Prevention of corolla abscission in New Guinea impatiens during simulated shipping and holding in an interior environment

Edwin Saragih
Iowa State University

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Prevention of corolla abscission in New Guinea impatiens during simulated shipping and holding in an interior environment

by

Edwin Saragih

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

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Signatures have been redacted for privacy

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Ames, Iowa
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I. INTRODUCTION

A. Background of Problem

New Guinea impatiens have become increasingly popular since the first hybrid plants were introduced at Longwood Gardens in 1972 (Martin, 1984). Their nomenclature still is ambiguous because of extensive interspecific breeding programs and because they have been produced under various species and cultivar names. To overcome this ambiguity, it has been suggested that impatiens clones in cultivation are named as Impatiens Xhawkeri Bull. (Grey-Wilson, 1980).

These impatiens have festive, colorful, and large flowers and interesting leaf variegation. These qualities make them attractive in hanging baskets or as bedding or balcony plants. Because of their success in the shade (Martin, 1984) and versatility (Weigle and Stephens, 1984), these plants also may be grown indoors, and this means an improvement in market value. Also, because of their capability for year-round flowering and their availability in a wide range of colors, they may be used for special holiday occasions such as Christmas, Mother's Day, or Valentine's Day.

One major problem is that New Guinea impatiens exhibit corolla abscission during shipping and marketing, and this is considered as quality lost by producers, retailers, and consumers. Woltering (1986) observed
that most of the economically important ornamental crops were less sensitive to this abscission problem and perhaps they have been unintentionally selected by consumers and producers.

Various environmental factors cause physiological changes that accelerate abscission of flowers or other parts of plants. In many cases, the physiological changes relate to an increase in ethylene (C$_2$H$_4$) production, especially in the tissues distal to an abscission zone before the plant parts abscise (Addicott, 1982; Jackson and Osborne, 1970).

This abscission problem may be reduced through breeding programs, improvement of cultivation techniques and handling environments, and application of chemical sprays that reduce, if not prevent, C$_2$H$_4$ production and/or action in plants. Several chemical substances reduce flower abscission and senescence of potted and cut florist crops. These include silver thiosulfate (STS), a putative inhibitor of C$_2$H$_4$ action and (aminooxy)acetic acid (AOA), an inhibitor of C$_2$H$_4$ biosynthesis. These chemicals effectively reduce C$_2$H$_4$-induced flower abscission or senescence of various crops (Cameron and Reid, 1983; Veen, 1983; Fujino et al., 1980; Wang and Baker, 1980). If these chemicals are effective, and adequate spray programs to prevent corolla abscission during handling can be developed, *Impatiens Xhawkeri* Bull. may become more accepted as an economically important indoor florist crop.
B. Objectives

The primary objective of this research was to develop a possible preventive chemical spray program that stops or reduces C\textsubscript{2}H\textsubscript{4}-induced corolla abscission of *Impatiens xhawkeri* Bull. during shipping and holding in an interior environment.

Three specific objectives of this research were:

1) To determine the effect of temperature and time on corolla abscission of *Impatiens xhawkeri* Bull. during simulated shipping;

2) To develop preventive spray programs that use C\textsubscript{2}H\textsubscript{4}-inhibiting compounds (STS and AOA) to stop or reduce corolla abscission under simulated shipping conditions; and

3) To determine whether AOA and STS are effective in extending flower longevity during holding in a simulated interior environment.
II. LITERATURE REVIEW

A. Ethylene and Flower Abscission

Ethylene, the simplest unsaturated hydrocarbon compound, exists in the gaseous state under normal physiological conditions, and it is considered to be a plant hormone. Its physiological effects and mode of action in plants have been studied since Neljubov, in 1901, reported his studies on pea (Abeles, 1973; Lieberman, 1979; and Yang and Hoffman, 1984). This compound has been related to almost all aspects of plant growth and development: seed germination (Ketring and Morgan, 1972), vegetative growth (Abeles and Rubinstein, 1964; Burg and Burg, 1968; Hillman et al., 1985; Lurssen and Konze, 1985; and Musgrave and Walters, 1973), flowering (Hall and Forsyth, 1967), fruit ripening (Grierson et al., 1985), and abscission and senescence of plant organs (Addicott, 1982; Kozlowski, 1973; and Sexton et al., 1985).

In 1908, it was reported for the first time that \( \text{C}_2\text{H}_4 \) was a potent plant growth regulator that could cause floral senescence and abscission (Crocker and Knight, 1908). Floral abscission may involve the entire inflorescence, flowers, or the corolla. The mechanism seems to be analogous to those in leaves and fruits, with the formation of an abscission layer and accelerated cell division in this region. Petal or corolla abscission, however, shows no abscission layer, although a rise in
the activity of cell-wall hydrolytic enzymes has been detected (Mayak and Halevy, 1980).

Natural flower senescence or abscission usually occurs after pollination and fertilization (Arditti and Flick, 1973; Halevy, 1986). It was shown that the production of C_2H_4 increased within 15 minutes after application of pollen to the stigma of Dianthus caryophyllus L. Analysis of materials removed from pollen showed the presence of elevated concentrations of the C_2H_4 precursor 1-aminocyclopropane-1-carboxylic acid (ACC). This compound, which is present in the pollen of a number of flowering species and which increases in concentration as the anthers develop, may be an important mediator of the early response of flowers to pollination (Whitehead et al., 1983).

Ethylene-induced flower abscission often occurs before pollination due to an increase in the endogenous C_2H_4 level that may occur when the plants are exposed to external factors such as mechanical wounding (Boller and Kende, 1980), suboptimum temperatures (Field, 1985), phytopathogens (Achilea et al., 1985), water stress (Graves and Gladon, 1985; McMichael et al., 1972), air pollutants such as SO_2, ozone, halogens, and heavy metals (Meyer et al. 1987), or exposure to exogenous C_2H_4 (Abeles, 1973).
B. Ethylene Biosynthesis

Ethylene biosynthesis has been reviewed extensively by several authors (Yang and Hoffman, 1984; Yang, 1985). Lieberman et al. (1965, 1967) and Burg and Clagett (1967) presented evidence that established methionine as a precursor of C\textsubscript{2}H\textsubscript{4}. Studies by Adams and Yang (1977) suggested that C\textsubscript{2}H\textsubscript{4} was derived from methionine via S-adenosylmethionine (SAM), based on results that showed 5-methylthioadenosine (MTA) and 5-methylthioribose (MTR) as part of the degradation products. Further experiments by these investigators (Adams and Yang, 1979) demonstrated the existence of another intermediate that was identified as ACC, which was converted rapidly into C\textsubscript{2}H\textsubscript{4} in an oxygen-dependent reaction. It has been established that this compound, ACC, is the immediate precursor of C\textsubscript{2}H\textsubscript{4}.

When ACC was oxidized to C\textsubscript{2}H\textsubscript{4}, CO\textsubscript{2} and HCN were by-products of this degradation. This step was followed by detoxification of HCN by β-cyanoalanine synthase, which is distributed widely in plant tissues (Yang and Hoffman, 1984). ACC also may be conjugated irreversibly to malonyl-ACC (Hoffman et al., 1982; Peiser, 1986) as a control step of the C\textsubscript{2}H\textsubscript{4} production rate. However, there was evidence of an MACC-metabolizing system that might be the source of ACC, which occasionally was observed during the postclimacteric stage of C\textsubscript{2}H\textsubscript{4} production (Matern et al., 1984).

