-5-pyrimidinemethanal (ancymidol) to lilies under poor phosphorous nutritional regimes (19) and ethylene exposure (22) have both been related to foliar chlorosis in the greenhouse. Exposure to ethylene during production also results in abortion of less mature flower buds and partial opening of mature buds (12). Abortion and abscission of *Lilium* 'Enchantment' buds are related to both ethylene exposure and periods of darkness at 21°C (4) and are reduced by STS application (16). However, no relationship of senescence of Easter lily flowers with ethylene exposure or production has been established.

Petal senescence has been linked to loss of membrane integrity (20), while membrane degradation in vegetative tissue has been related to the activity of lipoxygenase (5, 11). Application of phenidone, a known inhibitor of lipoxygenase activity (18), has delayed carnation senescence (2). Unlike STS, phenidone does not appear to function by reduction of ethylene action, but by a more direct effect on membrane integrity. The effect of phenidone application on senescence of Easter lily flowers or floral crops other than carnation has not been reported.

The present studies with potted Easter lilies were conducted to a) determine the impact of duration of refrigerated storage and simulated shipment on foliar chlorosis and floral longevity, b) examine the possible role of STS or phenidone application in alleviating storage disorders, c) relate bud abortion and floral senescence to ethylene exposure during handling, and d) study flower ethylene production and respiration from bud opening through floral senescence as affected by STS and phenidone application.

## Materials and Methods

*Plant material.* Studies were conducted during Spring 1984 and 1985. 'Nellie White' bulbs were obtained from a commercial supplier and forced by the controlled temperature forcing method according to standard commercial procedures (17). Bulbs were planted in a medium composed of peat, vermiculite, and perlite (Sunshine Mix No. 1) and grown at 32 (year 1) or 19 (year 2) plants per $m^2$ of bench area with constant liquid feed of 20N–0P–16.6K (250 ppm and N). Regular drenches with methyl[1-[(butylamino)carbonyl]-1*H*-benzimidazol-2-yl]carbamate (benomyl) [50% wettable powder (WP), 0.6 g·liter$^{-1}$] and 5-ethoxy-3-trichloro-methyl-1,2,4-thiadiazole(ethazol) (30% WP, 0.6 g·liter$^{-1}$) (year 1) or benomyl and *N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-DL-alanine methyl ester (metalaxyl) (25% emulsifiable concentrate, 0.8 ml·liter$^{-1}$) (year 2) were applied to control root rot. Only plants visually free of root rot were selected for study.

*Cold storage.* Prior to storage, plants were sprayed with benomyl (50% WP, 0.6 g·liter$^{-1}$) to prevent Botrytis. Conditions were 1.5° to 2.5°C and 65–85% RH in the dark with all plants being watered when needed.

*Interior holding.* After storage, plants were evaluated for keeping quality under a simulated consumer environment of 20° ± 0.5°C and 60–80% RH with 12 hr of light (8–11 μmol·s$^{-1}$·m$^{-2}$, 400–700 nm) per day from cool-white fluorescent (CWF) bulbs. Constant subirrigation was maintained with

Received for publication 28 Apr. 1986. Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State Univ. Journal Article no. 54–86. We thank the Ohio Floriculture Foundation for their financial support of this research. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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pans under each pot containing 1 cm of tap water (year 1) or plants were watered when needed (year 2).

*STS and storage (year 1).* Entire plants were sprayed to runoff (11–14 ml) with STS prepared by mixing equal volumes of $AgNO_3$ and $Na_2S_2O_3 \cdot 5H_2O$ in a molar ratio of 1 to 8. Plants were sprayed when the first bud of each plant was 6–9 cm in length with 0, 0.1, or 0.2 mM Ag in an aqueous solution of 0.1% (v/v) Tween-20. Plants were harvested with the most mature buds at the puffy white stage (7–10 days after spraying) and cold-stored for 0, 1, 2, 3, or 4 weeks. Three replicate plants with an average of 7.6 buds/plant were used for each STS–storage treatment combination in a completely randomized design. Upon removal from storage, plants were placed in the simulated indoor environment described previously. Each individual flower bud was observed for bud abortion or longevity of buds that opened. Flowers were considered senesced when the tepals lost turgidity and developed brown discoloration. At harvest, after cold storage, and on the day the last primary bud of each plant opened, the percentage of foliage that was chlorotic was estimated visually to the nearest 5%.

