

light cropping. AR treatments of 100 gal/acre had salable yields that were equivalent to that of normal hand thinning, with substantially reduced hand-thinning times. Return bloom in 1996 was improved 11% to 23% by reduced cropping due to bloom thinning but was not statistically different from controls.

There were no treatment effects on fruit set in 1996, although set by canopy location was different (Table 2). When the 200-gal/acre carrier volume, common to California cling peach growers' management practices, was used with 1% AR in 1996, fruit set was not reduced below acceptable levels, unlike in 1995 when 3% AR at 200 gal/acre resulted in overthinning. Treatment 1 (3% AR, 100 gal/acre) resulted in 25% fewer fruits thinned per half tree compared to the control (Table 2). There was no significant difference among treatments with regard to fruit diameter at thinning or harvest in 1996 (Table 2). Fruit mass at thinning and harvest in 1996 was improved by AR treatment at 3% (100 gal/acre) compared to the control, but not by the 1% AR treatment. Total yields were not different among treatments in 1996 (data not shown). An increase in salable yield (total yield – undersized, unsalable fruit) was found in 1996, with Treatment 2 (1% AR, 200 gal/acre) significantly increasing salable yield compared to that of the control.

Bloom thinning substantially reduced fruit set in 1 out of 2 years, thereby reducing hand thinning. For AR to be effective, buds must have broken and flowers must be at an advanced stage of anthesis, with the greatest effectiveness achieved when a maximum number of flowers are at the same advanced bloom stage (Byers and Lyons, 1982). Under typical California climatic conditions at bloom, fruit set tends to be very heavy in cling peaches pruned to produce for the canning industry, and a well-managed bloom thinner would not tend to overthin. Lack of fruit clustering and lower return bloom in 1996 did not allow the same thinning strategy as was used in 1995. Clustering in most years contributes greatly to the perceived need-to-thin in cling peaches, and AR bloom thinning in 1995 should be

more representative of expected results in normal-chill years by California standards. Under climatic conditions such as very low chill hour accumulation, use of AR may not be desirable. However, a single application of 3% AR at 100 gal/acre with commercial equipment at 50% to 60% full bloom will work in most years and not overthin in low-chill and long-bloom years. At higher volumes (200 gal/acre) lower concentrations of AR per acre should be used.

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Evaluation of ethylene inhibitors for postharvest treatment of *Gypsophila paniculata* L.

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ADDITIONAL INDEX WORDS. silver thiosulfate, STS, flower opening, flower senescence, 1-methylcyclopropene, baby's breath

SUMMARY. Commercial floral products with claimed anti-ethylene effects were evaluated for their efficacy in promoting postharvest longevity of gypsophila ('Perfecta', 'Gilboa', and 'Golan' baby's breath, *Gypsophila paniculata* L.). These products were applied according to label directions and compared to a laboratory preparation of silver thiosulfate (STS) prepared as a short pulse treatment and as an overnight treatment; they were also compared to the new anti-ethylene gas, 1-methylcyclopropene (1-MCP). After these pretreatments, the flowers were exposed to ambient air or to 0.7 ppm ethylene gas for 36 hours; other flowers received a simulated shipping treatment. Products containing adequate concentrations of silver consistently extended the display life of gypsophila. Products with low concentrations of silver (<10 ppm) or containing aminoethoxyvinylglycine (AVG)

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offered no more protection than treatments without anti-ethylene compounds. Overnight treatments with STS were as effective as short pulse treatments. Although 1-MCP pretreatment helped prevent the effects of ethylene on flowers that were open at the time of pretreatment, it provided no protection for buds that opened subsequently. There were no marked differences in ethylene sensitivity among three *gypsophila* cultivars.

G*ypsophila* is an important floral crop used as a filler flower in fresh and dried arrangements. According to suppliers, its popularity has declined as more durable filler flowers have been introduced. The relatively poor vase life of fresh *gypsophila* is due to improper postharvest handling. Early senescence is known to be related to ethylene exposure and endogenous ethylene production (van Doorn and Reid, 1992). These researchers found that an individual flower longevity of 16.5 d could be obtained by pretreating with the anionic silver thiosulfate (STS) complex (4 mmol·L⁻¹ for 30 min) and then holding the flowers in a solution containing 200 ppm Phisan (a proprietary quaternary ammonium compound) plus 15 g·L⁻¹ sucrose.