In general, ACC synthase, which catalyzes the conversion of SAM to ACC, is the rate-controlling factor in C\textsubscript{2}H\textsubscript{4} biosynthesis. The synthesis of
this enzyme can be induced by various internal and external factors, and it leads to a dramatic increase in \( \text{C}_2\text{H}_4 \) production (Yang, 1985).

The activity of the enzyme that converts ACC to \( \text{C}_2\text{H}_4 \) has not been characterized, although its activity was detected \textit{in vivo}. Ethylene-Forming-Enzyme (EFE) or ACC-oxidase was activated by CO\(_2\) and inhibited by dinitrophenol (DNP), Co\(^{2+}\), and various internal and external factors. Low activity of EFE limits \( \text{C}_2\text{H}_4 \) production in immature fruits and flowers (Yang, 1985). The continuation of \( \text{C}_2\text{H}_4 \) biosynthesis is guaranteed by the recycling of MTA or MTR liberated during the conversion of SAM to ACC to regenerate methionine via 2-keto-4-methylthiobutyrate (KMB) as demonstrated by Kushad et al. (1983).

\section*{C. Ethylene Action and Abscission}

Even though evidence that demonstrates the relationship between \( \text{C}_2\text{H}_4 \) production and flower abscission is abundant, the mechanism of the relationship remains in question. The disagreement continues among investigators as to whether \( \text{C}_2\text{H}_4 \) acts as the actual trigger of senescence, if its production is a consequence of earlier processes of senescence, or if \( \text{C}_2\text{H}_4 \) is simply an accelerating agent. This problem arises because the pattern of \( \text{C}_2\text{H}_4 \) production during aging differs among many species and among many organ types.
In carnation, the visible signs of senescence occur simultaneously or slightly after the burst of \( C_2H_4 \) production (Downs and Lovell, 1986; Trippi and Paulin, 1984), and an increased level of \( C_2H_4 \) is required for in-rolling of petals (Halevy and Mayak, 1981). In contrast, \( C_2H_4 \) production of *Ipomoea* and *Tradescantia* increased after the flowers showed significant signs of fading, and this suggested that \( C_2H_4 \) production may be a consequence of aging (Kende and Baumgartner, 1974; Suttle and Kende, 1978). Exposure of *Ipomoea* immature petals to \( C_2H_4 \) induced senescence without any increase in \( C_2H_4 \) evolution, while mature flowers shows both phenomena. Perhaps some metabolic events occurred before aging and caused the tissue to become sensitive to \( C_2H_4 \). When \( C_2H_4 \) was present, it served as an accelerating agent of abscission.

Abeles et al. (1971) proposed that \( C_2H_4 \) played a dual role in the abscission of bean petioles. First, it promoted or actually was required in the aging process. They demonstrated that exposure to \( C_2H_4 \) at the initiation of the aging process (when IAA was able to prevent the loss of break strength) enhanced the subsequent reduction in break strength. Secondly, \( C_2H_4 \) induced the enzymes required for cell separation. Subsequent exposure to \( C_2H_4 \) during the aging period caused the promotion of cellulase synthesis.

Ethylene metabolism may be related directly to its mode of action (Beyer, 1979), even though the rate of \( C_2H_4 \) metabolism in higher plants is low in comparison with the physiological \( C_2H_4 \) concentration.
Sanders et al. (1986) suggested that \( \text{C}_2\text{H}_4 \) was oxidized to produce ethylene oxide, which interacted with a binding site to bring about the appropriate biochemical response. They referred to the earlier Burg and Burg (1967) hypothesis of a metal-protein binding site in \( \text{C}_2\text{H}_4 \) action.

Osborne (1977, 1979) proposed the existence of \( \text{C}_2\text{H}_4 \)-responsive target cells for which differentiation is critical for an abscission event to occur. These cells are stimulated by \( \text{C}_2\text{H}_4 \) to enlarge and divide and to produce and secrete polysaccharide-hydrolyzing enzymes that weaken the middle lamellae and matrix structure of cell walls. Ultimately, these events lead to abscission. In female flower buds of squirting cucumber (\textit{Ecballium elaterium}), these target cells are distinct and are caused to enlarge in the presumptive separation region. These cell possess a large-sized nucleus and can be identified by their content of endoreduplicated (8C) nuclear DNA (Wong and Osborne, 1978).

Trewavas (1982) suggested that the sensitivity of plant tissues to hormones likely is the limiting factor for the biochemical responses, rather than the concentration of the hormone. In general, sensitivity of abscission zones of leaves, fruits, and flowers to \( \text{C}_2\text{H}_4 \) increases as they mature (Abeles, 1973), and flowers are considered to have the greatest sensitivity to \( \text{C}_2\text{H}_4 \) among plant organs. Abscission can occur after 2 to 4 hours of exogenous \( \text{C}_2\text{H}_4 \) exposure (Leshem et al., 1986). Some environmental factors such as a high temperature and water stress also may increase the sensitivity of the tissue to \( \text{C}_2\text{H}_4 \) (Leshem et al., 1986; Spikman, 1986).
Tissue sensitivity to \( \text{C}_2\text{H}_4 \) relates to the endogenous auxin content of the tissue (Beyer, 1975). The more auxin present in the abscission zone, the less sensitive it is to \( \text{C}_2\text{H}_4 \). The sensitivity of the tissue also may be related to the changes in the binding sites (Sanders et al. 1986) or to the formation of specific target cells (Osborne, 1979).

D. Abscission Related to Environmental Stress

Various environmental stresses have been implicated in increased plant sensitivity to \( \text{C}_2\text{H}_4 \). The stresses also cause increased \( \text{C}_2\text{H}_4 \) evolution from tissue. Ethylene production was stimulated in Freesia buds if the inflorescences were stressed through detachment, and this coincided with an increased level of ACC and MACC (Spikman, 1987). Similar responses were shown in water-stressed wheat leaves (Hoffman et al., 1983; Wright, 1981). In carnations, AOA, which inhibits \( \text{C}_2\text{H}_4 \) biosynthesis, relieved the water-stress effect in storage environments (Mayak and Faragher, 1986). Graves and Gladon (1985) demonstrated that endogenous \( \text{C}_2\text{H}_4 \) increased rapidly and then declined gradually within 6 hours after a water stress treatment.

Waterlogging also influenced \( \text{C}_2\text{H}_4 \) production in the plant shoot (Jackson and Campbell, 1976). It was shown that ACC conversion to \( \text{C}_2\text{H}_4 \) was blocked under anaerobic conditions in the root. Subsequently, ACC was transported to the shoot through the vascular systems (Bradford and Yang, 1980). The conversion of SAM to ACC seems to be the key reaction that controls the production of stress-induced \( \text{C}_2\text{H}_4 \). AVG, a potent inhibitor of
ACC synthase, and cycloheximide, a protein synthesis inhibitor, reduced ACC production and stress C₂H₄ production (Amrhein et al., 1982).

High or low temperature has been responsible for abscission in many species (Addicott, 1968). Flower abscission of seed geraniums can be prevented if they are transported under cool temperatures (Armitage et al., 1980). When cut carnations were removed from low to ambient temperature, C₂H₄ production increased immediately. Apparently, ACC production continued during storage, while C₂H₄ action was suppressed. This lead to a sudden increase in C₂H₄ production when the temperature was returned to the optimum level (Mayak and Faragher, 1986).

It has been suggested that light (irradiance) has a regulatory effect on abscission. A low light intensity caused leaf abscission of several species and this suggested that the important effect of light is on photosynthesis and consequently on the supply of carbohydrates (Addicott, 1982). However, several studies suggested that the response of abscission due to light is more likely photomorphogenic. At low levels, a red-light treatment prevented dark-induced leaf abscission of mung bean (Vigna radiata) cuttings. The amount of inhibition depended upon the wavelength of the light treatment, and red light was more influential than other wavelengths (Decoteau and Craker, 1983; Heindl and Brunn, 1983). It seems that phytochrome is involved in light-regulated abscission, and because phytochrome cannot be formed in dark, abscission is accelerated (Curtis,
1978). The manner in which phytochrome mediates hormonal responses in the plants is not well understood.

