Dwarfing Effects of Chlormequat Chloride and Uniconazole on Potted Baby Primrose

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ADDITIONAL INDEX WORDS. **floriculture, height control, pedicel, peduncle, plant growth regulators, *Primula forbesii***

SUMMARY. **Baby primrose (*Primula forbesii*) is a newly cultivated and valuable ornamental plant with great market potential for both indoor and landscape use. As a container plant, baby primrose has long, weak flower stalks that can easily lodge, resulting in poor-quality plants, especially during transportation. To control plant height and subsequently prevent flower peduncle lodging, we investigated the effects of two plant growth regulators (PGRs), chlormequat chloride (CCC) at 0, 250, 500, or 750 ppm and uniconazole (UNI) at 25, 50, or 75 ppm on growth, development, and flowering of two cultivars of baby primrose, Fragrant Luolan and Red Star. Plant growth regulators at the proposed concentrations were applied twice throughout the experiment. Both PGRs significantly suppressed plant height in both cultivars, with a 16% to 27% reduction by CCC and 50% to 59% by UNI compared with untreated plants. Among CCC-treated groups, plants were shortest when CCC was applied at 500 ppm; plant height was suppressed more when treated with UNI. In both cultivars, UNI significantly suppressed the first, second, and third peduncle lengths. Furthermore, CCC affected peduncle length, but to a lesser extent than UNI. Plant growth regulator applications generally had little effect on flower characteristics of baby primrose. Neither PGRs influenced the inflorescence number and flower size; however, PGRs did increase the number of floral whorls and suppressed pedicel length of 'Red Star'. New leaf growth was suppressed by both PGRs. In addition, peduncle cell length and width were both significantly suppressed by PGR applications. We concluded that two foliar applications of UNI at 25 ppm comprised the most effective method of controlling baby primrose plant height while maintaining desirable flower traits at a relatively low production cost. Results of this study provide guidance for techniques that can be used to effectively control the plant height of potted baby primrose for commercial greenhouse production.**

Traditionally cultivated in China, primrose (*Primula* sp.) is popular for its early spring blooming in December through April. Although some species have medicinal uses, most of them are being bred and cultivated as ornamental plants, including common primrose (*Primula vulgaris*), chinese primrose (*Primula sinensis*), poisonous primrose (*Primula obconica*), and baby primrose (*Primula forbesii*) (Šarić-Kundalić et al., 2010). Baby primrose is a biennial temperate wildflower commonly found in Yunnan, Sichuan, and Tibet in China. Seeds of baby primrose were originally collected from the wild habitat of Kunming and were selectively bred and cultivated to obtain new cultivars with desirable flower traits at the end of 20th century (Jia et al., 2010b). With its long flowering season, proliferation of showy blooms, and pleasant fragrance, baby primrose is valuable as both a container plant and landscape plant (Jia et al., 2014). However, greenhouse-cultivated baby primrose often develop long flower peduncles that can result in lodging and decreased commercial marketability. Therefore, controlling the height of baby primrose in greenhouse environments is critical to its potential commercial success.

Plant growth regulators (PGRs) are synthetic chemical compounds or extractions of natural plant hormones that regulate plant growth and development. They are often used to influence plant cell division, rooting, germination, branching, flowering, and abscission at lower concentrations (Rademacher, 2015). Applications of PGRs are common in the production of bedding plants to inhibit stem elongation to meet the specific plant target heights. The effectiveness of PGR applications depends on several factors, including the active ingredient, application volume and concentration, time and method of application, crop species, and environmental conditions (Runkle, 2015, 2017). They can be applied by a substrate drench, a foliar spray, or a combination of both (Barrett, 1999; Blanchard and Runkle, 2007). Many PGRs are known to block the multistep biosynthesis pathways of gibberellic acid (GA). Depending on the compound, some act during earlier steps of the GA biosynthesis pathways, such as chlormequat chloride (CCC), whereas others, such as daminozide, act later (Runkle, 2017).