*STS and shipping stress (year 1).* Plants were sprayed similarly to those above with STS at 0 or 0.2 mM Ag. After harvest, all were cold-stored for 3 weeks. After storage, the plants were sleeved and kept in boxes at 23°C and 55–75% RH for 0, 1, 2, or 3 simulated shipping days. Two replicate boxes, each containing six plants with an average of 6.7 buds per plants, were used for each STS–shipping treatment combination in a completely randomized design. Plants were placed subsequently in the simulated interior environment and evaluated. In addition, the percentage of buds that opened in the boxes and the percent foliar chlorosis upon removal from the boxes were observed. Buds that opened in the boxes were not included in the longevity data.

*STS rate response (year 2).* STS was applied in the same manner as in year one at 0, 0.5, 0.1, 1.5, and 2.0 mM Ag. After harvest, the plants were cold-stored for 0 or 3 weeks. Three replicate plants with 6.2 buds/plant were used for each STS–storage treatment combination in a completely randomized design. Floral abortion, floral longevity, and foliar chlorosis at harvest, after storage, and in the interior environment were observed.

*STS and ethephon application (year 2).* STS in an aqueous solution of 0.1% Tween-20 surfactant was applied to entire plants at 0 and 1 mM Ag when the first bud had reached the puffy white stage. Plants then were cold-stored for 3 weeks. After removal from storage, entire plants were sprayed to runoff (11–14 ml) with 0, 3.8, or 7.6 mM ethephon as an ethylene source. Three replicate plants with 6.3 buds/plant were used for each STS–ethephon treatment combination in a completely randomized design. Floral longevity and bud abortion were observed in the interior environment.

*Phenidone application (year 2).* Phenidone in a solution of 3.3% (v/v) acetone (for solubility) and 0.1% Tween-20 surfactant was applied to entire plants to runoff (11–14 ml). Rates of 0.1, 1.0, and 10 mM phenidone were applied when the most-mature bud had reached the puffy white stage. Plants were then harvested and cold-stored for 0 or 3 weeks. Three replicate plants with 6.0 buds/plant were used for each phenidone–storage treatment combination in a completely randomized design. After storage, floral longevity, bud abortion, and foliar chlorosis were observed in the interior environment.

*Excised bud studies (year 2).* Individual buds were excised from plants 1 day prior to their opening and placed in individual vials containing deionized water or solutions of 0.5% (v/v) acetone, 0.1 mM phenidone and 0.5% acetone, or STS at 0.4 mM Ag for 30 min followed by deionized water. The water and acetone treatments served as controls for the STS and phenidone treatments, respectively. The vials were placed in 1.9-liter jars equipped with serum stoppers for gas sampling. Jars were flushed daily with compressed air, sealed, and kept at 20°C under 12 hr/day of light from CWF bulbs (27 $\mu mol \cdot s^{-1} \cdot m^{-2}$, 400–700 nm). Three replicate jars of each treatment or control as well as three additional control jars containing vials with water only were used in a completely randomized design. Solution uptake was measured during the study. Days to senescence were observed. At various intervals, gas samples were withdrawn for ethylene (1 ml) or $CO_2$ (3 ml) analysis by gas chromatography. Ethylene and $CO_2$ production rates then were calculated.

*Statistical analysis.* Analysis of variance was used in all studies, with planned F tests used to reveal specific trends or comparisons. Nonsignificant single degree of freedom tests for interactions are not shown in the tables, unless needed for clarity or uniformity. The arcsin transformation was performed prior to analysis of the percentage of chlorotic foliage data since it was a visual estimation with mean-dependent error (7).