Light-controlled flower bud abscission of *Lilium* X'Enchantment' was mediated by C₂H₄ (van Meeteren and de Proft, 1982). Light inhibited C₂H₄ production in oat (*Avena sativa*) leaf segments by suppressing the conversion of ACC to C₂H₄ (Preger and Gepstein, 1984), and the same results have been shown in excised rice (*Oryza sativa*) and the cotyledons of tobacco (*Nicotiana tabacum* L.), where CO₂ markedly reduced the inhibition (Kao and Yang, 1982).

E. STS and Flower Abscission

Silver ion (Ag⁺) is a potent inhibitor of the mode of action of C₂H₄ (Beyer, 1976). The discovery of the mobile, anionic complex of silver and thiosulfate, best represented as [Ag(S₂O₃)₂]³⁻, has led to treatments for the prevention of C₂H₄ injury and increased longevity of certain flowers (Veen and van de Geijn, 1978; Veen, 1983). This compound stopped or reduced several C₂H₄-related problems of certain florist crops.

Studies on *Schlumbergera truncata* showed that pretreatment with 2 mM STS retained all buds and flowers after even days of exposure to 0.5 ul/l C₂H₄ (Cameron and Reid, 1981a). Agnew et al. (1985) showed that foliar sprays at 0.5 mM and 1 mM applied one week before simulated shipping reduced corolla abscission of *Streptocarpus Xhybridus* to 0 %. This
chemical also was effective in the reduction of flower and bud abscission of *Streptocarpus* caused by exposure to exogenous C$_2$H$_4$, although there was a problem with phytotoxicity (Rewinkel-Jansen, 1986). A similar response was recorded in *Calceolaria herbeohybrida* Vass., where STS foliar sprays at 0.5 mM reduced flower abscission during holding in the dark for four days or two days exposure to 1 ul/l C$_2$H$_4$ (Cameron and Reid, 1983).

Silver thiosulfate also prevented C$_2$H$_4$-induced flower malformation and bud abscission of *Begonia Xcheimantha* Everett (Moe and Smith-Eriksen, 1986), and STS-sprayed *Hibiscus rosa-sinensis* exhibited better bud retention than control plants after 20 days of holding in a simulated interior environment (Hoyer, 1986). Petal drop that normally is associated with postharvest handling of seed-derived *Pelargonium Xhortorum* was inhibited by STS sprays at 0.5 mM applied during early development of flower buds. Foliar sprays with STS also caused all buds on each inflorescence to open and it gave a better flower shape (Farthing and Chappel, 1982).

The activity of Ag$^+$ in reducing flower abscission is not understood completely. It was suggested that Ag$^+$ interfered with the C$_2$H$_4$-binding complex because Ag$^+$ significantly lowered C$_2$H$_4$ binding in a plant extract (Sisler, 1982). Sisler et al. (1986) studied this binding site by using an isotope competition technique. In a study that used 2,5-norbornadiene (NBD) and STS, Veen (1986) proposed a theoretical model for the antiethylene effect of the two inhibitors. It was hypothesized that NBD
and \( C_2H_4 \) compete for a site at a proteinaceous, regulatory unit that is a part of the \( C_2H_4 \) receptor site. This unit must be activated by a copper atom(s), and when the unit received \( C_2H_4 \), it caused an allosteric change, whereas NBD did not. In addition, the \( C_2H_4 \) receptor also consisted of one or more enzymic subunits that were activated by copper atom(s). Because of the similarity in their atomic structure, silver seems to compete with copper for a site in the enzymic units, and when silver binds, the enzymic activity is not activated.

F. AOA and Flower Abscission

When ACC was identified as the intermediate between SAM and \( C_2H_4 \) in the \( C_2H_4 \) biosynthesis pathway, it also was shown that the conversion was mediated by a pyridoxal-phosphate enzyme, because the formation of ACC was blocked by inhibitors of pyridoxal-phosphate-mediated enzyme reactions (Adams and Yang, 1979). These results were confirmed by Yu et al. (1979) who showed that ACC synthase activity was inhibited competitively by AOA, a compound for which general reactivity towards pyridoxal phosphate-dependent enzymes was well recognized (Amrhein and Wenker, 1979; John and Charteris, 1978). The practical use of this compound in potted ornamental plants has not been demonstrated as widely as STS. However, its capability to inhibit \( C_2H_4 \) biosynthesis has been shown in carnation (Fujino et al., 1980; Wang and Baker, 1980) and apple and mung bean tissues (Amrhein and Wenker, 1979). Auxin-induced epinastic growth of tomato petioles was suppressed by AOA (Amrhein and Schneebeck, 1980).
This compound alone is not effective in the prevention of the effect of exogenous \( C_2H_4 \) (Broun and Mayak, 1981), but in the future, when shipping and handling environments can be improved, AOA may become useful. van Staden and Beekhuizen (1986) combined AOA with three plant growth regulators (gibberellic acid, kinetin, and daminozide) plus the detergent Triton X-100 with promising results. This formula increased the vase life of carnations after exposure to 0.21 ul/1 \( C_2H_4 \) during simulated transport, and the result was comparable to that in STS treated plants. It also was mentioned that the organic nature of AOA offers an advantage, compared with STS, for environmental conservation reasons.
III. MATERIALS AND METHODS

A. Plant Material

'Enterprise', 'Meteor', 'Solared', and 'Sunfire' New Guinea impatiens were grown sequentially in greenhouses at the Department of Horticulture at Iowa State University from July, 1987, until December, 1988. Stock plants of these "Sunshine Series TM" impatiens were obtained from Mikkelsen's, Inc., Ashtabula, Ohio.

Tip cuttings of length 3 to 4 cm were propagated in a perlite and 
Hypnum peat moss mix (1:1 v/v) in 7.5-cm (volume) square pots under mist for two weeks. After another two or three weeks, plants were transplanted into a root medium that contained Sphagnum peat moss, perlite, and field soil (40:40:20 by volume) in 13-cm (volume) azalea pots. Water was applied once or twice daily with semiautomatic drip irrigation. Peters' 20-10-20 (N-P-K) soluble fertilizer was applied at 235 mg/l N once per week, and it was alternated with the application of a calcium nitrate/potassium nitrate mix (250 mg/l N and 270 mg/l K) twice a week. Peters' soluble trace elements mix was applied at full dosage several days after the plants were transplanted into the azalea pots, and it was repeated every two months.

The plants were grown under natural light conditions at a temperature maintained at 21C day and night. However, during some summer days, the temperature reached 30C. When the plants had five flowers or more, they were considered marketable and ready for treatment.
B. Experiment 1: Effect of Temperature and Time of Simulated Shipping on Corolla Abscission of *Impatiens Xhawkeri* Bull.

This experiment was conducted from December 19, 1987, to January 15, 1988, on *Impatiens Xhawkeri* Bull. 'Enterprise' and 'Meteor'. Before simulated shipping, the plants were watered to field capacity to avoid water stress. Aging, abnormal or damaged flowers were removed and the number of open corollas were counted. The shipping simulation involved placement of the plants in plastic sleeves and placement of them individually into 33cm x 33cm x 33cm ventilated cardboard boxes. They were arranged in three different walk-in growth chambers with temperatures set at 11.5, 22.5, and 33 ± 1°C as measured with thermocouples (Bailey Instruments Co., Inc., Saddle Brook, NJ). The plants were kept in the chambers for 48, 72, or 96 hours without light. Relative humidity in the chambers during treatment was 70 to 80 percent as measured with an aspirated psychrometer. Simulated shipment began at the same time for all treatments, and each treatment was removed according to the assigned length of shipment time.