The use of STS to overcome problems associated with exposure to ethylene gas was demonstrated nearly 2 decades ago (Veen and van de Geijn, 1978). Various commercial products containing STS or other complexed forms of silver have since been introduced, such as Silflor (Floralife Inc., Burr Ridge, Ill.), but these products have not been widely used by United States flower growers. Two major reasons are proposed for this: 1) concern that STS products may eventually be unavailable for floricultural use (as in Holland, where the products are restricted on potted plants and cut carnations because of the environmental effects of heavy metals) or that there may be increased regulations regarding product disposal, and 2) the two-step process is usually recommended (consisting of pulsing the flowers in the product for a specific period, then moving the flowers to a sucrose-containing vase solution) can be cumbersome to manage when treating many buckets of flowers during the day,

because the STS pulse period must be carefully timed to ensure efficacy and yet avoid phytotoxicity.

Rogard RS-System (Gard/Rogard, Inc., Alonquin, Ill.) and Florish (Smithers-Oasis, Kent, Ohio) are two commercial anti-ethylene products used in the United States introduced with the aim of eliminating one or both of these problems. Rogard RS is a combination of a floral preservative and a low concentration of a silver complex. The manufacturer states that the product can be safely used as a continuous treatment, eliminating the two-step process: other ingredients in the product make the low silver concentration more effective and more easily taken up by the flowers. It is also claimed that the product can be disposed legally anywhere in the United States without using special silver recovery systems.

Florish contains analogs of aminoethoxyvinylglycine (AVG) (Staby et al., 1993); this compound inhibits ethylene biosynthesis in plant tissues (Yang and Hoffman, 1984). Although the Dutch flower auctions have approved a product containing an ethylene biosynthesis inhibitor as an alternative to STS for treating standard and miniature carnations (Nell, 1992), previous research has indicated that ethylene biosynthesis inhibitors do not protect flowers from the effects of exposure to exogenous ethylene (Fujino et al., 1981; Serek and Reid, 1993; Staby et al., 1993).

Researchers have continued to seek effective alternatives to STS to use on ethylene-sensitive floral crops. One exciting new approach is the use of a gaseous binding-site competitor, 1-methylcyclopropene (1-MCP), which appears to give ethylene protection equivalent to that obtained from STS (Serek et al., 1994). This material is presently being registered for use on cut flowers and other horticultural crops (G.L. Staby, personal communication). Another approach is to seek germplasm that is resistant to the senescence-inducing effect of ethylene (Wu et al., 1991).

The objective of our study was to compare the efficacy and practicality of various commercial and experimental products with claimed anti-ethylene properties in extending the life of *gypsophila* inflorescences. In addition, the sensitivity to ethylene of some common *gypsophila* cultivars was examined.

Materials and methods

EVALUATION OF COMMERCIAL FLORAL PRESERVATIVES AND 1-MCP. Three experiments were conducted to evaluate ethylene inhibitors. Fresh samples of commercial products with claimed anti-ethylene properties were obtained from suppliers or cooperating growers and used to pretreat freshly harvested commercial bunches of 'Perfecta' *gypsophila*. These products were compared to laboratory preparations containing 1 or 4 mmol·L⁻¹ STS, applied, respectively, as an overnight pretreatment or as a 1-h pulse (Reid et al., 1980); in one experiment these commercial products were also compared to 200 ppb 1-MCP (Serek et al., 1994).

These pretreatments were evaluated in several ways that provide an indication of their commercial effectiveness: 1) floral vase-life was evaluated in air directly after the pretreatment, 2) vase life was evaluated after flowers were packed in commercial boxes for 2 d at ambient temperature to simulate high-stress transport conditions, and 3) vase life was evaluated after ethylene exposure.

