Ethylene Affects Postproduction Quality of Easter Cactus

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Abstract. Experiments were performed to determine the effects of ethylene (C_2H_4) on the postproduction quality of Easter cactus [*Hatiora gaertneri* (Reg.) Barthlott and *H. ×graeseri* (Werderm.) Barthlott]. Significant differences in percent bud abscission were observed among cultivars when plants were exposed to 0.4 or 1.0 $\mu L \cdot L^{-1}$ C_2H_4 for 48 hours. Fewer buds abscised on 'Andre' and 'Red Pride' than on 'Evita', 'Rood', and 'Thor-Anne'. Stage of floral development at the time of C_2H_4 exposure affected the pattern and severity of bud abscission for 'Crimson Giant'. Percent bud abscission was greater for plants treated with 0.5 $\mu L \cdot L^{-1}$ C_2H_4 in the small-bud stage (largest buds 7 to 13 days from anthesis) than for plants treated in the medium-bud stage (largest buds 3 to 4 days from anthesis) or large-bud stage (largest buds 1 day from anthesis). Application of 1 or 2 mM silver thiosulfate (STS) was as effective as 3 mM STS in reducing bud abscission on plants exposed to 0.5 $\mu L \cdot L^{-1}$ C_2H_4 in the small-bud stage. Treatment with 2 mM STS before C_2H_4 exposure increased the display life (number of days from anthesis of the first flower to senescence of the last flower) of 'Andre' in all three developmental stages, but increased the display life of 'Crimson Giant' only in the small bud stage. These results demonstrate that the response of Easter cactus to C_2H_4 is affected by cultivar, C_2H_4 concentration, stage of floral development at the time of C_2H_4 exposure, and STS pretreatment.

Exogenous C_2H_4 hastens floral senescence and abscission in many potted plants (Cameron and Reid, 1981; Høyer, 1984, 1985; Woltering, 1987). Floral responses to exogenous C_2H_4 depend on several factors, including concentration, duration of exposure, and stage of floral development at the time of exposure (Whitehead et al., 1984; Woltering, 1987). Postproduction quality of *Hibiscus rosa-sinensis* L. (Høyer, 1984) and *Begonia elatior* Hort. (*B. ×hiemalis* Fotsch.) (Høyer, 1985) were reduced by exposure to only 0.05 $\mu L \cdot L^{-1}$ C_2H_4 for 72 h, indicating that many flowering potted plants have a low threshold for C_2H_4 injury. Ethylene at concentrations from 0.02 to 2.95 $\mu L \cdot L^{-1}$ has been detected during transit and in retail display areas (Morris et al., 1978). Hence, the likelihood of C_2H_4 exposure during transit and retail display is considerable. Flower senescence and abscission may be delayed by treating C_2H_4 -sensitive plants with chemicals that inhibit the biosynthesis or action of C_2H_4 . The anionic complex silver thiosulfate (STS) inhibits C_2H_4 action and is used to prolong the display life of several flowering potted plants (Cameron and Reid, 1981; Høyer, 1986; Veen, 1983). Application of STS, however, increases production costs and poses an environmental risk (Nell, 1992; Staby, 1992). An alternative to STS is cultivation of genotypes that are less sensitive or insensitive to C_2H_4 or other stresses encountered during shipping or retail display.

Easter cactus is a relatively new crop in North America, but is a prominent flowering potted plant in northern Europe (Boyle, 1991a). Information on the postproduction handling of Easter cactus is lacking. In the related species *Schlumbergera truncata* (Haw.) Moran (zygocactus), flower and bud abscission are induced by exogenous C_2H_4 or stress (high temperature and low irradiance), and abscission can be greatly reduced by applying STS before C_2H_4

exposure (Cameron and Reid, 1981). The objective of this study was to determine the effects of C_2H_4 concentration, cultivar, stage of floral development, and STS concentration on the postproduction quality of Easter cactus.