Plant growth regulators have been tested on a wide array of plants, including herbaceous perennials and agronomic crops (Hamaker et al., 1996; Shekoofa and Emam, 2008;

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1	micron(s)	µm	1
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274×10^{-5}
1	ppm	$mg \cdot L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Whipker, 2015). Chlormequat chloride and uniconazole (UNI) have been successfully used in floriculture as a drench or foliar spray (Rademacher, 1995). Chlormequat chloride was first found to inhibit stem elongation, increase stem thickness, and enhance leaf greenness of poinsettia (*Euphorbia pulcherrima*) and chrysanthemum (*Chrysanthemum* ×*morifolium*) by Lindstrom and Tolbert (1960), and it is now commonly used for height and flowering control in greenhouse or container production operations (Runkle, 2014). Chlormequat chloride is easily absorbed by plant leaves and roots, metabolized rapidly inside plants, and works efficiently in drench and foliar spray, with a common rate of 750 to 1500 ppm (Runkle, 2014). For example, poinsettia height was 8% to 23% shorter when 1500 ppm CCC was applied after pinching compared with poinsettia without CCC application (Karunananda and Peiris, 2010). Similarly, CCC suppressed the height of scarlet rosemallow (*Hibiscus coccineus*), monarch rosemallow (*Hibiscus radiatus*), and venice mallow (*Hibiscus trionum*) by 87%, 42%, and 52%, respectively, 28 d after the application of 2000 ppm compared with untreated plants (Warner and Erwin, 2003). However, phytotoxicity, including leaf yellow spotting, discoloration, and necrosis, may occur when CCC spray was more than 1500 ppm (Whipker et al., 2001). A combined application of CCC and daminozideis is often used to provide greater height control at a lower application rate and reduce the potential for phytotoxicity (Whipker, 2015). For example, Lewis et al. (2004) reported chlorotic spots on ‘Winter Rose Dark Red’ poinsettia leaves 2 d after 1500 ppm CCC spray application alone, but a mixture with daminozide at varying rate from 1500 to 4500 ppm with the same rate of CCC did not cause phytotoxicity but did reduce poinsettia sensitivity to CCC phytotoxicity.

Uniconazole is the most active, persistent, and effective PGR on a parts per million basis (Runkle, 2011). Unlike CCC, it is primarily absorbed by plant stems; therefore, spraying is the most common application method, but it can also be successfully applied as substrate drench and liner soak (Runkle, 2011; Whipker, 2015). Dependent on the species, single UNI sprays at 1 to 2, 4 to 6, and 10 to 15 ppm have been recommended, respectively, for bedding plants with moderate vigor such as celosia (*Celosia argentea*), more aggressive crops such as petunia (*Petunia* ×*hybrida*) and marigold (*Tagetes erecta*), and aggressive herbaceous perennials such as phlox (*Phlox paniculata*) and echinacea (*Echinacea purpurea*) (Runkle, 2011). The height of chrysanthemum was suppressed by 53%, 43%, and 17%, respectively, when 30 ppm of UNI was applied 0, 2, and 4 weeks after pinching (Gilbertz, 1992). In addition to CCC and UNI, several other PGRs, including daminozide, ancymidol, flurprimidol, paclobutrazol, ethephon, and benzyladenine, have also been registered and successfully used in the production of ornamental crops (Latimer and Whipker, 2019; Whipker, 2015).

At application rates of 500 ppm or more, CCC failed to achieve optimal height control of container-produced baby primrose (Jia et al., 2010a). Therefore, additional research examining baby primrose height in response to lower rates of CCC is warranted. Moreover, to find a more effective way to control baby primrose plant height, UNI application was also evaluated. In addition, little information is available regarding the efficacy of CCC and UNI application on baby primrose. To directly address these needs, the specific objectives were to 1) investigate the effects and efficacy of CCC and UNI as foliar spray on plant height control and flowering of baby primrose, and 2) investigate the cytological basis of PGRs for baby primrose height control. Results of this study will provide critical information and guidance regarding PGR application for height control of greenhouse-produced baby primrose.

Materials and methods

Plant materials. Seeds of two cultivars of baby primrose, Fragrant Luolan and Red Star, were obtained internally through the baby primrose breeding program in Beijing Forestry University (Beijing, China) that was begun in 2000. These two cultivars with steady flower traits were officially obtained in 2008 through eight generations of targeted and selective breeding (Jia et al., 2010b). Seeds of ‘Fragrant Luolan’ and ‘Red Star’ were sown in 128-cell trays on 25 Sept. 2015 in a greenhouse located at Beijing Forestry University (lat. 45°N, long. 116°E) under natural daylength with soilless substrate (Pindstrup Sphagnum; Pindstrup Mosebrug, Ryomgaard, Denmark) that comprised peatmoss and perlite (3:1 by volume). The average greenhouse temperature was 16.6 ± 0.4 °C with relative humidity of 56.2% ± 0.8%, as recorded by a thermo recorder (TR-72U; T&D, Matsumoto, Japan). After a 50-d germination period, seedlings were transplanted to 15-cm-diameter containers with soilless substrate as described upon the emergence of four to six true leaves on 16 Jan. 2016. Approximately 1 week after transplant, 420 of the most uniform plants of each cultivar were selected, placed on three benches as three replications, and randomly assigned to each chemical application treatment within each bench. Plants were hand-irrigated as needed.

