Postharvest Handling of Cut *Heuchera sanguinea* Engelm. Flowers: Effects of Sucrose and Silver Thiosulfate

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Abstract. Postharvest quality of cut *Heuchera sanguinea* Engelm. ‘Splendens’ and ‘Bressingham’ was significantly improved and vase life significantly increased by pulsing the inflorescences with 4 mM silver thiosulfate (STS) for 4 hours followed by placing the stems in vase solutions containing 0.5% sucrose and 200 mg·L⁻¹ 8-hydroxyquinoline citrate. Under these conditions, nearly all of the buds (>92%) on inflorescences harvested with ≈2% to 3% open flowers developed to anthesis, in comparison with 26% to 28% of the controls. Sucrose concentrations higher than 1% were detrimental and resulted in stem toppling. Treatment with 4 mM STS for 4 hours delayed bud and flower abscission, but longer treatment times resulted in blackening and shriveling of the flower buds. With the absence of sucrose in the vase solutions, flower buds on STS-treated inflorescences did not continue to develop. Ethylene is probably involved in the natural senescence of the flower buds, since exogenous ethylene induced rapid flower abscission, and senescence was delayed by treatment with STS.

Heuchera sanguinea Engelm., commonly known as coral bells, is a popular garden perennial with great potential for use as flowering potted plants and cut flowers. The inflorescence is a panicle consisting of many branching racemes. Flower buds on each raceme open acropetally. The slender scapes that bear open clusters of flower buds at various developmental stages could be used in bouquets in place of *Gypsophila paniculata* L. (Iversen, 1990). Coral bells can be forced to flower in the greenhouse after placing mature plants at ≈5 °C for 10 to 12 weeks (Han, 1984; Iversen, 1990). The first inflorescence flowers in 6 to 9 weeks after transfer to a greenhouse with 16 °C night temperature, depending on cultivar, environmental conditions, and length of the vernalization treatment.

Optimal postharvest life of cut flowers is often improved by use of suitable vase solutions (Halevy and Mayak, 1979, 1981). Addition of sucrose to the vase solution often improves the postharvest quality of flowers by promoting the opening of immature buds, reducing petal sensitivity to ethylene, and delaying senescence of open flowers (Halevy and Mayak, 1979; Mayak and Dilley, 1976). The effects are most evident on flowers harvested at the bud stage (Halevy and Mayak, 1979) or on cut stems with numerous buds at various developmental stages, such as *Gladiolus*

xhortulanus L., *Gypsophila paniculata* L., *Dianthus caryophyllus* L., and *Liatis spicata* (L.) Willd. (Borochov and Mayak, 1984; Downs et al., 1988; Han, 1992; Kofranek and Halevy, 1976). The role of ethylene in flower senescence varies greatly depending on plant species. For sensitive species, ethylene-induced senescence and abscission of flowers may result from endogenous production of ethylene or from exposure to exogenous ethylene (Halevy and Mayak, 1979). Silver thiosulfate (Veen and van de Geijn, 1978) and 1-methylcyclopropene (Serek et al., 1995) can be applied to cut flowers to counteract the effects of ethylene. This study investigated how sucrose in the vase solution affects bud development and vase life of coral bells and the role of ethylene in the senescence of the flower buds.

Materials and Methods

Plant material. *Heuchera sanguinea* ‘Bressingham’ and ‘Splendens’ were grown from seed and produced in 1.4-L (15-cm-diameter) pots. Plants were grown in glass-houses at the Univ. of Massachusetts, Amherst, (lat. 42°22.5’N) at 21 °C day/18 °C night temperatures under natural daylength. Air temperatures were recorded by a datalogger (LI-1000; LI-COR, Lincoln, Neb.) equipped with a thermistor (LI-1000-16). Plants were fertilized with 20N–4.3P–16.6K using N at 200 mg·L⁻¹.

