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1-MCP Improves Display Life in *Begonia* × *hiemalis* 'Blitz' and 'Carnival'

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Abstract. We investigated the effect of 1-methylcyclopropene (1-MCP) on ethylene production induced by simulated transport stress in *Begonia* × *hiemalis* 'Blitz' and 'Carnival' to improve the display life in potted plants. The simulated transportation conditions were imposed for 4 days in simulated export containers with darkness, vibration with continuous shaking (150 ± 20 rpm) on a rotary lab shaker, and low temperature (12ºC). Plants were treated with 1-MCP at three concentrations (5, 25, or 125 $nL \cdot L^{-1}$) and for three different periods (0, 6, or 12 hours) before undergoing the simulated transport stress treatments. Treatment with 25 or 125 $nL \cdot L^{-1}$ 1-MCP inhibited the abscission of open flowers by more than 40% as compared to the untreated plants. One week after the treatments, the ethylene production decreased in the plants treated with 125 $nL \cdot L^{-1}$ 1-MCP for 'Blitz' and 25 $nL \cdot L^{-1}$ for 'Carnival'. Ethylene production was correlated with concentration and duration of 1-MCP treatment in 'Blitz', but not in 'Carnival'. To reduce flower abscission and ethylene production, thus improve the display life when plants are exposed to transportation stress, we recommend pre-treatment with 1-MCP before packaging, using concentrations and durations specific to each cultivar, 125 $nL \cdot L^{-1}$ for 6 h and 25 $nL \cdot L^{-1}$ for 12 hours for 'Blitz' and 'Carnival', respectively.

***Additional key words*:** 1-methylcyclopropene, ethylene, potted flower, stress

Introduction

The quality and display life of ornamental plants are often reduced by ethylene at physiological active concentrations (Reid and Wu, 1992). Ethylene causes yellowing and shedding of leaves, shrinking and shedding of buds or flowers, and ultimately reduces postharvest quality (Hwang et al., 1995). 1-methylcyclopropene (1-MCP) has been shown to prevent the deleterious effects of ethylene in plants (Serek and Sisler, 2001). The anti-ethylene effects of this compound are associated with excessive structural molecular strain that permits very tight binding to electron donor compounds such as low valence metals, which act to relieve the strain in the receptor. 1-MCP competes with ethylene by binding to its receptor (Sisler et al., 1996, 1999). The activity of 1-MCP has been reported according to the concentration required for activation of the receptor as well as the duration of binding (Sisler et al., 1996, 1999). Low concentrations of 1-MCP applied over longer periods may be as effective as high concentrations over shorter periods (Blankenship and Dole, 2003). The 1-MCP effectively blocks ethylene action in many floricultural crops including phlox (Porat et al., 1995), tuberous begonia, kalanchoe (Serek et al., 1994), and *Cymbidium* orchid (Heyes and Johnston, 1998) at low concentrations ranging from 2.5 to 200 $nL \cdot L^{-1}$. Flower abscission was also inhibited by 1-MCP in ethylene-sensitive cut flowers such as carnation, stock, wax-flower, and snapdragon (Blankenship and Dole, 2003).

Begonia × *hiemalis* is one of the most popular potted flowering plants, and is commercially grown in Korea for exportation to Japan or China (Kim et al., 2008). This important crop is ethylene-sensitive, as exposure to ethylene accelerates the abscission of flowers and inhibits the development of new flower buds (Fjeld, 1989; Moe and Eriksen, 1986). Fjeld (1989) demonstrated that concentrations of ethylene as low as 14 $nL \cdot L^{-1}$ causes begonia flowers to wilt or destroying the ornamental value of the plant. During transportation and postharvest handling, plants are subjected to stresses that in turn may stimulate endogenous ethylene production because there is a sharp transient decrease in the irradiance level and temperature changes (Rudnicki et al., 1993). The quality

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and display life of potted flowering plants are often reduced by the effects of ethylene in the environment. Physiological effects such as leaf drop, bud abortion, and abscission are attributed to ethylene production (Serek and Sisler, 2001). The need for chemical protection from ethylene action has been recommended for many potted flowering plants in which low concentrations of ethylene cause rapid loss in display quality (Serek et al., 1994).

Therefore, the objective of this study was to investigate the differences in display lives of begonia flowers after exposure to transportation stresses following pre-treatment with 1-MCP. We identified treatment conditions, such as concentration of and duration of exposure to 1-MCP that would most effectively improve the display life of *Begonia* × *hiemalis*.