Chemical application treatments. Two PGRs, CCC (C114434; Aladdin, Shanghai, China) and UNI (U114871; Aladdin), were used in our experiment. Plant growth regulators were applied twice throughout the experiment with a manual spray bottle. The first PGR application was performed on 15 Feb. 2016 at the time of visual emergence of the primary inflorescence, whereas the second application was performed 20 d later. Twenty plants of each cultivar on each bench received foliar spray with water as the control, or CCC at 250, 500, or 750 ppm, or UNI at 25, 50, or 75 ppm until runoff, with ≈25 mL on each plant. Chemical applications were made between 0800 to 0900 HR to minimize drift, avoid high temperatures, and maximize chemical retention on plants. Plants were manually irrigated early in the morning before PGR application and remained dry until the next irrigation schedule 2 d later.

Plant height parameters measurements. Plant height, defined as the final inflorescence height (from the substrate surface to the meristem on primary inflorescence), was recorded with a measuring tape when the flower on the first floral whorl (from the bottom) of the primary inflorescence started to wither and fall (Fig. 1). The first, second, and third peduncle lengths were calculated by

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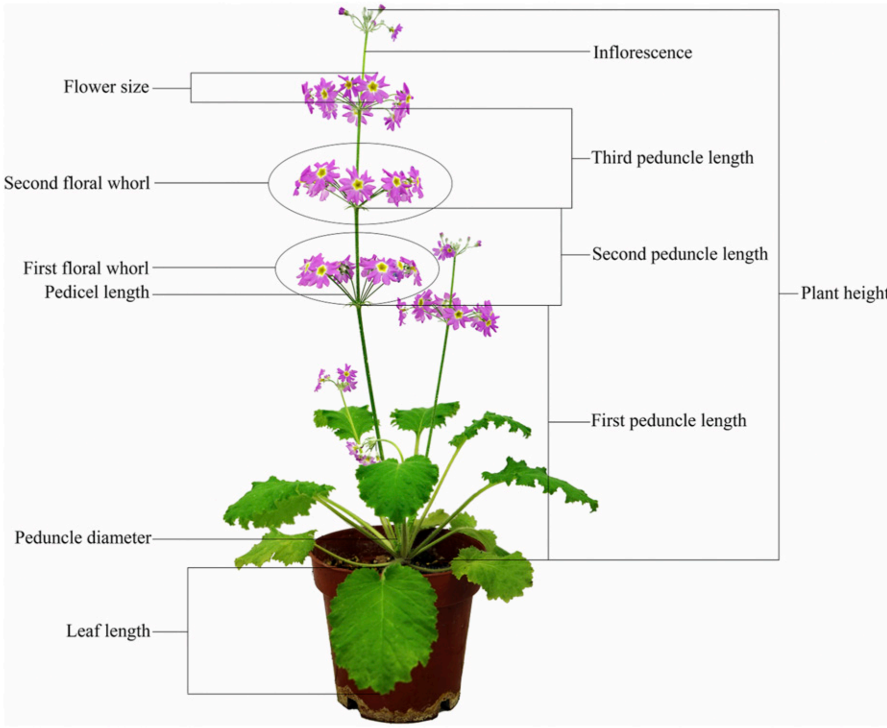

Fig. 1. Plant structure and morphology description of baby primrose.

the differences between the height from the first floral whorl to the substrate surface, length between the first and second floral whorl, and length between the second and third floral whorl counting from the bottom, respectively, on the primary inflorescence.

Flowering and leaf parameters measurement. The inflorescence numbers within the container and the number of floral whorls on the primary inflorescence were recorded at the end of the experiment (Fig. 1). Three major inflorescences were randomly selected from each container and the diameter was measured with a waterproof digital caliper (IP67; Jiangsu BC Magnets Co., Jiangsu, China) at the substrate surface level. Pedicel length and flower size were measured on three randomly selected individual mature flowers on the first floral whorl on primary inflorescences. Old leaf and new leaf, defined as mature leaf before and after PGR treatment application, respectively, were measured with a measuring stick.