The first experiment was conducted in a packing house in Saticoy, Calif., in 1993. Rogard RS and Silflor were prepared according to manufacturers' recommendations and compared to 4 mmol·L⁻¹ STS and to two control treatments, a sucrose-containing floral preservative without silver (Rogard Gold Sustaining Solution) and distilled water. Twenty-five uniformly-sized *gypsophila* flower stems (five per treatment) were randomly selected and assigned to treatments. Flower stems pretreated with Silflor and STS were pulsed for 1 h at 18 °C before overnight refrigeration at 2 to 4 °C; all other treatments were pulsed for 24 h in the refrigerator. Following these pretreatments, flowers were placed in vases containing the commercial floral preservative, and were held in air for 12 d.

The second experiment was later conducted at the Univ. of California, Davis, in 1993. The objective of this experiment was to evaluate the efficacy of pretreatments when flowers were exposed to endogenous ethylene in shipping boxes. The procedure was similar to that used in the first experiment except that, after treatment and overnight refrigeration, the flowers were packed into boxes with other bunches of *gypsophila* flowers. They

were kept in the boxes at 20 °C for 2 d to simulate shipping before being placed in a vase solution containing Physan-sucrose, where they were held in air for 14 d. In this experiment, Chrysal AVB (Pokon & Chrysal USA, Miami, Fla.) was an additional commercial product that we evaluated. All commercial products were applied as long-term pulse treatments for 24 h at 2 °C; we evaluated STS as a short pulse and as an overnight treatment.

The objective of the third experiment, conducted at the Univ. of California, Davis, in 1996, was to evaluate the effect of pretreatments after exposure to ethylene gas. Florish and 1-MCP were additional pretreatments we evaluated; all products were applied as overnight pulses at 2 °C.

Sprigs containing ≈ 100 flowers plus buds were excised, placed in tubes containing Physan-sucrose solutions, and exposed to one of the following treatments:

- 1) an early exposure treatment where flowers were exposed to ethylene gas after the initial pretreatments with the anti-ethylene products,
- 2) a late exposure treatment where flowers were pretreated and then held for 8 d in Physan-sucrose solutions at 20 °C before treatment with ethylene, and
- 3) an untreated control where pretreated flowers remained in ambient air (<5 ppb ethylene).

Flowers were treated with ethylene by placing them in a sealed 25-L tank ventilated (40 to 60 L·h⁻¹) with a flowing air stream containing 0.7 ppm ethylene at 20 °C. After 36 h, they were removed from the tank for evaluation of quality and vase life in ambient air.

SILVER ANALYSES. The soluble silver content of pretreatment solutions was determined at the Univ. of California, Davis, in 1993 and 1996 by standard methods (Varian Techtron, 1972).

CULTIVAR SENSITIVITY. The ethylene sensitivity of 'Perfecta', 'Gilboa', and 'Golan' gypsophila was evaluated by exposing replicate sprigs from each cultivar to ambient air (<5 ppb ethylene), 0.2, 0.8, and 15 ppm ethylene for 72 h at 20 °C in an experiment conducted at the Univ. of California, Davis, in 1996.

FLOWER QUALITY. In all experiments, flower quality was evaluated by

determining the number of open flowers, buds, and dead flowers on a selected flowering unit on each stem in the vases or tubes. In the cultivar sensitivity experiment, fresh weights of five live flowers from each stem were also obtained. Data were analyzed using analysis of variance (ANOVA) and means separated using Duncan's multiple range test (MSTAT, Michigan State Univ.). Regression analysis was used for determining the relationship between the logarithm of the ethylene concentration and the quality of flowers from the three tested cultivars.

Results

SILVER CONTENT OF PRETREATMENT SOLUTIONS. The silver content of the pretreatment solutions varied widely; the amounts found in commercial product samples used in 1996 were less than those found in samples used in 1993 (Table 1). Analysis was not conducted on Florish, as this product does not contain silver.