Materials and Methods

Plant Materials

Potted flowering plants of *Begonia* × *hiemalis* 'Blitz' and 'Carnival' were obtained from a commercial grower at the bud stage (Goyang, Korea) and transported to the greenhouse at the experimental farm of the College of Agriculture and Life Sciences at Seoul National University in Suwon, Korea. The conditions in the greenhouse were 21/20°C, 380 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for 9 h per day, and 50 ± 5% relative humidity (RH). Two weeks after transfer to the university greenhouse, the plants of *Begonia* × *hiemalis* 'Blitz' and 'Carnival' were treated at bud stage (10-15 mm) with 1-MCP.

Treatment with 1-MCP and Transport Simulation

1-MCP was obtained from KyungNong (Seoul, Korea), in 3.3% active ingredient formulations (SmartFresh®). Plants were placed in a well-sealed plastic chamber (47 cm × 35 cm × 23 cm) at 20°C. SmartFresh® powder was placed in a small glass bottle taped to the inside wall of the chamber. The chamber lid was sealed and 1 mL of distilled water was injected into the glass bottle containing SmartFresh® powder using a hypodermic needle punctured through a septum in the lid. A significant proportion of the 1-MCP was released immediately after the addition of water. 1-MCP concentrations were measured using gas chromatography (M-600D, Young Lin Instrument Co. Ltd., Anyang, Korea) as reported previously (Mir et al., 2001). A standard for quantifying 1-MCP was prepared using 1.00 $\mu L \cdot L^{-1}$ 1-butene (Matheson Gas Products, Suwon, Korea). Plants were treated with 0, 5, 25, or 125 $nL \cdot L^{-1}$ 1-MCP in sealed plastic chambers at 20°C with different durations (0, 6, or 12 h).

Control plants were sealed in identical chambers containing air at 20°C without the addition of 1-MCP. After treatment with 1-MCP, the plants were immediately exposed to transport simulations. Transportation conditions for an export container were simulated by keeping the plants for 4 days in darkness with continuous shaking (150 ± 20 rpm) on a rotary lab shaker (temperature, 12°C; RH, 50 ± 10%) (Park et al., 2011). Control plants were placed at 20°C with 9 h light without vibration.

Data Collection and Analysis

Display life was defined as the period starting from the day of introduction to the interior environment to the day when the plants lost visual quality. Plants with visible symptoms of senescence, 50% of healthy flowers, or 30% of open flowers with yellowing were considered to have lost visual quality. Display life was recorded every 3 days until the end of the experiment. Healthy flowers were defined as half-open or open flowers that were not abscised and had no senescence symptoms. Abscised or wilted flower number divided by total flower number was calculated for flower abscission (%). Leaf chlorophyll contents were determined every 3 days for each plant using a SPAD-502 meter (Minolta Camera Co., Ltd., Osaka, Japan).

Ethylene measurement for each treatment was conducted twice; for each measurement, three replicate plants were placed in 35 L containers sealed with a septum, and kept for 2 h at 20°C. A 1 mL aliquot of the air in the containers was withdrawn for measurement of ethylene, using a gas chromatograph (M-600D, Young Lin Instrument Co. Ltd., Anyang, Korea) fitted with a photoionization detector. A complete randomized design was used for the experiments and the experiments were repeated three times with ten replicates each. Statistically significant differences between mean values were assessed by Duncan's multiple range test ($P < 0.5\%$ level) using SAS (SAS Institute Inc., Cary, NC, USA) for analysis.

Results and Discussion

The display life after simulated transport was about 14 days for 'Blitz' and 17 days for 'Carnival'. The main negative effects of simulated transport were flower senescence, yellowing, and wilting. The display life of 'Blitz' and 'Carnival' treated with 5, 25, or 125 $nL \cdot L^{-1}$ 1-MCP prior to simulated transport was 16-23 days and 18-24 days, respectively (Table 1). Serek et al. (1994) previously reported that 1-MCP prevented petal and bud abscission and flower senescence in begonia, miniature roses, and kalanchoe. The display life of both the cultivars were not extended by treatment with 5 $nL \cdot L^{-1}$ 1-MCP. In 'Blitz', at lower concentrations, the inhibitory effect was less marked; only 25 $nL \cdot L^{-1}$ for 6 h and 125 $nL \cdot L^{-1}$ for 6 h or 12 h treatment was significantly increased the display

Table 1. Display life of *Begonia* × *hiemalis* 'Blitz' and 'Carnival' pre-treated with three different concentrations of 1-MCP for different durations.