Mature plants (at least 10 months after sowing) were placed at 2 ± 0.6 °C and illuminated continuously for 10 to 12 weeks with a photosynthetically photon flux (PPF) of 8 μmol·m⁻²·s⁻¹ from fluorescent lights. Following the vernalization treatment, plants were forced under natural daylength in the glass-

house under conditions described above. Unless otherwise stated, the developmental stages of the inflorescences at harvest ranged from one open flower per inflorescence to one open flower per lateral raceme on the inflorescences (≈2% to 3% open flowers per inflorescence). The average number of flower buds per inflorescence was 57 ± 16 and 86 ± 16 for ‘Bressingham’ and ‘Splendens’, respectively. Inflorescences used in the sucrose concentration studies were harvested between May and July, whereas those used in other experiments were harvested between December and February. Unless otherwise stated, postharvest studies were conducted in a 22 °C room illuminated for 12 per day with a PPF of 11.1 μmol·m⁻²·s⁻¹ from a cool-white fluorescent lamp. Inflorescences were examined daily and the vase life of each inflorescence was considered terminated when the number of senescing flowers exceeded that of the open flowers.

Sucrose concentrations. In a preliminary experiment, cut inflorescences of ‘Bressingham’ and ‘Splendens’ were placed individually with their bases in solutions containing 0%, 2.5%, or 5% sucrose, with six replicates per treatment. All solutions contained 200 mg·L⁻¹ of 8-hydroxyquinoline citrate (8-HQC) to prevent the growth of microorganisms. In a subsequent experiment with six replications, lower concentrations of sucrose, i.e., 0%, 0.5%, and 1%, were tested. The vase life of each inflorescence and the percentage of buds (estimated at 10% increments) that had fully opened by the end of the experiment were determined.

Silver thiosulfate (STS) treatments. In one experiment, eight replicate inflorescences of ‘Bressingham’ were pulsed with 4 mM of STS for 0 (control), 4, 8, or 24 h in a 20 °C chamber illuminated for 12 h per day with 12 ± 2 μmol·m⁻²·s⁻¹ PPF from cool-white fluorescent lamps. Following the STS treatment, stems were rinsed with water and then placed individually in test tubes containing deionized water. In a second experiment, the bases of inflorescences of ‘Bressingham’ (12 replications) and ‘Splendens’ (eight replications) with 5% to 10% open flowers were held in deionized water or 4 mM STS for 4 h. Inflorescences were then placed in solutions containing 0.5% sucrose and 200 mg·L⁻¹ of 8-HQC. The percentages of flower and bud abscission and the vase life of each inflorescence were determined.

Ethylene (C₂H₄) treatments. The bases of inflorescences of ‘Bressingham’ with ≈50% open buds were placed in solutions containing 0.5% sucrose and 200 mg·L⁻¹ 8-HQC. Stems were then placed in 30-L tanks and treated for 24 h in a flow-through system at the rate of 35 L·h⁻¹ with either ethylene-free air or air containing ethylene at 1.2 μL·L⁻¹. The tanks were in a 20 ± 1 °C chamber illuminated for 12 h per day with 17 ± 3 μmol·m⁻²·s⁻¹ PPF provided by cool-white fluorescent lamps. The percentages of flower and bud abscission during and after the ethylene treatment were recorded. The experiment was terminated at day 4 when the vase life of the C₂H₄-treated inflorescences ended.

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C_2H_4 and STS. Inflorescences of 'Bressingham' and 'Splendens' were pulsed with 4 mM STS for 4 h or with deionized water before being exposed for 48 h to ethylene-free air or air containing ethylene at $0.5 \mu L \cdot L^{-1}$ for 48 h. Inflorescences were then placed in solutions containing 0.5% sucrose and $200 \text{ mg} \cdot L^{-1}$ of 8-HQC. The vase life of each inflorescence and the percentages of flower and bud abscission were determined.

Statistical analysis. Data were analyzed with the SAS General Linear Model procedure (SAS Institute, 1990). Percent data were transformed ($\arcsin \sqrt{\%}$) prior to analysis. Differences among treatments were analyzed further with regression and Duncan's multiple range test.