The experiment was arranged in a split-plot design with temperature as the main plot, and cultivar by time as the sub-plots. The experiment was conducted in three replications over time, with two individual observations per replication.

Percentage corolla abscission was observed immediately after the simulated shipping time, and it was based on the ratio of the number of
abscised corollas to the number of open corollas counted before shipping. A flower was defined as abscised when one or more petals in the corolla were separated from the flower after being touched with a finger.

C. Experiment 2: Effect of STS and AOA on Corolla Abscission of Impatiens Xhawkeri Bull. during Simulated Shipping

'Enterprise', 'Meteor', 'Solared', and 'Sunfire' were sprayed with STS or AOA solutions until run-off (about 40 ml/plant) with an atomizing, plastic spray bottle. Each chemical was applied at 0.0, 0.5, 1.0, 1.5, or 2.0 mM of each chemical. These dosages were applied 1, 2, or 4 weeks before shipment. Silver thiosulfate was obtained by mixing AgNO₃ (Fisher) and Na₂S₂O₃·5H₂O (Fisher) at molar ratio of 1 : 8 [Ag⁺:(S₂O₃)²⁻] as suggested by Veen and van de Geijn (1978). Before spraying, all open flowers were removed.

Simulated shipping was conducted in dark walk-in growth chambers at 25 ± 1°C as measured with a thermocouple. Relative humidity was measured and it was approximately 80 percent. Simulated shipping exposure time was 72 hours. Cardboard boxes with dimensions of 35cm x 33cm x 48cm were used to ship two plants (observations) in each box. Other conditions were the same as those recorded in experiment 1.

Shipment of STS-treated plants was conducted between August 26, 1988, and September 18, 1988, while the AOA-treated plants were shipped between
October 20, 1988, and November 12, 1988. Every treatment was replicated three times (over time) with two observations in each replication. The experiment was arranged a split-plot design with cultivar as the main plot and chemical concentration by time as the sub-plot. Observations on corolla abscission were done in the same manner in which experiment 1 was conducted.

D. Experiment 3: Effect of STS and AOA Spray Treatments on Flower Longevity of Impatiens Xhawkeri Bull. in a Simulated Interior Environment

Foliar sprays of STS and AOA were applied to 'Enterprise', 'Meteor', 'Solared', and 'Sunfire' two weeks before exposure to a simulated interior environment. Each chemical was sprayed at 0.0, 0.5, or 1.0 mM until run-off (about 40 ml/plant).

The simulated interior environment experiment began on December 19, 1988, and it lasted for 25 days in a room with continuous fluorescent light at 10 to 15 umols m⁻²s⁻¹ as measured with an Li-170 quantum radiometer (LI-COR, Lincoln, NB.) with the quantum sensor on the surface of tables where the plants were placed. The temperature was 19 ± 1°C as measured with thermocouples (Bailey Instruments Co., Inc., Saddle Brook, NJ) with a relative humidity of 45 percent measured with an aspirated psychrometer. Clear vinyl saucers were used to collect water that percolated through the root medium after watering. Watering was performed twice per day.
Ten open flowers (corollas) were tagged randomly with paper tags at day 0. Succession of corolla senescence was observed every two or three days. The term corolla senescence was used because the flowers started to wilt when the observations were made.

The experiment was arranged in a randomized block design with three single plant replications. Statistical analysis was done on cumulative percentage of corolla senescence on each observation day to determine the effects of the treatment.
IV. RESULTS

A. Experiment 1

Statistical analysis showed that the interaction between temperature and cultivar was significant (Table 1). As temperature increased from 11.5 to 22.5 to 33.0°C, corolla abscission in 'Meteor' increased from 29 to 71 to 80%, respectively (Table 2). In contrast, 'Enterprise' showed a lower corolla abscission on the 33.0°C-treated plants, and the highest percentage corolla abscission was observed with plants treated at 11.5°C and 22.5°C (Table 2). It also was observed that, at 33°C, 'Meteor' was injured severely (phytotoxicity), especially when the shipping time was either 72 or 96 hours. On the other hand, temperature did not cause phytotoxicity in 'Enterprise' (Fig. 1).

Table 1. ANOVA of the effect of temperature and time of simulated shipping on percentage corolla abscission in 'Enterprise' and 'Meteor'

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F</th>
<th>PR&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPLICATION</td>
<td>2</td>
<td>0.1286</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>2</td>
<td>1.3659</td>
<td>72.70</td>
<td>0.0007</td>
</tr>
<tr>
<td>ERROR (A)</td>
<td>4</td>
<td>0.0376</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>2</td>
<td>1.8125</td>
<td>26.14</td>
<td>0.0001</td>
</tr>
<tr>
<td>CULTIVAR</td>
<td>1</td>
<td>1.4244</td>
<td>41.09</td>
<td>0.0001</td>
</tr>
<tr>
<td>TIME*CUL</td>
<td>2</td>
<td>0.0972</td>
<td>1.40</td>
<td>0.2618</td>
</tr>
<tr>
<td>TEMP*TIME</td>
<td>4</td>
<td>0.0762</td>
<td>0.55</td>
<td>0.7007</td>
</tr>
<tr>
<td>TEMP*CUL</td>
<td>2</td>
<td>1.7316</td>
<td>24.97</td>
<td>0.0001</td>
</tr>
<tr>
<td>TEMP<em>TIME</em>CUL</td>
<td>4</td>
<td>0.2413</td>
<td>1.74</td>
<td>0.1673</td>
</tr>
<tr>
<td>ERROR (B)</td>
<td>30</td>
<td>1.0400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Means of percentage corolla abscission as a function of temperature during simulated shipping

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>'Meteor'</th>
<th>'Enterprise'</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5</td>
<td>29</td>
<td>37</td>
</tr>
<tr>
<td>22.5</td>
<td>71</td>
<td>48</td>
</tr>
<tr>
<td>33.0</td>
<td>80</td>
<td>26</td>
</tr>
<tr>
<td>LSD0.05</td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>

Shipping time also was an important factor during simulated shipping. A shipping time of 72 or more hours significantly increased corolla abscission of both cultivars (Table 3).

Table 3. Means of corolla abscission averaged over both cultivars as a function of length of time of simulated shipping

<table>
<thead>
<tr>
<th>Shipping time (hours)</th>
<th>Corolla abscission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>31</td>
</tr>
<tr>
<td>72</td>
<td>53</td>
</tr>
<tr>
<td>96</td>
<td>62</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>9</td>
</tr>
</tbody>
</table>
Fig. 1. 'Meteor' (left) and 'Enterprise' (right) after shipment at 33°C for 96 hours
B. Experiment 2

1. **Effect of STS**

Analysis of variance showed that the interactions between cultivar and concentration, cultivar and time, and time and concentration were significant (Table 4). Corolla abscission in 'Enterprise' decreased with increasing STS concentrations. Compared with untreated plants, a significant decrease in corolla abscission occurred when the STS concentration was 1.0 mM or greater (Table 5). STS sprays at 1.0, 1.5, and 2.0 mM caused corolla abscission to decrease from 57% to 41, 43, and 36%, respectively. For the other three cultivars, decreased corolla abscission was independent of the STS concentration, within the range of concentrations that were used. Corolla abscission was reduced by 22 to 30% in 'Meteor', 28 to 32% in 'Solared', and 32 to 42% in 'Sunfire' (Table 5).