Materials and Methods

General procedures. Six cultivars were used for this study (Table 1), all propagated vegetatively from stock plants. In late February, whole phylloclades were propagated in 72-cell plastic trays, using one phylloclade per 35-cm³ cell. Plants were potted individually into 220-cm³ (7.6-cm-diameter) plastic pots in mid-July. A commercial soilless mix (mix no. 2, Conrad Fafard, Springfield, Mass.) was used for propagation and growing. Plants were fertilized at each watering with 20N–4.3P–16.6K (12% NO₃-N, 8% NH₄-N) at 200 mg N/L. Fertilization began after phylloclades were rooted and continued until the start of C_2H_4 treatments.

Plants were propagated and grown in a shaded glasshouse [$\leq 500 \mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux (PPF)] with temperature setpoints of 18/22 °C (heat/vent). Actual glasshouse temperatures ranged from 16 °C minimum to about 40 °C maximum for short durations during summer months. In Expts. 2 and 4, plants in different stages of floral development were obtained by varying the time of transferring plants from inductive conditions [10 ± 2 °C night/ 12 ± 2 °C day and natural daylength (ND)] to forcing conditions (18 ± 2 °C nights/ 21 ± 2 °C days and long days) (Boyle, 1991b). In all experiments, uniform bud development was achieved by removing immature apical phylloclades 1 week after the start of forcing conditions.

Table 1. The Easter cactus cultivars used for study and their taxonomic status and source.

Cultivar	Binomial	Source
Andre	<i>H. ×graeseri</i>	Rainbow Gardens, Vista, Calif.
Crimson Giant	<i>H. gaertneri</i>	Univ. of Maryland, College Park, Md.
Evita	<i>H. ×graeseri</i>	J. de Vries, Aalsmeer, The Netherlands
Red Pride	<i>H. ×graeseri</i>	J. de Vries, Aalsmeer, The Netherlands
Rood	<i>H. ×graeseri</i>	J. de Vries, Aalsmeer, The Netherlands
Thor-Anne	<i>H. ×graeseri</i>	Gartneriet Thoruplund, Odense, Denmark

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Table 2. Influence of C_2H_4 concentration on percent bud abscission for five cultivars of Easter cactus. Plants were exposed to C_2H_4 for 48 h and data were collected 5 d after C_2H_4 treatments.

Cultivar	C_2H_4 concn ($\mu L \cdot L^{-1}$)			Significance
	0	0.4	1.0	
Andre	6.2 ± 1.8	2.6 ± 1.4	9.2 ± 4.2	NS
Evita	4.4 ± 1.5	10.1 ± 2.3	51.9 ± 6.0	L***Q**
Red Pride	6.3 ± 1.3	11.5 ± 3.6	13.0 ± 3.9	NS
Rood	3.8 ± 1.4	31.0 ± 5.0	66.4 ± 5.6	L***
Thor-Anne	5.4 ± 1.9	14.3 ± 3.7	38.8 ± 8.4	L***
Significance ^z	NS	***	***	

^zHeterogeneity chi-square tests for differences among cultivars at each C_2H_4 concentration.

NS,***Nonsignificant or significant at $0.001 < P \leq 0.01$ or $P \leq 0.001$; L = linear, Q = quadratic.

Ethylene treatment. Plants were treated with C_2H_4 or with C_2H_4 -free air in 30-L glass tanks that were housed in a growth chamber (model 818; Precision Scientific, Chicago). Unless otherwise stated, chamber conditions were $19 \pm 1^\circ C$ and continuous darkness. Air temperatures in the tanks were recorded with a datalogger (LI-1000, LI-COR, Lincoln, Neb.) equipped with a thermistor (LI-1000-16). Relative humidity in the tanks was not controlled but remained at $\geq 90\%$ during C_2H_4 treatments. C_2H_4 concentrations in each tank were determined daily with a gas chromatograph (Shimadzu GC-9A, Kyoto, Japan) equipped with a flame ionization detector and an activated alumina column (GDX 502; Tianjing no. 2 Chemical Reagents Factory, Tianjing, China). Gas was delivered to the tanks at a flow rate of one air exchange per hour, and the desired C_2H_4 concentrations were attained within 3 h after sealing the tanks. The duration of the treatments were 48 h in all experiments.