Plant microstructure preparation and measurement. Preparation of the sample cell slices of baby primrose peduncle cells was performed according to the modified methods of Chen et al. (2018) and Šalgovičová et al. (2007). A 3-cm stem from the first peduncle of the primary inflorescences was collected at the end of the experiment from each treatment and soaked in FAA solution (50% ethanol:formaldehyde:acetic acid at 90:5:5 by volume) for 24 h at 4 °C. Samples were dehydrated in a series of increasing ethanol concentrations (70%, 80%, 90%, and 95%) and then subjected to two changes of 100% ethanol, each for 40 min. Dehydrated samples were immersed in a mixture of xylene and ethanol (1:1 by volume) and two changes of 100% xylene, each for 40 min. Samples were then placed in a mixture of paraffin wax and xylene (1:1 by volume) at 40 °C for 12 h and incubated four times in 100% paraffin wax at 60 °C for 4 h each time. The samples were embedded in paraffin, cooled for at least 24 h, sliced into 8- to 10-µm cross-section units using a microtome (RM2235; Leica Biosystem, Shanghai, China), and dried at 42 °C for 24 h. Subsequently, the cross-sections were soaked two times in 100% xylene for 30 min each, a mixture of xylene and ethanol (1:1 by volume) for 3 min, and then rehydrated in a series of decreasing ethanol concentrations (100%, 95%, 90%, 80%, 70%, and 50%), each for 3 min. Finally, they were placed in a mixture of safranin and xylene (1:1 by volume) staining for 6 h. Samples were then subjected to a series of increasing ethanol concentrations (50%, 70%, 80%, 90%, and 95%), each for 1 min, and placed in fast-green staining for 30 s. Samples were then immersed in 100% ethanol two times, each for 30 s, followed by a mixture of xylene and ethanol (1:1 by volume) for 3 min and two changes of 100% xylene, each for 5 min. Finally, cross-sections were sealed on microslides using a neutral resin and observed under a light microscope (CX21; Olympus, Beijing, China); peduncle cell sizes were measured using a Nano Measurer (Fudan University, Shanghai, China).

Experimental design and data analysis. The experiment was arranged as a randomized complete block design with subsamples. Three benches were considered three blocks (replications) to account for variability in environmental conditions. Four-hundred twenty plants of each cultivar were placed on three benches, with 140 plants on each bench. Seven PGR application treatments were randomly assigned to 140 plants, with 20 plants per treatment on each bench. Twenty individual plants from each treatment from each bench were considered the subsamples. Data were pooled from three replications and analyzed with SAS (version 9.4; SAS Institute, Cary, NC) using a mixed model (PROC MIXED) and glimmix model (PROC GLIMMIX) procedures. Pairwise comparisons between PGR application treatments were performed with Tukey's honestly significant difference test at $P \leq 0.05$.

Results

Baby primrose generally produces one to several inflorescences within the container. Leaves are arranged in a cluster at the base of the plant. Plant height is typically determined by the length of the primary inflorescences (Fig. 1).

Height characteristics of baby primrose. Plant growth regulators suppressed the plant height of baby primrose, with the greatest suppression occurring with UNI treatments for both cultivars (Figs. 2 and 3) compared with untreated plants. Among CCC-treated groups, plants were the shortest when CCC was applied at 500 ppm, and they were

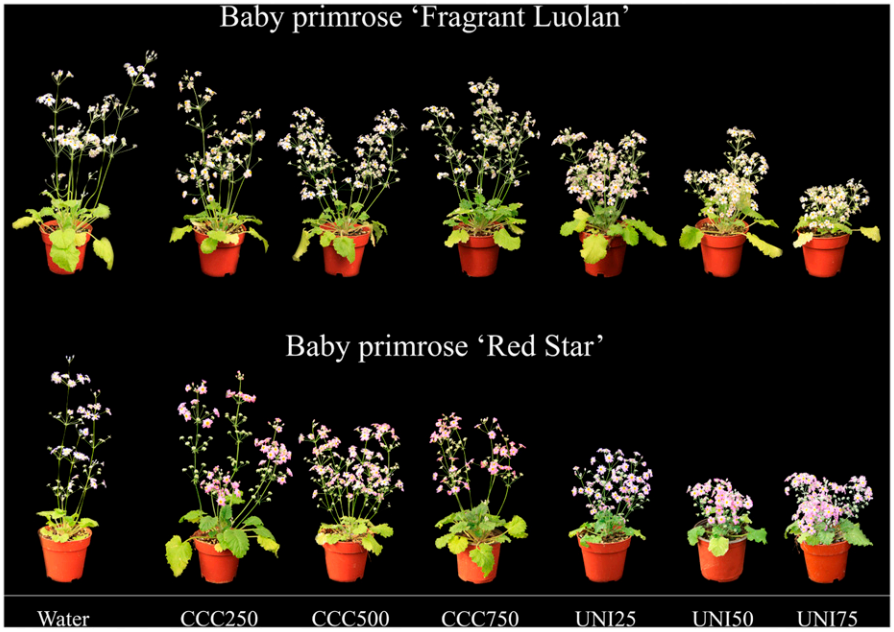

Fig. 2. Dwarfing effects of chlormequat chloride (CCC) and uniconazole (UNI) on potted baby primrose 'Fragrant Luolan' and 'Red Star'. Plants were foliar-sprayed with water (as the control), CCC at 250, 500, and 750 ppm, and UNI at 25, 50, and 75 ppm. This photo was obtained at the end of the experiment; 1 ppm = 1 mg·L^{-1}.

