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Ethylene Inhibitors Efficacy on Flower Opening and Lifespan of Potted *Kalanchoe blossfeldiana* Grown in a Greenhouse after Simulated Export Conditions

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Abstract. Ethylene sensitivity has been shown in several studies as a problem in kalanchoe. An ethylene-contaminated environment such as transportation or display stands in supermarkets deteriorates visual appearance and display life. In this study we determined the efficacy of two ethylene inhibitors, silver thiosulfate (STS) and 1-methylcyclopropene (1-MCP), on flower opening and lifespan of *Kalanchoe blossfeldiana* 'New Alter' cultivated in a greenhouse after simulated transport. STS and 1-MCP were applied to kalanchoe plants at similar commercial maturity prior to simulated transport (dark, 12℃ and 60% relative humidity). STS (0.2 mM, 0.5 mM, and 1 mM) was sprayed and 1-MCP (50 $nL\cdot L^{-1}$, 100 $nL\cdot L^{-1}$, and 200 $nL\cdot L^{-1}$) was injected into sealed glass chambers containing kalanchoe plants for 6 hours. After simulated export for 5 days, the plants were immediately moved to a simulated retail room. The number of inflorescence, buds, and dead florets on all inflorescence were counted weekly for 7 weeks. Percentages of open flowers and dead florets were then calculated. Both STS and 1-MCP had significant effects on improving the quality of kalanchoe flowers by inducing flower opening or extending lifespan compared to the control, suggesting the inhibition of ethylene production by these inhibitors. Among the treatments, 0.5 mM and 1 mM STS showed the best results for induction of flowering and extension of lifespan. 1-MCP was not as effective as STS although the inhibitor had significantly better effects on flower opening than the control. Thus, in this study we showed great possibilities for practical usage of these two ethylene inhibitors on potted kalanchoe plants.

***Additional key words*:** display life, flower senescence, 'New Alter', STS, 1-MCP

Introduction

In an ethylene-contaminated environment such as shipping trucks during transportation or display stands in supermarkets, visual appearance and display life of flowering potted plants readily deteriorate due to ethylene (Reid and Wu, 1992; Van Doorn and Stead, 1997). Transportation by shipping, which is a common method for export and import, can induce the production of endogenous ethylene because of mechanical stresses such as vibration and shock, resulting in severe damage of potted plants (Bulle et al., 2000; Cushman et al., 1994; Hiraki and Ota, 1975; Sacalis, 1978; Saltveit and Larson, 1981).

Kalanchoe blossfeldiana is a popular and commercially important potted plant in the greenhouse industry due to its diversity in cultivar and flower color (Dole and Wilkins, 1999; Leonard and Nell, 1998) and minimum care at home (Marousky and Harbaugh, 1979). However, kalanchoe plants are known to be very sensitive to ethylene (Marousky and Harbaugh, 1979; Serek and Reid, 2000). Inrolling of petals and senescence of the open flowers occur more rapidly under exogenous ethylene than under normal conditions (Dole and Wilkins, 1999; Marousky and Harbaugh, 1979). Thus, ethylene-free environment has been a key issue for maintaining the quality of kalanchoe plants in terms of flower opening and display life.

As ethylene inhibitors, silver thiosulfate (STS) and 1-methylcyclopropene (1-MCP) effectively prevent the injurious symptoms caused by ethylene in plants (Serek et al., 1994). STS or 1-MCP applied to flowering potted plants as a pre-treatment had dramatic impacts on extending flower life and reducing bud and flower drop, leaf abscission, and flower

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senescence (Celikel et al., 2002; Jones et al., 2001; Reid et al., 2002; Serek et al., 1994; Serek and Reid, 2000). Especially, STS has been known to have effects on improving the deleterious physiological symptoms caused by ethylene in potted flowering plants (Serek and Reid, 1993; Veen, 1983), but it has been restricted in some countries due to its potential as an environmental pollutant. As an alternative gaseous ethylene inhibitor, 1-MCP has proven to be a desirable compound for preventing potted plants such as miniature rose, begonia, and kalanchoe from ethylene damage without environmental pollution (Serek et al., 1994). Currently, 1-MCP is commercially adopted to replace STS in the floriculture industry (Kebenei et al., 2003). The effects of STS and 1-MCP on Kalanchoe with various cultivars have been investigated in many previous studies (Reid et al., 2002; Serek et al., 1994; Serek and Reid, 2000), but there is no study in a simulated transport as ethylene contaminant environment.