Table 4. **ANOVA of corolla abscission from four cultivars of New Guinea impatiens held in simulated shipping after treatment with STS**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F</th>
<th>PR&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPLICATION</td>
<td>2</td>
<td>0.0147</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CULTIVAR</td>
<td>3</td>
<td>2.7197</td>
<td>11.47</td>
<td>0.0068</td>
</tr>
<tr>
<td>ERROR (A)</td>
<td>6</td>
<td>0.4744</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONCENTRATION</td>
<td>4</td>
<td>4.3220</td>
<td>46.91</td>
<td>0.0001</td>
</tr>
<tr>
<td>TIME</td>
<td>2</td>
<td>2.2514</td>
<td>48.88</td>
<td>0.0001</td>
</tr>
<tr>
<td>TIME*CONC</td>
<td>8</td>
<td>0.8950</td>
<td>4.86</td>
<td>0.0001</td>
</tr>
<tr>
<td>CUL*TIME</td>
<td>6</td>
<td>0.9530</td>
<td>6.90</td>
<td>0.0001</td>
</tr>
<tr>
<td>CUL*CONC</td>
<td>12</td>
<td>0.6951</td>
<td>2.51</td>
<td>0.0058</td>
</tr>
<tr>
<td>CUL<em>TIME</em>CONC</td>
<td>24</td>
<td>0.5468</td>
<td>0.99</td>
<td>0.4860</td>
</tr>
<tr>
<td>ERROR (B)</td>
<td>112</td>
<td>2.5796</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. Means of percentage corolla abscission for each cultivar as a function of STS concentration

<table>
<thead>
<tr>
<th>STS Concentration (mM)</th>
<th>Corolla abscission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'Enterprise'</td>
</tr>
<tr>
<td>0.0</td>
<td>57</td>
</tr>
<tr>
<td>0.5</td>
<td>48</td>
</tr>
<tr>
<td>1.0</td>
<td>41</td>
</tr>
<tr>
<td>1.5</td>
<td>43</td>
</tr>
<tr>
<td>2.0</td>
<td>36</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>10</td>
</tr>
</tbody>
</table>

Application of STS to 'Enterprise', 'Meteor', and 'Sunfire' one or two weeks before simulated shipping reduced corolla abscission significantly when compared with plants treated four weeks before simulated shipping (Table 6). The approximate reduction of corolla abscission due to the time of STS treatment was 11 to 17% in 'Enterprise', 22 to 24% in 'Meteor', and 24 to 29% in 'Sunfire'. In 'Solared', the time of STS application before simulated shipping did not make any difference.

Table 6. Means of percentage corolla abscission for each cultivar as a function of time of STS application before simulated shipping

<table>
<thead>
<tr>
<th>Time (weeks before simulated shipping)</th>
<th>Corolla abscission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'Enterprise'</td>
</tr>
<tr>
<td>1</td>
<td>43</td>
</tr>
<tr>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>9</td>
</tr>
</tbody>
</table>
The interaction of time of application with STS concentration showed that the lowest percentage corolla abscission for every STS concentration appeared on the treatments made one or two weeks before simulated shipping. In essence, STS lost efficacy when it was applied four weeks before simulated shipping (Table 7).

Table 7. Means of percentage corolla abscission over all four cultivars for each time of STS application as a function of STS concentration

<table>
<thead>
<tr>
<th>Time (weeks before simulated shipping)</th>
<th>Corolla abscission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0 mM</td>
</tr>
<tr>
<td>1</td>
<td>72</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>9</td>
</tr>
</tbody>
</table>

Despite the capability of STS to reduce abscission, severe phytotoxicity was observed in every cultivar treated with 1.5 mM or 2.0 mM STS. Symptoms of phytotoxicity began to appear approximately one week after the treatment. Reddish and brown lesions were scattered mostly on older leaves, and subsequently, the leaves senesced (Fig. 2). Some flowers on the STS-treated plants opened to smaller-sized and faded color (by observation; data not presented). In 'Solared' and 'Meteor', this phytotoxicity was more obvious after simulated shipping, and it was characterized by an increased width of the lesions (data not presented).
Fig. 2. Symptoms of STS phytotoxicity were indicated by reddish and brown lesions scattered mostly on older leaves.
2. **Effect of AOA**

Statistical analysis of the data for 'Meteor' was performed separately from the other cultivars due to severe phytotoxicity that occurred on the plants treated with 1.0 mM or more AOA (statistical analysis not presented). Injury to 'Meteor' was so severe that almost no flowers were left on the plants, and no observations on corolla abscission were possible. For the three other cultivars, analysis of variance showed that the interaction of cultivar, AOA concentration, and time of application was significant (Table 8).

Table 8. ANOVA of percentage corolla abscission for plants of 'Enterprise', 'Solared', and 'Sunfire' treated with AOA before simulated shipping

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F</th>
<th>PR&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPLICATION</td>
<td>2</td>
<td>0.2997</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CULTIVAR</td>
<td>2</td>
<td>0.8500</td>
<td>16.68</td>
<td>0.0115</td>
</tr>
<tr>
<td>ERROR (A)</td>
<td>4</td>
<td>0.1019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONCENTRATION</td>
<td>4</td>
<td>3.0029</td>
<td>37.02</td>
<td>0.0001</td>
</tr>
<tr>
<td>TIME</td>
<td>2</td>
<td>1.6503</td>
<td>40.69</td>
<td>0.0001</td>
</tr>
<tr>
<td>CONC*TIME</td>
<td>8</td>
<td>0.5488</td>
<td>3.38</td>
<td>0.0021</td>
</tr>
<tr>
<td>CUL*CONC</td>
<td>8</td>
<td>0.4750</td>
<td>2.93</td>
<td>0.0062</td>
</tr>
<tr>
<td>CUL*TIME</td>
<td>4</td>
<td>0.2422</td>
<td>2.99</td>
<td>0.0234</td>
</tr>
<tr>
<td>CUL<em>CONC</em>TIME</td>
<td>16</td>
<td>0.5884</td>
<td>1.81</td>
<td>0.0425</td>
</tr>
<tr>
<td>ERROR (B)</td>
<td>84</td>
<td>1.7036</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage corolla abscission responses to AOA were plotted for each cultivar (Fig. 3). For 'Enterprise', the all four AOA concentrations reduced corolla abscission equally
Fig. 3. Effects of concentration and time of AOA application on corolla abscission of 'Enterprise' (A), 'Solared' (B), Sunfire (C), and 'Meteor' (D) during simulated shipping.
and significantly when it was applied one or two weeks before shipping (Fig. 3A). When compared with untreated plants, corolla abscission was reduced by about 50% when the AOA sprays were applied one week before simulated shipping, and abscission was reduced by about 30% when the sprays were applied two weeks before simulated shipping. The efficacy of the AOA treatment was lost if it was applied four weeks before shipping (Fig. 3A).

For 'Solared', AOA applications one or two weeks before shipping reduced corolla abscission, except the treatments with 1.0 mM one week before simulated shipping, and 2.0 mM two weeks before simulated shipping (Fig. 3B). AOA sprays at 0.5, 1.5, and 2.0 mM one week before shipping reduced corolla abscission of 'Solared' by about 20%. When the sprays were applied two weeks before shipping, STS at 0.5, 1.0, and 1.5 mM reduced corolla abscission from 52% to 35, 22, and 23%, respectively.

