POSTPRODUCTION STUDIES OF A SPRAYABLE FORMULATION OF 1-METHYLCYCLOPROPENE IN BEDDING PLANTS

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Masters of Science

by

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January 2014

ABSTRACT

Studies were conducted with a sprayable formulation of 1-methylcyclopropene (1-MCP), formulation AFxRD-038 (Rohm and Hass, Philadelphia, PA), to determine the sensitivity to exogenous ethylene and efficacy of 1-methylcyclopropene (1-MCP) on bedding plants. Effects of ethylene concentration, plastic bag enclosure, 1-MCP concentration and volume, water quality, solution age, timing and length of irrigation, delay of ethylene challenge, surfactants, extended darkness and high postproduction storage temperatures on efficacy of 1-MCP in protecting *Impatiens walleriana* and *I. hawkeri* from premature floral senescence were evaluated. The sensitivity to exogenous ethylene and efficacy of sprayable formulation of 1-MCP of seventy-three cultivars from twenty species of annual bedding plants was investigated.

Impatiens walleriana and *I. hawkeri* exposure to 1.0 $\mu l \cdot liter^{-1}$ ethylene for 18 hours caused complete senescence of open flowers, 1-MCP at 2.5 mg $ai \cdot liter^{-1}$ protected plants from ethylene exposure. Placing plants in unsealed High Density Polyethylene (HDPE) produce bags had no effect on flower abscission in the presence or absence of ethylene or 1-MCP. At 5 and 10 mg $ai \cdot liter^{-2}$, the efficacy of 1-MCP increased as spray volume increased from 102 $ml \cdot meter^{-2}$ to 306 $ml \cdot meter^{-2}$. 1-MCP appeared to be effective within 1 minute after application with no decrease in efficacy regardless of irrigation water applied after 1-MCP pretreatment. There was no significant effect of surfactant concentration (Capsil, Aquatrols, Paulsboro, NJ) on 1-MCP activity though some plants exhibited phytotoxicity symptoms on flower petals with Capsil rates above 1.0 $ml \cdot liter^{-1}$. Increasing pH of the 1-MCP solution from 6 to 9 resulted in slightly reduced efficacy but not enough to reduce marketability of plants. Prepared 1-MCP solutions (10 mg $ai \cdot liter^{-1}$) remained effective up to two weeks after mixing if held in airtight containers. With *Impatiens,* 1-MCP provided protection against exogenous ethylene for a maximum of four

days. 1-MCP provided protection against darkness and high temperature stress related abscission for at least three days of extended darkness in the absence of ethylene and two days at high temperatures (28 °C).

In the second study, 73 cultivars from twenty species of annual bedding plants were grown from seed or vegetative cuttings under optimum greenhouse production until mature at which time they were sprayed with 0 or 25 mg ai·liter^{-1} 1-MCP and then exposed to 0 or 1.0 µl·liter^{-1} for 18 hours in darkness at 21°C to simulate postproduction stress. Immediately after postproduction stress, plants were assessed for senescence symptoms including flower abscission, wilting or discoloration, leaf epinasty and abscission. There were three groups of ethylene sensitivity: no response to ethylene (*Bidens ferulifolia, Heliotropium arborescens, Osteospermum ecklonis, Scaevola aemula*), transient ethylene symptoms (*Solenostemon scutellarioides*), and permanent ethylene damage. Plants showing ethylene damage were split into two groups, those that were completely protected by 1-MCP (*Angelonia angustifolia, Begonia x benariensis, Calibrachoa x hybrida, Catharanthus rosea, Cleome hassleriana, Diascia barberae, Euphorbia hypericifolia, Impatiens x hawkeri, I. walleriana, Lantana camara, Lobelia erinus, Petunia hybrida, Vebena hybrida*) and those for which 1-MCP provided incomplete protection (*Cuphea ramosissima, Pelargonium x hortorum* [Interspecific and Zonal hybrids], *P. peltatum*)

BIOGRAPHICAL SKETCH

Polyxeni (Cheni) Filios was born in Ithaca, New York and grew up in nearby Trumansburg, New York. She spent her free time with friends and family exploring the Finger Lakes area, swimming, hiking, and enjoying the broad range of gastronomical offerings. She has always loved gardening with her mother and father. Cheni enjoys traveling with her family and friends, experiencing foreign cultures, food and horticulture.

Cheni began her undergraduate degree in Plant Sciences at Cornell University in 2004. She focused her studies in Ornamental Horticulture and worked with Dr. William Miller in the Flowerbulb Research Lab beginning in her sophomore year. Her passions for travel lead her to study abroad in Florence, Italy the spring of her Junior year. In Italy she took classes in the Renaissance, cooking and historical gardens.

Upon completion of her undergraduate degree, Cheni worked as a technician with Dr. William Miller in the Flowerbulb Research Lab, after a year of research she began a Master's degree. She has continued to travel for horticulture education, leisure and pleasure. In 2012 she received the Dreer Fellowship Award. She spent four months in New Zealand at Plant and Food Research working with Dr. Jason Johnston and seven months in England at Ball Colegrave, a commercial floriculture company.

This thesis is dedicated to my family.

Thank you all for your encouragement and support.

You know what's right,
You know what's wrong,
Do what's right.
-Achilles Filios

ACKNOWLEDGEMENTS

I would like to thank the companies and individuals that made it possible for me to conduct this research. AgroFresh (Rohm and Hass, Philadelphia, PA) and the Cornell Department of Horticulture for financial support, technician Rose Harmon and Melissa Kitchen, the greenhouse staff at Ken Post Greenhouses, Blue Grass Lane summer interns, the 'Dutch guys and gals', student workers Allison Hyrcik and Madeline Olberg and my committee members Dr. Bill Miller and Dr. Miguel Gomez.

I would also like to thank all my friends and family for your continued support. Housemates and Cornellians, especially Deirdre, Chad, and Emily, thank you for always keeping me entertained and for eating whatever I decided to put in front of your lovely faces. To all my fellow Cornell Department of Horticulture students thank you for your continued support. To my T-burgers for putting up with me never being around but still loving me all the same, especially the Bowers' and Fritz/Bond clan.

Mom, Dad, Cassie, Eleni, Brad, and Bunny, thank you for always listening to me complain, feeding me, curing general malaise and continually entertaining my whims.

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Introduction and Literature Review

Introduction

The floriculture industry in the United States is one of the few segments that continues to show positive growth and expansion regardless of the rise and fall of the economy. In recent years production has been moving away from small 'mom-and-pop' grower retailers and towards large production facilities, which supply mass merchandising stores. Consolidation of production leads to increased duration of the transportation and handling phases before plants reach the retail location. Postproduction stress can lead to decreased shelf life of flowering plants and at least some of this accelerated senescence can be attributed to exposure to the plant hormone, ethylene.

There has been continual development of technologies for improving postproduction quality of floriculture crops including use of the ethylene action inhibitor, 1-methylcyclopropene (1-MCP). A new sprayable formulation of 1-MCP (AFxRD-038) has been registered for in-field use on fruit and field crops (as the products Harvista™ and Invinsa™) but information regarding use on floriculture crops is limited and at present, the material is not labeled for floriculture use. The number of plant species in floriculture continues to grow and there is limited information on postproduction responsiveness to exogenous ethylene exposure and efficacy of 1-MCP protection. Two objectives in particular were addressed through this research. They were as follows:

1) Determine the efficacy of AFxRD-038 formulation of 1-MCP on bedding plants.
2) Determine ethylene damage on a range commercial bedding plants and potential for protection by 1-MCP applications.

The following chapter contains background information on the floriculture industry and the current status of annual bedding plant production, postproduction stress management, effects of ethylene and uses of 1-MCP in the horticulture industry.

Floriculture

The United States Department of Agriculture, Floriculture Crop 2012 Summary, estimates the wholesale value of floriculture crops in 2012 at $4.13 billion, a one percent increase from 2011. These figures are of the top 15 producing states in the United States. Floriculture crops are defined as annual bedding and garden plants, potted herbaceous perennials, indoor potted plants, foliage plants, cut flowers and greens, and propagative floriculture materials. California and Florida are the leading states with crop values of $985 and $812 million, respectively. In order of decreasing gross expanded wholesale value the 15 states include California, Florida, Michigan, Texas, North Carolina, Ohio, New Jersey, Pennsylvania, New York, Washington, Oregon, Illinois, Maryland, South Carolina and Hawaii. Production area of floriculture crops was 702 million square feet, down 1 percent from 2011, while the number of producers in 2012 is down 6 percent from 2011 with approximately 5,419 in the 15-state survey (USDA, 2013).

The wholesale value of the bedding and garden plant segment was estimated at $1.96 billion in 2012, accounting for 49 percent of the total floriculture crop estimated value. Of this, 70 percent or $1.36 billion is attributed to sales of annuals (USDA, 2013). Fifty seven percent of all bedding and garden plants are produced within five states; California, Michigan, Texas, North Carolina and Ohio. Bedding plants are grown for use in garden beds or containers for aesthetic purpose of creating decorative displays. They are usually treated as annuals and are enjoyed a

portion of the year and discarded after use. In the United State there are over 100 species grown under the bedding plant category and more plants are added each year with great opportunity for sales (Nelson, 2012). The eight most popular bedding plants in the United States in approximate order of wholesale value are petunia, geranium (seed and vegetative), pansy and viola, impatiens (non-New Guinea type), begonia, New Guinea impatiens, marigold (USDA, 2013).

Production and postproduction

Most bedding plants are grown from seed or vegetative cuttings and are raised in greenhouses or covered growing areas. Bedding plants are sold in a variety of formats including flats, hanging baskets, and pots of all sizes. Flats are multiple numbers of plants sold as one unit, often these plants are not fully mature and the purpose is for consumers to transplant into larger containers. Flats are less expensive per plant than other formats due to reduced cost to the grower such as reduced greenhouse space requirement and fewer inputs of growing medium and fertilizer. In the United States bedding plant pot sizes are generally 4, 6, 8 and 10 inches. Hanging baskets are larger and generally more mature than pots and contain more than one plant, often multiple colors and species. Hanging baskets have the highest per plant wholesale cost due to higher input costs including increased length of growing, multiple points of handling/care, material costs. The greatest quantities of bedding plants are sold in pots followed by flats and finally hanging baskets (USDA, 2013).

Advancement of interstate highway systems and refrigerated trucking has led to consolidation of floriculture production in the United States since World War II. The largest centers of floriculture production are located near major markets (Nelson, 2012). Trends show that number of bedding plant producers is declining while production space is increasing

(USDA, 2013). With few small growers, large production areas are inevitably located further away from central markets, requiring increased distance in transportation of finished products. The greatest proportion of production is located in coastal locations (USDA, 2007) and generally dispersed production in the central states (Figure 1.1). As plants must to travel further to reach markets, they will likely suffer effects of postproduction stress.

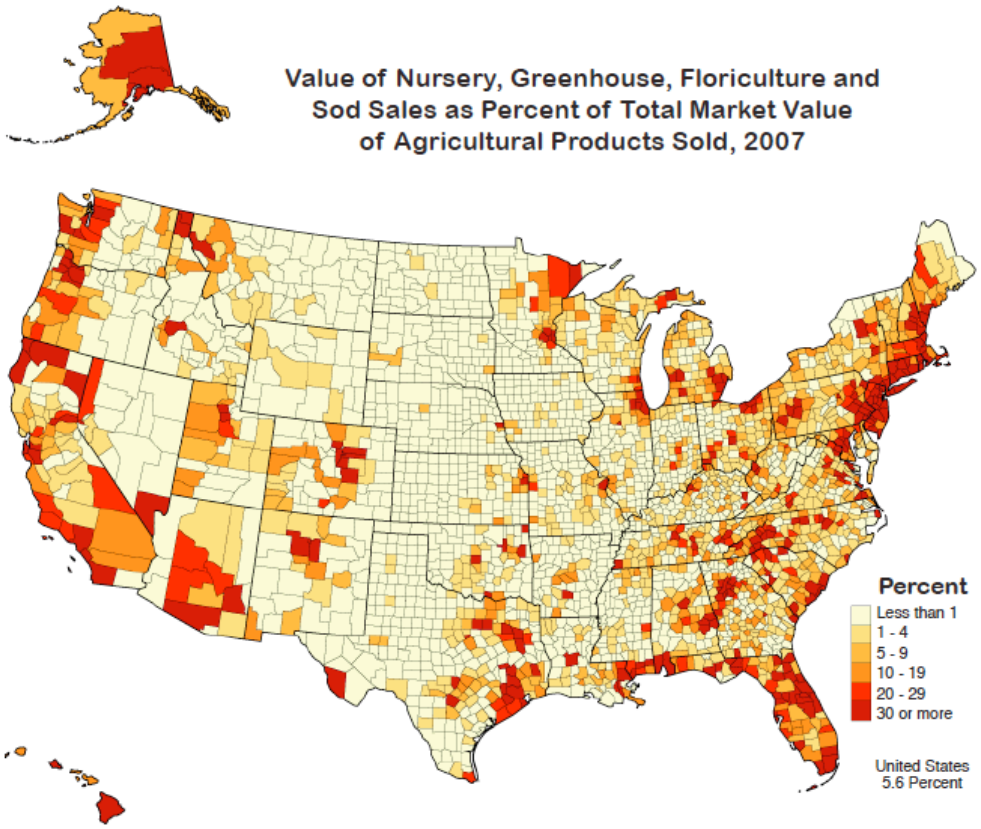

Figure 1.1. Value of Nursery, Greenhouse, Floriculture, and Sod as Percent of Total Market Value of Agricultural Products Sold. (USDA, 2007).

The goal of production is for plants to be at their highest quality just before shipping to allow for maximum sales potential and plants should be handled properly by shippers, retailers, and consumers to maintain quality and maximize shelf life (Dole and Wilkins, 2005). Stresses at any point in the postproduction chain will negatively affect the final plant quality. It is estimated that postproduction losses can reach 30 percent due to improper care of plants (Jones, 2002). In recent years, a shift has been seen in increased purchasing at large 'box stores' that work on the principle of 'pay-by-scan' where the grower is paid only for product that is purchased (Starman et al., 2007). Product must start at a high quality to resist adverse affects of the postproduction chain to ensure sell through at market.

Growers prepare for the postproduction chain by ensuring plants are properly irrigated, have low media EC, free of insects or disease, proper root growth, and have been grown under adequate light and temperature levels. These cultural factors can help to reduce impact of postproduction stresses after removal from ideal growing environment (Dole and Wilkins, 2005). Postproduction stresses include reduced quality of air, prolonged periods of darkness, variations in relative humidity and temperature, exposure to ethylene (Nell and Hoye, 1995; Jones, 2002; Starman et al., 2007), improper irrigation (usually drought) and mechanical disturbance (Cameron and Reid, 1983; Starman et al. 2007). High humidity and warm temperatures can exaggerate fungal problems such as *Botrytis* (Dole and Wilkins, 2005). Exposure to stresses can stimulate endogenous ethylene production (Kim, H., et al., 2007). These stresses can lead to premature senescence including lower leaf chlorosis, internode elongation, flower and bud abscission, bud abortion, color fading, decreasing size of future flowers and stem dieback (Starman et al., 2007). Plants that arrive at market exhibiting these senescence symptoms are unmarketable (Jones and Edelman, 2013).

Consumers, retailers and growers would all benefit from plants that are resistant to postproduction stresses yet this is unrealistic for the broad range of genera, species, cultivars and colors of bedding plants in the industry. Growers should routinely sample a few of each cultivar to observe postproduction characteristics. There may be similar color options available that are more tolerant to postproduction handling and will reduce losses (Dole and Wilkins, 2005). Some breeding efforts are being put forth to introduce new genotypes of bedding plants, such as *Pelargonium x domesticum,* with reduced ethylene sensitivity that demonstrate superior postproduction quality (Kim et al., 2006).

To optimize plant health in postproduction it is best water plants in the morning; allow them to dry and to pack plants in the afternoon when carbohydrate levels are highest. Low carbohydrate levels due to high respiration and lack of photosynthesis (in low light conditions) can also increase senescence symptoms similar to ethylene exposure (Nelson, 2012). In large production companies, plants are placed into trays and tightly packed onto shipping carts. The entire cart is wrapped with plastic to prevent movement during transport (Nell and Hoye, 1995). For some markets bedding plants are placed in sleeves and boxed for transportation (Jones, 2002), these sleeves should have holes for ventilation and be removed immediately upon delivery (Jones and Edelman, 2013).

Transportation vehicles should be refrigerated and ventilated to reduce: buildup of harmful chemicals like ethylene, fungal and disease pathogens, transpiration and respiration rates of plants; this in turn will slow depletion of carbohydrates and reduce effects of ethylene and pathogens in plants (Nelson, 2012). Postproduction stress is visible in most bedding plants after two days of shipping with leaf chlorosis developing first followed by flower abscission (Starman et al., 2007). Some plants will display symptoms immediately after being removed from

shipping conditions such as flower abscission in *Diascia* and *Nemesia* after two days of simulated shipping whereas other plants (*Calibrachoa* and *Sutera*) will show abscission within a week after plants have been placed in postproduction environments such as retail stores (Starman et al., 2007). It is possible for plants to stay in boxes an additional 1 or 2 days until they are unpacked at the retail center (Jones, 2002; Starman et al., 2007) senescence symptoms will be aggravated with increased exposure to poor postproduction conditions.