## Results

*STS and storage.* Bud abortion began with the most immature buds and was observed as loss of green coloration leading to tepal dessication. Abortion on plants in the interior environment increased linearly with increased duration of refrigerated storage (Table 1). STS application at 0.1 or 0.2 mM Ag did not reduce the abortion resulting from cold storage.

Average floral longevity decreased linearly with increased storage duration (Table 1). STS application did not prevent this loss of longevity during storage.

About 15% of the plants' foliage was chlorotic at harvest and remained so through cold storage. Increased storage duration led to more rapid development of foliar chlorosis in the interior environment (Table 1), which was not reduced by STS.

*STS and shipping stress.* Simulated shipping was accompanied by opening of the flower buds in the boxes, an effect

Table 1. Bud abortion, average floral longevity, and foliar chlorosis of potted 'Nellie White' lilies after preharvest STS sprays and 0 to 4 weeks storage at 2°C (year 1).

| | Buds aborted (%) | | Floral longevity (days) | | Chlorotic[z] foliage (%) | |
|---|---|---|---|---|---|---|
| | | | STS rate (mM Ag)[y] | | | |
| Storage weeks | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 |
| 0 | 0 | 0 | 8.3 | 8.5 | 20 | 22 |
| 1 | 4 | 4 | 8.3 | 8.5 | 37 | 37 |
| 2 | 30 | 28 | 7.3 | 8.0 | 50 | 55 |
| 3 | 23 | 27 | 6.3 | 7.3 | 66 | 58 |
| 4 | 39 | 34 | 6.1 | 6.3 | 88 | 83 |
| F tests[x] | | | | | | |
| Weeks | | L*** | | L*** | | L*** |
| STS | | NS | | * | | NS |

[z]Determined at opening of last primary bud. Data anlayzed on arcsin-transformed scale.

[y]Responses to 0.2 mM Ag were not statistically different from 0.1 mM; data not shown.

[x]F tests were nonsignificant (NS) or significant at the 5% (*) or 0.1% (***) level and were linear (L).

that was not influenced by STS (Table 2). Floral longevity was not affected significantly by the simulated boxed shipment or STS treatment.

Bud abortion (Table 2) was reduced by STS application compared to nontreated plants after 0 or 1 day of shipping, but this benefit was not observed after 2 or 3 days (significant STS × days interaction). Ethylene levels in the boxes were ≈5 nl·liter$^{-1}$ during simulated shipment.

The percentage of foliar chlorosis observed immediately after removal from the boxes was not influenced by STS application, but increased cubically with increased shipping days. The greatest increase in chlorosis occurred between 1 and 2 days of shipping (Table 2).

*STS rate study*. Increasing the STS concentration from 0.5 to 2.0 mM Ag enhanced floral longevity of nonstored plants but had little effect on plants stored for 3 weeks (Table 3). Bud abortion was reduced by STS application at any rate compared to controls on both stored and nonstored plants (Table 3). STS had no significant effect on the development of foliar chlorosis (data not shown).

*STS and ethephon application*. Application of ethephon increased the percentage of buds aborted (Table 4). The least-mature buds at harvest tended to abort while those more mature tended to open abnormally. These abnormal flowers were greatly reduced in size while the exterior of the tepals was desiccated along the midrib. Prior application of STS reduced abortion on non-ethephon treated plants and also prevented floral abnormality on ethephon-treated plants (Table 4). On non-STS-treated plants, floral longevity was reduced by either rate of ethephon while the longevity decline was not as severe on STS-treated plants (Table 4). Neither ethephon application nor STS application significantly influenced foliar chlorosis development in the interior environment (data not shown).

*Phenidone studies*. Increasing the phenidone application rate from 0.1 to 1.0 mM decreased bud abortion on stored and nonstored plants (Table 5). A further increase to 10.0 mM increased bud abortion and also led to necrotic edges on the tepals. Floral longevity was not influenced by phenidone application at any rate, but it was reduced by 3 storage weeks.