All four AOA concentrations reduced corolla abscission of 'Sunfire' for each time of application (Fig. 3C). The difference in percentage corolla abscission between the control and the plants treated with 0.5, 1.0, and 1.5 mM, was about 35% for treatment one or two weeks before simulated shipping, and about 25 to 35% for the treatment four weeks before simulated shipping. At 2.0 mM, AOA was not as effective as it was at the lower concentrations, but a significant difference from the control plants still was shown (Fig. 3C).
Sprays with 0.5 mM AOA one or two weeks before shipping reduced corolla abscission of 'Meteor'. Corolla abscission was reduced from 48 to 13% when the application was made one week before simulated shipping, and it was reduced from 50 to 23% when the application was made two weeks before simulated shipping. The effect of AOA on corolla abscission reduction in 'Meteor' was reduced to zero when the application was made four weeks before simulated shipping (Fig. 3D). Application of AOA to 'Meteor' at concentrations of 1.0, 1.5, and 2.0 mM damaged the plants so severely that data could not be taken.

Phytotoxicity was observed in 'Enterprise', 'Sunfire' and 'Solared' sprayed with 1.5 and 2.0 mM AOA. The physical damage of plants caused by treatment with AOA at these concentrations mostly was found on young shoots and leaves, and to some extent, it reduced the number of corollas usable for observations (Fig. 4). Smaller-sized and faded-color flowers also were observed on the treated plants.

C. Experiment 3

In this experiment, phytotoxicity symptoms caused by AOA were observed in 'Meteor', and it was similar to the phytotoxicity that was observed in experiment 2. Severe flower damage occurred on this cultivar when it was treated with 1.0 mM or more AOA, and observations on flower senescence were not possible. Therefore, for this cultivar, statistical analysis was performed separately and only two concentrations (0.0 and 0.5 mM) of both chemicals were analyzed.
Fig 4. Symptoms of AOA phytotoxicity on New Guinea impatiens. Most of the phytotoxicity was observed on the terminal portions of the shoots.
Statistical analysis was conducted for each day of observation. The effects of the treatments on 'Meteor' (as represented by concentration) were significant starting at day 6 and ending on day 10 (Table 9). Analysis of variance on the three other cultivars, 'Enterprise', 'Solared', and 'Sunfire', showed that the interaction between cultivar and chemical were significant on days 6, 8, and 10. Concentration effects were significant on day 6 through day 13. In addition, cultivar differences were significant on day 13 (Table 10). The concentration effects on 'Enterprise' were observed until day 22. Therefore, data for corolla senescence on day 16 and day 22 from this cultivar have been analyzed and presented separately (Table 11).

Table 9. ANOVA of percentage cumulative corolla senescence for plants of 'Meteor' treated and then held in a simulated interior environment

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>day 6</th>
<th>day 8</th>
<th>day 10</th>
<th>day 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>2</td>
<td>0.000</td>
<td>0.012</td>
<td>0.007</td>
<td>0.015</td>
</tr>
<tr>
<td>Chemical</td>
<td>1</td>
<td>0.030</td>
<td>0.90</td>
<td>0.083</td>
<td>4.35</td>
</tr>
<tr>
<td>Concentration</td>
<td>1</td>
<td>0.273</td>
<td>8.10*</td>
<td>0.213</td>
<td>11.13*</td>
</tr>
<tr>
<td>Chem*Conc</td>
<td>2</td>
<td>0.000</td>
<td>0.00</td>
<td>0.003</td>
<td>0.17</td>
</tr>
</tbody>
</table>

* Significant at 5% level.
Table 10. ANOVA of percentage cumulative corolla senescence for plants of 'Enterprise', 'Solared', and 'Sunfire' treated and then held in a simulated interior environment.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F</th>
<th>SS</th>
<th>F</th>
<th>SS</th>
<th>F</th>
<th>SS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPLICATION</td>
<td>2</td>
<td>0.043</td>
<td>0.003</td>
<td>0.033</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEMICAL</td>
<td>1</td>
<td>0.327</td>
<td>13.6*</td>
<td>0.189</td>
<td>12.48*</td>
<td>0.090</td>
<td>6.83*</td>
<td>0.031</td>
<td>2.92</td>
</tr>
<tr>
<td>CULTIVAR</td>
<td>2</td>
<td>1.921</td>
<td>39.99*</td>
<td>3.481</td>
<td>114*</td>
<td>4.327</td>
<td>164.8*</td>
<td>3.745</td>
<td>174*</td>
</tr>
<tr>
<td>CONCENTRATION</td>
<td>2</td>
<td>0.413</td>
<td>8.60*</td>
<td>0.413</td>
<td>13.60*</td>
<td>0.489</td>
<td>18.64*</td>
<td>0.323</td>
<td>15*</td>
</tr>
<tr>
<td>CHEM*CONC</td>
<td>2</td>
<td>0.031</td>
<td>0.65</td>
<td>0.064</td>
<td>2.10</td>
<td>0.065</td>
<td>2.47</td>
<td>0.065</td>
<td>3.03</td>
</tr>
<tr>
<td>CHEM*CUL</td>
<td>2</td>
<td>0.243</td>
<td>5.07*</td>
<td>0.251</td>
<td>8.27*</td>
<td>0.116</td>
<td>4.42*</td>
<td>0.000</td>
<td>0.02</td>
</tr>
<tr>
<td>CUL*CONC</td>
<td>4</td>
<td>0.096</td>
<td>0.99</td>
<td>0.048</td>
<td>0.80</td>
<td>0.040</td>
<td>0.75</td>
<td>0.663</td>
<td>1.55</td>
</tr>
<tr>
<td>CHEM<em>CUL</em>CONC</td>
<td>4</td>
<td>0.049</td>
<td>0.51</td>
<td>0.065</td>
<td>1.07</td>
<td>0.059</td>
<td>1.14</td>
<td>0.048</td>
<td>1.13</td>
</tr>
</tbody>
</table>

* Significant at 5% level.

Table 11. ANOVA of percentage cumulative corolla senescence for plants of 'Enterprise' treated and then held in a simulated interior environment on day 16 and 22.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>day-16 SS</th>
<th>F</th>
<th>day-22 SS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPLICATION</td>
<td>2</td>
<td>0.003</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEMICAL</td>
<td>1</td>
<td>0.005</td>
<td>0.15</td>
<td>0.005</td>
<td>0.18</td>
</tr>
<tr>
<td>CONCENTRATION</td>
<td>2</td>
<td>0.390</td>
<td>5.79*</td>
<td>0.334</td>
<td>6.00*</td>
</tr>
<tr>
<td>CHEM*CONC</td>
<td>2</td>
<td>0.023</td>
<td>0.42</td>
<td>0.023</td>
<td>0.42</td>
</tr>
</tbody>
</table>

* Significant at 5% level.

Percentage of cumulative corolla senescence was plotted for each cultivar (Fig. 5). Untreated plants of 'Meteor', 'Sunfire', and 'Solared' exhibited a rapid rate of corolla senescence starting at day 3, and by day 10, they had lost at least 78% of their flowers. Treated plants showed a lower senescence rate that started at day 6. However, flower senescence in
these cultivars still occurred on the treated plants, and at day 13, the treatment did not make any difference in 'Meteor', and at day 16 it did not make a difference for 'Sunfire' and 'Solared'. In 'Enterprise', the treated plants showed a lower percentage of corolla senescence starting at day 6 and continuing through day 22 (Fig. 5).

Data for percentage cumulative corolla senescence for day 8 is presented as representative of observations with significant treatment effects. The interaction between chemical and cultivar, which was significant, showed the difference in response of the cultivars to each chemical on day 8. STS-treated 'Solared' exhibited a lower cumulative percentage of corolla senescence compared with AOA-treated plants (Table 12). This indicated that STS worked better than AOA in reducing corolla senescence of 'Solared' in the simulated interior environment. For 'Enterprise' and 'Sunfire', the chemicals did not make any difference (Table 12).