To avoid ethylene in postproduction plants should be healthy; wounds and infected tissue can accelerate senescence damage due to increased levels of endogenous ethylene. All plants should be cleaned of old and damaged foliage and flowers before packing to eliminate this source of ethylene and pathogens (Nelson, 2012; Jones and Edelman, 2013). Shipping trucks should be ventilated and temperature controlled and plants should be kept at the lowest possible temperature to reduce ethylene damage but high enough to avoid chilling injury (Dole and Wilkins, 1995; Jones, 2002; Nelson, 2012). If flowering plants are to be shipped long distances, less mature plants should be selected because open flowers are generally more sensitive to ethylene than buds (Jones, 2002). Upon arrival plants should be immediately unpacked, removed from sleeves and given ample space. It is often the case that less than ideal conditions await plants in the retail chain including low light, inadequate irrigation and fertilization and warm temperatures (Starman et al., 2007).

Ethylene

Ethylene is a simple alkene hydrocarbon with the chemical formula C_2H_4. Ethylene is the historic name for the molecule and has been replaced by the nomenclature systematic name ‘ethene’ as determined by the International Union of Pure and Applied Chemistry (IUPAC);

'eth' referring to 2 carbon atoms and 'ene' for its classification in the alkene series of hydrocarbons. For the purposes of this thesis we will refer to the molecule by its historic name, ethylene.

Ethylene is a colorless gaseous plant hormone with a sweet ether-like odor (Abeles, 1973). It is active at very low concentrations in plants; the presence or absence of which will exhibit positive or negative effects on plant growth depending on the stage of plant development (Abeles, 1973). Ethylene is beneficial to plant development in processes such as seed germination, flower induction in bromeliads, sex expression in cucurbits, tuber and bulb formation, removing flowers from stock plants, keeping plants short and ripening fruit. Among other effects ethylene can be harmful or damaging to horticulture crops by hastening senescence of leaves, flowers and fruit when the goal of postproduction is to extend shelf life (Abeles, 1973).

Throughout normal growth and development ethylene is produced internally in plants through the ethylene biosynthesis pathway. The pathway can be triggered by external stimuli such as wounding, disease, environmental stress (high and low temperatures, flooding and drought), chemicals (auxin) and ethylene itself (Abeles, 1973). Ethylene is also produced by a variety of biological and non-biological sources. Sources of biologically produced ethylene include off-gassing from senescing plant material and microorganisms such as *Fusarium* (Dole and Wilkins, 2005; Flood, 1999). Sources of non-biologically produced ethylene include natural gas, incomplete combustion of fuels, engine exhaust, and smoke (Dole and Wilkins, 2005; Flood, 1999).

Ethylene and Floriculture

Ethylene can injure plants throughout growth. Symptoms of ethylene damage in growing floriculture crops include malformed leaves and flowers, thickened stems and leaves, stunted growth, excessive branching, abortion of flowers and leaves and abscission of flowers, buds and leaves (Gibson et al., 2000). Finished crops that are ready for market can be negatively impacted by ethylene through abscission of flowers, buds and leaves, epinasty, and hastening of senescence (Gibson et al., 2000). A dose-response relationship for many ethylene-mediated processes shows that there is no effect below 0.01 $\mu l \cdot liter^{-1}$, between 0.01 and 0.10 $\mu l \cdot liter^{-1}$ for a half-maximal effect, and 10 $\mu l \cdot liter^{-1}$ for a saturating dose (Abeles, 1973).

Woltering (1987) classified sensitivity of ornamental pot plants according to symptoms seen after treatment with exogenous ethylene concentrations from 0-15 $\mu l \cdot liter^{-1}$; the most prevalent symptoms included abscission of leaves and flowers, leaf chlorosis and epinasty. Abscission was time dependent with flowers abscising after 24 hours while leaves remained on plants until approximately 72 hours of exposure. Abscission was also dependent on the age of tissues with older leaves abscising first and young buds requiring higher concentrations than older flowers.

Woltering and Van Doorn (1988) conducted experiments to classify cut flowers into senescence categories by exposing flowers to exogenous ethylene for 24 hours. They proposed three main types of petal senescence: 1) wilting apparently mediated by ethylene, 2) wilting apparently not mediated by ethylene, and 3) abscission that is apparently mediated by ethylene. Exogenous ethylene applied to cut flowers show hastened senescence in many families and the effect is the same as would occur in natural senescence (such as wilting and abscission). Wilted petals generally remain attached to the flower stem or abscise after wilting, whereas petals that

exhibit true abscission showed no initial symptoms of wilting. In a few cases flowers showed senescence as color change before wilting or abscising, mainly within the Orchidaceae family. It was concluded that flower families that show natural senescence as abscission are usually very sensitive to exogenous ethylene whereas families that senesce via wilting are usually not sensitive to exogenous ethylene (with notable exceptions Campanulaceae, Caryophyllaceae, Malvaceae and Orchidaceae). Sensitivity to ethylene in these cut flower families was found to be similar within genera, species and even cultivar (Woltering and Van Doorn, 1988).

The extent and type of ethylene damage varies with many factors including plant species, stage and state of plant development, duration of exposure, ethylene concentration, and temperature (Dole and Wilkins, 2005; Gibson et al, 2000). *Pelargonium x domesticum* is highly sensitive to ethylene yet sensitivity varies between cultivars, some begin to abscise flowers less than 2 hours after exposure to 0.5 $\mu l \cdot liter^{-1}$ (Deneke et al., 1990). Age related sensitivity is also noted with younger *P. x domesticum* florets requiring a higher concentration of ethylene and longer duration of exposure to induce abscission than older flowers (Deneke et al., 1990; Evensen, 1991). Similar increase in sensitivity to ethylene with flower age was seen in *P. peltatum* (Cameron and Reid, 2001) and *P. x hortorum* (Evensen, 1991; Cameron and Reid, 2001). Increased ethylene sensitivity in mature tissue could be attributed to increased endogenous ethylene production to pollination and/or natural senescence (Deneke et al., 1990).

Ethylene Sources and Measurement

During greenhouse production of floriculture crops it is important remove potential ethylene sources. One common ethylene source is natural gas-fired unit heaters common in the greenhouse industry. It is important to maintain heaters to ensure they are running efficiently.

Leaks, rust and clogging of heating systems can cause ethylene off-gassing caused by incomplete combustion (Gibson et al, 2000; Nelson, 2012). Many growers reduce ventilation at night and in winter to save heat, but without proper oxygen levels, heaters cannot complete combustion and greenhouse air will become contaminated (Nelson, 2012). Growing areas that are airtight such as newly glazed and iced over glass greenhouses can result in high levels of ethylene contamination and require ventilation with clean air (Gibson et al., 2000). Losses from ethylene contamination can be very large (Filios and Miller, 2011).

Ethylene levels from suspected contamination areas can be measured using gas chromatography. In plant production facilities it is sometimes valuable to use an ethylene-sensitive indicator plant to assess ethylene levels, for example tomato petioles show epinastic response or a downward bending of the leaf. The leaf will remain turgid and the plant will be otherwise healthy. When removed from the ethylene environment the leaves soon return to their normal positions (Gibson et al., 2000).

Skog et al. (2001) measured ethylene levels in mid-size to multi-million dollar wholesale and retail businesses in Ontario, Canada. Detectable levels of ethylene (>0.01 $\mu l \cdot liter^{-1}$) were measured in 63% of air samples and these levels ranged from 0.01 to 10 $\mu l \cdot liter^{-1}$. Sources of ethylene included: fresh, processed and rotting produce, propane forklifts, truck exhaust, smoke, heating equipment, leaks from ethylene rooms used for gassing produce, and recently gassed produce. Areas that contained only flowers and had no produce on the premises exhibited ethylene concentrations ranging from undetectable (<0.01) to moderate (1.44 $\mu l \cdot liter^{-1}$). Loading areas should be kept separate from active growing plants and within these confined areas there is a need for ample fresh air, proper maintenance of equipment, and removal of plant debris to reduce ethylene contamination.

Ethylene Removal

Ethylene removal has been studied for many years with varying success. One class of ethylene removal is absorbers, which remove ethylene from air via chemical reaction as air is passed through a matrix of the absorber. Common products include brominated activated carbon and potassium permanganate ($KMnO_4$) (Abeles, 1973). Potassium permanganate absorber at low concentration (70 $g \cdot m^{-3}$) was utilized by Skog et al. (2001) to reduce the presence of ethylene in flowering potted and bedding plants without great improvement of quality. Notable exceptions included improved long term performance of *Impatiens x hawker* 'Paradise Aglia' compared to control and improved recovery after ethylene exposure of *Impatiens walleriana* 'Seashell'. Higher concentrations of absorber (90 $g \cdot m^{-3}$) was effective in protecting *Rosa x hybrida* 'Parade Fame' against immediate exposure to ethylene but provided no additional long-term protection. When used, ethylene absorbers must be able to remove ethylene below the plants' ethylene threshold response concentration (Skog, 2001). Other methods include ozone and UV light to neutralize and eliminate ethylene from air (Abeles, 1973).

Reducing Ethylene Synthesis and Effects

Chemicals such as aminoethyoxyvinylglycine (AVG) and aminooxyacetic acid (AOA) block endogenous ethylene production by inhibiting the ethylene biosynthesis pathway, butare not effective in reducing symptoms caused by contact with exogenous ethylene (Porat, 1995).

A more effective method of reducing the effect of ethylene is by inhibiting ethylene perception and blocking the ethylene receptor molecule. The union of an ethylene blocker and the ethylene plant receptor molecule is permanent; if all the receptor molecules are blocked then ethylene has nowhere to bind and it remains inactive (Nelson, 2012).

Silver thiosulfate (STS) and 1-methylcyclopropene are commercially available materials that inhibit ethylene binding (Nelson, 2012). Beyer (1976) demonstrated that silver nitrate inhibits abscission of fruits, leaves and fruits caused by ethylene, yet silver is immobile in the plant. In the form of silver thiosulfate, silver is readily mobile within the plant and has been shown to be a long lasting antagonist of both endogenous and exogenous ethylene (Veen and Van de Geijn, 1978). Unlike STS, 1-MCP, while irreversibly binding to the ethylene receptor molecule, is not as long lasting, and many flowers gradually develop new ethylene sensitivity after application (Blankenship and Dole, 2003). In the presence of 1 $\mu l \cdot liter^{-1}$ ethylene there was no significant difference in longevity of cut flowers *Alstromeria, Antirrhinum majus, Consolida ambigua, Dianthus barbatus, Matthiola incana* and *Penstemon hartwegii* pretreated with 1mM STS or 20 $nl \cdot liter^{-1}$ 1-MCP, both prevented accelerated flower or petal abscission compared to the controls (Serek et al., 1995). 1-MCP has proven to be equal in effectiveness as STS for short-term treatments and both chemicals work on virtually all plants that are sensitive to ethylene (Nelson, 2012).

Silver Thiosulfate (STS)

STS is a very powerful tool for increasing postharvest shelf life of potted plants and cut flowers. STS, used as a spray on potted *Pelargonium peltatum* was still effective two to three weeks after treatment with newly emerged flower stalks showing insensitivity to exogenous ethylene. This indicates that STS was freely mobile in the plant over the three-week period (Cameron and Reid, 1983) and after synthesis of new ethylene receptor sites these silver ions remained unbound in the plant and could continuously inactivate ethylene responses (Serek and Sisler, 2001). STS is prevalent in the cut flower industry due to its long lasting ability to reduce

of effects of internal and external ethylene. It is important to precisely time the length of exposure to STS because it can become toxic and in many cases, STS is most effective at concentrations close to the point of phytotoxicity (Cameron and Reid, 1983). Disposal of silver has become an environmental concern (Serek et al., 1995) and some countries have banned the direct disposal of STS due to levels of silver in the floral solutions. A kit is available to reclaim the silver contained in STS (Nelson, 2012). This environmental concern has also extended in some countries to restriction of use on potted flowering plants (Serek et al., 1994).

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is a gas at standard temperature and pressure with the chemical formula C_4H_6. The safety, toxicity, and environmental profiles of 1-MCP are very favorable and the compound, when used at low rates, has a non-toxic mode of action (EPA, 2002). 1-MCP was developed by Edward Sisler and Sylvia Blankenship, North Carolina University. It is thought that when 1-MCP comes in contact with a plant it occupies the ethylene receptors and does not allow ethylene to bind (Blankenship and Dole, 2003). It is proposed that 1-MCP has 10 times greater affinity for the ethylene receptor than ethylene itself (Sisler and Serek, 1997). Other chemicals have been considered for use against ethylene but none proved to be as beneficial as 1-MCP; 2.5-norbornadiene has a foul odor and requires constant exposure, silver cannot be used on feed or food, diazocyclopentadiene (DACP) is highly explosive, 3-MCP is required in high concentration and cyclopropene is highly volatile (Sisler and Serek, 1997).

In 1999, 1-MCP was approved in the United States by the Environmental Protection Agency (EPA) for use on ornamentals. It was initially sold under the name EthyBloc® by Floralife, Inc. (Walterboro, SC). This formulation encapsulated 1-MCP into α-cyclodextrin

powder that releases 1-MCP (when mixed with water) in approximately 20-30 minutes at standard temperature and pressure (Blankenship and Dole, 2003). Longer times are required for release and application at lower temperatures, likely because of the reduced sensitivity to ethylene at low temperatures (Blankenship and Dole, 2003).

Blankenship and Dole (2003) noted that concentrations of 1-MCP required to protect horticulture crops from ethylene range from 10-800 nl·liter^{-1} with duration of exposure from 2-24 hours. Most treatments are applied at 20-25°C and treatment durations of 12-24 hours to achieve a full response. Factors such as temperature, cultivar and development stage need to be taken into account when determining a treatment. Treatment on *Penstemon hartwegii* with 1-MCP at 20°C were effective in protecting against exogenous ethylene, whereas treatments at 2°C were not (Serek et al., 1995). There was a sigmoidal response between treatment temperature and efficacy of 1-MCP in *Dianthus barbatus*, with complete inhibition of ethylene injury with 1-MCP treatment at 20°C and no protection at 0°C (Reid and Çelikel, 2008).

It is possible to reduce duration of 1-MCP treatment by increasing 1-MCP concentration (Serek et al., 1995). There have been no reports of toxic effects of 1-MCP on flowers though there is a saturation point when all ethylene receptor sites are bound and concentrations above this saturation point will be no more effective at inhibiting effects of ethylene (Cameron, 2000; Serek and Sisler, 2001). The dose necessary to reach saturation of all receptor sites can vary depending on cultivar. Kim et al. (2007) reported 1-MCP was most effective at concentrations of 125 nl·liter^{-1} for 12 hour exposure for *Begonia x hiemalis* 'Blitz' whereas 25 nl·liter^{-1} for 12 hour exposure was most effective for *Begonia x hiemalis* 'Carneval'. The length of time for 1-MCP treatments to be effective was dependent on the presence or absence of ethylene; in the absence of ethylene *Dianthus barbatus* flowers achieved full protection from 1-MCP treatment

in 30 minutes whereas in the presence of ethylene and 1-MCP, treatment required 6 hours to achieve full inhibitory effects (Reid and Çelikel, 2008).

1-MCP protects plants from both endogenous and exogenous ethylene. Some plants (*Antirrhinum majus, Begonia x semervirens-cultorum, Delphinium elatum, Gypsophila paniculata, Impatiens x hawker, Impatiens walleriana, Petunia x hybrida, Nicotiana alta, Streptocarpella x hybrid* (Skog et al., 2001), *Schlumbergera truncata* (Serek and Sisler, 2001), *Dianthus caryophyllus* (Serek et al. 1995)) benefit from 1-MCP regardless of the presence of exogenous ethylene with increased postproduction life compared to untreated controls. Others show benefits from 1-MCP only if they are subsequently exposed to exogenous ethylene (*Alstromeria x hybrida, Begonia x hiemalis, Calceolaria herberohybrida, Catharanthus roseus, Kalanchoe blossfeldiana, Pelargonium x domesticum, Pelargonium x hortorum, Petunia x hybrida,* (Skog et al., 2001), *Rosa hybrida* (Skog et al., 2001; Serek et al., 1994), *Begonia x elatior, Kalanchoe blossfeldiana* (Serek et al., 1994)). The effectiveness of 1-MCP in the presence or absence of ethylene depends on many factors and including cultivar. 1-MCP treatment decreased the rates of senescence of *Pelargonium x hortorum* 'Fox' in the absence of ethylene (Jones et al., 2001) whereas *Pelargonium x hortorum* 'Elite Red' only showed effect of 1-MCP when exposed to ethylene (Skog et al., 2001).

1-MCP in the EthyBloc® formulation must be released in an enclosed environment; in floriculture these are generally holding rooms, coolers or delivery trucks. 1-MCP gas will only bind to unblocked ethylene receptor sites, once a plant is removed from the environment containing 1-MCP new receptor sites that form will not be protected against ethylene (Nelson, 2012). One treatment of 1-MCP may be sufficient to protect single-bloom plants that are at the same development stage. Many potted plants will bloom continuously and therefore 1-MCP

treatments are only effective in protecting against exogenous ethylene for a limited amount of time, further plant development will lead to synthesis of ethylene receptor sites and such new sites are not protected by 1-MCP (Serek and Sisler, 2001; Nelson, 2012). Spike or spray flower stems and potted plants with flowers of many different stages of growth and tissue ages will have potentially varied responsiveness to 1-MCP treatments (Sisler et al. 1996; Blankenship and Dole, 2003).