*Excised bud studies*. Solution uptake during the STS pulse was 2.5 ml (1 μmol Ag) per pulsed bud. Solution uptake from the vials during the monitoring period was 10 ml/bud for water and the 0.5% acetone controls, 8 ml (0.8 μmol) per bud for phenidone, and 15 ml of deionized water for each STS-pulsed bud.

Respiration rates of STS- or phenidone-treated flowers were not significantly different from controls on any sampling date (Fig. 1A). Respiration of all flowers was constant or slightly increased through 4 to 6 days and declined thereafter.

Bud opening for all treatments occurred during the first day following excision. Both STS and phenidone treatment resulted in significantly higher ethylene production than either control during bud opening the first day, with STS resulting in nearly double the ethylene production compared to phenidone treatment (Fig. 1B). Ethylene production from both treatments declined after bud opening. Both controls and phenidone-treated flowers reached peaks in ethylene production 9 days after excision, while the peak ethylene production of STS-treated flow-

Table 2. Quality characteristics of potted 'Nellie White' lilies after preharvest STS sprays, 3 weeks storage at 2°C, and 0, 1, 2, or 3 days simulated shipment in boxes at 23° (year 1).

| STS rate (mM Ag) | Simulated shipping days | Buds opened in box (%) | Buds aborted (%) | Floral longevity (days) | Chlorosis[z] after shipping (%) |
|---|---|---|---|---|---|
| 0.0 | 0 | --- | 42 | 6.8 | 19 |
| 0.0 | 1 | 43 | 46 | 6.4 | 19 |
| 0.0 | 2 | 42 | 37 | 7.1 | 52 |
| 0.0 | 3 | 64 | 36 | 6.0 | 70 |
| 0.2 | 0 | --- | 28 | 7.4 | 17 |
| 0.2 | 1 | 38 | 26 | 7.3 | 19 |
| 0.2 | 2 | 31 | 38 | 7.1 | 55 |
| 0.2 | 3 | 65 | 42 | 7.0 | 60 |
| F tests[y] | | | | | |
| SYS | --- | NS | NS | NS | NS |
| Days | --- | L**Q* | NS | NS | L***C** |
| STS × days | --- | NS | L* | NS | NS |

[z]Data analyzed on arcsin-transformed scale.
[y]F tests were nonsignificant (NS) or significant at the 5% (*), 1% (**), or 0.1% (***) level and were linear (L), quadratic (Q), or cubic (C).

Table 3. Bud abortion and average floral longevity of potted 'Nellie White' lilies after preharvest STS sprays and 0 or 3 weeks storage at 2°C (year 2).

| | Buds aborted (%) | | Floral longevity (days) | |
|---|---|---|---|---|
| | Storage (weeks) | | | |
| STS rate (mM Ag) | 0 | 3 | 0 | 3 |
| 0.0 | 14 | 21 | 8.3 | 8.9 |
| 0.5 | 0 | 0 | 8.6 | 9.2 |
| 1.0 | 0 | 11 | 8.8 | 9.3 |
| 1.5 | 0 | 0 | 9.2 | 9.1 |
| 2.0 | 0 | 0 | 9.8 | 9.1 |
| F tests[z] | | | | |
| STS vs. no STS | | ---[y] | | * |
| STS rate | | --- | | NS |
| Weeks | | --- | | NS |
| Rate × weeks | | --- | | C* |

[z]F tests were nonsignificant (NS) or significant at the 5% (*) level and were cubic (C).
[y]Assumptions of analysis of variance violated.