Table 12. Means of cumulative percentage corolla senescence for 'Enterprise', 'Sunfire' and 'Solared' (over all concentrations) as recorded on day 8 in the simulated interior environment

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>AOA</th>
<th>STS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>corolla senescence (%)</td>
<td></td>
</tr>
<tr>
<td>'Enterprise'</td>
<td>14.4</td>
<td>13.3</td>
</tr>
<tr>
<td>'Sunfire'</td>
<td>61.1</td>
<td>57.7</td>
</tr>
<tr>
<td>'Solared'</td>
<td>88.8</td>
<td>57.7  *</td>
</tr>
</tbody>
</table>

* Significant at 0.05 level.
Fig. 5. Percentage cumulative corolla senescence for STS and AOA treatments on 'Meteor' (A), 'Sunfire' (B), 'Solared' (C), and 'Enterprise' (D) held in a simulated interior environment after treatment.
Corolla senescence (%) 

C

Simulated Interior

Holding time (days)

Corolla senescence (%) 

D

Simulated Interior

Holding time (days)
On day 8, both chemicals at 0.5 or 1.0 mM reduced corolla senescence of three cultivars, 'Enterprise', 'Sunfire', and 'Solared', by 17 and 20%, respectively (Table 13). At the same time, a concentration of 0.5 mM of both chemicals reduced corolla senescence in 'Meteor' by 27%. Data on the other days when the treatment effects were significant followed the pattern of this data data on day 8 (data not presented). However, the difference between the treated and untreated plants, in most cases, was smaller.

Table 13. Means of cumulative percentage corolla senescence over 'Enterprise', 'Sunfire', and 'Solared', and over 'Meteor', for each concentration of both chemicals, as recorded on day 8

<table>
<thead>
<tr>
<th>Concentration (mM)</th>
<th>'Enterprise', 'Sunfire' and 'Solared' (pooled)</th>
<th>'Meteor'</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>61</td>
<td>80</td>
</tr>
<tr>
<td>0.5</td>
<td>44</td>
<td>53</td>
</tr>
<tr>
<td>1.0</td>
<td>41</td>
<td>...</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>8</td>
<td>20</td>
</tr>
</tbody>
</table>

Cumulative percentage corolla senescence of 'Enterprise' over both chemicals for each concentration as recorded on day 16 has been presented because this cultivar lasted longer in the simulated interior environment. On day 16, corolla senescence was reduced only by treatment with 1.0 mM of either chemical (Table 14). When compared with the control, corolla senescence was reduced from 63 to 28% by the 1.0 mM treatment.
Table 14. Means of cumulative percentage corolla senescence on 'Enterprise' for AOA and STS (pooled) as recorded on day 16

<table>
<thead>
<tr>
<th>Concentration (mM)</th>
<th>Corolla senescence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>63</td>
</tr>
<tr>
<td>0.5</td>
<td>53</td>
</tr>
<tr>
<td>1.0</td>
<td>28</td>
</tr>
<tr>
<td>LSD_{0.05}</td>
<td>23</td>
</tr>
</tbody>
</table>

During this experiment, two each of the STS-treated 'Sunfire' and 'Meteor' plants died. Infection by *Pythium* spp. was confirmed by examination by a plant pathologist (Dr. Mark Gleason, Iowa State University, personal communication).
V. DISCUSSION

'Enterprise' and 'Meteor' responded differently to temperature during simulated shipping. 'Enterprise' performed well even after simulated shipping at 33C. This cultivar also exhibited the lowest percentage corolla abscission after simulated shipping, while 'Meteor' suffered severe damage and showed the highest percentage corolla abscission. These results indicated that temperature requirements for shipping vary from one New Guinea impatiens cultivar to another. Cultivars such as 'Meteor' require cool temperatures for shipping, while 'Enterprise' was more resistant to high-temperature-related corolla abscission.

It has been observed that abscission is influenced by high temperature, and various responses have been recorded in various species. Petal abscission of seed-derived geraniums was increased in high-temperature handling (Armitage et al., 1980). However, retardation of abscission also was possible in extreme temperature conditions, such as heat or frost, because damage occurred around the abscission zone and caused the process not to take place (Addicott, 1968). Therefore, it may be premature to suggest that 'Enterprise' should be handled at a warm temperature such as 33C. It is important to note that the observations on corolla abscission in this experiment were performed promptly after the opening of shipping boxes, and therefore, the long-term effects of the treatments were not determined. In the future, it may be necessary to
determine whether or not the quality of the plants can be maintained for a certain length of time after being exposed to such treatment.

The results of this experiment suggest that prompt shipment of New Guinea impatiens is necessary in order to maintain their quality. It was shown that extension of the simulated shipping time from 2 to 3 or 4 days increased corolla abscission two-fold. This may indicate that New Guinea impatiens are not suitable for long-term transport.

The response of the plants to AOA and STS in the simulated shipping experiments confirmed the results of previous work on several other species (Agnew et al., 1985; Broun and Mayak, 1981; and Cameron and Reid, 1983). Even though phytotoxicity occurred, it did not interfere with the efficacy of the chemicals in reducing corolla abscission. The different response among cultivars to the application of STS and AOA suggests the importance of developing preventive spray programs for a broader range of New Guinea impatiens cultivars. From the four cultivars used in this experiment, three cultivars, 'Enterprise', 'Sunfire', and 'Solared', did not show any phytotoxicity symptoms when they were sprayed with 1 mM or lower of either chemical, while the efficacy of the chemicals still was observed. However, 'Meteor' exhibited serious injury when it was sprayed with AOA at 1.0 mM or higher concentrations. Therefore, for practical purposes, sprays should not exceed this critical concentration level.
Within the nonphytotoxic concentration range, STS reduced corolla abscission of 'Enterprise' at 1.0 mM STS, while in the three other cultivars, corolla abscission was reduced by 0.5 or 1.0 mM STS. 'Enterprise', 'Meteor', and 'Sunfire' showed the lowest percentage corolla abscission when the application of STS was done one or two weeks before shipping. In 'Solared', the time of STS application before simulated shipping did not make any difference. These spray programs are comparable to the preventive spray programs recommended by Veen (1983) for several species of ornamental crops.

The best application time for AOA at 0.5 or 1.0 mM was one or two weeks before shipping for 'Enterprise'. For 'Solared', corolla abscission was reduced by the application of 0.5 mM AOA one or two weeks before simulated shipping and 1.0 mM AOA two weeks before simulated shipping. Corolla abscission of 'Sunfire' was reduced by the application of 0.5 and 1.0 mM AOA at each time of application. 'Meteor' showed the lowest corolla abscission when AOA was applied at 0.5 mM one week before shipping. These results may be useful for recommendations for preventive spray programs with AOA.

One factor that must be considered is the amount that corolla abscission is reduced by the chemicals, which relates to the visual effects and improvement of plant quality. In this experiment, the reduction of corolla abscission in 'Enterprise', when sprayed with 1.0 mM STS, was 16%. Visually, this number may not be significant in increasing the quality of
this cultivar. In the other cultivars, the reduction was about 20 to 40 percent, and the visual effect of the reduction was greater than the reduction observed in 'Enterprise'.