In the case of *Pelargonium peltatum* one treatment of 1-MCP was effective in protecting against exogenous ethylene for approximately 4 days (Cameron and Reid, 2001). It is possible to re-apply 1-MCP multiple times, with reestablishment of beneficial effects for the same length of time with is no evidence of toxicity (Cameron and Reid, 2001). The temperature at which plants are stored after they have been treated with 1-MCP can influence the length of inhibitory effect, *Pelargonium peltatum* treated with 1-MCP were protected for 4 days at 25°C or for 5 days at 20.7°C (Cameron and Reid, 2001).

EthylBloc® and Ethylene Buster® (Crysal Americas, Miami, FL) are currently the only commercially available 1-MCP product registered for use on ornamental plants. These 1-MCP products are available in multiple formats. EthylBloc® truck-kits are used in large shipments, a bucket of water or mild alkali is placed at the rear of a loaded truck, a water-soluble pouch is placed in the bucket of liquid and the doors are sealed. The pouch will dissolve and 1-MCP will be liberated into the truck. The doors need to remain sealed for a specified length of time to ensure complete inhibition of ethylene (Reid and Çelikel, 2008). Depending on the size of the truck, different sizes of 1-MCP pouches are available. EthylBloc® and Ethylene Buster® sachets can be utilized for smaller shipments such as individual boxes, these small teabag-like sachets are filled with 1-MCP and are dipped into water and then placed inside a box, the water

dissolves the cyclodextrin slowly and releases 1-MCP in the box (Reid and Çelikel, 2008). Multiple sachets can be used in one box to achieve the concentration desirable to inhibit the effects of ethylene. EthylBloc® and Ethylene Buster® are also available in tablet form which when dissolved in activator solution will release a precise amount of 1-MCP.

Current research on 1-MCP technologies has been primarily focused on food crops. A new formulation of 1-MCP registered with the EPA, AFxRD-038, is used as a spray. A water-soluble pouch filled with this formulation of 1-MCP is placed in a spray tank filled with water, adjuvant and surfactant. The spray is then applied directly on to crops in the field, with sufficient volume to ensure uniform coverage of the target plant (EPA US LABEL, 2010). AFxRD-038 is registered for use as Harvista™ on fruit crops apples, pears, kiwifruit, walnuts, tomatoes and peppers and Invinsa™ on field crops corn, soybean, cotton, sunflower, wheat and rice. It is not registered for use on ornamental plants (EPA US LABEL, 2010).

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CHAPTER 2

Use of a Sprayable Formulation of 1-Methylcyclopropene on Annual Bedding Plants *Impatiens walleriana* and *I. hawkerii*

Abstract

A study was conducted with a sprayable formulation of 1-methylcyclopropene, 1-MCP, (formulation AFxRD-038, Rohm and Hass, Philadelphia, PA), to determine the effects of ethylene concentration, plastic bag enclosure, 1-MCP concentration and volume, water quality, age, timing and length of irrigation, delay of ethylene challenge, surfactants, extended darkness and high storage temperatures on efficacy of 1-MCP to protect *Impatiens walleriana* and *I. hawkeri* from premature floral senescence. Ethylene exposure of 1.0 µl·liter^{-1} for 18 hours caused complete senescence of open flowers, 1-MCP at 2.5 mg ai·liter^{-1} protected plants from ethylene exposure. Surrounding plants with High Density Polyethylene (HDPE) produce bags had no effect on flower abscission in the presence or absence of ethylene or 1-MCP. At 5 and 10 mg ai·liter^{-2}, the efficacy of 1-MCP increased with increased spray volume from 102 ml·meter^{-2} to 306 ml·meter^{-2}. 1-MCP appeared to be effective within 1 minute after application with no decrease in efficacy regardless of overhead irrigation water applied after 1-MCP pretreatment. There was no significant effect of surfactant concentration (Capsil, Aquatrols, Paulsboro, NJ) on 1-MCP activity though some plants exhibited phytotoxicity symptoms on flower petals with rates above 1.0 ml·liter^{-1}. Increasing pH of the 1-MCP solution from 6 to 9 resulted in slightly reduced efficacy but not enough to reduce marketability of plants. Prepared 1-MCP solutions (10 mg ai·liter^{-1}) remained effective up to two weeks after mixing if held in airtight containers. 1-MCP provided protection against exogenous ethylene for a maximum of four days. 1-MCP provided protection against darkness and high temperature stress related abscission for at least

three days of extended darkness in the absence of ethylene and two days at high temperatures (28°C).

Introduction

Postproduction of finished annual bedding plants includes packaging, handling and care of plants from the time they are removed from optimal growing conditions until the customer enjoys them. It is of the utmost importance to deliver plants to customers that are at peak of performance exhibiting no damage or senescence symptoms. Ethylene, a gaseous hormone, is known to cause accelerated senescence of plants such as leaf and flower abscission and wilting (Ables, 1973). Ethylene is an odorless, colorless gas, which can be produced from biological sources such as decaying, ripening or senescing plant material and pathogens and non-biological sources such as engine exhaust, leaking heating systems and smoke (Gibson et al.; 2000; Jones, 2002; Dole and Wilkins, 2005; Nelson, 2012).

Due to the variety of ethylene sources there are many points at which annual bedding plants can come into contact with ethylene during postproduction such as exhaust from trucks, off-gassing from ripening fruit and plant debris being held in the same location, leaks from ethylene ripening rooms, production from the plants themselves if wounded or stressed (Gibson et al.; 2000; Jones, 2002; Dole and Wilkins, 2005; Nelson, 2012). It is recommended that plants be shipped at peak of nutrition, fully irrigated and with no injuries, and that these plants should be well ventilated and kept cold, (if appropriate and when possible), to reduce respiration and reduce incidence of ethylene damage (Jones, 2002; Dole and Wilkins, 2002; Nelson, 2012; Jones and Edelman, 2013).

In a survey conducted by Skog et al. (2001) of wholesalers and retailers of floriculture crops in Ontario, Canada, levels of ethylene were detected in 63% of air samples taken ranging

from 0.01 to 10 μl·liter^{-1} with highest contamination in locations that contained produce and cut flowers while locations with only potted crops ranged from 0.01 to 1.44 μl·liter^{-1}, this also being the threshold concentration for ethylene injury on flowering plants (Nelson, 2012).

It is unlikely to guarantee complete removal of ethylene from the postproduction chain and thus it is becomes necessary to look for other technologies to reduce the effect of ethylene on annual bedding plants. 1-Methylcyclopropene (1-MCP) binds to ethylene receptor sites on the plant and with proper application will render plants unsusceptible to endogenous and exogenous ethylene for a period of time depending on plant growth (Blankenship and Dole, 2013). Current use of 1-MCP in floriculture is limited to a gaseous formulation sold under the name EthylBloc® (Floralife Inc., Walterboro, SC). In this system plants are enclosed in an airtight location and a wetting agent is added to the 1-MCP powder, releasing the gaseous molecule, and the area must remain closed for a specified length of time. This treatment method can be limiting to postproduction efficiency and convenience because the length of time that plants must be enclosed in the 1-MCP atmosphere can extend from four to ten hours to achieve full protection from ethylene (Reid and Çelikel, 2008; Jones and Edelman, 2013). Other release mechanisms include 1-MCP sachets that can be dipped in water and placed into shipping boxes and once sealed the gas will build and bind to ethylene receptors on the plants (Jones and Edelman, 2013).

The wholesale value of annual bedding and garden plants was more than $1.361 billion in 2012 (USDA, 2013) and of this 11.2% can be attributed to sales of New Guinea impatiens and other impatiens. Wholesale value of New Guinea impatiens (*Impatiens x hawkeri)* was $50 million with the largest contribution from potted plants and wholesale value of other impatiens (primarily *I. walleriana*) was $102.5 million with more than half this coming from $65.5 million sales of plants in flats (USDA, 2013). Impatiens are valued for their broad range of colors and

long duration of flowering in the landscape thus making them one of the most important genus of crops in United States floriculture production. Impatiens plants are very sensitive to ethylene and show flower abscission damage when exposed to very low concentrations of ethylene (Dostal et al., 1990). It has been shown that when exposed to postproduction conditions both *Impatiens x hawkeri* (Dostal et al., 1990; Han, 2003) and *I. walleriana* can benefit from 1-MCP protection to extend postharvest condition (Skog, 2001; Han, 2003).

A new formulation of 1-MCP, AFxRD-038, (Rohm and Hass, Philadelphia, PA) has been developed that allows for application via direct spraying or dipping plants with the aqueous 1-MCP solution. This technology is labeled for in-field applications on fruit and vegetable crops such as apples, pears, kiwifruit and walnuts, tomatoes and peppers, under the trade name Harvista™ and on field crops (corn, soybean, cotton, sunflower, wheat and rice), under the trade name Invinsa™ (EPA US LABEL, 2010). MacKinnon et al. (2009) explored the effects of surfactants, nozzle types, spray volumes, and simulated rain on 1-MCP efficacy on tomato plants, which were then treated with an ethylene releasing spray, ethephon, to elicit epinastic responses in leaves. Tomato plants were protected from ethylene exposure with pretreatment of sprayable 1-MCP (25 and 50 $g \cdot ha^{-1}$), 1-MCP increased in efficacy with increased spray volumes (400 $l \cdot ha^{-}1$), and 1-MCP appeared to be rainfast within 15 minutes after application while nozzle type had no effect on 1-MCP efficacy (MacKinnon, 2009).

AFxRD-038 sprayable 1-MCP has not yet been labeled for use on floriculture crops, thus it is necessary to explore the potential value of this sprayable 1-MCP technology for the floriculture industry. *Impatiens x hawkeri* and *I. walleriana* provide excellent model systems for exploring the use of sprayable 1-MCP in floriculture due to their economic importance as one of the most produced floriculture crop and their high sensitivity to ethylene and positive

responsiveness to traditional 1-MCP application. The objectives of this research were: 1) to determine ethylene rates necessary to induce damage, which renders *Impatiens* plants un-marketable; 2) to determine efficacy of different 1- MCP application concentrations on *Impatiens* response to ethylene; 3) to determine impact of 1-MCP application spray volume, age of solution, water quality and surfactant rate on *Impatiens* response to ethylene; 4) to determine effect of irrigation on efficacy of 1-MCP on *Impatiens*; and 5) to determine the length of 1-MCP efficacy after application on *Impatiens* kept in ideal growing conditions or exposed to heat and dark stresses.

Materials and Methods

Plant production

Impatiens walleriana 'Super Elfin Rose Improved', and 'Super Elfin White' (Ball Horticultural Co., West Chicago, IL), and *Impatiens hawkeri* 'Tamarinda Purple' (Fides Oro, Santa Paula, CA) were grown from seed or vegetative cuttings. Individual plants were transplanted into 10 or 14-cm containers filled with a commercial greenhouse substrate (LM-111; Lambert Peat Moss, Inc.). Plants were irrigated as needed with tap water supplemented with 200 mg $N \cdot L^{-1}$ from (*Jack's LX*™ 21-5-20; J.R. Peter's Inc., Allentown, PA). Plants were grown in a glass greenhouse at constant air temperature set point of 20 °C and ambient light. Plants were pinched to encourage compact growth without the use of plant growth regulators.

Plant selection

Plants were selected at market stage with enough foliage to cover the growing media in the container and a minimum of six open flowers. Approximately one week prior to experiments

plants were cleaned to remove older flowers and leaves, ensuring only young flowers were present when experiments started. Plants for each experiment were selected for uniformity in size and flower number from blocks of approximately 50 plants.

1-MCP application

A formulation of sprayable 1-MCP powder (AFxRD-038, 3.8% w/w active 1-MCP; AgroFresh, Inc. Springhouse, PA) was mixed with reverse osmosis (RO) water in a sealed container until all powder was dissolved and solution was clear. Solution was transferred to a 1-gallon pump sprayer and pressurized immediately. The solution was sprayed onto plants until runoff and allowed to dry, approximately one hour.

Ethylene treatment

Plants were moved into 0.4 m^3 plexiglass boxes with two small fans mounted inside and boxes were sealed. Unless mentioned, plants were placed into individual #2 High Density Polyethylene (HDPE) produce bags (Crown Poly Inc., Huntington Park, CA) to ensure abscised plant tissues were isolated. In genera which exogenous ethylene damage does not show tissue abscission, plants were not bagged before being placed in treatment boxes. The boxes were located in an ethylene-free growth chamber at 21C in darkness. Air flowing through boxes was either clean air or diluted ethylene and was exhausted into a line leading to the outdoors. Ethylene streams were prepared by diluting 3% ethylene (balance N_2) into air flowing at 10L·min^{-1} using mass flow controllers and a microprocessor control device (Aalborg Inc., Orangeburg, NY). Ethylene concentrations were verified by gas chromatography and were maintained within 5% of desired set point. Additional studies were conducted in a closed static

system by enclosing plants under an airtight plastic tent and injecting desired concentration of ethylene gas.

Senescence data

All senescence data were recorded immediately after the plants were removed from the plexiglass experiment boxes. Preliminary experiments showed that no additional senescence attributed to exogenous ethylene treatments was observed several hours to several days after plants were removed from treatment boxes. *Impatiens walleriana* and *I. hawkeri* were evaluated for flower and bud abscission. All such abscised flowers and buds were turgid and showed no signs of natural senescence (discoloration, damage or wilting).

Expt. 1. Concentration of ethylene to induce abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were placed into plexiglass boxes with three concentrations of ethylene (0.25, 0.75, and 1.0 $\mu l \cdot liter^{-1}$) as described previously for 18 hours. Four single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed and analysis of variance was performed to test for significance of linear and quadratic regression fit (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 2. Plastic bag enclosure treatments and concentration of ethylene to induce abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were split into two sets, one set of plants was gently placed into individual #2 High Density Polyethylene (HDPE) produce bags (Crown Poly Inc., Huntington Park, CA) and the second set was not enclosed. Plants were then moved into plexiglass boxes with three concentrations of ethylene (0.25, 0.45, and 0.55 $\mu l \cdot liter^{-1}$)

as described previously for 18 hours. Non-enclosed plants were spaced apart from one-another to ensure abscised tissues were isolated. One additional set of plants was kept in the growth chamber at the same temperature and darkness to represent a non-ethylene (0 μl·liter^{-1}) treatment. Four single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed. Analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and analysis of variance tests were conducted and Student's *t* test was used to conduct pair wise comparisons of bagged verses open (no-bag) pooled treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 3. Concentration of sprayable 1-MCP to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were sprayed with 1-MCP at rates of 0, 2.5, 5.0, 10 and 15 mg ai·liter^{-1} and allowed to dry. All spray treatments were mixed with Capsil at 0.5 ml·liter^{-1}. Plants were then placed into plexiglass boxes with 1.0 μl·liter^{-1} ethylene as described previously for 18 hours. Five single-plant replicates were used per treatment. One additional set of plants treated with 0 mg ai·liter^{-1} 1-MCP and was kept in the growth chamber at the same temperature and darkness to represent a non-ethylene non-1-MCP control. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and analysis of variance was performed to test for significance of linear and quadratic fit of 1-MCP treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 4. Lower concentrations of sprayable 1-MCP to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were sprayed with 1-MCP at rates of 0, 0.1, 0.5, 1.0 and 2.0 mg ai ·liter^{-1} and allowed to dry. All spray treatments were mixed with Capsil at 0.5 ml·liter^{-1}. Plants were then placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene as described previously for 18 hours. Five single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and analysis of variance was performed to test for significance of linear and quadratic fit of 1-MCP treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 5. Concentration and volume of sprayable 1-MCP to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were sprayed with two concentrations of 1-MCP (5.0 and 10 mg ai ·liter^{-1}) and three volumes (102, 204 and 306 ml·meter^{-2}) and allowed to dry. All spray treatments were mixed with Capsil at 0.5 ml·liter^{-1}. Plants were then placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene as described previously for 18 hours. Five single-plant replicates were used per treatment. Two additional sets of plants were treated with 0 mg ai ·liter^{-1} 1-MCP, one set was placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene overnight and the second set was kept in an ethylene-free growth chamber at the same temperature and darkness as controls. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all 1-MCP spray treatments and least squares fit was used to estimate model significance of 1-MCP and volume treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 6. Water quality and efficacy of sprayable 1-MCP

Solutions of 10 mg ai ·liter^{-1} 1-MCP were mixed using water collected from a municipal source, reverse osmosis (RO) or Milli-Q (Milli-Q Advantage A10 System, Millipore Corp., Billerica, MA). The pH of all water was measured before 1-MCP and 0.5 ml·liter^{-1} Capsil were added. Six additional 1-MCP treatments were made with RO water adjusted to pH of 4, 5, 6, 7, 8 and 9. The pH was adjusted using 1.0M NaOH to increase pH and 0.1M HCl to decrease pH. *Impatiens walleriana* 'Super Elfin Rose Improved' plants were sprayed with 1-MCP solutions and allowed to dry. Plants were then placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene flow through as described previously for 18 hours. Three single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all 1-MCP spray treatments and least squares fit was used to estimate model significance of pH on flower abscission (JMP Pro v 10, SAS Institute, Cary, NC).