EVALUATION IN AIR. When the flowers were held in air for 12 d after pretreatment, those pretreated with Silflor or STS were better than those

Table 1. Analysis of the silver content of commercial ethylene inhibitors and laboratory preparations of STS from experiments conducted in 1993 and 1996.

Product	Recommended time in solution	Ag ⁺ in solution (ppm)	
		1993	1996
Chrysal AVB	2–72 h	23	0
Rogard RS	Continuous	7	2
Silflor	1–2 h	115	100
STS 1 mmol·L ⁻¹	16–24 h	91	107
STS 4 mmol·L ⁻¹	0.5–1 h	419	404

Table 2. The effect of pretreatments on the flower condition of 'Perfecta' gypsophila after air exposure. Flowers were treated according to the manufacturers' recommendations; the 4-mmol·L⁻¹ STS treatment was for 1 h. After pretreatment for 24 h, the flowers were placed in a floral preservative (Rogard Sustaining Solution) and held for 12 d in ethylene-free air.

Treatment	Open, live flowers (%)	Dead flowers (%)
Silflor	44.0 a ^z	6.1 a
STS 4 mmol·L ⁻¹	37.6 a	6.9 a
Rogard RS	29.3 b	18.0 b
Rogard Sustaining Solution	27.0 b	18.6 b
Distilled water	11.6 c	33.9 c

^zMean separation within columns by Duncan's multiple range test, $P=0.05$. Each value is the mean of five observations.

Table 3. The effect of recommended pretreatment on the flower condition of 'Perfecta' gypsophila after simulated shipping. Flowers were treated according to the manufacturer's recommendations; the 4-mmol·L⁻¹ STS treatment was for 1 h, the 1-mmol·L⁻¹ treatment was overnight. After pretreatment, the flowers were packed in shipping boxes and held at 18 °C for 2 d before being placed in a vase solution containing 200 ppm Physan plus 15 g·L⁻¹ sucrose. Flowers were evaluated 14 d later.

Treatment	Open, live flowers (%)	Dead flowers (%)
Chrysal AVB	86.6 a	6.0 a
STS 4 mmol·L ⁻¹	70.0 ab	23.2 ab
Silflor	60.7 bc	23.7 ab
STS 1 mmol·L ⁻¹	53.7 bc	42.8 bcd
Rogard RS	21.3 dc	63.0 d
Physan-sucrose	12.1 e	55.1 cd

^zMean separation within columns by Duncan's multiple range test, $P=0.05$. Each value is the mean of five observations 16 d after treatment.

given other pretreatments, with a greater proportion of open, live flowers and a lower proportion of dead flowers (Table 2). Flowers pretreated with Rogard RS were no better than those pretreated with a floral preservative containing no silver (Rogard Gold Sustaining Solution), although they were better than those pretreated with distilled water.

EFFECTS OF SIMULATED TRANSPORT.

Under simulated transport conditions, Rogard RS was not as effective overall as Silflor or Chrysal (Table 3). There were no differences between short- and long-term STS treatments.

EFFECTS OF ETHYLENE EXPOSURE.

Because there was significant three-way interaction between all test variables (anti-ethylene treatments, ethylene exposure treatments, and evaluation date) indicating that all factors affected the experiment, we examined the results of early and delayed ethylene exposure treatments during two intervals to interpret the results. When flowers were exposed to ethylene immediately after pretreatment, the proportion of live flowers 1 week after ethylene initiation was relatively high

in those flowers pretreated with 1-MCP or with the high silver-containing solutions, STS and Silflor (Fig. 1). After 2 weeks, the proportion of live flowers in stems that had been pretreated with solutions containing high silver concentrations remained high; other pretreatments, including 1-MCP, did not provide any long-lasting benefit, even for flowers that were not initially exposed to ethylene (Fig. 2).

Delayed exposure to ethylene of flowers that had been pulsed with different pretreatments had a marked effect on the percent open flowers 1 week later (Fig. 3). Flowers that had been pretreated with STS or Silflor were only marginally affected by the ethylene exposure; the quality of the other flowers, including those pretreated with 1-MCP, was dramatically reduced, even in the air controls.