Another important factor is the time of application. In this experiment, the chemicals, in most cases, were more effective when sprayed one or two weeks before shipment. To decide when the plants should be sprayed, it also is important to determine the number of flower buds that should be open by the time of shipment. If removal of open flowers before spraying or shipment is involved, it may take more than one week to obtain full recovery of the desired number of new, open flowers. However, flower removal is considered costly, and it is not practical. If plants are sprayed when their flowers are open, the chemicals may cause flower damage. Therefore, it may be necessary to estimate the spraying time from the number of the 'ready to open' flower buds. At this stage, buds start to show color, and their size is 1 to 1.5 cm.

In previous work, STS prevented corolla abscission of New Guinea impatiens during exposure to exogenous C$_2$H$_4$, while AOA did not (Richard Gladon and Nancy Agnew, Dept. of Horticulture, Iowa State University, personal communication). This fact agreed with other results that distinguished the modes of action of the two chemicals (Broun and Mayak, 1981; Woltering and Sterling, 1986). AOA effectively prevented C$_2$H$_4$ biosynthesis, while STS both prevented C$_2$H$_4$ biosynthesis and mode of action. Therefore, when exogenous C$_2$H$_4$ was present in the
environment of the plants, AOA did not have the capability to stop \( C_2H_4 \)-induced corolla abscission, while STS had this capability.

The mode of action of \( C_2H_4 \) has been linked to its autocatalytic capability (Bufler, 1986). If \( C_2H_4 \) biosynthesis is the consequence of its own mode of action, STS will have the capability to inhibit indirectly \( C_2H_4 \) biosynthesis. The results of the second experiment support this argument. The shipping-environment conditions (dark and humid) potentially induced \( C_2H_4 \) production in the plant tissues, and the application of either STS or AOA prevented it. However, application of AOA is not recommended if exogenous \( C_2H_4 \) is likely to occur during shipping (e.g., mixed-load transport, bad engine combustion, etc.). In this case, application of STS probably would prevent damage from the exogenous \( C_2H_4 \).

In the third experiment, STS effectively delayed flower senescence in all four cultivars, while AOA was effective only on 'Enterprise' and 'Sunfire'. The delay ranged from four days in 'Meteor', seven days in 'Sunfire' and 'Solared', and up to about 16 days in 'Enterprise'. These results implicate \( C_2H_4 \) involvement during flower senescence in the simulated interior environment. This possibly was induced by low-light conditions or other environmental factors.

It is important to note that this delay only occurred with a portion of the open flowers. This leads to the question of whether the spray treatment is worth the time delay. Control plants of 'Meteor', 'Sunfire',
and 'Solared' exhibited rapid flower senescence after three days in the simulated interior environment. At day 10, almost all open flowers had senesced. During this same period, the treated plants still held 30 to 40% of their old flowers. Assuming that the rate of flower-bud opening was the same between the control and the treated plants, the performance of the treated plants was only slightly better. However, the treated plants lost almost all of these flowers after 13 days.

It was observed that the flowers that opened during the time that they were in the simulated interior environment had less color and size. Hence, the performance of these plants was dependent upon the longevity of the old flowers, and flower buds that opened within the first few days of the beginning of the interior environment simulation. If average consumers consider two weeks as an acceptable time to maintain the plants at a level of good quality, treated 'Meteor', 'Sunfire', and 'Solared' will not meet this criterion.

The results with 'Enterprise' are more promising. This cultivar seems to be more adaptable to an interior environment than the other three cultivars. Control plants retained about 50% of their flowers after 13 days in the simulated interior environment. Treatment with either STS or AOA increased that number to about 70 to 85%. Plant quality was maintained, if not improved, by the addition of new flowers from the opening of buds. After 21 days, treated plants of 'Enterprise' still performed well in the simulated interior environment, while the other three
cultivars showed a much poorer quality. Therefore, application of either STS or AOA may be worthwhile only for the cultivars that have better adaptability to a simulated interior environment.

The *Pythium* infection observed during the third experiment probably was related to the application of STS. Previous studies by Hausbeck (1985) showed that application of STS to seed geraniums increased damping-off caused by *Pythium ultimum* Trow. The mechanism of this causal relationship was not clear. Presumably, STS had created plant stress and increased the susceptibility of the plant to *Pythium*. The simulated interior environment conditions (cool temperature, too wet soil, and low relative humidity) likely facilitated a rapid proliferation of the pathogen. Hausbeck et al. (1988) demonstrated that application of several fungicides after STS application reduced the damping-off problem.

It was observed that, during holding in the simulated interior environment, New Guinea impatiens required frequent watering and wilted rapidly if water stress occurred (data were not taken). This may create maintenance problems for the consumer. Perhaps hybrid lines that are more resistant to water stress and modifications of the root medium may resolve this problem.

In future studies, the temperature requirements for shipping of New Guinea impatiens should be obtained for a broader range of cultivars. It also may be important to observe the long-term effect of the treatment, for
example, by exposing plants to the simulated interior environment for a certain period of time.

Studies on the prevention of corolla abscission by application of STS or AOA also should be conducted for a broader range of cultivars, and the concentration of both of these chemicals can be narrowed to concentrations that are less than 1.0 mM. One alternative may be a multiple-spray program with lower concentrations. Information on the efficacy of the chemicals for the prevention of corolla abscission in atmospheres that contain C$_2$H$_4$ is necessary for the ornamental plant industry because this problem may be more common and serious than first was realized.
VI. CONCLUSIONS

Temperature requirements for simulated shipping of New Guinea impatiens vary among cultivars. Corolla abscission in a cultivar such as 'Meteor' increased significantly with an increased temperature. In 'Enterprise', simulated shipping at 33°C gave the lowest level of corolla abscission, while at 11.5°C and 22.5°C, corolla abscission was the greatest.

Immediate shipping is necessary for the prevention of a large percentage of corolla abscission. When shipping time was extended to more than two days, corolla abscission of 'Meteor' and 'Enterprise' increased dramatically.

Silver thiosulfate (STS) and (Aminooxy)acetic acid (AOA) effectively reduced corolla abscission during simulated shipping. However, phytotoxicity was observed on plants sprayed with 1.5 mM and 2.0 mM solutions of both chemicals. In 'Meteor', AOA at 1.0 mM or more caused severe damage, and observations on corolla abscission were not possible.

Corolla abscission in 'Enterprise' decreased with increasing STS concentrations. Application one or two weeks before simulated shipping was considered the best for this cultivar. Decreased corolla abscission in 'Meteor', 'Sunfire', and 'Solared' was independent of the STS concentration, provided that STS was applied. Application of STS at one or two weeks before simulated shipping reduced corolla abscission of 'Meteor'
and 'Sunfire' significantly, while in 'Solared', the time of STS application before simulated shipping did not make any difference.

All four AOA concentrations used in this experiment reduced corolla abscission of 'Enterprise' equally when they were applied one or two weeks before simulated shipping. For 'Solared', AOA applications one or two weeks before shipping reduced corolla abscission, except the treatments with 1.0 mM one week before shipping, and 2.0 mM two weeks before simulated shipping. All four AOA concentrations reduced corolla abscission of 'Sunfire' for each time of application. Sprays with 0.5 mM AOA one or two weeks before simulated shipping reduced corolla abscission of 'Meteor'.

Flower longevity of the four cultivars was extended effectively by the STS pre-treatment, while AOA was only successful on 'Enterprise' and 'Sunfire. Treated plants of every cultivar showed more flowers than control plants starting on day 6. The delay of flower senescence was observed until day 10 in 'Meteor', day 13 in 'Sunfire' and 'Solared', and day 22 in 'Enterprise'. 
VII. LITERATURE CITED


Cameron, A. C. and M. S. Reid. 1981b. The use of silver thiosulfate anionic complex as a foliar spray. II. Prevention of shattering in potted geraniums. HortScience 16:405