The experiment was repeated using *Impatiens hawkeri* 'Tamarinda Purple' with 1-MCP treatments were made with RO water adjusted to pH of 7, 8, 9 and 10. The pH was adjusted using 1.0M NaOH to increase pH. Plants were sprayed with 1-MCP solutions and allowed to dry. Plants were then placed into tents injected with 2.5 µl·liter^{-1} ethylene static system for 18 hours. Four single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all 1-MCP spray treatments and least squares fit was used to estimate model significance of pH on flower abscission (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 7. Concentration of surfactant in 1-MCP sprays

Impatiens walleriana 'Super Elfin White' plants were sprayed with 10 mg ai ·liter^{-1} 1-MCP prepared with RO water containing the surfactant, 'Capsil', at rates of 0, 0.5, 1.0 and 2.0 ml·liter^{-1} and allowed to dry. Plants were then placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene as described previously for 18 hours. Three single-plant replicates were used per treatment. Data on percentage of abscised flowers were arcsin-transformed, analysis of variance was performed to test for significance of linear and quadratic fit of ethylene treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 8. Length of 1-MCP effectiveness to prevent abscission

Four *Impatiens walleriana* 'Super Elfin White' plants were sprayed with freshly made 1-MCP at 10 mg ai ·liter^{-1} daily, for six days, and were left under optimum greenhouse conditions. On the sixth day, all plants were placed into plexiglass boxes with 1.0 µl·liter^{-1} ethylene as described previously. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and analysis of variance was performed to test for significance of linear and quadratic fit of delay of ethylene treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 9. Length of time between 1-MCP treatment and overhead irrigation to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were sprayed with 10 mg ai·liter^{-1} 1-MCP solutions containing 0.5 ml·liter^{-1} Capsil. Plants were allowed to stand for

varying lengths of time (1, 2, 3, 4, 5, 10, 30 minutes) before they were irrigated with 100 mL tap water directly overhead. Three single-plant replicates were used per treatment. One set of plants was sprayed with 1-MCP and not irrigated. One set of control plants were not treated with 1-MCP or irrigated. After 1-MCP and irrigation treatment, plants were allowed to dry completely and were placed into plexiglass boxes with 1.0 $\mu l \cdot liter^{-1}$ ethylene as described previously. Data on percentage-abscised flowers were arcsin-transformed, least squares fit was used to estimate model significance of length of time between 1-MCP treatment and irrigation on flower abscission (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 10. Duration of overhead irrigation after 1-MCP treatment to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants were sprayed with 10 mg $ai \cdot liter^{-1}$ 1-MCP solutions with 0.5 $ml \cdot liter^{-1}$ Capsil. Plants were allowed to dry for 1 or 2 minutes before they were irrigated for one or five seconds with tap water (0.45 or 2.25 L, respectively) directly overhead using a hose fitted with a water breaker. Three single-plant replicates were used per treatment. One set of plants was allowed to dry immediately after 1-MCP treatment without an irrigation treatment. After 1-MCP and irrigation treatment plants were allowed to dry completely and were placed into plexiglass boxes with 1.0 $\mu l \cdot liter^{-1}$ ethylene as described previously. Data on percentage-abscised flowers were arcsin-transformed, least squares fit was used to estimate model significance of time and volume of irrigation treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 11. Age of 1-MCP solution to prevent abscission

Solutions of 10 mg ai ·liter^{-1} 1-MCP were mixed with 0.5 ml·liter^{-1} Capsil over a period of seven weeks. Solutions were kept in airtight glass jars in darkness. On the seventh week a selection of these solutions were and a freshly mixed solution of 1-MCP were sprayed on *Impatiens hawkeri* 'Tamarinda Purple' allowed to dry. Plants were then placed under plastic tents with static 2.5 µl·liter^{-1} ethylene as described previously for 18 hours. Six single-plant replicates were used per treatment. Two additional sets of plants were treated with 0 mg ai·liter^{-1} 1-MCP, one set was placed into tent 2.5 µl·liter^{-1} ethylene overnight and the second set was kept in an ethylene-free area at the same temperature and darkness as controls. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all 1-MCP spray treatments and least squares fit was used to estimate model significance of 1-MCP age treatments (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 12. 1-MCP to prevent abscission in prolonged darkness

Impatiens hawkeri 'Tamarinda Purple' plants were sprayed with 0 or 10 mg ai·liter^{-1} 1-MCP and allowed to dry. Plants were then placed into an ethylene free dark room at 22°C for 1, 2, 3, or 4 days hours. Four or five single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance was performed to test for significance of 1-MCP, darkness treatments and the interaction. (JMP Pro v 10, SAS Institute, Cary, NC).

Expt. 13. 1-MCP to prevent abscission at high temperatures

Impatiens hawkeri 'Tamarinda Purple' plants were sprayed with 0 or 10 mg ai ·liter^{-1} 1-MCP and allowed to dry. Plants were then placed into plexiglass boxes at 0 or 1.0 µl·liter^{-1} ethylene as described previously at 28°C for 40 hours. Five single-plant replicates were used per treatment. Data on percentage-abscised flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and analysis of variance was performed to test for significance of 1-MCP, ethylene treatments and the interaction. (JMP Pro v 10, SAS Institute, Cary, NC).

Results and Discussion

Expt. 1. Concentration of ethylene to induce abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants exhibited a linear increase in flower abscission as ethylene concentration increased from 0.25 to 1.0 µl·liter^{-1} for an 18 hour exposure (Table 2.1). Similar dose dependent response results were seen in *Phlox paniculata* with 50% abscission attained after 12 hour treatment with 1 µl·liter^{-1} and 90% abscission was at was attained after 12 hour treatment with 3 µl·liter^{-1} (Porat et al., 1995). Previous experiments showed that placement of *I. walleriana* plants in an ethylene-free plexiglass treatment box overnight resulted in zero flower abscission (data not shown). The data from this experiment show that concentrations of ethylene as low as 0.25 µl·liter^{-1} for 18 hours can cause approximately 50% flower abscission, which would be enough damage to render plants unmarketable. Ethylene concentrations of 1 µl·liter^{-1} were high enough to cause essentially all open flowers and many flower buds (data not shown) to abscise. This linear relationship of increase damage with ethylene concentration reflects the dose-response

relationship found in many ethylene-mediated processes with no effect below 0.01 μl·liter^{-1}, a half-maximal effect between 0.01 and 0.10 μl·liter^{-1}, and 10 μl·liter^{-1} for a saturating dose (Abeles, 1973). According to Woltering (1987) abscission of flowers, flower buds, or entire inflorescences occurring within a 24-hour ethylene treatment is classified as highly sensitive. Woltering and Van Doorn (1988) state that plants exhibiting natural senescence as petal abscission are more likely to be very sensitive to exogenous ethylene than plants that exhibit petal wilting. Dostal et al. (1991) found that *Impatiens x hawkeri* had the greatest increase in flower abscission between 0 and 1.0 μl·liter^{-1}, with 100% abscission occurring after 6 hour exposure to 1, 5 or 10 μl·liter^{-1}. Based on this study, further experiments in this thesis were conducted using 1 μl·liter^{-1} exogenous ethylene for 18 hours to allow for clear distinction between damage caused by exogenous ethylene, natural senescence and any treatments to mitigate the effects of exogenous ethylene.

Table 2.1. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' exposed to varying concentrations of ethylene for 18 hours in darkness.

Ethylene treatment (μl·liter^{-1})	Flower abscission (%)
0.25	53^{z} (47)^{y}
0.75	98 (84)
1.0	100 (90)
Significance	L*** Q**

^{z}Data are means of four replicates per treatment
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
**, ***Significant at P≤0.01, or 0.001, respectively.

Expt. 2. Plastic bag enclosure treatments and concentration of ethylene to induce abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants treated with ethylene concentrations from 0.25 to 0.55 $\mu l \cdot liter^{-1}$ exhibited significantly higher flower abscission than plants not treated with ethylene regardless of plastic bag enclosure treatment (Table 2.2). Plastic bag treatments had no effect on flower abscission within ethylene levels (Table 2.2) showing that ethylene can readily cause damage on plants that are enclosed in plastic such as plants that are sleeved for shipment during postproduction (Jones, 2002; Jones and Edelman, 2013). A significant difference was only seen between the lowest and highest levels of ethylene (0.25 and 0.55 $\mu l \cdot liter^{-1}$ respectively) similar to results shown in Expt. 1, where 0.25 $\mu l \cdot liter^{-1}$ ethylene was low enough to damage plants beyond marketability. As ethylene concentration increased there was an increase in flower abscission until nearly 100% of flowers abscised (Table 2.2). Based on this study, further experiments were conducted using #2 High Density Polyethylene (HDPE) produce bags (Crown Poly Inc., Huntington Park, CA) when necessary to ensure abscised plant tissues were isolated.

Table 2.2. Flower abscission (%) of plastic bag enclosed and open (no bag) *Impatiens walleriana* 'Super Elfin Rose Improved' exposed to varying concentrations of ethylene for 18 hours in darkness.

Ethylene treatment ($\mu l \cdot liter^{-1}$)	Bag or open (no bag)	Flower abscission (%)
0	bagged	8[z] (16)[y]
0.25	bagged	79 (63) c[x]
0.25	open	87 (69) bc
0.45	bagged	93 (75) abc
0.45	open	93 (75) abc
0.55	bagged	97 (83) ab
0.55	open	96 (81) a

[z]Data are means of four replicates per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

Expt. 3. Concentration of sprayable 1-MCP to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants sprayed with 1-MCP at concentrations from 2.5 to 15 mg ai·liter^{-1} exhibited significantly less flower abscission than untreated plants when exposed to 1 µl·liter^{-1} exogenous ethylene (Table 2.3). There were no differences between 1-MCP concentrations and 1-MCP concentrations showed no significant linear or quadratic regressions (Table 2.3). These results suggest as little as 2.5 mg ai ·liter^{-1} 1-MCP spray concentration is sufficient for protection against an overnight exposure to 1.0 µl·liter^{-1} ethylene challenge.

Literature suggests that most flowering plants will be fully protected from exogenous ethylene with a pretreatment of gaseous 1-MCP less than 1.0 µl·liter^{-1} with concentration as low as 2.5 nl·liter^{-1} for carnation (Blankenship and Dole, 2003) and 1.0 µl·liter^{-1} for *Pelargonium peltatum* (Cameron and Reid, 2001). *Impatiens walleriana* treated with 0.1 or 1.0 µl·liter^{-1} gaseous 1-MCP significantly increased floret longevity compared to untreated controls (Burana et al., 2013). There was no toxicity seen at higher concentrations of gaseous 1-MCP (Porat et al., 1995) and levels above 1.0 µl·liter^{-1} 1-MCP did not provide additional protection against ethylene-induced petal abscission in *Pelargonium peltatum* (Cameron and Reid, 2001).

Experiments using a different formulation of sprayable 1-MCP (AFxRD-300, 2% active ingredient) on tomato fruit established that 1 minute immersion in 625 µl·liter^{-1} 1-MCP was comparable in efficacy as treatment with 500 nl·liter^{-1} gaseous 1-MCP for 9 hours (Choi et al., 2008). Initial experiments showed that there was no significant difference between flower abscission in *Impatiens* pretreated with 10 mg ai·liter^{-1} sprayable 1-MCP than those treated with 1 µl·liter^{-1} gaseous 1-MCP for 8 hours (data not shown).

Table 2.3. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated with varying concentrations of sprayable 1-MCP. After pre-treatment plants were exposed 1 $\mu l \cdot liter^{-1}$ ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

1-MCP pre-treatment (mg ai·liter^{-1})	Ethylene treatment ($\mu l \cdot liter^{-1}$)	Flower abscission (%)
0 (control)	0	4[z] (10)[y] a[x]
0	1	93 (77) b
2.5	1	10 (18) a
5.0	1	10 (16) a
10.0	1	14 (21) a
15.0	1	5 (12) a
Significance		L[NS] Q[NS]

[z]Data are means of five replicates per treatment
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[NS] Not significant between plants treated with 1-MCP.

Expt. 4. Lower concentrations of sprayable 1-MCP to prevent abscission

Impatiens walleriana 'Super Elfin Rose Improved' plants treated with 1-MCP concentrations from 0.1 to 2.0 mg ai·liter^{-1} exhibited significantly less flower abscission than plants not treated 1-MCP when exposed to 1 µl·liter^{-1} exogenous ethylene (Table 2.4). There was a significant difference between plants treated with 2.0 mg ai·liter^{-1} 1-MCP compared to 0.1 mg ai·liter^{-1} 1-MCP rates treatments. The linear and quadratic regressions were highly significant at $P \leq 0.001$ and $P \leq 0.01$, respectively (Table 2.4). The 25% abscission seen with 2.0 mg ai·liter^{-1} 1-MCP would render plants unmarketable. This confirms results from Expt. 3 that rates of 1-MCP at or above 2.5 mg ai·liter^{-1} are necessary to protect *I. walleriana* from overnight exposure to 1.0 µl·liter^{-1} exogenous ethylene.

A rare case of 1-MCP toxicity on flowering plants was recorded with high concentrations of 1-MCP, 50 mg ai·liter^{-1}, on *Phlox* and *Antirrhinum*, resulting in phytotoxicity to the open florets, causing higher flower abscission than at lower application concentrations (Daly, 2010). Though further experiments on *I. walleriana* at rates of 50 mg ai·liter^{-1} 1-MCP showed no evidence phytotoxicity (data not shown). With no other toxicity reported within reasonable concentrations above minimum amount necessary for saturation of all ethylene binding sites (Blankenship and Dole, 2003; Cameron and Reid, 2001), further experiments in this thesis chapter were conducted with 10 mg ai·liter^{-1} 1-MCP treatments to ensure complete protection from postproduction stress treatments and account for possible differences in ethylene responsiveness due to cultivar (Kim, Y., et al, 2007) and species (Han, 2003).

Table 2.4. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated with varying low concentrations of sprayable 1-MCP. After pre-treatment plants were exposed 1 μl·liter^{-1} ethylene for 18 hours in darkness.

1-MCP pre-treatment (mg ai·liter^{-1})	Flower abscission (%)
0	96^{z} (81)^{y} a^{x}
0.1	73 (59) b
0.5	47 (42) bc
1.0	43 (40) bc
2.0	25 (29) c
Significance	L*** Q**

^{z}Data are means of five replicates per treatment.
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
$^{**, ***}$Significant at P≤0.01 or 0.001, respectively.

Expt. 5. Concentration and volume of sprayable 1-MCP to prevent abscission

In this experiment only 1-MCP spray volume was significant (P=0.004), 1-MCP concentration and the concentration x volume interaction were not significant (P=0.1983 and P=0.0829, respectively) (Table 2.5). Within 1-MCP concentrations, the percentage of flowers that abscised decreased as the spray volume increased. MacKinnon et al. (2009) saw similar results in tomato with higher spray volume leading to higher efficacy of 1-MCP in preventing epinasty after ethylene exposure. This is likely due to better coverage of plants with high spray volumes. It is suggested that 1-MCP in the aqueous form may have limited translocation in tomatoes (MacKinnon et al, 2009) and as seen here in *Impatiens* it is very important to fully cover all foliage and flowers with spray solution to achieve 1-MCP binding on open ethylene receptor sites.

Recent studies of aqueous 1-MCP on plums (Manganaris et al., 2007), tomatoes and avocadoes (Choi et al., 2008) suggest that complete coverage of target plant material is necessary to achieve full protection from ethylene-mediated senescence. When tomatoes and avocadoes were partially immersed in an aqueous 1-MCP solution there was not full protection of the whole fruit, rather partitioning of 1-MCP effects in the respective dipped fruit portions and untreated portions tending to senesce faster (Choi et al., 2008) showing limited diffusive capacity of aqueous 1-MCP on the surface of treated plants.

Volumes of 204 $ml \cdot meter^{-2}$ are generally recommended for greenhouse spraying and this experiment confirmed a spray volume of 204 $ml \cdot meter^{-2}$ provides sufficient coverage of 1-MCP at rates of 5 and 10 $mg\ ai \cdot liter^{-1}$ to protect *I. walleriana* from exposure to exogenous ethylene.

Table 2.5. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated with varying volumes and concentrations of a sprayable formulation of 1-MCP. After 1-MCP pre-treatment, plants were exposed 1 $\mu l \cdot liter^{-1}$ ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

1-MCP treatment (mg ai·liter^{-1})	Ethylene treatment ($\mu l \cdot liter^{-1}$)	Spray volume (ml·meter^{-2})	Flower abscission (%)
0	0 (control)	306	6[z] (11)[y]
0	1	306	95 (80)
5	1	102	34 (36)
5	1	204	10 (18)
5	1	306	9 (15)
10	1	102	17 (23)
10	1	204	11 (16)
10	1	306	7 (13)
1-MCP conc			NS
Spray volume			**
1-MCP conc x spray volume			NS

[z]Data are means of five replicates per treatment
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
NS,** Not significant, significant at $P \leq 0.01$, respectively.

Expt. 6. Water quality and sprayable 1-MCP efficacy

There was no difference among municipal, RO or Milli-Q water sources in abscission in the first experiment (Table 2.6a). There was a slight but significant reduction in abscission in plants treated with low pH 1-MCP solutions compared with high pH treatments. The linear regression was highly significant at $P \leq 0.001$ and the quadratic regression was not significant (Table 2.6a). The highest pH 1-MCP solution (9.0) resulted in 14 percent flower abscission but this was judged to be a market acceptable level.