Combined effects of cultivar and C_2H_4 concentration (Expt. 1).

Fig. 1. Bud abscission of 'Crimson Giant' Easter cactus following a 48 h exposure to C_2H_4 -free air (solid symbols) or $0.5 \mu L C_2H_4/L$ (open symbols) at two stages of bud development. Data are the means $\pm$ standard errors.

Plants of 'Andre', 'Evita', 'Red Pride', 'Rood', and 'Thor-Anne' in the large-bud stage (largest buds about 1 to 2 d to anthesis, with two or more open flowers/plant) were exposed to air containing 0, 0.4, or $1.0 \mu L C_2H_4/L$. Incubator conditions were $20 \pm 1^\circ C$ with a 12-h photoperiod ($17 \pm 3 \mu mol \cdot m^{-2} \cdot s^{-1}$ PPF) from cool-white fluorescent lamps. After C_2H_4 exposure, plants were transferred to a growth room maintained at $24 \pm 1^\circ C$ with a 24-h photoperiod ($12 \pm 2 \mu mol \cdot m^{-2} \cdot s^{-1}$ PPF) from cool-white fluorescent lamps. Plants were irrigated with tap water ($\leq 0.12 dS \cdot m^{-1}$ electrical conductivity) after C_2H_4 treatments. There were six replicate plants per treatment for 'Andre', 'Rood', and 'Thor-Anne', and ten replicate plants per treatment for 'Evita' and 'Red Pride'.

Effect of stage of floral development (Expt. 2). 'Crimson Giant' plants were exposed to C_2H_4 -free air or air containing $0.5 \mu L C_2H_4/L$ in either the small-bud stage (largest buds 2.6 ± 0.1 cm in length and about 10 days to anthesis) or the large-bud stage (largest buds ≥ 3.5 cm in length and about 1 to 2 days to anthesis, with 0 to 3 open flowers/plant). After C_2H_4 exposure, plants were transferred to a growth chamber providing $19 \pm 1^\circ C$ and a 12-h photoperiod ($12 \pm 2 \mu mol \cdot m^{-2} \cdot s^{-1}$ PPF) from cool-white fluorescent lamps. There were five and eight replicate plants in the air and C_2H_4 treatments, respectively. The experiment was terminated 20 days after C_2H_4 treatment.

Effect of STS concentration (Expt. 3). Budded plants of 'Crimson Giant' were sprayed with STS 5 d before C_2H_4 exposure. Treatments included STS at 1, 2, and 3 mM, and a sprayed control (0 mM STS). All solutions contained 1 mL Tween 20/L (polyoxyethylene sorbitan monolaurate) as a surfactant and were applied with a hand sprayer at a rate of about 9 mL/plant. Plants in the small-bud stage (largest buds 2.5 ± 0.1 cm in length and about 13 days to anthesis) were exposed to $0.5 \mu L \cdot L^{-1} C_2H_4$, and afterwards were transferred to a growth chamber providing the same temperature, irradiance, and photoperiod conditions described in Expt. 2. There were eight replicate plants per treatment. The experiment was terminated 20 d after C_2H_4 treatment.

Combined effects of STS pretreatment and stage of floral development (Expt. 4). One week before C_2H_4 exposure, plants of 'Crimson Giant' and 'Andre' in three stages of floral development were sprayed with 2 mM STS or deionized water (sprayed control). Solutions were prepared as described in Expt. 3. For each cultivar, there were six treatments (two STS treatments $\times$ three stages of floral development) with six replicate plants per treatment. On the day of C_2H_4 treatment, the mean length of the two largest buds and the number of open flowers were recorded for each plant. Plants were exposed to $0.5 \mu L \cdot L^{-1} C_2H_4$ and afterwards were kept in a shaded glasshouse providing $19.1 \pm 2.1^\circ C$ and $215 \pm 155 \mu mol \cdot m^{-2} \cdot s^{-1}$ PPF from natural daylight. Plants were maintained in a shaded glasshouse rather than a growth chamber (Expts. 2 and 3) to eliminate the possibility that low PPF may have enhanced bud abscission (van Meeteren and de Proft, 1982; Nell and Noordegraaf, 1992). Number of days from C_2H_4 treatment to anthesis of the first flower was recorded for plants in the small- and medium-bud stages.