Treatment				Display life (days)	
Stress	1-MCP	Concentration ($nL\cdot L^{-1}$)	Duration (h)	'Blitz'	'Carnival'
–[z]	–			23.3 a[y]	24.3 a
+	+	0	0	14.0 c	17.2 c
+	+	5	6	16.7 bc	18.3 bc
+	+		12	16.0 bc	19.7 bc
+	+	25	6	20.3 ab	21.7 ac
+	+		12	18.0 abc	23.7 a
+	+	125	6	20.0 ab	19.5 bc
+	+		12	22.7 a	19.0 bc
Significance					
Concentration				*	**
Duration				**	***
Concentration × Duration				NS	NS

[z]–, Not treated; +, treated.
[y]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.
[NS,*,**,***]Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2. The effects of 1-MCP treatment on flower abscission in *Begonia* × *hiemalis* 'Blitz' and 'Carnival' exposed to simulated transport stress[z].

Treatment				Flower abscission (%) at					
Stress	1-MCP	Concentration ($nL\cdot L^{-1}$)	Duration (h)	Day 1	Day 4	Day 7	Day 10	Day 13	Day16
						'Blitz'			
–[y]	–	0	0	0.0 c[x]	2.1 b	16.3 c	17.3 bc	18.3 d	19.4 e
+	+	0	0	18.3 a	26.4 a	31.2 b	39.2 b	52.2 b	70.1 ab
+	+	5	6	15.4 a	28.7 a	33.0 b	40.8 b	46.9 bc	58.0 bc
+	+		12	7.3 bc	11.1 b	60.9 a	70.1 a	75.4 a	78.9 a
+	+	25	6	11.7 ab	26.1 a	32.2 b	35.2 bc	35.2 bcd	45.8 cd
+	+		12	0.0 c	5.6 b	20.7 bc	32.2 bc	35.1 bcd	37.9 cde
+	+	125	6	2.8 c	8.3 b	13.9 c	13.9 c	23.6 cd	27.7 de
+	+		12	2.6 c	12.6 b	23.1 bc	25.6 bc	31.1 bcd	32.6 de
Significance									
Concentration				***	**	***	***	***	***
Duration				***	***	**	**	**	***
Concentration × Duration				*	**	***	NS	NS	NS
						'Carnival'			
–	–	0	0	0.0 a	1.1 b	5.2 de	14.1 cde	19.2 cd	24.7 cd
+	+	0	0	0.0 a	22.3 a	31.8 b	34.9 b	40.0 b	43.5 b
+	+	5	6	2.8 a	18.6 a	44.9 a	63.6 a	71.8 a	73.7 a
+	+		12	0.0 a	25.8 a	23.2 bc	26.1 bc	37.4 bc	39.8 bc
+	+	25	6	1.1 a	2.4 b	14.7 cd	24.6 bcd	28.7 bcd	33.4 bcd
+	+		12	0.0 a	4.4 b	7.6 de	10.6 de	15.5 d	21.7 d
+	+	125	6	4.0 a	2.9 b	4.0 e	3.7 e	17.6 d	22.5 cd
+	+		12	2.0 a	5.5 b	5.5 de	19.2 cd	26.5 bcd	35.6 bcd
Significance									
Concentration				NS	***	***	***	***	***
Duration				NS	***	***	***	**	**
Concentration × Duration				*	**	***	NS	NS	**

[z]Transportation condition for export container was simulated by keeping the plants for 4 days in darkness with continuous shaking (150 ± 20 rpm) on a rotary lab shaker; temperature was 12°C and RH 50 ± 10%.
[y]–, Not treated; +, treated.
[x]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.
[NS,*,**,***]Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

life (Table 1). In 'Carnival', treatment with 25 nL·L^{-1} 1-MCP for 6 h or 12 h improved display life, compared to other concentrations. 1-MCP pre-treatment prior to packing flowers for simulated shipment also increased the length of vase life in *Dendrobium* orchids (Uthaichay et al., 2007). Similarly, 1-MCP prevented damage due to exogenous ethylene in many potted plants species, including prevention of flower abscission in *Begonia* × *hiemalis* 'Najada' and 'Rosa', *Begonia* × *tuberhybrida* 'Non-Stop', and kalanchoe 'Tropicana' (Serek et al., 1994, 1995). Increasing the concentration of 1-MCP to more than 25 nL·L^{-1} did not result in additional improvement in the display life of 'Carnival'.

Ethylene production due to stress significantly reduced floret number by causing petal abscission in both cultivars (Table 2). Ethylene-induced petal abscission of florets was significantly inhibited by 1-MCP in both cultivars compared to control after treatment with 125 nL·L^{-1} for 6 h in 'Blitz', and 25 nL·L^{-1} for 12 h and 125 nL·L^{-1} for 6 h in 'Carnival' (Table 2). 1-MCP strongly inhibited the abscission of open flowers during the display life in both cultivars. Our results indicate that enhancement of the display life via 1-MCP treatment can be a strategy for improving the quality of ethylene-sensitive flower crops (Kim et al., 2007). Abscission of open flowers increased rapidly from day 4 and reached

Table 3. The effects of 1-MCP treatment on chlorophyll contents in *Begonia* × *hiemalis* 'Blitz' and 'Carnival' exposed to simulated transport stress[z].