With *I. hawkeri* 'Tamarinda Purple' there was also a slight but significant difference between plants, low pH 1-MCP solutions gave slightly less abscission compared with high pH treatments (Table 2.6b). The linear regression was significant at $P \leq 0.05$ and the quadratic regression was not significant (Table 2.6b). Overall, solution pH of spray mixtures of this formulation has little effect on 1-MCP efficacy.

Table 2.6a. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated 10 mg ai·liter^{-1} sprayable 1-MCP mixed using different water sources and pH levels. After pre-treatment plants were exposed to 1 µl·liter^{-1} ethylene for 18 hours in darkness.

Water source	pH	Flower abscission (%)
Milli-Q	5.69	5[z] (13)[y] b[x]
RO	5.82	8 (17) ab
Tap	7.82	10 (18) ab
RO (pH adjusted)	4.0 b	4 (11) b
RO (pH adjusted)	5.0 ab	8 (16) ab
RO (pH adjusted)	6.0 ab	6 (14) ab
RO (pH adjusted)	7.0 ab	11 (19) ab
RO (pH adjusted)	8.0 ab	10 (19) ab
RO (pH adjusted)	9.0 a	14 (22) a
Significance		L***Q[NS]

[z]Data are means of three replicates per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent mean separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[NS, ***]Not significant or significant at P≤ 0.001, respectively.

Table 2.6b. Flower abscission (%) of *Impatiens hawkeri* 'Tamarinda Purple' pre-treated 10 mg ai·liter^{-1} sprayable 1-MCP mixed using water at different pH levels. After pre-treatment plants were exposed to 2.5 µl·liter^{-1} ethylene for 18 hours in darkness.

Water source	pH	Flower abscission (%)
RO	6.26	9^{z} (17)^{y} b^{x}
RO (pH adjusted)	7.0	10 (18) b
RO (pH adjusted)	8.0	10 (18) b
RO (pH adjusted)	9.0	15 (22) a
RO (pH adjusted)	10.0	13 (21) ab
Significance		L*Q^{NS}

^{z}Data are means of three replicates per treatment.
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values represent mean separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
$^{NS, *}$Not significant or significant at P≤ 0.05, respectively.

Expt. 7. Concentration of surfactant in 1-MCP sprays

Neither linear nor quadratic regressions were significant; flower abscission was not affected by surfactant concentration (Table 2.7). MacKinnon et al. (2009) found that a range of surfactants were comparable in delivering aqueous 1-MCP on the surface of tomato leaves to provide efficacy against exogenous ethylene, while other surfactants delivering the same concentration of 1-MCP were less effective. The largest factor was the volume of spray applied and surfactants could aid in foliage coverage due to limited translocation of 1-MCP. Capsil label rates for application of pesticides are between 0.5-1.25 ml·liter^{-1}. However, *Impatiens walleriana* 'Super Elfin White' plants exhibited phytotoxicity at the 1.0 and 2.0 ml·liter^{-1} Capsil rates. Phytotoxicity symptoms showed as necrotic spots on petals and petal edges (Figure 2.1).

These results suggest that with high enough volume and 1-MCP concentration no surfactant is necessary for 1-MCP to be effective on flowering *Impatiens* and that suggested label rates of certain surfactants can cause damage to flowers of this cultivar. At the 0.5 ml·liter^{-1} Capsil rate there was no phytotoxicity on 'Super Elfin White' and earlier experiments on 'Super Elfin Rose Improved' showed no signs of phytotoxicity to 0.5 ml·liter^{-1} Capsil (data not shown). As a result of this finding, further investigations of 1-MCP and ethylene tolerance over a range of herbaceous crops (Chapter 3) were conducted without the use of a surfactant or at the low 0.5 ml·liter^{-1} rate to avoid potential phytotoxicity.

Table 2.7. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin White' pre-treated with 10 mg ai·liter^{-1} sprayable 1-MCP and varying concentrations of surfactant 'Capsil'. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene for 18 hours in darkness.

Capsil concentration (ml·liter^{-1})	Flower abscission (%)	Signs of phytotoxicity
0	7[z] (15)[y]	none
0.5	7 (15)	none
1	10 (18)	slight necrotic petal edge
2	11 (20)	significant necrotic petal edge
Significance	NS	

[z]Data are means of three replicates per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[NS] Not significant.

Figure 2.1. Necrotic injury from 1.0 ml·liter^{-1} (top) and 2.0 ml·liter^{-1} (bottom) Capsil treatment.

Expt. 8. Length of 1-MCP effectiveness to prevent abscission

Impatiens walleriana 'Super Elfin White' plants challenged with ethylene within three days of 1-MCP treatment exhibited significantly less flower abscission than plants challenged with ethylene four or more days after 1-MCP treatment (Table 2.8). Plants with four or more days delay between 1-MCP treatment and ethylene challenge showed more than 25% flower abscission and were unmarketable. Linear and quadratic regressions were significant at $P<0.001$ and $P<0.01$, respectively. *Pelargonium peltatum* pretreated with 1.0 $\mu l \cdot liter^{-1}$ gaseous 1-MCP for 2 hours completely inhibited ethylene-induced petal abscission however the half-life of 1-MCP activity was about 2, 3, and 6 days after 1-MCP treatment at 25, 20.7 and 12°C, respectively, with no residual effect of 1-MCP protection after 4 or 5 days at 25 or 20.7°C, respectively (Cameron and Reid, 2001). These results suggest is it necessary to apply 1-MCP a maximum of three days before plants will be exposed to exogenous ethylene. The likely reason for this transient effect is due to creation of new ethylene receptors, which are not protected by the previous 1-MCP treatment (Cameron and Reid, 2001; Blankenship and Dole, 2003).

Table 2.8. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' treated with 10 mg ai·liter^{-1} 1-MCP and exposed to 1 µl·liter^{-1} ethylene (for 18 hours in darkness) after varying lengths of time.

Delay between 1-MCP treatment and ethylene exposure (days)	Flower abscission (%)
0	4[z] (12)[y] d[x]
1	8 (16) cd
2	12 (21) c
3	15 (23) c
4	28 (32) b
5	54 (47) a
6	65 (54) a
Significance	L*** Q**

[z]Data are means of four replicates per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
, * Significant at P≤0.01, or 0.001, respectively.

Expt. 9. Length of time between 1-MCP treatment and overhead irrigation to prevent abscission

There was no significant difference in flower abscission between plants treated with 1-MCP only and those receiving overhead irrigation after 1-MCP treatment. The linear and quadratic regressions were not significant (Table 2.9). All 1-MCP and irrigation treatments protected plants from external ethylene at a market acceptable level showing that 1-MCP protection is conferred within one minute of 1-MCP application. MacKinnon et al. (2009) challenged tomatoes with irrigation 15 to 240 minutes after 1-MCP pretreatment and found that there was no significant difference from untreated controls suggesting that 1-MCP is rainfast on tomatoes as early as 15 minutes after application. This would allow practitioners the opportunity to apply sprayable 1-MCP without concern that future rain or irrigation will negatively affect the application.

Table 2.9. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated with sprayable 1-MCP. After pre-treatment, plants were allowed to dry for varying lengths of time and then irrigated with 100 mL tap water. After pre-treatment plants were allowed to dry fully, then exposed to 1 $\mu l \cdot liter^{-1}$ ethylene for 18 hours in darkness.

1-MCP treatment (mg ai·liter^{-1})	Time elapsed before irrigation (minutes)	Flower abscission (%)
0 (control)	N/A[x]	97[z] (84)[y]
10	N/A	3 (5)
10	1	1 (4)
10	2	1 (4)
10	3	4 (7)
10	4	2 (4)
10	5	0 (0)
10	10	3 (8)
10	30	2 (4)
Significance		NS

[z]Data are means of three replicates per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]N/A plants were allowed to dry after 1-MCP treatments and were not irrigated.
[NS]Not significant, refers only to data on plants treated with 1-MCP.

Expt. 10. Amount of overhead irrigation after 1-MCP treatment

There was no significant difference between *Impatiens walleriana* 'Super Elfin Rose Improved' plants treated with 1-MCP solutions only and those receiving an overhead irrigation treatment. The time between 1-MCP application and irrigation, irrigation volume and the interaction of time x volume were all non-significant (Table 2.10). The US Label for AFxRD-038 suggests that 1-MCP sprays should be applied under drying conditions, in early morning or at night to allow for adequate absorption, irrigation should not be used for at least 2 hours following application and spray should be use 1 hour prior to expected rain (EPA, 2010). These results, with the results of Expt. 9, show that irrigation one minute after 1-MCP treatment, regardless of irrigation volume, will not reduce 1-MCP efficacy in *Impatiens* plants and that the EPA label is overly cautious in irrigation or rain guidelines.

Table 2.10. Flower abscission (%) of *Impatiens walleriana* 'Super Elfin Rose Improved' pre-treated 10 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were allowed to dry for 1 or 2 minutes and then irrigated with 0.45 or 2.25L tap water. After pre-treatment plants were allowed to dry and were exposed to 1 µl·liter^{-1} ethylene for 18 hours in darkness.

Time elapsed before irrigation (minutes)	Volume of irrigation (L)	Flower abscission (%)
N/A[z]	N/A	8[y] (17)[x]
1	0.45	5 (13)
1	2.25	4 (10)
2	0.45	4 (11)
2	2.25	7 (12)
Time		NS
Volume		NS
Time x Volume		NS

[z]N/A plants were allowed to dry after 1-MCP treatments and were not irrigated.
[y]Data are means of three replicates per treatment.
[x]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[NS]Not significant.

Expt. 11. Age of 1-MCP solution to prevent abscission

1-MCP solutions (10 mg ai·liter^{-1}) maintained efficacy for up to two weeks after preparation. The linear regression was highly significant at $P<0.001$ and the quadratic regression was not significant (Table 2.11). The US Label for AFxRD-038 states that applicators should not agitate 1-MCP solution for more than 10 minutes and spraying should begin as soon as possible after solution has been thoroughly mixed and no more than 60 minutes after preparation of tank mixture (EPA, 2010). From this experiment we see that 10 mg ai·liter^{-1} solutions made two weeks prior to spraying, there were stored in an airtight container, were effective at protecting against exogenous ethylene. However, given that 1-MCP solutions are effective at concentrations as low as 2.5 mg ai·liter^{-1} (this chapter), a substantial amount of the initial 10 mg ai·liter^{-1} 1-MCP could have been lost during storage while still maintaining effectiveness.

Table 2.11. Flower abscission (%) of *Impatiens hawkeri* 'Tamarina Purple' pre-treated with sprayable formulation of 10 mg ai·liter^{-1} 1-MCP mixed over a period of 0-7 weeks. After 1-MCP pre-treatment, plants were exposed 2.5 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

1-MCP treatment (mg ai·liter^{-1})	Ethylene treatment (µl·liter^{-1})	1-MCP Age (weeks)	Flower abscission (%)
0 (control)	0 (control)	N/A	12[z] (20)[y]
0	1	N/A	100 (90)
10	1	0	13 (21) c
10	1	1	12 (20) c
10	1	2	13 (21) c
10	1	4	97 (85) a
10	1	5	70 (60) b
10	1	7	100 (90) a
Significance			L***Q^{NS}

[z]Data are means of five replicates per treatment
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
NS,*** Not significant, significant at P≤0.001, respectively.

Expt. 12. 1-MCP to prevent abscission in prolonged darkness

In the absence of an ethylene challenge, *Impatiens hawkeri* 'Tamarinda Purple' plants treated with 1-MCP exhibited significantly less flower abscission than untreated plants when left in darkness for three or more days. When plants were kept in darkness for less than three days there was no difference in flower abscission with or without 1-MCP treatment. The effects of 1-MCP treatment, days in darkness and the 1-MCP x days in darkness interaction were all highly significant ($P<0.001$) (Table 2.12).

Shipping conditions are generally dark (not allowing for photosynthesis) and are often warm. During this period carbohydrate levels decrease and plants have been observed to show symptoms of senescence such as lower leaf chlorosis, internode elongation and abscission of buds and flowers (Jones, 2002). Postproduction stresses can also include temperature change and vibration, of all these stresses darkness had the greatest effect on *Begonia* flower and bud abscission and reduced display life, while pretreatment with 1-MCP helped to reduce abscission and increase display life (Kim Y. et al., 2007). Skog et al. (2001) also showed that *Impatiens x hawkeri* 'Paradise Aglia', *Impatiens walleriana* 'Accent White' and 'Seashell' were improved with gaseous 1-MCP pre-treatment in the presence or absence of ethylene during postproduction.

In a study of *Impatiens x hawkeri, I. walleriana* and double *Impatiens,* it was found that placing plants in cardboard boxes for three or five days significantly increased bud drop, and pre-treatment with 1-MCP significantly reduced it (Han, 2003). From this we suggest that *Impatiens* plants that will be subjected to postproduction stresses for more than two days should be pretreated with 1-MCP.

Table 2.12. Flower abscission (%) of *Impatiens hawkeri* 'Tamarinda Purple' pre-treated with sprayable 1-MCP. After pre-treatment plants were kept in darkness for 1, 2, 3, or 4 days at 22C.

1-MCP pre-treatment (mg ai·liter^{-1})	Length of darkness (days)	Flower abscission (%)
0	1	0[z] (0)[y] b[x]
0	2	5 (11) b
0	3	19 (25) a
0	4	34 (35) a
10	1	0 (0) a
10	2	1 (3) a
10	3	0 (0) a
10	4	3 (8) a
1-MCP		***
Darkness		***
1-MCP x Darkness		***

[z]Data are means of five replicates per treatment
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*** Significant at P<0.001.

Expt. 13. 1-MCP to prevent abscission at high temperatures

Impatiens hawkeri 'Tamarinda Purple' plants kept in darkness and high temperature for two days exhibited significantly less flower abscission if treated with 1-MCP than untreated plants regardless of the presence of exogenous ethylene (Table 2.13). The effects of 1-MCP, ethylene and 1-MCP x ethylene were highly significant ($P<0.0001$). Flower abscission damage to plants without a 1-MCP pretreatment was seen within 48 hours in the absence of ethylene in warm temperatures (28°C) (Table 2.13) whereas damage was seen in three days when plants were kept at cooler temperatures (22°C) in Experiment 12 (Table 2.12).

A survey of vegetatively propagated annual bedding plants by Starman et al. (2007) showed that under simulated shipping conditions (dark and warm, 26.7°C) for 0, 1 or 2 days major symptoms of postproduction stress developed as lower leaf chlorosis (81% of cultivars), internode elongation (38% of cultivars), flower senescence (38% of cultivars), and bud abortion (33% of cultivars). Potted *Rosa hybrida* plants subjected to dark storage conditions for various durations and temperatures showed increased flower development (leading to senescence) with storage duration more than 2 days and the interaction of storage duration, temperature, and cultivar were significant with less development at 4°C than 16°C and greatest development at 28°C (Cushman et al., 1998).

In experiments on water-stressed cotton plants it was shown that 1-MCP has the potential to increase stomatal resistance, water potential, antioxidant enzyme activity, and decrease membrane leakage (Kawakami et al., 2008), in turn potentially increasing yield, boll weight or boll number (Oosterhuis et al., 2009). Similar results were seen in heat stressed soybean plants with 1-MCP application resulting in delayed leaf senescence, decrease flower abscission and increased pots set percentage (Djanaguiraman et al., 2011). During shipping and transport

bedding plants can often be exposed to stresses such as high temperatures and darkness for 48 hours, so annual bedding plants may benefit from treatment with 1-MCP to prevent postproduction stress symptom of flower abscission.

Table 2.13. Flower abscission (%) of *Impatiens hawkeri* 'Tamarinda Purple' pre-treated with sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere in darkness for 2 days at 28C.

1-MCP pre-treatment (mg ai·liter^{-1})	Ethylene treatment (µl·liter^{-1})	Flower abscission (%)
0 (control)	0 (control)	6^{z} (14)^{y} b^{x}
0	1	100 (90) a
10	0	0 (0) d
10	1	2 (7) c
1-MCP		***
Ethylene		***
1-MCP x Ethylene		***

^{z}Data are means of five replicates per treatment
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*** Significant at P<0.001.

Conclusions

The results obtained from this series of studies provide information to create a protocol for further experimentation of sprayable 1-MCP on a range of ornamental floriculture crops. Use of plastic bags or sleeves to separate plants from one another had no effect on flower abscission if properly applied and removed as not to cause physical damage. Sprays of 1-MCP (AFxRD-038 formulation) at 10 mg ai·liter^{-1} should be adequate to protect highly sensitive flowers from 1.0 µl·liter^{-1} exogenous ethylene for 18 hours in darkness without causing phytotoxicity symptoms, while lower concentrations of 2.5 mg ai·liter^{-1} will likely provide protection if applied at high volume (at or above 204 ml·meter^{-2}). Addition of a surfactant is not necessary at 10 mg ai·liter^{-1} if spray volume is sufficient to cover all plant tissue that could elicit a negative response to postproduction stress, likely at or above 204 ml·meter^{-2} for greenhouse applications. 1-MCP appears to be rainfast within one minute of application and should be used soon after upon mixing but if held in an airtight container it will stay active for up to two weeks. Plants should be treated with 1-MCP within three days of the end of a potential postproduction event for full protection against stressors such as heat, darkness and ethylene. AFxRD-038 shows great promise for use in the floriculture industry to provide protection against postproduction stress and mediate ethylene damage in flowering plants. Further tests should include evaluation of additional surfactants to potentially decrease concentrations of 1-MCP needed for full protection as well as additional water quality studies to ensure efficacy over a range of water pH.