25% to 27% shorter than those treated with water. Applications of CCC at 250 and 750 ppm suppressed the plant height of 'Fragrant Luolan' by 16% to 19% and that of 'Red Star' by 14% to 18%; however, no differences were observed with CCC at these two concentrations for both cultivars. Uniconazole suppressed 'Fragrant Luolan' plant height by 50% to 56% and that of 'Red Star' by 54% to 59%; however, there were no differences among UNI treatments.

The first peduncle length of 'Fragrant Luolan' was not influenced by CCC, but the second peduncle length was suppressed by 20% when CCC was applied at 500 ppm (Fig. 3). The third peduncle length was shortened by 23% to 33% when plants were treated with CCC at 250 and 500 ppm as compared with plants treated with water; however, no differences were observed among CCC treatments. Uniconazole had a greater dwarfing effect than CCC and shortened the first, second, and third peduncle lengths by 45% to 51%, 40% to 49%, and 54% to 58%, respectively, when compared with untreated plants; however, there were no differences among UNI treatments. Similarly, the first peduncle length of 'Red Star' was unaffected by CCC, except when applied at 500 ppm, which suppressed the length by 13%. The second peduncle length was significantly reduced by 18% to 27% in response to the CCC application as compared with plants treated with water. Similarly, the third peduncle length was shortened by 17%, 28%, and 33% in response to CCC application rates of 250, 500, and 750 ppm, respectively, as compared with untreated plants. Similar to 'Fragrant Luolan', UNI suppressed the peduncle length of 'Red Star' more effectively than CCC. The first peduncle length of 'Red Star' was suppressed by more than 50% in response to UNI at 50 ppm compared with plants treated with water. In addition, UNI suppressed the second and third peduncle lengths by 55% to 66% and 60% to 66%, respectively.

Flower characteristics of baby primrose. Generally, PGRs had little effect on the inflorescence number and flower size in both cultivars compared with those treated with water (Table 1). Plant growth regulators had no effects on the inflorescence diameter and number of floral whorls on the primary inflorescence of 'Fragrant Luolan'. The pedicel length of plants treated with CCC was similar to that of untreated plants; however, UNI suppressed pedicel length by 10% to 18%. Applications of UNI of 50 ppm or more decreased the inflorescence diameter of 'Red Star' by 23% to 27% compared with the control, but there were no differences among other treatments. The number of floral whorls was promoted by 18%, 27%, and 17% when CCC was applied at 500 and 750 ppm and when UNI was applied at 75 ppm, respectively. Pedicel length was shortened by 16% to 18% when CCC was applied at 500 ppm or more and by 25% to 30% when treated with UNI compared with plants grown without PGRs.

Leaf characteristics of baby primrose. In both cultivars, old leaves were unaffected by PGR applications and were statistically similar among treatments (data not shown). All PGRs suppressed the length of new leaves in both cultivars; generally, UNI had a stronger effect on new leaves than CCC (Fig. 4). Chlormequat chloride shortened the new leaf length of 'Fragrant Luolan' by 13%, 22%, and 27% when applied at 250, 500, and 750 ppm, respectively, compared with plants that were treated with water. Uniconazole suppressed new leaf length by 39% to 41% compared with untreated plants, but no differences were found among UNI treatments. Similarly, the new leaf length of 'Red Star' was shortened by 15% to 25% and 37% to 43% when treated with CCC and UNI, respectively, compared with plants without PGR applications, with the greatest suppression occurring when UNI was applied at 50 ppm.