Results and Discussion

Cut coral bells had a vase life of only about 6 d when held in water (Table 1), mainly due to failure of buds to open and to rapid abscission of open flowers. The limited carbohydrate supply in the leafless, slender scapes, together with the many undeveloped buds in the inflorescences, may have resulted in a

large number of unopened as well as faded buds. As in the case of many other flowers (Halevy and Mayak, 1979), continuous development of immature buds of coral bells probably requires an external supply of carbohydrates, since the vase life was significantly improved when placed in sucrose solutions (Table 1). However, a preliminary experiment showed that concentrations of sucrose higher than 1% resulted in collapse of the stem. The percentage of stems that collapsed was 0%, 30%, and 75% for solutions containing 0%, 2.5%, and 5% sucrose, respectively. Negative effects of high concentrations of sucrose on postharvest quality of cut flowers have also been reported for other species (Kofranek, 1985). Vase life of 'Splendens' inflorescences almost doubled in solutions containing 0.5% or 1% sucrose (Table 1). Furthermore, >92% of the flower buds opened fully as compared with the 28% that opened only partially in the controls. Inflorescences of 'Bressingham' also benefited from the sucrose treatment, though to a lesser extent. Regardless of cultivar, solutions containing 0.5% or 1% sucrose significantly increased the vase life as well as the percentage of buds that opened fully.

The large amount of abscission observed on the control (water-treated) inflorescences suggested that ethylene might be involved in the abscission and that pretreatment with STS might improve the postharvest quality of the stems. In fact, treatment with 4 mM STS prevented abscission of nearly all flowers and buds. Prolonged treatment, however, resulted in phytotoxicity expressed as petal desiccation. The percentages of buds with phytotoxic symptoms were 0, 6.5, 45.8, and 100 for inflorescences treated with 4 mM STS for 0, 4, 8, and 24 h, respectively, increasing linearly and quadratically with treatment time.

In gladiolus, STS treatment alone improves the postharvest quality of the spikes by stimulating the opening of immature buds that would otherwise abort due to carbohydrate depletion (Serek et al., 1994). Although STS reduced abscission in coral bells, it did not increase opening of immature buds (data not shown) nor did it improve the postharvest quality. Addition of 0.5% sucrose to the vase solution of inflorescences pretreated with STS for 4 h,

however, significantly extended their vase life of the inflorescences (Table 2) by increasing the opening of flower buds (Table 2).

To determine if coral bells are sensitive to exogenous ethylene, inflorescences of 'Bressingham' were exposed to $1.2 \mu L \cdot L^{-1}$ of ethylene for 1 d. Forty percent of the buds (Fig. 1) and nearly all of the open flowers (data not shown) abscised during the ethylene treatment. Abscission ceased upon termination of the treatment, suggesting that exogenous ethylene did not induce autocatalytic ethylene production as reported in many senescing plant organs (Salisbury and Ross, 1985). The flower abscission that occurred during ethylene treatment was greatly reduced by pretreatment with 4 mM STS for 4 h (Table 3). The vase life of inflorescences of both cultivars pulsed with STS for 4 h was significantly longer than that of those not treated with STS, and did not differ from that of those pretreated and then exposed to exogenous ethylene, suggesting that STS pretreatment completely counteracted the damaging effects of ethylene.

Two sets of abscission data (Table 3), demonstrate the differences in the timing of abscission between treatments. Abscission was determined 1) at day 4 for 'Splendens' and at day 5 for 'Bressingham', when the vase life of the C_2H_4 -treated inflorescences ended, and again 2) when the vase life of each inflorescence ended. The former demonstrated the rapid abscission of flowers and buds from the ethylene treatment, as reported in Fig. 1. At day 4 and 5, significantly fewer flowers and buds had abscised on inflorescences not treated with C_2H_4 . On the other hand, the percentage abscission of control inflorescences, when their vase life ended, was higher than that of those treated with C_2H_4 (Table 3). The higher abscission rate of the controls, however, did not indicate a lower postharvest quality, because their flower buds developed to anthesis before they abscised and prior to the termination of vase life. In comparison, buds in the C_2H_4 -treated inflorescences did not reach anthesis and abscised within 4 to 5 d after harvest. Buds on inflorescences pulsed with STS also continued to develop and open in the postharvest environment, but the open flowers remained on the stems longer than did control flowers,

Table 1. Effects of sucrose in the vase solutions on bud opening and vase life of two cultivars of cut *Heuchera sanguinea* Engelm. All vase solutions contained $200 \text{ mg} \cdot L^{-1}$ 8-HQC. The experiment was conducted in a simulated interior environment. Vase life of each inflorescence was considered terminated when the number of senesced flowers exceeded that of open flowers.

Cultivar	Sucrose concn (%)	Vase life ^a (d)	Bud opening (%)
Splendens	0 (control)	6.3 b	28.3 b
	0.5	12.2 a	97.0 a
	1.0	12.0 a	92.0 a
Bressingham	0	6.6 b	26.0 c
	0.5	9.3 a	98.8 a
	1.0	11.0 a	75.0 b

^aMean separation within columns and cultivars by Duncan's multiple range test, $P \leq 0.05$.