Data collection and analysis. Immediately before C_2H_4 treatments, the number of unopened buds was counted on each plant and open flowers were marked on the calyx with white latex paint to distinguish them from buds that reached anthesis during or after C_2H_4 treatment. In Expt. 1, the number of buds and open flowers remaining on the plants was recorded at 5 d after C_2H_4 treatments, whereas in all other experiments, the number of buds and flowers remaining on the plants was recorded every 2 d until the experiment was terminated. Percent bud abscission was calculated from the data. In Expt. 1, heterogeneity chi-square tests were used to test

Fig. 2. Effects of STS pretreatment on 'Crimson Giant' Easter cactus treated with $0.5 \mu\text{L C}_2\text{H}_4/\text{L}$ for 48 h. STS was applied 5 d before C_2H_4 treatment. Data are the average of eight replicate plants.

for cultivar differences in percent bud abscission. In Expt. 4, the percentage of buds that reached anthesis and the display life (number of days from anthesis of the first flower to senescence of the last flower) were determined. Percentage data were transformed ($\arcsin \%$) before analysis by SAS's (Cary, N.C.) General Linear Model procedure.

Results

Experiment 1. For 'Evita', 'Rood', and 'Thor-Anne', percent bud abscission increased as C_2H_4 concentration increased from 0 to $1.0 \mu\text{L}\cdot\text{L}^{-1}$ (Table 2), but exposure to $\leq 1.0 \mu\text{L}\cdot\text{L}^{-1} \text{C}_2\text{H}_4$ did not affect bud abscission for 'Andre' and 'Red Pride'. Percent bud abscission was similar for all cultivars when plants were exposed to $0 \mu\text{L C}_2\text{H}_4/\text{L}$, but the cultivars responded differently when plants were exposed to either 0.4 or $1.0 \mu\text{L C}_2\text{H}_4/\text{L}$.

Experiment 2. Stage of floral development at the time of C_2H_4 exposure affected the pattern and severity of bud abscission for 'Crimson Giant'. Bud abscission commenced earlier on plants treated in the large-bud stage than on those treated in the small-bud stage (Fig. 1). However, by 20 d after C_2H_4 treatment, nearly 35% of the buds had abscised on plants exposed to C_2H_4 in the small-bud stage, whereas only 18% of the buds had abscised on plants exposed to C_2H_4 in the large-bud stage (Fig. 1). In comparison, only about 5% of the buds abscised from plants treated with C_2H_4 -free air, regardless of stage of floral development.

Experiment 3. Treating 'Crimson Giant' plants with STS before C_2H_4 exposure reduced bud

abscission by about 50% (Fig. 2). Differences between STS-treated plants and controls became apparent at 14 d after C_2H_4 exposure and increased further between 14 and 20 d after exposure to C_2H_4 . Orthogonal contrasts revealed that application of 1 or 2 mM STS was as effective as 3 mM STS in reducing bud abscission (data not presented). No phytotoxicity was observed on 'Crimson Giant' plants treated with 1 to 3 mM STS.

Experiment 4. Three floral development stages were distinguished for 'Andre' and 'Crimson Giant': small-, medium-, and large-bud (Table 3). The two cultivars exhibited similar responses to C_2H_4 (Fig. 3). For both cultivars, plants in the small-bud stage were the most sensitive to C_2H_4 injury, whereas those in the large-bud stage were least sensitive to C_2H_4 injury. For plants in the small-bud stage, the greatest increase in bud abscission occurred between 6 and 8 d after C_2H_4 exposure for 'Andre', and between 6 and 10 d after C_2H_4 exposure for 'Crimson Giant'. Paired comparisons indicated that treatment with 2 mM STS before C_2H_4 exposure significantly reduced bud abscission on plants in the small-bud stage and 'Andre' in the medium-bud stage, but was ineffective for plants in the large-bud stage (Fig. 3). Decreased bud abscission resulted in a higher percentage of buds that reached anthesis (Table 4). Treatment with 2 mM STS increased the display life of 'Andre' in all three developmental stages, but increased the display life of 'Crimson Giant' only in the small bud stage.