Thus, the objective of this study was to determine the effects of STS and 1-MCP at different concentrations on flower opening and lifespan of kalanchoe plants after a simulated transport process.

Materials and Methods

Plant materials and growing conditions

Kalanchoe blossfeldiana 'New Alter' was grown in a greenhouse at Kon-Kuk University, Seoul, South Korea. Each kalanchoe cutting in a 6-cm (diameter) pot containing growing medium (peatmoss: perlite = 7:3 (v/v)) was cultivated under mat subirrigation system. The Sonneveld solution of 11.7 N − 1.5 P − 5.5 K (1.6 dS·m^{-1}, pH 6.5) was used with a minor modification (Sonneveld, 1989). One hundred and twenty six plants at normal commercial maturity (2 or 3 opened flowers per inflorescence) were used in this experiment (Kebenei et al., 2003).

Ethylene inhibitors

The plants were treated with STS and 1-MCP prior to simulated transport. STS (0.2 mM, 0.5 mM, and 1 mM) with 1% Tween 20 surfactant was sprayed (10 mL per plant) to leaves, buds, and flowers of kalanchoe plants in a laboratory (Auer and McConnell, 1984). Gaseous 1-MCP (50 nL·L^{-1}, 100 nL·L^{-1}, and 200 nL·L^{-1}) was injected into sealed glass chambers containing kalanchoe plants. The chamber was sealed for 6 hours and air in the chamber was circulated by a fan at 22℃.

Simulated export conditions

All plants were sleeved and randomly put into cardboard boxes (65×45×25 cm) to simulate export practices 24 hours after the STS and 1-MCP treatments. To simulate export conditions by ship to Japan from South Korea, the boxed kalanchoe were placed in a dark closed chamber (12℃ and 60% relative humidity) equipped with a fan for air circulation. Ethylene of 1 μL·L^{-1} (Marousky and Harbaugh, 1979; Serek and Reid, 2000) was injected into the chamber once to exposure the plants ethylene contaminant environment. After 5 days of simulated export, the plants were immediately transferred to a simulated retail condition room (30 μmol·m^{-2}·s^{-1} for 12 hours of photoperiod at 23 ± 2℃ and 55 ± 5% RH) and watered once a week.

Measurement parameters

The number of inflorescence, buds, and dead florets on all inflorescence, total height, and plant width were counted before the ethylene inhibitor treatments (0 week) and weekly after the simulated export for 7 weeks. Eighteen plants per treatment were used. Based on the number of inflorescence, buds, and dead florets, the percentages of open flowers and dead florets were calculated as followed:

$$\text{\% of open flowers} = \frac{\text{The number of inflorescence}}{\text{Sum of the numbers of buds, inflorescence, and dead florets}} \times 100$$

$$\text{\% of dead florets} = \frac{\text{The number of dead florets}}{\text{Sum of the numbers of buds, inflorescence, and dead florets}} \times 100$$

Plant height was the length from the pot bottom to the top of the plant canopy. The diameter of the plant was measured at the widest part of the plant and used to calculate plant volume.

Data analysis

A completely randomized experimental design was used. Analysis of variance (ANOVA) was performed by the Statistical Analysis System (SAS version 9 for Windows, SAS Institute Inc, Cary, NC). Multiple comparisons among means were determined by Duncan's multiple range test.

Results and Discussion

Effects of STS and 1-MCP on opening flower

Kalanchoe plants treated with STS and 1-MCP had significantly more inflorescence than the control plants (Fig. 1). The effect of the ethylene inhibitors was first exhibited at 3 weeks after the simulated export treatment. Inflorescence opening was inhibited in control plants especially after 2 to 3 weeks of simulated export. In contrast, plants treated with ethylene inhibitors showed linear increases in number of inflorescence up to 4 weeks of simulated export.

The number of buds significantly decreased in STS and 1-MCP treatments compared to the control from 3 weeks of simulated export (Fig. 2), indicating that buds of plants under STS or 1-MCP treatment opened effectively while some buds of plants in the control conditions did not open due to ethylene and resulted in premature wilting. In previous studies, ethylene inhibitors including STS promoted bud opening of sweet pea (Mor et al., 1984; Sexton et al., 1995). This means that increased ethylene production in plants retards bud opening. In addition, bud opening was inhibited under external application of ethylene (Reid and Wu, 1992).

There was a clear effect of two ethylene inhibitors on flower opening in kalanchoe plants. At least 20% more fully opened flowers were observed in plants treated with the inhibitors than control plants regardless of concentration and type from 3 weeks to 6 weeks (Fig. 3). This resulted from more inflorescence and less buds in plants treated with STS and 1-MCP. STS and 1-MCP resulted in more open flowers than the control plants, thus making a fuller floral display.