Treatment				Chlorophyll contents (SPAD value) at					
Stress	1-MCP	Concentration (nL·L^{-1})	Duration (h)	Day 0	Day 2	Day 5	Day 8	Day 11	Day14
						'Blitz'			
–[y]	–	0	0	42.0 a[x]	38.4 a	40.7 b	41.7 a	44.2 a	44.5 a
+	+	0	0	49.8 a	40.2 a	38.5 ab	41.5 a	46.0 a	46.2 a
+	+	5	6	46.5 a	39.7 a	37.7 ab	39.0 a	47.9 a	45.8 a
+	+		12	48.2 a	38.0 a	42.7 a	41.6 a	46.9 a	44.6 a
+	+	25	6	48.0 a	40.8 a	40.4 ab	40.0 a	46.6 a	44.7 a
+	+		12	48.3 a	37.8 a	36.2 b	42.0 a	46.7 a	45.3 a
+	+	125	6	49.0 a	39.1 a	39.5 ab	39.0 a	45.4 a	42.8 a
+	+		12	47.7 a	40.7 a	42.9 a	42.6 a	46.4 a	44.8 a
Significance									
Concentration				NS	NS	NS	NS	NS	NS
Duration				NS	NS	NS	NS	NS	NS
Concentration × Duration				NS	NS	NS	NS	NS	NS
						'Carnival'			
–	–	0	0	43.1 bc	41.6 ab	41.7 ab	37.6 a	37.6 a	38.6 b
+	+	0	0	44.0 b	44.4 a	43.5 ab	39.5 a	39.5 a	42.4 ab
+	+	5	6	47.1 a	44.8 a	44.5 ab	41.9 a	41.9 a	43.1 a
+	+		12	43.3 bc	43.8 a	45.1 ab	42.6 a	42.6 a	42.1 ab
+	+	25	6	43.0 bc	43.6 ab	43.3 ab	41.5 a	41.5 a	42.1 ab
+	+		12	40.7 c	38.9 b	39.6 b	38.2 a	38.2 a	38.1 b
+	+	125	6	41.7 bc	45.8 a	42.8 ab	40.0 a	40.0 a	41.5 ab
+	+		12	42.6 bc	43.4 ab	46.4 a	39.7 a	39.7 a	43.3 a
Significance									
Concentration				**	NS	NS	NS	NS	NS
Duration				NS	*	NS	NS	NS	NS
Concentration × Duration				*	NS	NS	NS	NS	NS

[z]Transportation condition for export container was simulated by keeping the plants for 4 days in darkness with continuous shaking (150 ± 20 rpm) on a rotary lab shaker; temperature was 12°C and RH 50 ± 10%.
[y]–, Not treated; +, treated.
[x]Mean separation within columns by Duncan's multiple range test at P < 0.05.
[NS,*,**,***]Nonsignificant or significant at P < 0.05, 0.01, or 0.001, respectively.

about 70% by the end of day 16 in untreated 'Blitz' plants (Table 2). 1-MCP treatment prior to ethylene exposure prevented the effects of ethylene on flower abscission until day 10 of the experiment. Treatment also prevented open flowers from falling until day 16 (Table 2). However, pre-treatment with 5 $nL \cdot L^{-1}$ of 1-MCP for 6 or 12 h had no effect on total bud or flower drop in either cultivar. Flower abscission was not reduced by increased duration of 125 $nL \cdot L^{-1}$ 1-MCP treatment in either cultivar. The leaf chlorophyll contents were not affected by 1-MCP treatment in *Begonia* × *hiemalis* 'Blitz' and 'Carnival' (Table 3). Further, the amount of ethylene production induced by stress in this experiment did not affect begonia leaf condition. Høyer (1985) also reported that the number and color of the *Begonia elatior* 'Sirene' leaves were not affected by darkness or ethylene.

Untreated plants exposed to stress showed a rapid increase in ethylene production until day 7 in both cultivars (Table 4). Pre-treatment of the plants with 1-MCP strongly inhibited the effects of ethylene on both flower senescence and abscission. The 1-MCP treatment was prevented ethylene-mediated flower senescence and drop, although the ethylene inhibiting effect varied depending on the treatment concentration. The high efficacy of a single pre-treatment of 1-MCP under the export conditions is explained by the irreversible blocking of the ethylene receptors (Kenigsbuch et al., 2007). Treatment of 'Blitz' with 125 $nL \cdot L^{-1}$ 1-MCP for 6 h eliminated ethylene

Table 4. The effects of 1-MCP on ethylene production of *Begonia* × *hiemalis* 'Blitz' during simulated transport stress[z].