CULTIVAR SENSITIVITY. There was significant (<0.01) linear reduction in percent open, live flowers with logarithmic increase in ethylene concentration for 'Gilboa' and 'Golan' (Fig. 4); similar linear relationships were shown for fresh weight of the open flowers (data not shown). All three

cultivars were sensitive to ethylene, although comparisons of the slopes of the significant regression lines showed no differences between cultivars. Control inflorescences of 'Gilboa' lasted 20 d in the vase, whereas the vase life of control 'Perfecta' inflorescences of similar quality was 16 d.

Discussion

In carnations, the effects of ethylene are inhibited when a flower has taken up enough STS to provide 1 μmol of silver. The amount of STS taken up depends on the hydric status of the flower, the temperature at which the flower is treated, and the concentration of STS in the treatment solution (Reid, 1992). Rogard RS was ineffective in our experiments, presumably because it contains such low levels of silver (≤ 7 ppm); flowers would have to be pulsed in this product over an extended period of time to obtain sufficient silver to achieve the results obtained with a standard 4 $\text{mmol}\cdot\text{L}^{-1}$ STS solution containing >400 ppm silver. Assuming a constant rate of solution uptake, it would require a treatment of >57 h with a 7-ppm

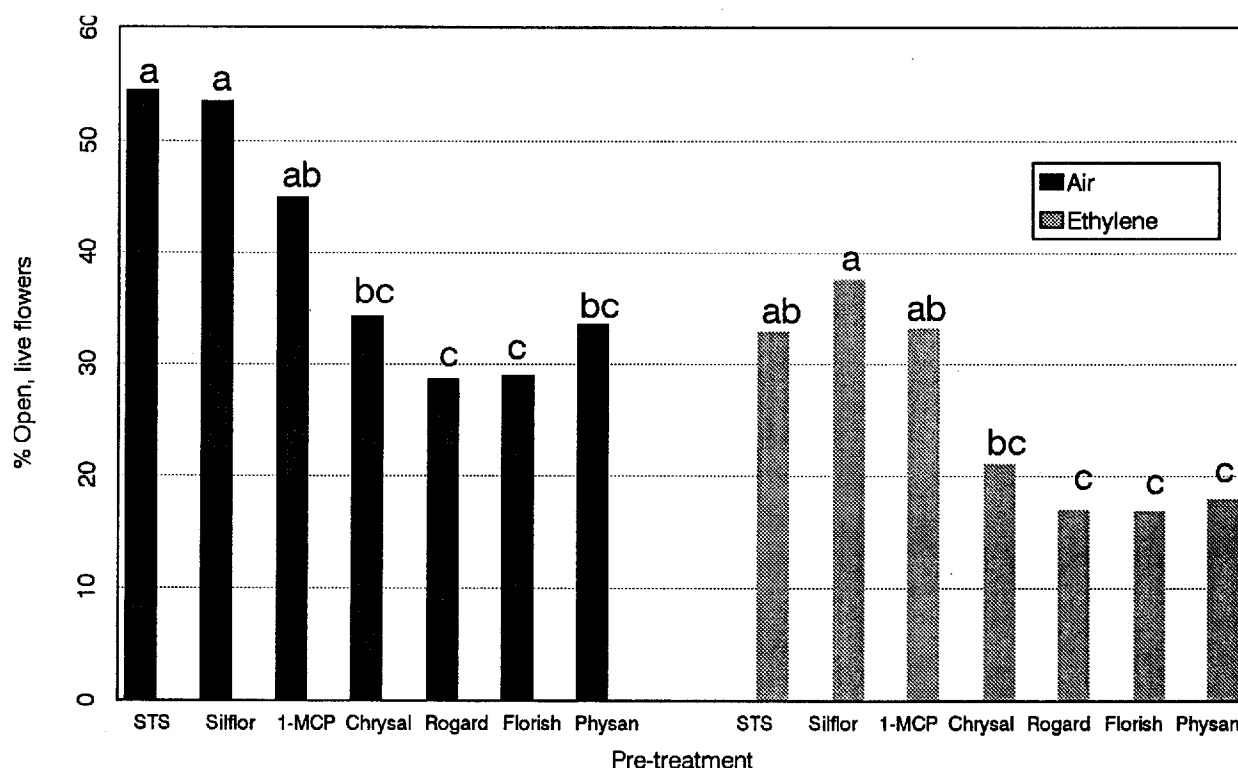


Fig. 1. The effect of various pretreatments and an early ethylene exposure on flower longevity of gypsophila 'Gilboa' after 8 d. After pretreatment for 24 h, the inflorescences were exposed to 0.7 ppm ethylene for 36 h at 20 °C; they were then placed in Physan-sucrose solutions in vase life conditions for 5 d. The percentage of open, live flowers was determined 8 d after the initiation of the experiment. Each value is the mean of seven observations; means with the same letter are not different by Duncan's multiple range test, $P = 0.01$.

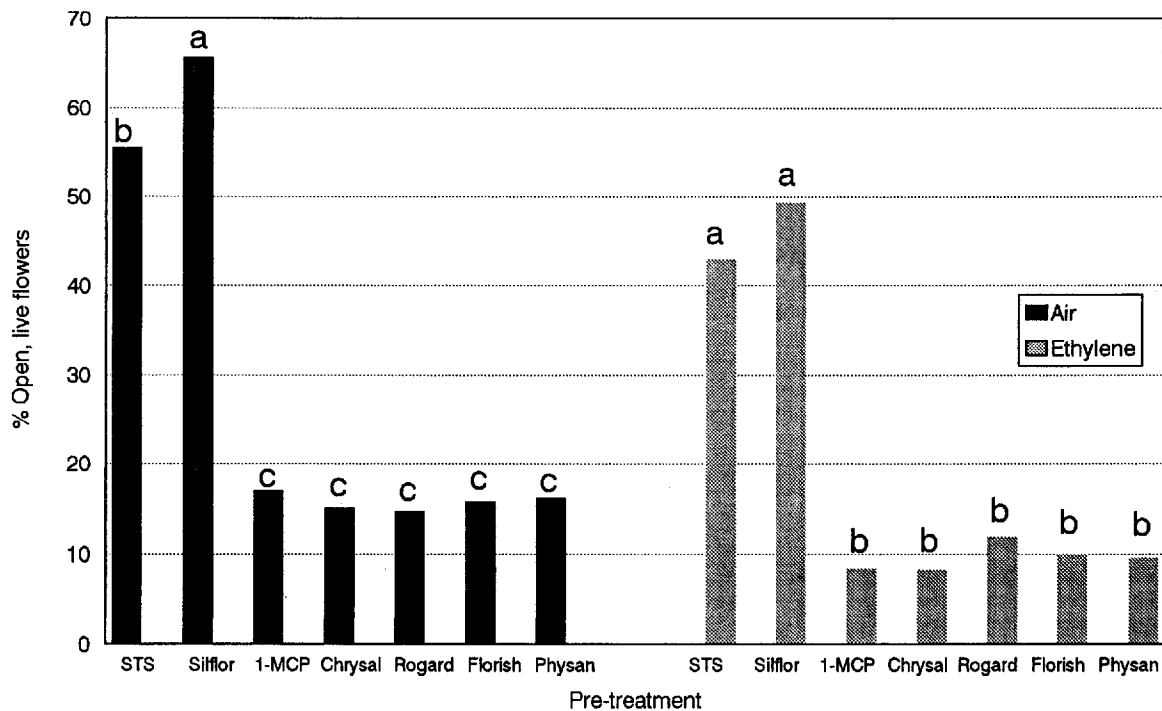


Fig. 2. The effect of various pretreatments and an early ethylene exposure on flower longevity of gypsophila 'Gilboa' after 16 d. After pretreatment for 24 h, the inflorescences were exposed to 0.7 ppm ethylene for 36 h at 20 °C; they were then placed in Physan-sucrose solutions for vase life conditions for 13 d. The percentage of open, live flowers was determined 16 d after the initiation of the experiment. Each value is the mean of seven observations; means with the same letter are not different by Duncan's multiple range test, $P = 0.01$.