There was no significant difference between the two ethylene inhibitors in opening flowers regardless of concentration applied during the first 5 weeks of simulated export. However, STS was more effective after 5 weeks of simulated export compared to 1-MCP (Fig. 1). High concentrations of STS (0.5 mM and 1 mM) induced more fully opened flowers compared to plants that received 0.2 mM STS (Fig. 1). No significant difference in bud number was observed between the two ethylene inhibitors during the whole experimental period (Fig. 2).

Effects of STS and 1-MCP on inflorescence lifespan

Wilting of the inflorescence was observed after 3 weeks

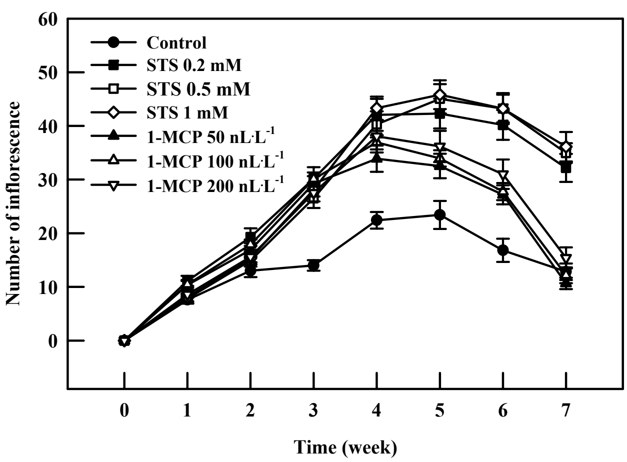

Fig. 1. The number of inflorescence of potted *Kalanchoe blossfeldiana* 'New Alter' treated with STS and 1-MCP after simulated transport. Vertical bars indicate the standard errors (n=18).

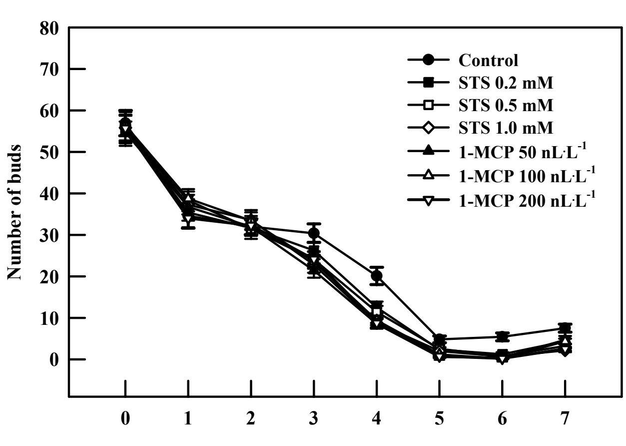

Fig. 2. The number of buds of potted *Kalanchoe blossfeldiana* 'New Alter' treated with STS and 1-MCP after simulated transport. Vertical bars indicate the standard errors (n=18).

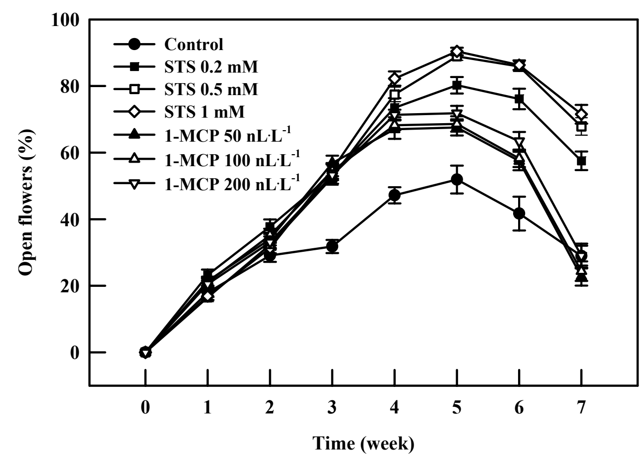

Fig. 3. The percentage of open flowers of potted *Kalanchoe blossfeldiana* 'New Alter' treated with STS and 1-MCP after simulated transport. Vertical bars indicate the standard errors (n=18).