Treatment				Ethylene production ($nL \cdot L^{-1}$) at				
Stress	1-MCP	Concentration ($nL \cdot L^{-1}$)	Time (h)	Day 1	Day 4	Day 7	Day 10	Day 13
						'Blitz'		
–[y]	–	0	0	0.0 b[x]	0.0 c	0.2 c	5.6 a	5.4 b
+	+	0	0	16.9 a	20.9 a	16.7 ab	6.1 a	5.3 ab
+	+	5	6	20.6 a	12.2 b	18.2 ab	5.7 a	4.8 ab
+	+		12	21.4 a	14.2 b	14.8 ab	5.3 a	4.6 ab
+	+	25	6	20.6 a	16.7 ab	24.0 a	4.8 a	4.9 ab
+	+		12	18.8 a	4.1 c	7.2 bc	0.7 b	2.1 b
+	+	125	6	0.9 b	0.0 c	3.9 bc	3.8 ab	1.8 b
+	+		12	21.3 a	6.0 c	8.5 bc	5.6 a	8.6 a
Significance								
Concentration				***	***	NS	NS	NS
Duration				***	***	*	NS	NS
Concentration × Duration				***	***	NS	NS	**
						'Carnival'		
–	–	0	0	0.1 c	0.0 b	0.0 c	0.3 c	2.2 a
+	+	0	0	5.6 a	4.7 a	4.9 ab	0.6 c	4.1 a
+	+	5	6	4.0 ab	4.9 a	3.9 ab	6.5 ac	6.4 a
+	+		12	1.9 bc	5.7 a	3.4 ab	8.7 a	6.3 a
+	+	25	6	2.1 bc	0.1 b	1.1 bc	2.9 bc	2.7 a
+	+		12	1.9 bc	0.0 b	1.6 bc	0.6 c	1.9 a
+	+	125	6	3.0 ab	2.6 ab	7.4 a	5.0 ab	3.8 a
+	+		12	0.5 bc	5.7 a	4.7 ab	2.5 bc	4.4 a
Significance								
Concentration				*	**	*	***	**
Duration				**	*	**	NS	NS
Concentration × Duration				NS	NS	NS	NS	NS

[z]Transportation condition for export container was simulated by keeping the plants for 4 days in darkness with continuous shaking (150 ± 20 rpm) on a rotary lab shaker; temperature was 12°C and RH 50 ± 10%.
[y]–, Not treated; +, treated.
[x]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.
[NS,*,**,***]Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

production, whereas treatment with 25 nL·L^{-1} 1-MCP was effective for reducing ethylene production in 'Carnival' (Table 4). This finding demonstrates that different cultivars require different 1-MCP treatment conditions. For cut phlox flower, a 6 h pre-treatment with 25 nL·L^{-1} 1-MCP completely inhibited ethylene-induced flower abscission and reduced the number of open flowers on the stems, compared with 500 nL·L^{-1} treatment (Porat et al., 1995). However, 1-MCP pre-treatment inhibited ethylene production for less than 10 days in both cultivars (Table 4). Since 1-MCP is a gas, unbound material diffuses out of the plant tissue once the treatment is completed. 1-MCP is no longer available to bind new ethylene binding sites as they are synthesized in the developing florets, leaving them unprotected. Park et al. (2011) reported that 1-MCP acts for a limited time as an ethylene inhibitor. Amounts of ethylene sufficient to induce abscission could easily accumulate in plants held at floral distribution centers and retailers (Kim and Wills, 1998). Repeated application of 1-MCP could re-establish the protection of florets opening after the initial 1-MCP treatment to continuously protect plants from ethylene exposure (Cameron and Reid, 2001), but this may not be practical (Kim et al., 2007). Nevertheless, pre-treatment with 1-MCP is still beneficial to protect the plants from ethylene exposure during shipping.

In conclusion, pre-treatment with 1-MCP decreased bud and flower abscission, and ultimately extended the display life for *Begonia* × *hiemalis* varieties 'Blitz' and 'Carnival'. To reduce ethylene production induced by transportation-related stress during exportation, we suggest pre-treatment with 1-MCP for concentrations and durations specific to each cultivar, 125 nL·L^{-1} for 6 h for 'Blitz' and 25 nL·L^{-1} for 12 h for 'Carnival'.

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