Discussion

These results demonstrate that the postproduction performance of many Easter cactus cultivars is affected adversely by exposure to C_2H_4 concentrations similar to those reported to occur during transit and in retail display (Morris et al., 1978). The data reported here also indicate that Easter cactus cultivars exhibit significant genetic variation in their susceptibility to C_2H_4 injury (Table 2). Differences among cultivars in their responses to C_2H_4 have been reported in several other floricultural crops, including *Dianthus caryophyllus* L. (Wu et al., 1991a, 1991b), *Pelargonium domesticum* L.H. Bailey (Deneke et al., 1990) and *Rosa x hybrida* (Reid et al., 1989). Selection of cultivars that are less sensitive to C_2H_4 injury appears to be a feasible method for optimizing the postproduction performance of Easter cactus. Information on cultivar responses to C_2H_4 could be useful for breeding programs directed toward improving the postproduction performance of Easter cactus.

Finished plants of Easter cactus are shipped to market primarily in the small-bud stage, i.e., when the largest buds are 7 to 10 d from opening (M.L. Cobia, personal communication). These conditions are conducive to bud abscission if plants are exposed to C_2H_4 at concentrations of $0.5 \mu\text{L}\cdot\text{L}^{-1}$ (Figs. 1 and 3). When 'Andre' and 'Crimson Giant' plants were exposed to C_2H_4 in the small-bud

Table 3. Characteristics of the plants used in evaluating the responses of three developmental stages of Easter cactus plants to C_2H_4 .

Cultivar	Developmental stage	Days before anthesis of the first bud ²	Length of the longest bud (cm)	Open flowers ³ (no.)
Andre	Small	7.3 ± 0.8	2.4 ± 0.1	0
	Medium	3.2 ± 0.4	3.0 ± 0.1	0
	Large	---	3.2 ± 0.0	4.1 ± 0.9
Crimson Giant	Small	10.0 ± 0.6	2.5 ± 0.1	0
	Medium	4.0 ± 0.5	3.2 ± 0.1	0
	Large	---	3.8 ± 0.1	2.1 ± 0.7

²Number of days from the commencement of the C_2H_4 treatment to anthesis of the first flower bud.

³Number of flowers open at the time of C_2H_4 treatment.

Fig. 3. Bud abscission of two cultivars and three developmental stages of Easter cactus were evaluated on plants treated with water (open symbols) or 2 mM STS (solid symbols) followed by a 48 h exposure to 0.5 $\mu\text{L C}_2\text{H}_4/\text{L}$. The three stages were (○) small-bud, (Δ) medium-bud, (□) large-bud stage. Data are the average of six replicate plants.

stage, an STS application before C_2H_4 exposure resulted in nearly twice as many buds reaching anthesis as compared to controls (Table 4). For plants exposed to C_2H_4 in the medium-bud stage, STS significantly increased the percentage of buds that reached anthesis for 'Andre' but not for 'Crimson Giant'. STS had no marked effect on the percentage of buds that reached anthesis when 'Andre' and 'Crimson Giant' were exposed to C_2H_4 in the large-bud stage. These results indicate that STS may significantly improve the postproduction quality of Easter cactus plants shipped in the small-bud or medium-bud stages, but not those shipped in the large-bud stage.

For potted plants with numerous flowers, postproduction quality may be defined in part by the percentage of flower buds that reach anthesis. Plants with more open flowers have a greater floral display and thus would be expected to increase consumer satisfaction. For 'Andre' and 'Crimson Giant', the percentage of flower buds that reached anthesis was strongly influenced by the STS treatment and the stage of floral development at the time of C_2H_4 exposure (Table 4). Display life is another criterion that is used frequently in defining postproduction quality of potted plants. Treatments that prolong the display life are highly desirable, as they improve product marketability and consumer satisfaction. STS exerted a greater influence on the display life of 'Andre' and 'Crimson Giant' than the stage of floral development at the time of C_2H_4 exposure (Table 4).