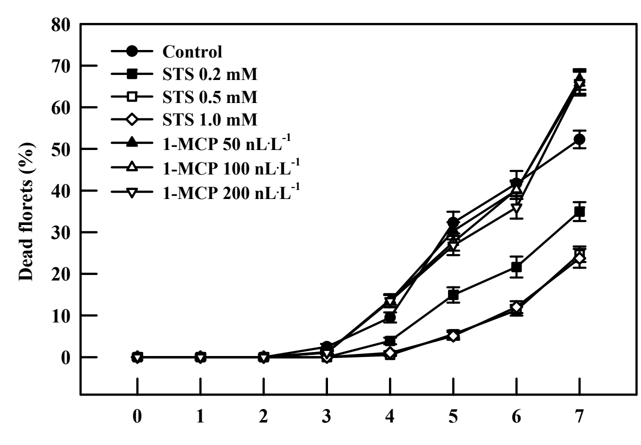

Fig. 4. The percentage of dead florets of potted *Kalanchoe blossfeldiana* 'New Alter' treated with STS and 1-MCP after simulated transport. Vertical bars indicate the standard errors (n=18).

of simulated export with over 50% of the plants in the control and the 1-MCP-treated plants having wilted inflorescence at the end of the experiment (Fig. 4). However, STS-treated plants showed little wilting inflorescence. 0.5 mM and 1 mM STS treatments almost completely protected Kalanchoe plants from the wilting of the inflorescence until 5 weeks after simulated export, with a low wilting rate of the inflorescence even after 7 weeks of simulated export. The low number of dead florets on plants treated with STS could extend the lifespan of kalanchoe flowers. As shown in Figure 5, plants treated with STS had inflorescence that lasted longer than plants in the control group, extending the lifespan up to 7 weeks after simulated export. However, 1-MCP treatments did not appear to work well on controlling of wilting for the inflorescence, although 1-MCP- treated plants showed better inflorescence status than the control plants with regard to number of inflorescence and buds. A previous study reported that 1-MCP treatment did not affect the longevity of individual inflorescence of kalanchoe plants (Serek and Reid, 2000). 1-MCP allows senescence of flowers because 1-MCP in flowers can block ethylene receptors for a while, although newly-produced ethylene receptors combine with endogenous ethylene resulting in flower senescence as time passes (Serek et al., 2006). In other words, gaseous 1-MCP functions for a limited period as an ethylene inhibitor but the effect on inflorescence lifespan for a longer period was