Acknowledgements

We thank AgroFresh Inc. for financial support of this project. Also thanks to Ball Horticultural Company for donation of seed and Kurt Weiss Greenhouse for donation of vegetative plants. We also thank Rose Harmon, Allison Hyrcik, Madeline Olberg, Julie Blaha, Jenny Rothenberg and Blue Grass Lane Summer Interns for greenhouse assistance and data collection.

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CHAPTER 3

Survey of Ethylene and 1-Methylcyclopropene Effects on Flower Senescence of Bedding Plants

Abstract

The sensitivity to exogenous ethylene and efficacy of sprayable formulation of 1-methylcyclopropene (1-MCP) of seventy-three cultivars from twenty species of annual bedding plants was investigated. Plants were grown from seed or vegetative cuttings until mature at which time they were sprayed with 0 or 25 mg ai·liter^{-1} 1-MCP and then exposed to 0 or 1.0 µl·liter^{-1} ethylene for 18 hours in darkness at 21°C to simulate postproduction stress. Immediately after postproduction stress, plants were assessed for senescence symptoms including flower abscission, wilting or discoloration. There were three groups of ethylene sensitivity: 1) no response to ethylene (*Bidens ferulifolia, Heliotropium arborescens, Osteospermum ecklonis, Scaevola aemula*), 2) transient ethylene symptoms (*Solenostemon scutellarioides*), and 3) permanent damage due to ethylene. Plants showing ethylene damage were split into two groups, those which were completely protected by 1-MCP (*Angelonia angustifolia, Begonia x benariensis, Calibrachoa x hybrida, Catharanthus rosea, Cleome hassleriana, Diascia barberae, Euphorbia hypericifolia, Impatiens x hawkeri, I. walleriana, Lantana camara, Lobelia erinus, Petunia hybrida, Vebena hybrida*) and those in which 1-MCP provided incomplete protection (*Cuphea ramosissima, P. peltatum, Pelargonium x hortorum* interspecific and zonal hybrids).

Introduction

Production of annual bedding plants continues to increase in the United States with wholesale value expanding beyond $1.36 billion in 2012 (USDA, 2013). Losses up to 30 percent can be incurred during postproduction of floriculture crops from stresses including extender periods of darkness, high and low temperatures, and ethylene damage (Jones, 2002). The author has personally seen extreme loss from abscission of New Guinea Impatiens flowers in commercial shipments from Florida to a New York distribution facility. Ethylene can be found throughout the postproduction chain and originates from biological sources (decaying and senescing plant material, wounded plants, pathogens) and non-biological sources (incomplete combustion of natural gas, leaking gas lines, improperly managed heating units, exhaust from vehicles, leaks from fruit ripening rooms) (Skog et al., 2001; Gibson et al., 2000; Nelson, 2012; Dole and Wilkins, 2005).

Within the top 15 floriculture producing states in the United States, the annual crops with largest wholesale value include petunia, geranium (seed and vegetative), pansy and viola, impatiens (non-New Guinea types), begonia, New Guinea impatiens and marigold (USDA, 2013). Except marigold, a member of the Asteraceae family, all of these crops are categorized as ethylene sensitive (Dole and Wilkins, 2005). Exposure to ethylene can cause immediate and severe damage including abscission of leaves, flowers and buds, leaf chlorosis and epinasty (Woltering, 1987; Gibson et al., 2000; Dole and Wilkins, 2005; Skog et al., 2001; Jones and Edelman, 2013). Ethylene sensitive plants generally show flower abscission within 24 hours of ethylene exposure, with mature flowers abscising at lower concentrations than young buds (Woltering, 1987). Leaves generally abscise after more than 72 hours of exposure, and older leaves abscise before young (Woltering, 1987).

The majority of flowers which exhibit petal abscission are ethylene sensitive, whereas those that senescence by of wilting are usually not sensitive to exogenous ethylene (Woltering and Van Doorn, 1988). Notable exceptions to this rule are Campanulaceae, Caryophyllaceae, Malvaceae, Orchidaceae (Woltering and Van Doorn, 1988) and Solanaceae (Dole and Wilkins, 2005) which tend to wilt during senescence yet they prove to be sensitive to exogenous ethylene. Previous studies of ethylene sensitivity were conducted in darkness with exposure to ethylene for 24 or 72 hours and focused on cut flowers (Woltering and Van Doorn, 1988) and ornamental pot plants (Woltering, 1987).

Each year many new cultivars of annual bedding plants are bred and released into commercial production. Detailed postproduction information is rarely provided for all species (Starman et al., 2007). It has been found that cultivars within a genus or species can have a range of postproduction habits even extending down to the series level (Woltering, 1988; Jones, 2002). A series is a group of plants that are similar in growth and habit; generally cultivars within a series differ in flower color. Series are often bred from the same parents and are usually (but not always) genetically similar. Ethylene sensitivity can vary between cultivars as seen in *Pelargonium x domesticum* with some cultivars beginning to abscise flowers less than two hours after exposure to 0.50 $\mu l \cdot liter^{-1}$ ethylene (Deneke, 1990).

In a two year study of *Pelargonium x domesticum* (Kim et al., 2006) ethylene responsiveness was measured in cultivars bred to resist ethylene stress and therefore improve postproduction. It was found that ethylene responsiveness was altered by the growth environment (daylength, temperature, etc.) (Kim et al., 2006). It is advisable for growers to test the postproduction responses of new cultivars of annual bedding plants (Jones, 2002).

There is a great potential for plants to be stressed due to production and shipping stresses, especially for major holidays (Mother's Day, Memorial Day Weekend) where high sales of annual bedding plants are expected. When flowering plants are shipped throughout the United States it is advisable for growers to utilize technologies such as 1-MCP to reduce ethylene mediated stress such as premature senescence and ensure delivery of plants to market in full flower.

Materials and Methods

Plant production

Angelonia angustifolia Archangel 'Pink', 'Purple', 'Raspberry', 'White', *Solenostemon scutellarioides* 'Honey Crisp, 'Vino' (BallFlora Plant, Ball Horticultural Co., West Chicago, IL)*; Angelonia angustifolia* Angelface 'Pink Imp', *Cleome hassleriana* 'Senorita Rosalita', *Euphorbia hypericifolia* 'Diamond Frost', *Impatiens x hawkeri* Infinity 'Salmon Bisque', *I. walleriana* Rockapulco 'Coral Reef', (Proven Winners, Pleasant View Gardens, Inc., Loudon, New Hampshire); *Begonia x benariensis* Whopper 'Red Bronze Leaf', 'Red Green Leaf', 'Rose Bronze Leaf', 'Rose Green Leaf' (Ball Seed, Ball Horticultural Co., West Chicago, IL)*; Bidens ferulifolia* 'Mexican Gold Improved', *Calibrachoa x hybrida* Callie 'Bright Red', 'Deep Yellow', *Catharanthus rosea* Nirvana 'Blush Pink', *Diascia barberae* Darla 'Red Imp', 'White 11', *Euphorbia hypericifolia* 'Euphoric White', *Heliotropium arborescens* 'Scentropia Dark Blue', *Impatiens x hawkeri* 'Sonic Magic Pink', 'Super Sonic Flame', 'Super Sonic Magenta 08', 'Super Sonic Orange Ice', 'Super Sonic Pink 07', 'Super Sonic Red', 'Super Sonic White', *I. walleriana* Kwik Kombo 'Pink Vibrations Mix', *I. walleriana* Tumbler 'Pink', 'Rose Star', 'Salmon', 'Scarlet', 'Violet', 'Violet Star', 'White', *Lantana camara* 'Bandana White', *Lobelia*

erinus Techno Heat ‘Dark Blue’, ‘Light Purple’, *Osteospermum ecklonis* Tradewinds ‘Purple Bicolor’, *Pelargonium x hortorum* interspecific Caliente ‘Deep Red’, ‘Fire 09’, ‘Orange’, *P. x hortorum* zonal Rocky Mountain ‘Dark Red’, *P. peltatum* Contessa ‘Sybil’, *Petunia hybrida* Picnic ‘Amethyst’, ‘White’; Sanguna ‘Lavender Vein’, ‘Purple Imp’, ‘White’; Whispers ‘Star Rose’, *Scaevola aemula* Bombay ‘Dark Blue’, *Vebena hybrida* Lanai ‘Upright Blue with Eye’ (Syngenta Flowers, Gilroy, CA); *Impatiens walleriana* Accent Premium ‘Bright Eyes’, ‘Deep Orange’, ‘Lilac’, ‘Orange Star’, ‘Red’, ‘Salmon’, ‘Violet’, ‘Violet Star’, ‘White’, *Pelargonium x hortorum* zonal Pinto Premium ‘Coral’, ‘Deep Red’, ‘Deep Rose’, ‘Lavender’, ‘Salmon’, ‘Salmon Splash’, ‘Scarlet’, ‘Violet’ (Goldsmith Seed, Syngenta Flowers, Gilroy, CA), were grown from seed or vegetative cuttings. Individual plants were transplanted into 10 cm containers filled with a commercial greenhouse substrate (LM-111; Lambert Peat Moss, Inc.). Plants were irrigated as needed with tap water supplemented with 200 mg ai $N \cdot L^{-1}$ from a complete complete fertilizer (Jack's LX™ 21-5-20; J.R. Peter’s Inc., Allentown, PA). Plants were grown in a glass greenhouse at constant air temperature set point of 20 °C and ambient light. Plants were pinched to encourage compact growth without the use of plant growth regulators.

Plant selection

Plants were selected at market stage with enough foliage to cover the growing media in the container and a minimum of six open flowers. Approximately one week prior to experiments plants were cleaned to remove older flowers and leaves, ensuring only young flowers were present when experiments started. Plants for each experiment were selected for uniformity in size and flower number from blocks of approximately 50 plants.

1-MCP application

A formulation of sprayable 1-MCP powder (AFxRD-038, 3.8% w/w active 1-MCP; AgroFresh, Inc. Springhouse, PA) at a rate of 0 or 25 mg ai·liter^{-1} was mixed with reverse osmosis (RO) water in a sealed container until all powder was dissolved and solution was clear. No surfactant was used in these experiments. Solution was transferred to a 1-gallon pump sprayer and pressurized immediately. The solution was sprayed on to plants until runoff, a volume of approximately 204 ml·meter^{-2}, and allowed to dry.

Ethylene treatment

Plants were moved into 0.4 m^3 plexiglass boxes with two small fans mounted inside and boxes were sealed. Abscission prone species of plants were placed into individual #2 High Density Polyethylene (HDPE) produce bags (Crown Poly Inc., Huntington Park, CA) to ensure abscised plant tissues were isolated. Bags remained upright without being sealed. In genera not prone to flower abscission, plants were not bagged before treatment. The boxes were located in an ethylene-free growth chamber at 21C in darkness. Air flowing through boxes was either clean air or 1.0 µl·liter^{-1} ethylene and was exhausted into a line leading to the outdoors. Ethylene streams were prepared by diluting 3% ethylene (balance N_2) into air flowing at 10L min^{-1} using mass flow controllers and a microprocessor control device (Aalborg Inc., Orangeburg, NY), giving approximately 1.5 air changes per hour. Ethylene concentrations were verified by gas chromatography and were maintained within 5% of desired set point.

Senescence data

All senescence data were recorded immediately after the plants were removed from the plexiglass boxes. Preliminary experiments showed that no additional senescence attributed to exogenous ethylene was observed several hours to several days after plants were removed from treatment boxes. Senescence symptoms included flower and bud abscission, leaf epinasty, flower wilting, flower discoloration. All such abscised flowers and buds were turgid and showed no signs of natural senescence. Data on percentage abscission and percentage of wilted flowers were arcsin-transformed, analysis of variance tests were conducted and Tukey-Kramer HSD method was used to conduct pair wise comparisons of all treatments and least squares fit was used to estimate model significance of 1-MCP and ethylene treatments. Tukey-Kramer HSD method and Student T's test were used to conduct comparisons of treatments within genus, series and cultivar (JMP Pro v 10, SAS Institute, Cary, NC).

Results and Discussion

Plants were assessed for senescence symptoms immediately after removal chambers. Symptoms included flower abscission, wilting or discoloration. All plants were grouped into three classes of ethylene sensitivity: 1) no response, 2) transient ethylene symptoms, and 3) permanent ethylene damage.

Species apparently insensitive to ethylene

Plants with no response to ethylene after 18 hours of 1 $\mu l \cdot liter^{-1}$ in darkness included *Bidens ferulifolia* 'Mexican Gold Improved'*, Heliotropium arborescens* Scentropia 'Dark Blue'*, Osteospermum ecklonis* Tradewinds 'Purple Bicolor'*,* and *Scaevola aemula* 'Bombay Dark

Blue'. In all of these cultivars there was no damage to flowers, buds or leaves in any of the ethylene or 1-MCP treatments (data not shown).

Bidens and *Osteospermum* are in the Asteraceae family, whose members are usually insensitive to exogenous ethylene (Dole and Wilkins, 2005; Woltering and Van Doorn, 1988). Marigolds may show slight leaf epinasty after 24 h exposure to 10 $\mu l \cdot liter^{-1}$ ethylene but recovered in less than a day and no flower damage occurred (Jones and Edelman, 2013). *Heliotropium arborescens* and *Scaevola aemula* are minor crops and there has been scant postproduction research done on these species. From this study we conclude these cultivars are insensitive to 18-hour exposure to 1 $\mu l \cdot liter^{-1}$. Since Woltering and Van Doorn (1988) found that ethylene symptoms can take up to 72 hours in continuous ethylene exposure to develop. Further studies should be conducted for longer lengths of exposure and/or high ethylene concentration to confirm this conclusion, and additional species should be examined.

Transient Ethylene Damage

Transient ethylene damage was seen in cultivars exhibiting leaf epinasty (MacKinnon et al., 2009), giving the impression of wilting when plants are fully watered and not suffering from water deficit. Species that exhibited epinasty included *Catharanthus roseus*, *Cuphea ramosissima, Impatiens x hawkeri* and *I. walleriana*. 1-MCP spray was effective in protecting all plants from epinasty (data not shown). Even though the epinasty in these plants was transient, these species were categorized as permanent ethylene damage due to flower senescence which was sustained during the treatment (abscission and wilting). Because these cultivars are sold for their flowers, transient leaf epinasty is a lesser problem than permanent flower damage.

Solenostemon scutellarioides ‘Honey Crisp’ and ‘Vino’ were epinastic and recovered within 24 hours (data not shown). *S. scutellarioides* (coleus) are only sold as foliage plants for the broad range of leaf colors, patterning and shapes. The flowers generally detract from the visual value of the plant and thus these plants were tested for the effects of ethylene only on the foliage. While we did not observe leaf abscission in coleous, in other work treatment with ethephon (ethylene releasing growth regulator) resulted in leaf abscission, increased axillary branching, leaf malformation and leaf discoloration in some cultivars (Boldt and Barrett, 2006). Further studies examining longer ethylene exposure times and concentrations may result in leaf abscission or discoloration, which would dramatically detract from thee economic value of these plants.

Permanent Ethylene Damage

Tables 3.1 – 3.21 summarize the symptoms and severity of damage on bedding plants due to exposure to ethylene. Plants showing ethylene damage were divided into two groups, those that were completely protected by 1-MCP from exogenous ethylene and those in which 1-MCP provided incomplete protection.

Incomplete protection was defined as 1- MCP pretreated plants exposed to ethylene showing greater flower senescence than plants not exposed to ethylene regardless of 1-MCP pretreatment. For example, *Cuphea ramosissima* ‘Cuphoric Pink’ showed incomplete protection from 1-MCP. *Cuphea* is known to be extremely sensitive to exogenous ethylene and complete flower abscission has been observed at low concentrations of 0.01 and 0.05 $\mu l \cdot liter^{-1}$ ethylene for 72 hours (Leatherwood and Mattson, 2010). In the absence of ethylene, flower abscission was 5 percent and increased to 93 percent in the absence of 1-MCP. If pretreated with 1-MCP, then

exposed to ethylene, flower abscission was 25 percent, higher than the non-ethylene challenged controls (Table 3.1). In the presence of ethylene without 1-MCP protection plants showed severe epinasty and recovered within 24 hours upon removal from ethylene.

Table 3.1 *Cuphea ramosissima* 'Cuphoric Pink' flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After 1-MCP treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
-	-	5[z] (13)[y] c[x]	1-MCP **
-	+	93 (74) a	Ethylene ***
+	-	5 (13) c	1-MCP x Ethylene **
+	+	25 (30) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[NS, *, **, ***]Not significant, significant at P≤0.05, 0.01 or 0.001, respectively.

Incomplete protection of 1-MCP from ethylene was also seen in *Pelargonium x hortorum* interspecific hybrids Caliente 'Deep Red', 'Fire 09', 'Orange' and in *P. x hortorum* zonal hybrid 'Rocky Mountain Dark Red', and zonal hybrids 'Coral', 'Deep Red', 'Deep Rose', 'Lavender', 'Salmon', 'Salmon Splash', 'Scarlet', and 'Violet' of the Pinto Premium series (Table 3.2). *Pelargonium* are known to be highly sensitive to ethylene (Woltering, 1987) and treatment with gaseous 1-MCP improves postharvest quality of *P. x hortorum* 'Elite Red' when exposed to exogenous ethylene for 3 days (Skog et al., 2001). For them, 1-MCP has the potential to prevent petal abscission in a non-ethylene environment (Jones et al., 2001).