Peduncle cell sizes of baby primrose. Chlormequat chloride did not influence the peduncle cell length of 'Fragrant Luolan' compared with plants treated with water (Fig. 5). Peduncle cell width, however, was suppressed by 15% to 32% when CCC was applied at 500 ppm or more. In addition, UNI suppressed both the cell length and width of 'Fragrant Luolan' by 35% to 52% and 25% to 39%, respectively. All PGR treatments suppressed both the cell length and width of 'Red Star'. Among CCC-treated groups, the peduncle cell size was smallest when CCC was applied at 500 ppm; cell length and width were reduced by 38% and 30%, respectively, compared with untreated plants. The peduncle

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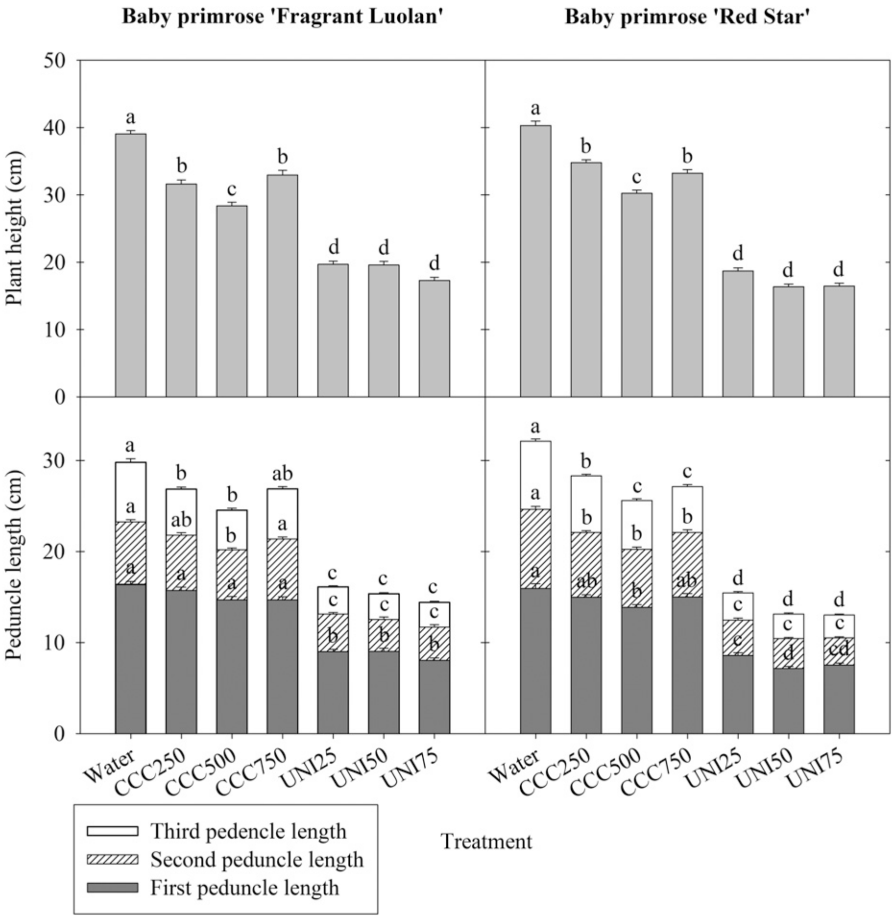

Fig. 3. Plant height and the first, second, and third peduncle lengths (as defined) of two cultivars of baby primrose treated with water, chlormequat chloride (CCC) at 250, 500, and 750 ppm, and uniconazole (UNI) at 25, 50, and 75 ppm. All data were pooled from three replications with 20 subsamples each (n = 60). A pairwise comparison was performed within each cultivar. Means sharing the same letter are not statistically different by Tukey's honestly significant difference test at $P \leq 0.05$. Error bars indicate SE; 1 ppm = 1 mg·L^{-1}, 1 cm = 0.3937 inch.

cell size was generally suppressed by 33% to 58% when treated with UNI.

Discussion

Overall, the plant growth of two baby primrose cultivars, Red Star and Fragrant Luolan, responded similarly to imposed PGR treatments. All PGR treatments suppressed the height of baby primrose, although UNI was relatively more effective than CCC for suppressing plant growth, including height, peduncle length, and cell size. Henderson and Nichols (1991) indicated that the height of two cultivars of scarlet firethorn (*Pyracantha coccinea*), Kasan and Lalandei, experienced little change with 3000 ppm CCC. In contrast, 25 ppm UNI reduced the height of 'Kasan' by 8% to 15% and that of 'Lalandei' by 9% to 10% compared with nontreated plants. Similarly, in a separate study, CCC with a rate of 750 to 3000 ppm had little to no effect on the height of three cultivars of new guinea impatiens (*Impatiens hawkeri*), whereas 5 to 20 ppm UNI significantly suppressed the height by 30% to 48% among cultivars (Currey et al., 2016). In our study, the final plant height of baby primrose was suppressed by 14% to 27% in response to a relatively high CCC rate. In contrast, height was suppressed more significantly, by 50% to 59%, under a relatively low dosage of UNI compared with untreated plants, suggesting that UNI had greater efficacy controlling plant height. Among CCC treatments, plants were the shortest when CCC was applied at 500 ppm. Findings were similar to those of Jia et al. (2010a), thus suggesting that 500 ppm is the optimum concentration to control the height of potted baby primrose with CCC. However, it was uncommon for CCC to have greater efficacy for controlling height at a lower concentration (500 ppm) than a higher concentration (750 ppm) in our study, because PGR efficacy generally increases with increased concentrations (Asgarian et al., 2013; Jia et al., 2010a; Warner and Erwin, 2003). Despite varying application rates of UNI, few differences in final plant height were observed. Great suppression in plant height in response to relatively low application rates of UNI suggested that it is more effective than CCC for controlling the height of 'Fragrant Luolan' and 'Red Star' baby primrose.