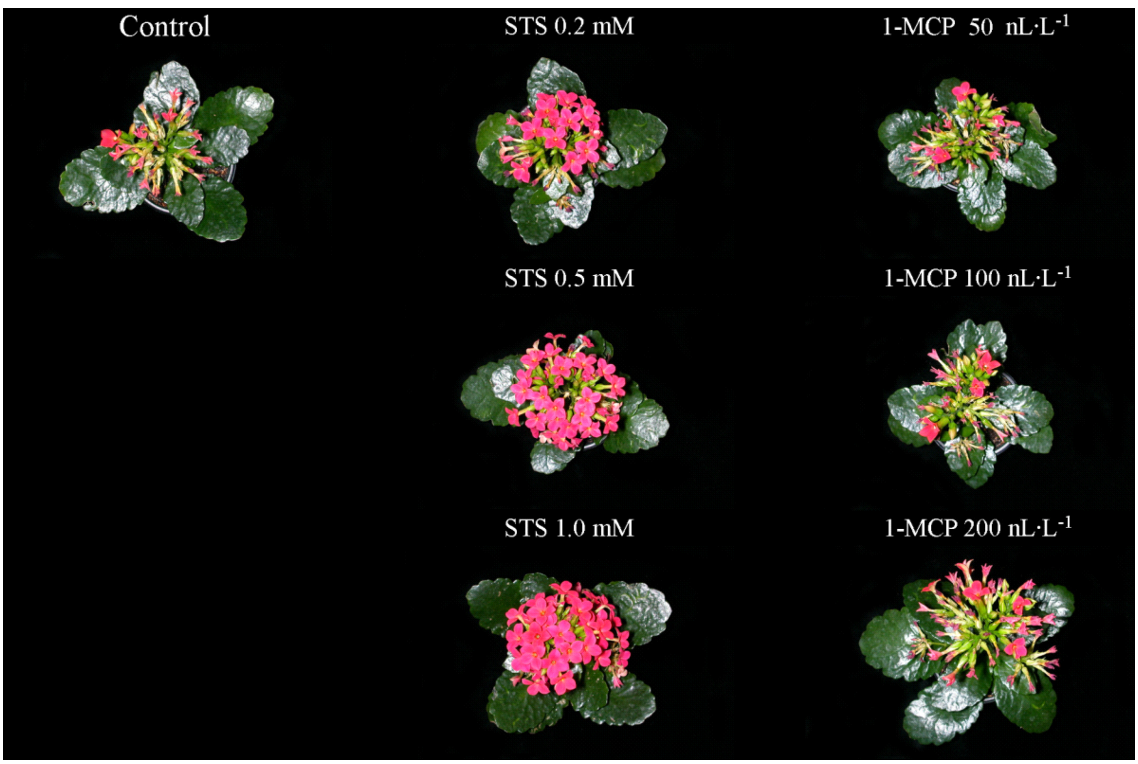

Fig. 5. Potted *Kalanchoe blossfeldiana* ‘New Alter’ treated with STS and 1-MCP 7 weeks after simulated transport.

Table 1. The number of inflorescence and buds and the rate of open flowers and dead florets in potted *Kalanchoe blossfeldiana* ‘New Alter’ treated with STS and 1-MCP at 5 weeks after simulated transport.

STS (mM)	1-MCP ($nL \cdot L^{-1}$)	Number of inflorescence	Number of buds	Open flowers (%)	Dead florets (%)
Control		23.4 d[z]	4.8 a	51.9 d	32.3 a
	0.2	42.3 abc	2.4 b	80.2 ab	14.9 b
	0.5	45.1 ab	2.5 b	88.9 a	5.5 c
	1.0	45.8 a	2.0 b	90.4 a	5.1 c
1-MCP ($nL \cdot L^{-1}$)	50	32.5 cd	0.6 b	67.6 c	30.3 a
	100	33.9 bcd	1.2 b	68.6 c	27.6 a
	200	36.2 abc	0.8 b	71.8 bc	26.8 a

[z]Mean separation within colums by Duncan’s multiple range test at P=0.05.

minimal compared to STS absorbed in plants.

Throughout the whole experimental period, 5 weeks of simulated export was the best time for enjoying full-blown kalanchoe inflorescence, regardless of treatments considering all factors that we measured such as number of inflorescence, number of buds, and open flowers and dead florets rates. Kalanchoe plants treated with 1-MCP or STS treatments at 5 weeks after simulated export showed significantly higher percentages of open flowers and number of inflorescence and lower number of buds and dead florets than control group, suggesting high commercial value as pot plants (Table 1). In addition, there was no adverse effect of STS and 1-MCP on plant weight and width during the whole experimental period (data not shown).

In summary, 0.5 mM and 1 mM STS treatments showed the best results for opening inflorescence and lifespan of *Kalanchoe blossfeldiana* 'New Alter' after simulated export treatment. Although 1-MCP was not effective as much as STS was in relation to the lifespan of kalanchoe inflorescence, 1-MCP also had significant effects on opening flowers than control.

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모의 수송 후 에틸렌 억제제가 온실재배된 칼랑코에의 개화와 수명에 미치는 효과

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초　록. 칼랑코에는 에틸렌에 민감한 식물로 알려져 있다. 운송환경이나 슈퍼마켓의 전시대와 같이 에틸렌이 많은 환경은 식물의 외관과 수명을 단축시킨다. 이 실험에서는 두 종류 에틸렌 억제제(STS와 1-MCP)가 온실재배된 분화 칼랑코에의 모의 수송 후 개화와 수명에 미치는 영향을 조사하였다. 두 억제제는 각각 모의 수송 전에 칼랑코에에 처리되었다(STS: 0.2, 0.5, 1mM, 1-MCP: 50, 100, 200nL·L^{-1}). 5일 동안의 모의 수송환경 처리 후 칼랑코에는 화원과 유사한 환경하에 두었다. 개화수, 화아수, 위조수를 7주 동안 매주 측정하여, 개화율과 위조율을 산출하였다. 두 억제제 모두 대조구에 비해 칼랑코에 주변의 에틸렌을 효과적으로 제거함으로써 개화수와 수명을 연장시켜 분화 칼랑코에 품질을 크게 향상시켰다. 여러 처리 중 STS 0.5mM과 1mM이 개화와 수명 연장에 가장 효과적이었다. 1-MCP의 경우 STS만큼 효과적이지는 못했지만, 대조구에 비해서 확연히 개화율을 향상시켰다. 따라서 이 실험을 통해서 분화 칼랑코에 식물에 대한 이 두가지 에틸렌 억제제의 실용 가능성을 확인할 수 있었다.

추가 주요어 : 관상 수명, 꽃의 노화, STS, 1-MCP