Florets of *Pelargonium x domesticum* show increased responsiveness to ethylene as they age (Deneke et al., 1990; Evensen, 1991). Sensitivity of *P. peltatum* petals to exogenous ethylene was influenced by stage of development, with the most mature flowers abscising regardless of 1-MCP pre-treatment, likely these flowers were already in stages of natural senescence before treatment with 1-MCP (Cameron and Reid, 2001).

Ethylene caused 100 percent flower abscission in the 'Caliente' series of *Pelargonium x hortorum* and the series showed less than 5 percent flower abscission if not exposed to ethylene (Table 3.2). If pre-treated with 25 mg ai·liter^{-1} 1-MCP, ethylene caused 50, 21 and 36 percent flower abscission in Caliente 'Deep Red', 'Fire 09', and 'Orange', respectively (Table 3.2). Similar results were seen in *P. x hortorum* zonal hybrid 'Pinto Premium' series with ethylene causing 35-75 percent abscission in 1-MCP pre-treated plants (Table 3.2). With *P. x hortorum* zonal hybrid Rocky Mountain 'Dark Red' 1-MCP gave much better protection against ethylene than other *P. x hortorum* (7 percent flower abscission compared to 21 to 75 percent seen in other cultivars) (Table 3.2). These differences in 1-MCP protection can potentially be attributed to

range of ethylene sensitivity between genotype (Kim et al., 2006) as seen in *P. x domesticum*, and cultivar in *P. x hortorum* (Deneke et al., 1990; Jones et al., 2001).

Pelargonium peltatum 'Contessa Sybil' had lower ethylene sensitivity than other *Pelargonium* in the experiment (Table 3.2). 'Contessa Sybil' is a double flowering *P. peltatum*. Due to the nature of data taking, flower senescence was based on complete petal abscission and in many double flowers some petals remained intact on the plant after ethylene exposure, reducing the appearance of damage. It has been seen in other bedding plants (*Impatiens walleriana* 'Rockapulco Coral Reef', Table 3.14) and it is unclear from this data if these double cultivars are actually more resistant to ethylene or not.

Table 3.2. *Pelargonium* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Genus	Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Pelargonium	Caliente	-	-	4^{z} (6)^{y} c^{x}	1-MCP ***
x hortorum	Deep Red	-	+	100 (90) a	Ethylene ***
Interspecific		+	-	0 (0) c	1-MCP x Ethylene *
		+	+	50 (45) b	
Pelargonium	Caliente	-	-	0^{z} (0)^{y} c^{x}	1-MCP ***
x hortorum	Fire 09	-	+	100 (90) a	Ethylene ***
Interspecific		+	-	0 (0) b	1-MCP x Ethylene ***
		+	+	21 (27) b	
Pelargonium	Caliente	-	-	5^{z} (11)^{y} b^{x}	1-MCP **
x hortorum	Orange	-	+	100 (90) a	Ethylene ***
Interspecific		+	-	0 (0) b	1-MCP x Ethylene *
		+	+	36 (31) b	
Pelargonium	Pinto Premium	-	-	9^{z} (14)^{y} c^{x}	1-MCP **
x hortorum	Coral	-	+	100 (90) a	Ethylene ***
Zonal		+	-	11 (19) c	1-MCP x Ethylene ***
		+	+	53 (47) b	
Pelargonium	Pinto Premium	-	-	7^{z} (15)^{y} c^{x}	1-MCP ***
x hortorum	Deep Red	-	+	100 (90) a	Ethylene ***
Zonal		+	-	8 (16) c	1-MCP x Ethylene ***
		+	+	49 (44) b	
Pelargonium	Pinto Premium	-	-	12^{z} (20)^{y} c^{x}	1-MCP ***
x hortorum	Deep Rose	-	+	100 (90) a	Ethylene ***
Zonal		+	-	12 (20) c	1-MCP x Ethylene ***
		+	+	64 (53) b	
Pelargonium	Pinto Premium	-	-	9^{z} (17)^{y} c^{x}	1-MCP ***
x hortorum	Lavender	-	+	100 (90) a	Ethylene ***
Zonal		+	-	5 (10) c	1-MCP x Ethylene ***
		+	+	39 (39) b	

Table 3.2. continued.

Series, Genus	Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Pelargonium	Pinto Premium	-	-	10[z] (19)[y] c[x]	1-MCP ***
x hortorum	Salmon	-	+	100 (90) a	Ethylene ***
Zonal		+	-	8 (16) c	1-MCP x Ethylene ***
		+	+	61 (51) b	
Pelargonium	Pinto Premium	-	-	10[z] (18)[y] c[x]	1-MCP ***
x hortorum	Salmon Splash	-	+	100 (90) a	Ethylene ***
Zonal		+	-	9 (18) c	1-MCP x Ethylene ***
		+	+	69 (56) b	
Pelargonium	Pinto Premium	-	-	6[z] (13)[y] c[x]	1-MCP ***
x hortorum	Scarlet	-	+	100 (90) a	Ethylene ***
Zonal		+	-	5 (12) c	1-MCP x Ethylene ***
		+	+	52 (46) b	
Pelargonium	Pinto Premium	-	-	16[z] (23)[y] c[x]	1-MCP ***
x hortorum	Violet	-	+	100 (90) a	Ethylene ***
Zonal		+	-	16 (23) c	1-MCP x Ethylene ***
		+	+	75 (60) b	
Pelargonium	Rocky Mountain	-	-	0[z] (0)[y] b[x]	1-MCP **
x hortorum	Dark Red	-	+	65 (54) a	Ethylene ***
Zonal		+	-	0 (0) b	1-MCP x Ethylene **
		+	+	7 (13) b	
Pelargonium	Contessa	-	-	0[z] (0)[y] b[x]	1-MCP ***
peltatum	Sybil	-	+	38 (38) a	Ethylene ***
		+	-	0 (0) b	1-MCP x Ethylene ***
		+	+	0 (0) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[***]Significant at P≤0.001.

When comparing all *Pelargonium* cultivars there was a significant difference in percent flower abscission due to ethylene exposure. The interspecific hybrid 'Caliente' series and the 'Pinto Premium' series of zonal hybrids showed complete flower abscission (100 percent) whereas *P. x hortorum* zonal hybrid 'Rocky Mountain Dark Red' exhibited 65 percent flower abscission and *P. peltatum* Contessa 'Sybil' only dropped 38 percent of flowers (Table 3.3).

P. x hortorum Rocky Mountain 'Dark Red' was treated in the ethylene chamber at the same time as *Impatiens hawkeri* Super Sonic 'Pink 07' (Table 3.12), *P. peltatum* Contessa 'Sybil' was treated in the ethylene chamber at the same time as *P. x hortorum* Caliente 'Orange'. In the presence of ethylene without 1-MCP pretreatment Super Sonic 'Pink 07' and Caliente 'Orange' abscised 100 percent of flowers whereas Rocky Mountain 'Dark Red' and Contessa 'Sybil' abscised 65 and 38 percent of flowers, respectively. Given these differences occurred in identical ethylene environments, it suggests there are genotypic differences between the cultivars. While more cultivars from the 'Rocky Mountain' and 'Contessa' series need to be tested to confirm that they indeed have lower ethylene sensitivity as compared to 'Caliente' and 'Pinto Premium', it is possible that differences between series and species do exist as seen in *P. x domesticum* (Deneke et al., 1990; Jones et al., 2001).

Table 3.3. *Pelargonium* flower senescence (%) following exposure to 1 μl·liter^{-1} ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Genus	Series, Cultivar	Flower senescence (%)
P. x hortorum Interspecific	Caliente Deep Red	100[z] (90)[y] a[x]
P. x hortorum Interspecific	Caliente Fire 09	100 (90) a
P. x hortorum Interspecific	Caliente Orange	100 (90) a
P. x hortorum Zonal	Pinto Premium Coral	100 (90) a
P. x hortorum Zonal	Pinto Premium Deep Red	100 (90) a
P. x hortorum Zonal	Pinto Premium Deep Rose	100 (90) a
P. x hortorum Zonal	Pinto Premium Lavender	100 (90) a
P. x hortorum Zonal	Pinto Premium Salmon	100 (90) a
P. x hortorum Zonal	Pinto Premium Salmon Splash	100 (90) a
P. x hortorum Zonal	Pinto Premium Scarlet	100 (90) a
P. x hortorum Zonal	Pinto Premium Violet	100 (90) a
P. x hortorum Zonal	Rocky Mountain Dark Red	65 (54) b
P. peltatum	Contessa Sybil	38 (38) c

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

1-MCP conferred complete protection when 1-MCP pre-treated ethylene exposed plants exhibited equal or less flower senescence than plants not exposed to ethylene regardless of 1-MCP pretreatment. *Angelonia angustifolia* exhibited flower wilting after exposure to ethylene when not protected by 1-MCP (Table 3.4). These wilted flowers abscised a few days after being placed in the greenhouse, but this abscission being significantly delayed, is not defined as classic senescence symptoms as seen in the Caryophyllaceae family (Woltering and Van Doorn, 1988). Further abscission, multiple days after ethylene treatment, is possible and this genus would benefit from additional observation after removal from ethylene. There was no difference in flower senescence between cultivars within the 'Archangel' series or across the 'Angelface' series (data not shown).

Table 3.4. *Angelonia angustifolia* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Angelface	-	-	4^{z} (11)^{y} b^{x}	1-MCP ***
Pink Improved	-	+	75 (60) a	Ethylene ***
	+	-	2 (8) b	1-MCP x Ethylene ***
	+	+	2 (8) b	
Archangel	-	-	3^{z} (9)^{y} b^{x}	1-MCP **
Pink	-	+	62 (52) a	Ethylene ***
	+	-	8 (16) b	1-MCP x Ethylene ***
	+	+	5 (13) b	
Archangel	-	-	5^{z} (13)^{y} b^{x}	1-MCP ***
Purple	-	+	58 (50) a	Ethylene **
	+	-	2 (8) b	1-MCP x Ethylene **
	+	+	3 (10) b	
Archangel	-	-	3^{z} (9)^{y} b^{x}	1-MCP *
Raspberry	-	+	55 (48) a	Ethylene **
	+	-	4 (11) b	1-MCP x Ethylene *
	+	+	5 (13) b	
Archangel	-	-	9^{z} (17)^{y} b^{x}	1-MCP ***
White	-	+	75 (60) a	Ethylene ***
	+	-	5 (13) b	1-MCP x Ethylene ***
	+	+	5 (13) b	

^{z}Data are means of three replicates per cultivar per treatment.
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*,**,***Significant at P≤0.05, 0.01 or 0.001, respectively.

Begonia x benariensis 'Whopper Rose Green' was apparently less sensitive to ethylene than other cultivars (Table 3.5). Yet, all colors in the series were equally and completely protected by 1-MCP pretreatment when exposed to ethylene (Table 3.6). Kim et al (2007) noted a difference in ethylene sensitivity between *B. x hiemalis* cultivars with 'Blitz' requiring higher concentration of 1-MCP to provide protection against exogenous ethylene than 'Carneval'.

Sensitivity of ethylene in *Begonia* appears to be species dependent. Skog et al. (2001) tested *B. x hiemalis* 'Elfe' and *B. x sempervirens-cultorum* 'Cocktail Gin' and found that when protected by gaseous 1-MCP (EthylBloc™) both cultivars were improved in the presence of ethylene whereas only 'Cocktail Gin' improved regardless of presence or absence of exogenous ethylene. Similarly, differences between species were seen with *B. x biemalis, B. x elatior hybrida, B. rieger* all dropping flowers in the presence of 0.1 $\mu l \cdot liter^{-1}$ ethylene for 24 hours whereas 1 $\mu l \cdot liter^{-1}$ ethylene for 12 hours had little effect on *B. sempervirens-cultorum* (Gibson et al., 2000).

Table 3.5. *Begonia x benariensis* 'Whopper' series flower senescence (%) following exposure to 1 $\mu l \cdot liter^{-1}$ ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Cultivar	Flower senescence (%)
Red Bronze	70[z] (57)[y] a[x]
Rose Bronze	63 (53) a
Red Green	63 (53) a
Rose Green	48 (44) b

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

Table 3.6. *Begonia x benariensis* 'Whopper' series flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Red Bronze Leaf	-	-	2[z] (7)[y] b[x]	1-MCP ***
	-	+	70 (57) a	Ethylene ***
	+	-	1 (5) b	1-MCP x Ethylene ***
	+	+	3 (9) b	
Red Green Leaf	-	-	5[z] (13)[y] b[x]	1-MCP ***
	-	+	63 (53) a	Ethylene ***
	+	-	2 (8) b	1-MCP x Ethylene ***
	+	+	8 (16) b	
Rose Bronze Leaf	-	-	6[z] (14)[y] b[x]	1-MCP ***
	-	+	63 (53) a	Ethylene ***
	+	-	6 (14) b	1-MCP x Ethylene ***
	+	+	7 (16) b	
Rose Green Leaf	-	-	1[z] (2)[y] c[x]	1-MCP ***
	-	+	48 (44) a	Ethylene ***
	+	-	2 (8) bc	1-MCP x Ethylene ***
	+	+	5 (13) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
**, ***Significant at P≤ 0.01 or 0.001, respectively.

Diascia barberae 'Darla' series also exhibited significant differences in ethylene sensitivity between colors with 'Darla Red Improved' and 'Darla White 11' showing 80 and 100 percent abscission in the presence of ethylene without 1-MCP protection, respectively (Table 3.7). Both cultivars of *Diascia* were completely protected by 1-MCP with no significant differences between other treatments (Table 3.8). As a member of the Scrophulariaceae family, *Diascia* is known for its high sensitivity to ethylene (Woltering and Van Doorn 1988). Beach and Starman (2004) found that pre-treating *Diascia x hybrida* with gaseous 1-MCP (EthylBloc™) significantly reduced flower and raceme abscission in plants subjected to simulated shipping. When *D. x hybrida* plants were treated with ethephon to reduce height it caused reduced flowering, showing the high sensitivity to ethylene (Starman et al., 2004).

Table 3.7. *Diascia barberae* 'Darla' series flower senescence (%) following exposure to 1 $\mu l \cdot liter^{-1}$ ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Cultivar	Flower senescence (%)
White 11	100[z] (90)[y] a[x]
Red Improved	80 (63) b

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

Table 3.8. *Diascia barberae* 'Darla' series flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Red Improved	-	-	0[z] (0)[y] b[x]	1-MCP ***
	-	+	80 (63) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
White 11	-	-	7[z] (13)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	6 (14) b	1-MCP x Ethylene ***
	+	+	11 (19) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[***]Significant at P≤0.001.

Impatiens walleriana exhibited differences in sensitivity to ethylene within the series 'Accent Premium' and 'Tumbler'. Without 1-MCP pretreatment, ethylene caused greater than 90 percent abscission Accent Premium 'Violet', 'Deep Orange' and 'Lilac', and only 78 and 68 percent for Accent Premium 'Salmon' and 'Bright Eyes', respectively (Table 3.9). Similarly in the Tumbler series 'Salmon', 'Scarlet' and 'Violet Star' ethylene caused 100 percent abscission but only 87 and 83 percent for 'White' and 'Rose Star', respectively (Table 3.10).

All *I. walleriana* cultivars exhibited high sensitivity to ethylene with abscission in the presence of ethylene without 1-MCP at or above 65 percent for all cultivars (Table 3.11). 1-MCP provided complete protection from ethylene with no significant differences between non-ethylene challenged plants and those pre-treated with 1-MCP before ethylene (Table 3.11). Burana et al. (2013) found *I. walleriana* 'Rouge' and 'Peach' plants treated with gaseous 1-MCP had significantly longer floret longevity than untreated controls when exposed to ethylene or left in an ethylene free environment (Burana, 2013). *I. walleriana* 'Accent White' and 'Seashell' treated with gaseous 1-MCP improved condition of plants in the presence or absence of exogenous ethylene (Skog et al., 2001).

The double flowered cultivars 'Rockapulco Coral Reef' and 'Kwik Kombo Pink Vibrations Mix' showed sensitivity to ethylene, both abscising 65 percent of flowers when exposed to exogenous ethylene without 1-MCP protection (Table 3.11). It is unclear if these cultivars truly have lower ethylene sensitivity than the 'Tumbler' and 'Accent Premium' series or if the lower abscission is due in part to their double flowers. Single impatiens have five petals and a spur whereas double impatiens have upwards of 20 petals and a spur. Abscission data were collected by counting abscised spurs, and the double impatiens often showed incomplete abscission with some petals and the spur still remaining intact on the plant upon removal from

ethylene. Han (2003) found that double impatiens were more susceptible to bud drop in postproduction stress environments than *I. hawkeri* or single flowered *I. walleriana* and that bud drop was reduced in double impatiens pre-treated with 1-MCP suggesting that bud drop was due to high sensitivity to ethylene.

All *I. walleriana* plants in the presence of ethylene without 1-MCP protection exhibited leaf epinasty. Plants recovered within 24 hours of removal from ethylene environment.