The majority of PGRs regulate plant height by inhibiting distinct steps in the biosynthesis and metabolism of GA and the subsequent regulations of cell elongation and division in the subapical meristems of plants (Grossmann et al., 1984; Rademacher, 1995). Rademacher (1995) indicated that PGRs can be divided into three groups based on their structural features and biochemical mode of action. The "onium" compound group, which includes CCC, typically possesses a positively charged ammonium, phosphonium, or sulfonium moiety. This group of PGRs primarily targets the very early stage of GA synthesis from geranylgeranyl diphosphate through ent-copalyl diphosphate to ent-kaurene (Graebe, 1987; Rademacher, 1995). The nitrogen-containing heterocycle compounds, which include UNI, act as inhibitors of the oxidative steps from ent-kaurene to ent-kaurenoic acid. Finally, acylcylcohexanediones and related compounds which include daminozide, interfere with the late steps of GA biosynthesis beyond GA_{12}-aldehyde. To achieve significant effects on larger plants, a relatively high concentration of "onium" compound group PGRs must be used due to the high likelihood of the GA biosynthesis pathway being mostly inactive (Rademacher, 1995). This was supported by our study that baby primrose had the smallest peduncle cell sizes when CCC was applied at 500 ppm and peduncle cells had further growth suppression under lower dosages of UNI treatments. Similarly, onion root tip cell size decreased by 13% to 36% and 17% to 44% when treated with 100 to 300 ppm CCC and UNI, respectively, compared with

Table 1. **Flowering characteristics of two cultivars of baby primrose treated with water, chlormequat chloride (CCC) at 250, 500, and 750 ppm, and uniconazole (UNI) at 25, 50, and 75 ppm.[z]**

Treatment	Inflorescence (no.)	Inflorescence diam (mm)[z]	Whorls on primary inflorescence (no.)	Flower size (cm)[z]	Pedicel length (cm)
	Flowering characteristic (mean ± SE)				
Fragrant Luolan					
Water	8.73 ± 0.39 ab[y]	1.29 ± 0.03[x]	3.93 ± 0.10[x]	1.90 ± 0.02 ab	6.92 ± 0.19 ab
CCC250	8.46 × 0.34 b	1.20 ± 0.02	3.85 ± 0.10	1.97 ± 0.02 a	7.01 ± 0.13 a
CCC500	8.74 ± 0.40 ab	1.20 ± 0.03	3.60 ± 0.12	1.91 ± 0.02 ab	6.78 ± 0.14 ab
CCC750	8.70 ± 0.34 ab	1.19 ± 0.02	3.63 ± 0.10	1.89 ± 0.02 ab	6.34 ± 0.14 bc
UNI25	9.39 ± 0.40 ab	1.16 ± 0.02	3.80 ± 0.10	1.84 ± 0.03 ab	5.66 ± 0.12 e
UNI50	9.71 ± 0.30 ab	1.12 ± 0.03	3.64 ± 0.11	1.77 ± 0.03 b	5.75 ± 0.12 de
UNI75	10.33 ± 0.36 a	1.18 ± 0.04	3.61 ± 0.10	1.79 ± 0.03 b	6.23 ± 0.11 cd
Red Star					
Water	7.03 ± 0.42[x]	1.27 ± 0.02 a	3.80 ± 0.15 c	1.90 ± 0.02 ab	7.66 ± 0.14 a
CCC250	8.26 ± 0.38	1.41 ± 0.03 a	4.3 ± 0.13 abc	1.97 ± 0.02 a	6.94 ± 0.14 ab
CCC500	8.76 ± 0.53	1.34 ± 0.03 a	4.47 ± 0.14 ab	1.91 ± 0.02 ab	6.43 ± 0.14 bc
CCC750	8.04 ± 0.31	1.46 ± 0.03 a	4.82 ± 0.12 a	1.89 ± 0.02 ab	6.29 ± 0.16 bcd
UNI25	7.80 ± 0.26	1.29 ± 0.04 a	4.23 ± 0.12 abc	1.84 ± 0.03 ab	5.74 ± 0.14 cde
UNI50	7.76 ± 0.41	0.93 ± 0.02 b	4.09 ± 0.09 bc	1.77 ± 0.03 b	5.59 ± 0.16 de
UNI75	8.11 ± 0.36	0.98 ± 0.03 b	4.43 ± 0.13 ab	1.79 ± 0.03 b	5.36 ± 0.12 e