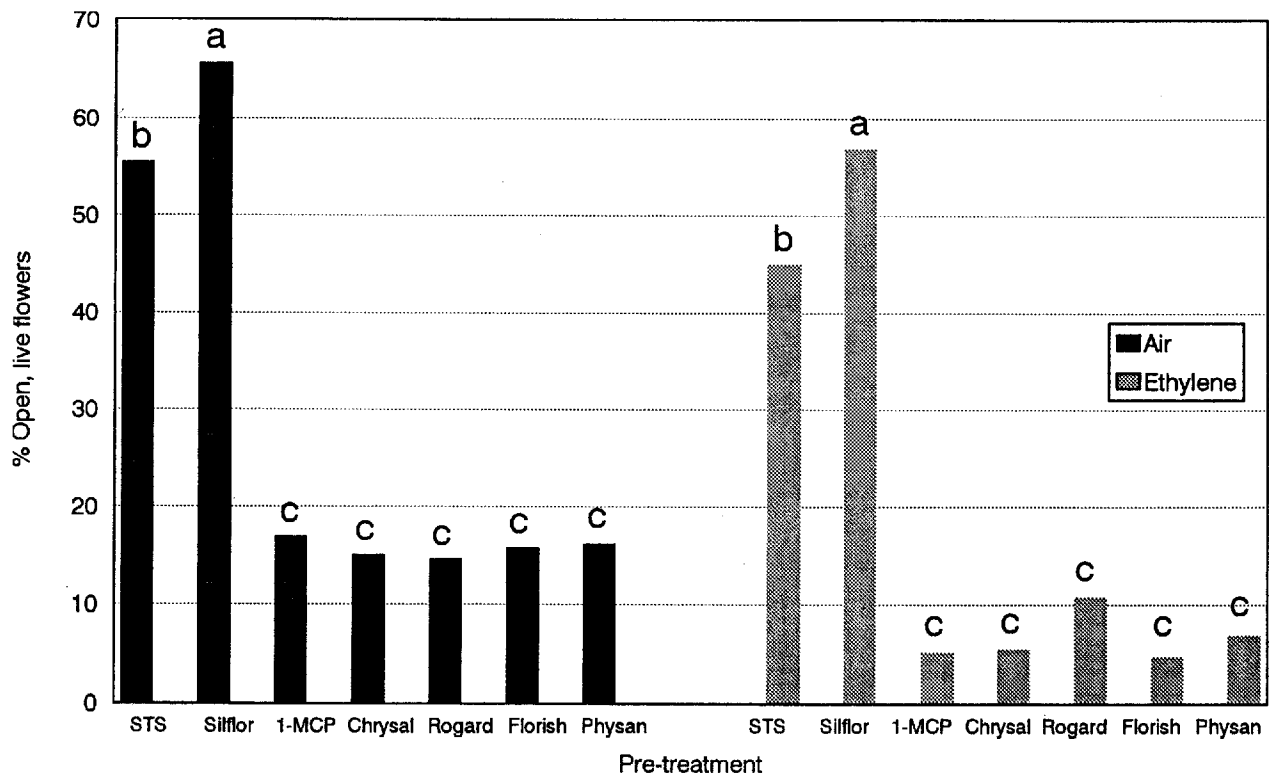


Fig. 3. The effect of various pretreatments and a delayed ethylene exposure on flower longevity of gypsophila 'Gilboa' after 16 d. After pretreatment for 24 h, the inflorescences were placed in Physan-sucrose solutions and held for 8 d in vase life conditions. They were then exposed to 0.7 ppm ethylene for 36 h at 20 °C and returned to vase life conditions for 5 d before determination of the percentage of open, live flowers 16 d after the initiation of the experiment. Each value is the mean of seven observations; means with the same letter are not different by Duncan's multiple range test, $P = 0.01$.