Exposure of Easter cactus 'Crimson Giant' plants to C_2H_4 markedly increased bud abscission, especially for plants treated at the small-bud stage (Fig. 1). When treated with air alone, only 5% of the buds abscised, regardless of stage of development. This result concurs with studies conducted on 'Evita', 'Purple Pride' and 'Red Pride' Easter cactus, in which $\leq 3\%$ of the floral buds abscised when plants were kept at irradiance levels of 7 or 14 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ for 12 $\text{h}\cdot\text{d}^{-1}$ and temperatures from 18 to 24 $^{\circ}\text{C}$ (Nell, personal communication). The delayed abscission of small buds exposed to C_2H_4 suggests that C_2H_4 may not directly affect the formation of the abscission zone, but instead acts in other ways, possibly by reducing the bud's sink strength. Reduced translocation of carbohydrates to the buds has been reported to cause bud abortion and abscission in several genera, including *Freesia* (Spikman, 1989), *Gladiolus* (Serek et al., 1994), and *Lilium* (van Meeteren and de Proft, 1982). The hypothesis that C_2H_4 mediates

Table 4. Percentage of buds that reached anthesis and the display life of two cultivars of Easter cactus treated with 0.5 $\mu\text{L C}_2\text{H}_4/\text{L}$ for 48 h. Display life was the number of days between opening of the first flower and senescence of the last flower.

Cultivar	Stage	Buds reaching anthesis (%)			Display life (days)		
		Pretreatment ²			Pretreatment		
		Water	2 mM STS	Contrast	Water	2 mM STS	Contrast
Andre	Small	41.1 $\pm$ 6.3	83.6 $\pm$ 3.1	***	22.0 $\pm$ 2.4	26.6 $\pm$ 0.9	*
	Medium	67.6 $\pm$ 7.1	89.3 $\pm$ 2.1	*	22.3 $\pm$ 2.0	27.0 $\pm$ 0.7	*
	Large	82.5 $\pm$ 3.2	91.0 $\pm$ 1.4	NS	17.3 $\pm$ 0.8	23.0 $\pm$ 1.2	**
Crimson Giant	Small	41.6 $\pm$ 4.0	73.2 $\pm$ 2.8	**	16.0 $\pm$ 0.9	23.3 $\pm$ 0.8	***
	Medium	66.4 $\pm$ 4.0	80.3 $\pm$ 2.7	NS	19.3 $\pm$ 0.8	22.3 $\pm$ 0.6	NS
	Large	89.1 $\pm$ 4.2	85.9 $\pm$ 5.0	NS	17.2 $\pm$ 0.5	19.6 $\pm$ 0.7	NS

²Plants were sprayed 1 week before the ethylene treatment.

NS, *, **, *** Single degree of freedom orthogonal contrast nonsignificant or significant at 0.01 < P $\leq$ 0.05, 0.001 < P $\leq$ 0.01, and P $\leq$ 0.001, respectively.

the sink strength of buds is supported by data of Serek et al. (1994), which showed that desiccation of young flower buds of *Gladiolus* was due to insufficient sink strength when competing for carbohydrates with larger, more developed flower buds. In their study, an STS pretreatment or addition of sugar to the vase solution were equally effective in improving the opening of young flower buds.

Horticultural significance. Ethylene exposure can reduce the postproduction quality of Easter cactus. Cultivars of Easter cactus vary in their responses to C_2H_4 , suggesting that postproduction performance may be improved by selecting cultivars that are less sensitive to C_2H_4 . Typically, plants that are exposed to C_2H_4 in the small-bud stage do not exhibit symptoms of C_2H_4 injury until several days after exposure (Fig. 2). This delayed response is significant, because bud abscission would be less likely to occur during transit than when plants are in retail display or the consumer's home. Ethylene injury to Easter cactus can be minimized by either treating plants with STS if they are intended for shipment in the small-bud stage, or by delaying shipment until plants reach the medium- or large-bud stage.

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