Table 3.9. *Impatiens walleriana* Accent Premium series flower senescence (%) following exposure to 1 µl·liter^{-1} ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Cultivar	Flower senescence (%)
Violet	98[z] (85)[y] a[x]
Deep Orange	91 (76) a
Lilac	91 (75) a
Violet Star	88 (72) ab
Red	86 (71) ab
White	85 (71) ab
Orange Star	86 (69) ab
Salmon	78 (62) b
Bright Eyes	68 (56) b

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

Table 3.10. *Impatiens walleriana* Tumbler series flower senescence (%) following exposure to 1 $\mu l \cdot liter^{-1}$ ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Cultivar	Flower senescence (%)
Salmon	100[z] (90)[y] a[x]
Scarlet	100 (90) a
Violet Star	100 (90) a
Violet	94 (78) ab
Pink	90 (75) ab
White	87 (73) b
Rose Star	83 (66) b

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Student T's test at $P < 0.05$. Means followed by the same letter are not significantly different.

Table 3.11. *Impatiens walleriana* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Accent Premium	-	-	3^{z} (6)^{y} b^{x}	1-MCP ***
Bright Eyes	-	+	68 (56) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	2 (5) b	
Accent Premium	-	-	1^{z} (2)^{y} b^{x}	1-MCP ***
Deep Orange	-	+	91 (76) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	1 (2) b	
Accent Premium	-	-	2^{z} (2)^{y} b^{x}	1-MCP ***
Lilac	-	+	91 (75) a	Ethylene ***
	+	-	1 (2) b	1-MCP x Ethylene ***
	+	+	1 (3) b	
Accent Premium	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Orange Star	-	+	86 (69) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Accent Premium	-	-	1^{z} (3)^{y} b^{x}	1-MCP ***
Red	-	+	86 (71) a	Ethylene ***
	+	-	1 (2) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Accent Premium	-	-	2^{z} (4)^{y} b^{x}	1-MCP ***
Salmon	-	+	78 (62) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Accent Premium	-	-	4^{z} (10)^{y} b^{x}	1-MCP ***
Violet	-	+	98 (85) a	Ethylene ***
	+	-	1 (2) b	1-MCP x Ethylene ***
	+	+	3 (7) b	
Accent Premium	-	-	2^{z} (6)^{y} b^{x}	1-MCP ***
Violet Star	-	+	88 (72) a	Ethylene ***
	+	-	1 (2) b	1-MCP x Ethylene ***
	+	+	2 (5) b	

Table 3.11, continued.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Accent Premium	-	-	1[z] (3)[y] b[x]	1-MCP ***
White	-	+	85 (72) a	Ethylene ***
	+	-	5 (11) b	1-MCP x Ethylene ***
	+	+	8 (16) b	
Kwik Kombo	-	-	5[z] (7)[y] b[x]	1-MCP *
Pink Vibrations Mix	-	+	65 (54) a	Ethylene **
	+	-	8 (14) b	1-MCP x Ethylene **
	+	+	9 (17) b	
Rockapulco	-	-	4[z] (12)[y] b[x]	1-MCP *
Coral Reef	-	+	73 (59) a	Ethylene **
	+	-	2 (6) b	1-MCP x Ethylene *
	+	+	5 (13) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Pink	-	+	90 (75) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Rose Star	-	+	83 (66) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Salmon	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Scarlet	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

Table 3.11, continued.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Violet	-	+	94 (78) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
Violet Star	-	+	90 (75) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Tumbler	-	-	0[z] (0)[y] b[x]	1-MCP ***
White	-	+	87 (73) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[***]Significant at P≤ 0.001.

The *I. x hawkeri* 'Sonic' and 'Super Sonic' series showed high sensitivity to ethylene resulting in 100 percent flower abscission in the plants exposed to ethylene without 1-MCP pre-treatment. The 'Salmon Bisque' cultivar from the 'Infinity' series had 91 percent abscission, slightly lower than the Sonic and Super Sonic series but still very highly sensitive to exogenous ethylene (Table 3.12). 1-MCP pre-treatments fully protected all *I. x hawkeri* against exogenous ethylene (Table 3.12). This confirms results that *I. x hawkeri* are highly sensitive to exogenous ethylene from Dostal et al. (1991) where plants were observed to have 100 percent flower abscission after exposure to 1, 5, or 10 $\mu l \cdot liter^{-1}$ ethylene for 6 hours and over 90 percent of flower abscised after 4 hour exposure to 5 or 10 $\mu l \cdot liter^{-1}$ ethylene. All *I. hawkeri* plants in the presence of ethylene without 1-MCP protection exhibited leaf epinasty. Plants recovered within 24 hours of removal from ethylene environment.

Table 3.12. *Impatiens x hawkeri* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Infinity	-	-	4^{z} (8)^{y} b^{x}	1-MCP ***
Salmon Bisque	-	+	91 (75) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	3 (6) b	
Sonic	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Magic Pink	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Super Sonic	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Flame	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Super Sonic	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Magenta 08	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Super Sonic	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Orange Ice	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Super Sonic	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Pink 07	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

Table 3.12, continued.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Super Sonic Red	-	-	0[z] (0)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	
Super Sonic White	-	-	0[z] (0)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
***Significant at P≤0.001.

Seven cultivars from three series of *Petunia hybrida* showed a significant range of ethylene sensitivity when exposed to exogenous ethylene without 1-MCP protection, ranging from 89 to 54 percent wilting in Sanguna 'Purple Improved' and Picnic 'Amethyst', respectively (Table 3.13). Ethylene damage on petunias is generally characterized as flower wilting (Dole and Wilkins, 2005). *Petunia* Sanguna 'Pastel Yellow' flowers were observed to senesce rapidly after 24 to 48 hour exposure to low levels of ethylene (0.01 and 0.05 $\mu l \cdot liter^{-1}$) (Leatherwood and Mattson, 2010).

Calibrachoa, a close relative of *Petunia,* showed moderate sensitivity to ethylene with plants not treated with 1-MCP and challenged with ethylene showing 58 and 54 percent wilting in 'Callie Bright Red and Deep Yellow', respectively (Table 3.15). Leatherwood and Mattson (2010) saw no significant change in *Calibrachoa* 'Callie Dark Blue' after exposure to 0.01 and 0.05 $\mu l \cdot liter^{-1}$ ethylene for 24 to 48 hours, suggesting that *Calibrachoa* is less sensitive to low levels of ethylene than *Petunia*. *Petunia* and *Calibrachoa* cultivars were completely protected from exogenous ethylene by 1-MCP pretreatment with no significant differences between non-ethylene challenged treatments and ethylene challenged with 1-MCP protection (Table 3.14 and 3.15).

Petunia belongs to the Solanaceae family, best known for tomato which exhibits ethylene damage as leaf epinasty and flower abortion (MacKinnon et al., 2009). A surge of breeding in the Solanaceae family has resulted in many new annual bedding plant products entering the market place including *Nicotiana* (flowering tobacco), *Calibrachoa* and *Capsicum* (ornamental peppers). It is well known that tomato is highly sensitive to exogenous ethylene and can be used as an indicator plant to allow producers to identify when there is ethylene contamination (MacKinnon et al., 2009). More research is necessary to see if high ethylene sensitivity extends

across the Solanaceous family as seen with *Petunia* (Table 3.14) and *Calibrachoa* (Table 3.15) and the extent of damage to annual bedding crops.

Table 3.13. *Petunia hybrida* flower senescence (%) following exposure to 1 μl·liter^{-1} ethylene for 18 hours in darkness. Plants were not pretreated with 1-MCP.

Series	Cultivar	Flower senescence (%)
Sanguna	Purple Improved	89[z] (70)[y] a[x]
Sanguna	Lavender Vein	88 (70) a
Whispers	Star Rose	82 (65) ab
Picnic	White	75 (60) ab
Sanguna	White	65 (53) ab
Picnic	Amethyst	54 (47) b

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.

Table 3.14. *Petunia hybrida* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Picnic	-	-	10[z] (18)[y] b[x]	1-MCP **
Amethyst	-	+	54 (47) a	Ethylene NS
	+	-	8 (17) c	1-MCP x Ethylene *
	+	+	6 (12) b	
Picnic	-	-	7[z] (15)[y] b[x]	1-MCP ***
White	-	+	75 (60) a	Ethylene ***
	+	-	5 (13) c	1-MCP x Ethylene ***
	+	+	8 (17) b	
Sanguna	-	-	0[z] (0)[y] c[x]	1-MCP ***
Lavender Vein	-	+	88 (70) a	Ethylene ***
	+	-	0 (0) c	1-MCP x Ethylene ***
	+	+	10 (18) b	
Sanguna	-	-	14[z] (16)[y] b[x]	1-MCP **
Purple Improved	-	+	89 (70) a	Ethylene **
	+	-	0 (0) b	1-MCP x Ethylene *
	+	+	10 (16) b	
Sanguna	-	-	5[z] (7)[y] b[x]	1-MCP *
White	-	+	65 (54) a	Ethylene **
	+	-	8 (14) c	1-MCP x Ethylene **
	+	+	9 (17) b	
Whispers	-	-	7[z] (12)[y] b[x]	1-MCP **
Star Rose	-	+	82 (65) a	Ethylene ***
	+	-	10 (19) b	1-MCP x Ethylene ***
	+	+	11 (20) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*,**,***Significant at P≤0.05, 0.01 or 0.001, respectively.

Table 3.15. *Calibrachoa x hybrida* 'Callie' series flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Bright Red	-	-	6[z] (11)[y] b[x]	1-MCP **
	-	+	58 (49) a	Ethylene **
	+	-	6 (14) b	1-MCP x Ethylene **
	+	+	5 (10) b	
Deep Yellow	-	-	10[z] (18)[y] b[x]	1-MCP **
	-	+	54 (47) a	Ethylene NS
	+	-	8 (19) b	1-MCP x Ethylene *
	+	+	6 (12) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*,**,***Significant at P≤0.05, 0.01 or 0.001, respectively.

Lobelia erinus is an important albeit minor, annual bedding crop due to the vibrant blue colors available for breeding. *L. erinus* Techno Heat 'Dark Blue' and 'Light Purple' had 100 percent flower wilting when exposed to exogenous ethylene without 1-MCP protection (Table 3.16). *Lobelia* is a member of the Campanulaceae family, known for its high sensitivity to ethylene and it is one of the few families that exhibits ethylene mediated senescence as wilting (Woltering and Van Doorn, 1988). *Campanula* cut-flowers wilt within 72 hours of exposure to exogenous ethylene (Woltering, 1987). Potted *C. carpatica* 'Dark Blue and Blue Clips' pre-treated with 1-MCP increased plant display life and flower longevity after exposure to 0.5 $\mu l \cdot liter^{-1}$ ethylene and 'Blue Clips' pre-treated with 1-MCP increased flower longevity in the absence of ethylene (Serek and Sisler, 2001).

Leatherwood and Mattson (2010) saw no significant change in *L. erinus* 'Riviera Blue Splash' after exposure to 0.01 and 0.05 $\mu l \cdot liter^{-1}$ ethylene for 24 to 48 hours, but long term continuous exposure to these low levels of ethylene reduced flower number compared to not challenged controls. With our experiments resulting in 100 percent flower wilting in the presence of 1.0 $\mu l \cdot liter^{-1}$ ethylene for 18 hours it is suggested that *L. erinus* is sensitive to higher concentrations of ethylene in the short-term, whereas lower concentrations will affect growth and development.

Table 3.16. *Lobelia erinus* 'Techno Heat' series flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Dark Blue	-	-	0[z] (0)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	10 (18) b	
Light Purple	-	-	0[z] (0)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[***]Significant at P≤ 0.001.

Tables 3.17 through 3.20 present data from *Cleome hassleriana* 'Senorita Rosalita', *Catharanthus rosea* 'Nirvana Blush Pink', *Lantana camara* 'Bandana White' and *Verbena x hybrida* 'Lanai Upright Blue with Eye'. All cultivars were sensitive to ethylene when not protected by 1-MCP. 'Senorita Rosalita' was the most sensitive with 100 percent flower abscission followed by 'Nirvana Blush Pink' (88 percent abscission) and 'Bandana White' at 75 percent abscission. 'Lanai Upright Blue with Eye' was the least sensitive at 53 percent abscission. All cultivars were completely protected from ethylene by 1-MCP and there was no significant difference between unchallenged treatments and ethylene challenged with 1-MCP pre-treatment.

L. camara 'Bandana White' plants in the presence of ethylene without 1-MCP protection showed increased leaf abscission compared to all other plants tested in this thesis. Further studies should be conducted for longer lengths of exposure and/or high ethylene concentration to confirm that leaf abscission is a symptom of ethylene damage on *L. camara.* *C. rosea* 'Nirvana Blush Pink' plants in the presence of ethylene without 1-MCP protection exhibited leaf epinasty. Plants recovered within 24 hours of removal from ethylene environment.

Table 3.17. *Cleome hassleriana* Flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Senorita Rosalita	-	-	5[z] (13)[y] b[x]	1-MCP ***
	-	+	100 (90) a	Ethylene ***
	+	-	4 (12) b	1-MCP x Ethylene ***
	+	+	8 (16) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[***]Significant at P≤ 0.001.

Table 3.18. *Catharanthus rosea* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Nirvana	-	-	0[z] (0)[y] b[x]	1-MCP ***
Blush Pink	-	+	88 (75) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

[z]Data are means of three replicates per cultivar per treatment.
[y]Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
[x]Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
[*,**,***]Significant at P≤0.05, 0.01 or 0.001, respectively.

Table 3.19. *Lantana camara* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Bandana	-	-	5^{z} (13)^{y} b^{x}	1-MCP ***
White	-	+	75 (60) a	Ethylene ***
	+	-	5 (13) b	1-MCP x Ethylene ***
	+	+	5 (13) b	

^{z}Data are means of three replicates per cultivar per treatment.
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*,**,***Significant at P≤0.05, 0.01 or 0.001, respectively.

Table 3.20. *Verbena x hyrbida* flower senescence (%) due to ethylene exposure of annual bedding plants pre-treated with 0 or 25 mg ai·liter^{-1} sprayable 1-MCP. After pre-treatment plants were exposed 1 µl·liter^{-1} ethylene or kept in an ethylene-free atmosphere for 18 hours in darkness.

Series, Cultivar	1-MCP	Ethylene	Flower senescence (%)	Fixed Effect
Lanai	-	-	0^{z} (0)^{y} b^{x}	1-MCP ***
Upright Blue with Eye	-	+	53 (47) a	Ethylene ***
	+	-	0 (0) b	1-MCP x Ethylene ***
	+	+	0 (0) b	

^{z}Data are means of three replicates per cultivar per treatment.
^{y}Percentage data were arcsin-transformed (in brackets) for statistical analysis, and values refer to these transformations.
^{x}Letters after values in each column represent means separation using Tukey-Kramer honestly significant difference (HSD) at P = 0.05. Means followed by the same letter are not significantly different.
*,**,***Significant at P≤0.05, 0.01 or 0.001, respectively.

Conclusions

This work clearly indicates that the vast majority of annual bedding plants in the marketplace today are sensitive to ethylene and exposure to relatively low levels of ethylene for a short period of time can cause serious damage. It is important for breeders to trial for postproduction sensitivity before new cultivars are released to the public, and if possible growers should also trial each new product under their specific growing conditions to assess the postproduction care necessary to deliver a quality crop to market. The present work further demonstrates that ethylene sensitivity varies at the species, series and cultivar levels. While cultivar differences in ethylene effects are well known and highly studied in other horticultural crops (e.g. apples), this has been less studied in ornamental horticulture, especially in herbaceous annuals. Perhaps this is due to rapid cultivar turnover seen in ornamental cultivars compared to long development of fruit cultivars. The present work suggests focused efforts with an objective at developing more ethylene resistant cultivars of the major genera might be fruitful.

Sprayable 1-MCP (AFxRD-038) protected the majority of ethylene sensitive crops and would be a valuable postproduction technology in greenhouse production. In some cases, 1-MCP will provide less protection, for example mature *Pelargonium* flowers beginning to senesce naturally may not be fully protected by 1-MCP. It is likely that rates lower than 25 mg ai·liter^{-1} 1-MCP, perhaps closer to 10 mg ai·liter^{-1}, would be sufficient for protecting plants against exogenous ethylene. Sprayable 1-MCP has proved to be a versatile technology that can be applied quickly and easily before plants leave a production facility and eliminates the need for plants to be isolated in a enclosed area for a long period of time for gaseous 1-MCP applications. It is important for growers to assess the potential for presence of ethylene in postproduction and

determine if 1-MCP would be a cost effective method of reducing premature senescence damage to annual bedding crops.

Further work can be done to assess annual bedding plants to longer exposure times to ethylene, the potential for 1-MCP to reduce non-ethylene postproduction stress such as darkness and high temperatures, and the long-term effects of ethylene exposure after plants have arrived at market. As mentioned, the data also suggest a potential for breeding ethylene resistance in a number of genera.

Acknowledgements

We thank AgroFresh Inc. for financial support of this project. Also thanks to Blue Grass Lane Summer Trials participants Ball Horticultural Company, Syngeta Flowers and Proven Winners for annual bedding plants. We also thank Rose Harmon, Allison Hyrcik, Julie Blaha, Jenny Rothenberg and Blue Grass Lane Summer Interns for greenhouse assistance and data collection.

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