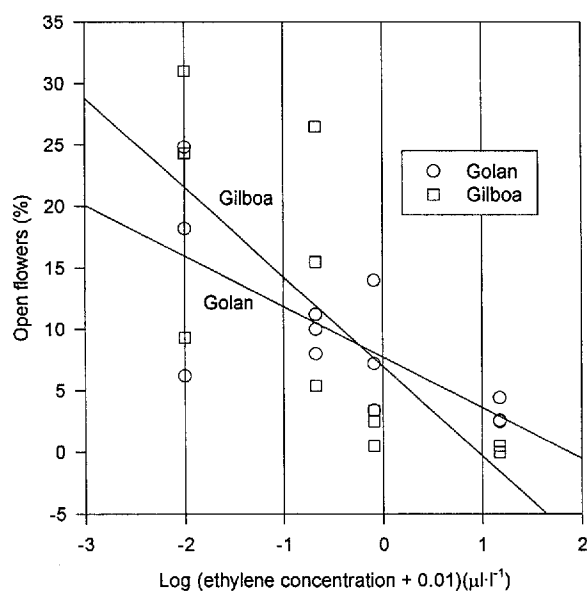


Fig. 4. Effect of ethylene concentration on quality of gypsophila inflorescences. Flowers of three cultivars were treated for 72 h with different concentrations of ethylene and then returned to air (three replications/treatment). Quality was determined 4 d later as percent open, live flowers. The significant ($P < 0.01$) regressions are presented. Equations: 'Golan,' $Y = 7.735 - 4.119X$ ($r^2 = 0.520$); 'Gilboa,' $Y = 7.008 - 7.282X$ ($r^2 = 0.573$).

Rogard RS solution to provide equivalent protection to that achieved using a 1-h pulse with 4 mmol·L⁻¹ STS; a 2 ppm Rogard solution would require 200 h. Moreover, while spent (waste) solutions of Rogard RS may be below the EPA accepted level of 5 ppm, some local sanitary districts in major floriculture production areas have a much lower tolerance level for silver in spent solutions.

Chrysal AVB was the most effective commercial anti-ethylene product evaluated in an experiment conducted in 1993 when our analysis showed it contained 23 ppm silver. In the 1996 experiment, however, we found no silver in the product, and it was not effective in protecting flowers from ethylene exposure.

Our research supports other studies that have shown that AVG analogs (e.g., Florish) do not protect sensitive flowers against exogenous ethylene. In gypsophila, even when flowers were not exposed to ethylene, Florish did no better than Physan, suggesting no

improvement in protection against endogenous ethylene. Staby et al. (1993) reported similar results even when flowers remained in Florish solutions during the experiment.

The most interesting aspect of our study was the relatively poor performance of 1-MCP. Although open flowers pretreated with this material were somewhat protected from ethylene action (Fig. 1), it was less effective than STS and Sillflor in extending the life of air control flowers or of flowers that had been exposed to ethylene after opening in the vase.

The gypsophila inflorescence bears a large number of flowers that develop sequentially, with young immature buds being present when other flowers are fully open (Downs et al., 1988). It seems that the 1-MCP treatment is able to protect fully open flowers but not buds that will later develop into flowers. This presumably relates to the gaseous nature of 1-MCP. Ethylene binding sites present at the time of 1-MCP treatment are inactivated, but those that develop with the opening of young buds are not. STS did protect newly opening flowers, and this seems likely to be the reason for its superiority over 1-MCP in protecting gypsophila. Presumably, this stable complex is able to move within the inflorescence, inactivating ethylene binding sites in developing buds.

In the future, new gypsophila varieties may be developed that are less sensitive to ethylene. In our study, all three commonly grown gypsophila cultivars were sensitive to ethylene, but there was some difference in postharvest performance, which might suggest the value of search for resistant germplasm, of the sort that has been demonstrated in carnation (Wu et al., 1991).

In the meantime, growers are advised to use standard STS products containing sufficient silver to protect gypsophila flowers against endogenous and exogenous ethylene effectively and to ensure maximum vase life. They should use silver recovery systems so that environmental contamination does not become an issue.

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