Table 4. Quality characteristics of potted 'Nellie White' lilies following STS sprays at harvest, 3 weeks storage at 2°C, and subsequent ethephon application (year 2).

| | Buds aborted (%) | | Abnormal flowers (%) | | Floral longevity (days) | |
|---|---|---|---|---|---|---|
| | | | STS rate (mM Ag) | | | |
| Ethephon rate (mM) | 0 | 1 | 0 | 1 | 0 | 1 |
| 0 | 16 | 0 | 0 | 0 | 8.6 | 9.6 |
| 3.8 | 58 | 32 | 21 | 0 | 7.2 | 9.1 |
| 7.6 | 53 | 39 | 41 | 0 | 6.0 | 8.9 |
| F tests[z] | | | | | | |
| STS | | ** | | ---[y] | | *** |
| Eth vs. no eth | | *** | | --- | | *** |
| Eth rate | | NS | | --- | | NS |
| STS × eth | | NS | | --- | | * |
| STS × eth rate | | NS | | --- | | NS |

[z]F tests were nonsignificant (NS) or significant at the 5% (*), 1% (**), or 0.1% (***) level.
[y]Assumptions of analysis of variance violated.

Table 5. Bud abortion and average floral longevity of potted 'Nellie White' lilies after phenidone sprays at harvest and 0 or 3 weeks storage at 2°C (year 2).

| Treatment | Buds aborted (%) | | Floral longevity (days) | |
|---|---|---|---|---|
| | Storage (weeks) | | | |
| | 0 | 3 | 0 | 3 |
| Phenidone (mM) | | | | |
| 0.1 | 6 | 25 | 8.7 | 7.9 |
| 1.0 | 0 | 14 | 8.3 | 8.3 |
| 10 | 20 | 37 | 8.5 | 8.3 |
| Controls | | | | |
| Water | 11 | 29 | 8.9 | 8.2 |
| 3.3% Acetone | 11 | 23 | 8.8 | 8.1 |
| F tests[z] | | | | |
| Weeks | | ** | | ** |
| Controls vs. phenidone | | NS | | NS |
| Water vs. acetone | | NS | | NS |
| Phenidone rate | | Q* | | NS |

[z]F tests were nonsignificant (NS) or significant at the 5% (*) or 1% (**) level and were quadratic (Q).

ers was delayed by at least 2 days. STS-pulsed buds senesced 11 days following excision, while buds from all other treatments senesced on the 10th day. Senescence for all treatments was marked by brown discoloration and loss of turgidity of the tepals.

## Discussion

Refrigerated storage in the dark increased bud abortion on potted Easter lilies in three separate studies (Tables 1, 3, and 5). STS application at rates up to 0.2 mM Ag in year 1 did not reduce storage-induced abortion (Table 1), but application of 0.5 to 2.0 mM Ag did reduce storage-induced bud abortion in year 2 (Table 3). STS application at 0.5 to 2 mM Ag therefore should be valuable on a commercial basis to reduce bud abortion, especially on plants destined for periods of refrigerated storage. Since STS application reduced both ethephon and storage-induced bud abortion (Table 3), it seems likely that ethylene has some role in storage-induced bud abortion. However, STS did not reduce bud abortion beyond 1 day in the boxes (Table 2). Under the dark, warm conditions in boxes, carbohydrate competition between the opening buds and the immature buds may play a role in abortion (24).

Floral longevity in the interior environment declined as prior cold storage duration increased. Application of 0.5 to 2.0 mM of Ag prevented this decline and increased the floral longevity on plants not stored (Table 3). However, these gains were minor compared to the dramatic results obtained with other species (3, 9, 10, 21). In later studies not reported here, STS application of up to 16 mM Ag did not extend longevity beyond that obtained with 2 mM in these studies. Therefore, it appears that STS will not be valuable on a commercial basis for floral longevity enhancement.