Table 2. Effects of STS pretreatment on the vase life and flower abscission of *Heuchera sanguinea* Engelm. 'Splendens' and 'Bressingham'. Inflorescences were treated with water or 4 mM STS for 4 h immediately after harvest and then placed in vase solutions containing 0.5% sucrose and $200 \text{ mg} \cdot L^{-1}$ of 8-hydroxyquinoline citrate. The experiment was conducted in a simulated interior environment and the vase life of each inflorescence was considered terminated when the number of senesced flowers exceeded that of open flowers.

Cultivar	Pre-treatment	Vase life ^a (d)	Abscission ^b (%)
Splendens	Water	8.1 b	76.5 a
	STS	16.4 a	15.0 b
Bressingham	Water	6.6 b	55.2 a
	STS	8.8 a	7.2 b

^aData were collected on the day when the vase life of each inflorescence ended.

^bMean separation within columns and cultivars by Duncan's multiple range test, $P \leq 0.05$.

Table 3. Effects of STS pretreatment and exogenous ethylene on the vase life and bud abscission of *Heuchera sanguinea* Engelm. Inflorescences were treated with deionized water or with 4 mM STS for 4 h, placed in vase solutions containing 0.5% sucrose and $200 \text{ mg} \cdot L^{-1}$ of 8-hydroxyquinoline citrate, and then treated with air or air containing $0.5 \mu L \cdot L^{-1}$ ethylene for 2 d. The experiment was conducted in a simulated interior environment and the vase life of each inflorescence was considered terminated when the number of senesced flowers exceeded that of the open flowers.

Cultivar	Treatment	Vase life ^a (d)	Abscission (%) at the end of the vase life of: ^b	
			C_2H_4 -treated inflorescence ^c	Each inflorescence
Splendens	Control	8.1 b	15.5 b	76.5 a
	STS	16.4 a	0.8 c	15.0 d
	C_2H_4	4.0 c	59.3 a	59.3 b
	STS+ C_2H_4	16.3 a	2.9 c	25.5 c
	STS	6.6 b	1.6 b	55.2 a
Bressingham	Control	6.6 b	1.6 b	55.2 a
	STS	8.8 a	0.2 b	7.2 c
	C_2H_4	5.2 c	32.9 a	32.9 b
	STS+ C_2H_4	9.3 a	1.4 b	4.5 c
	STS	8.8 a	0.2 b	7.2 c

^aVase life ended when the number of senesced flowers exceeded that of the open flowers.

^bMean separation within columns and cultivars by Duncan's multiple range test, $P \leq 0.05$.

^cFlower and bud abscission data collected on day 4 for 'Splendens' and day 5 for 'Bressingham'.

Fig. 1. Flower and bud abscission of *Heuchera sanguinea* Engelm. 'Bressingham' inflorescences placed in 0.5% sucrose and 200 mg·L⁻¹ 8-HQC and treated with air (○) or with 1.2 μL·L⁻¹ ethylene (●) for 24 h. Inflorescences were then placed in a 22 °C room illuminated with 11.1 μmol·m⁻²·s⁻¹ from cool-white fluorescent lamps. Data are means ± standard errors.

thus accounting for the longer vase life. Unlike inflorescences not treated with STS, where the termination of the vase life was associated with a high abscission rate of flowers and buds, open flowers on the STS-treated inflorescences eventually wilted and became desiccated, but remained attached. Although the production of endogenous ethylene from inflorescences was not determined, ethylene is presumably involved in the natural senescence of coral bells flowers since STS pretreatment significantly delayed the abscission of the open

flowers. The effects of STS varied for the two cultivars, being more effective on 'Splendens' than on 'Bressingham' (Tables 2 and 3).

In conclusion, cut inflorescences of coral bells can be used as filler flowers in floral arrangements when treated properly after harvest. Inflorescences of 'Splendens' and 'Bressingham' had a vase life of 16 and 9 d, respectively, and a low abscission rate if pulsed with 4 mM STS for 4 h and placed in vase solutions containing 0.5% sucrose and 200 mg·L⁻¹ 8-HQC.

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