Increased ethylene production after Ag application has been detected from some vegetative tissues during such stresses as sleeving, vibrational shock, or shoot tip excision (1, 13, 23). In our study, bud excision stress could have enhanced ethylene production during the first day after excision unrelated to bud opening. The tepals may have responded like vegetative tissue, since they are morphologically modified sepals. While the

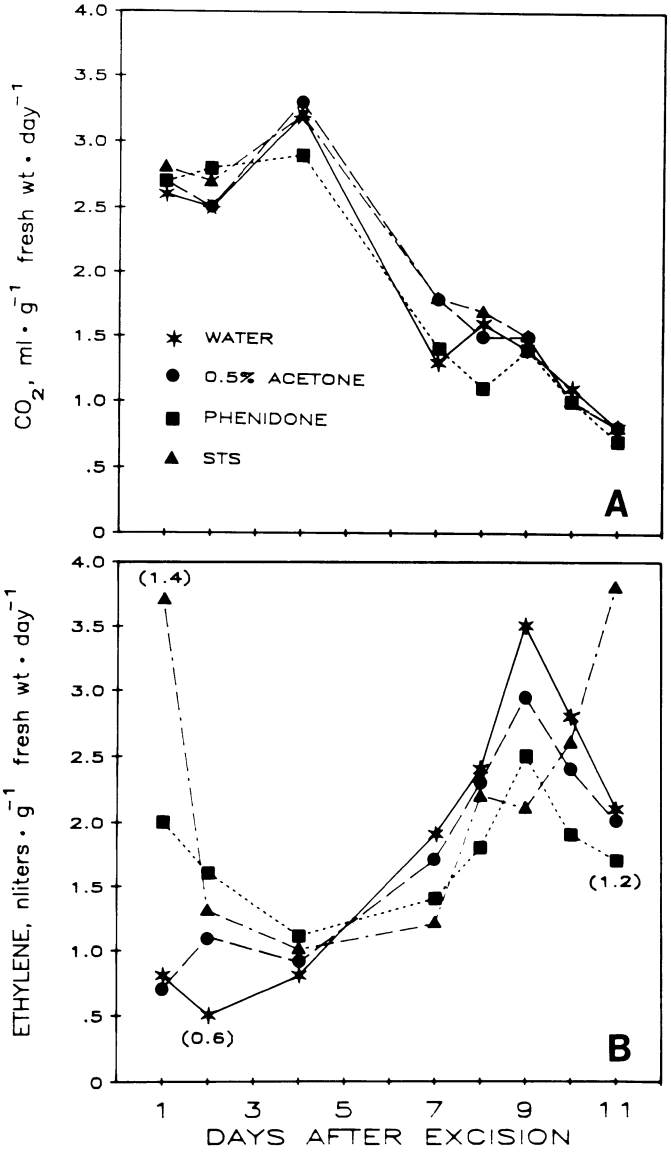


Fig. 1. Carbon dioxide (**A**) and ethylene (**B**) production of excised lily buds after a 30-min pulse of STS (0.4 mM Ag), or during continuous application of 0.1 mM phenidone, 0.5% acetone, or deionized water. Values in parentheses are Tukey's HSD ($P$ = 0.95) within sampling day. No value indicates no significant differences on that sampling day.

mechanism for Ag stimulation of ethylene production is unknown, nonspecific ion toxicity or interference with feedback inhibition of ethylene production have been suggested (23).

These studies suggest only a minor role of ethylene action in coordinating senescence of Easter lily flowers. A rise in ethylene production preceded senescence of excised flowers from all treatments, including STS-treated buds (Fig. 1B), suggesting that the rise in ethylene production is not from autocatalytic production, since this should have been greatly reduced by Ag application (21, 22). The induction of a climacteric respiratory response (14) by ethylene is apparently lacking in *L. longiflorum* (Fig. 1A).

The failure of phenidone to enhance floral longevity was likely due to lack of lipoxygenase inhibition or to little involvement of lipoxygenase activity in senescence of Easter lily flowers. Poor uptake may be ruled out as cause for failure, since application enhanced ethylene production (Fig. 1B) and bud abortion

was reduced by whole plant sprays (Table 5). The enhancement of ethylene production during opening was most likely a toxic response. The anti-abortive effect of phenidone was not as dramatic as that obtained from STS application, and the observed phytotoxicity could be a problem for commercial application.

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