[z]1 ppm = 1 $mg \cdot L^{-1}$, 1 mm = 0.0394 inches, 1 cm = 0.3937 inches.
[y]All data were pooled from three replications with 20 subsamples each (n = 60). A pairwise comparison was performed within each cultivar. Means sharing the same letter are not statistically different according to Tukey's honestly significant difference (HSD) test at $P \leq 0.05$.
[x]Nonsignificant by Tukey's HSD test at $P \leq 0.05$.

water-treated plants (Ud-Deen and Kabir, 2009). These collectively suggested that CCC and UNI inhibit the biosynthesis pathway of GA, suppress cell elongation and expansion, and subsequently reduce the peduncle length of baby primrose to eventually control plant height.

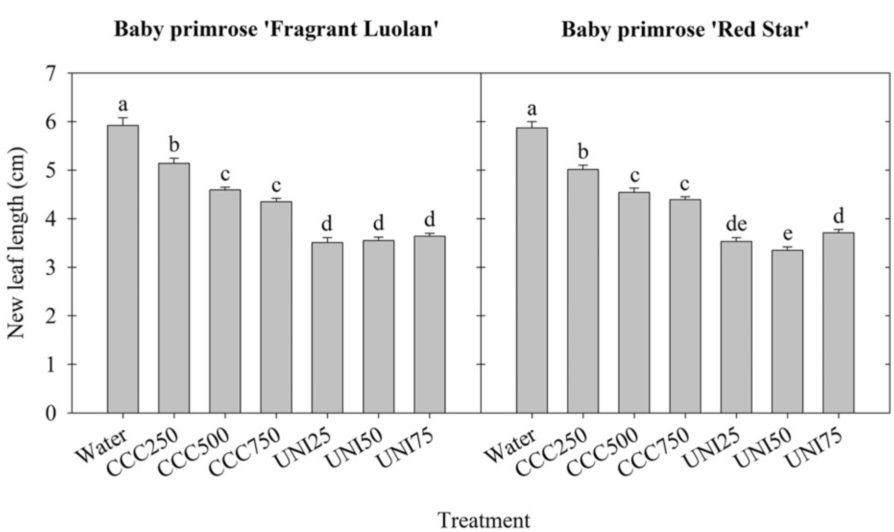

Fig. 4. New leaf length of two cultivars of baby primrose treated with water, chlormequat chloride (CCC) at 250, 500, and 750 ppm, and uniconazole (UNI) at 25, 50, and 75 ppm. All data were pooled from three replications with 20 subsamples each (n = 60). A pairwise comparison was performed within each cultivar. Means sharing the same letter are not statistically different by Tukey's honestly significant difference test at $P \leq 0.05$. Error bars indicate SE; 1 ppm = 1 $mg \cdot L^{-1}$, 1 cm = 0.3937 inch.

The effects of PGR applications on flowering are cultivar-specific. No effect on the inflorescence diameter of 'Puritan' chrysanthemum was observed in response to a single 20-ppm application of UNI (Starman, 1990). The inflorescence diameter was decreased by 8%, however, when UNI was applied to 'Favor' at the same application rate. In our study, both PGRs had no significant influence on the inflorescence diameter of 'Fragrant Luolan', but UNI suppressed the inflorescence diameter of 'Red Star' by 23% to 27%. Similarly, both PGRs did not influence the number of floral whorls on the primary inflorescence of 'Fragrant Luolan'; however, the number of floral whorls on the primary inflorescence of 'Red Star' was increased by 17% to 27%. In addition, neither PGR affected the inflorescence number or flower size of both cultivars of baby primrose. This was consistent with the studies by Jiao et al. (1990) and Starman (1991), which reported that UNI sprays did not influence the flower number of lisianthus (*Eustoma grandiflorum*) and six hybrid lily (*Lilium*) cultivars. In a separate study, the flower numbers per stem of five fan flower (*Scaevola albida*) cultivars were also unaffected by UNI applied either as spray or media drench (Starman and Williams, 2000). Together, these indicated that applications of CCC and UNI had a major suppression effect on plant height but little influence on flowering.

The highly competitive ornamental plant production industry requires rigorous control of production conditions and low associated costs so

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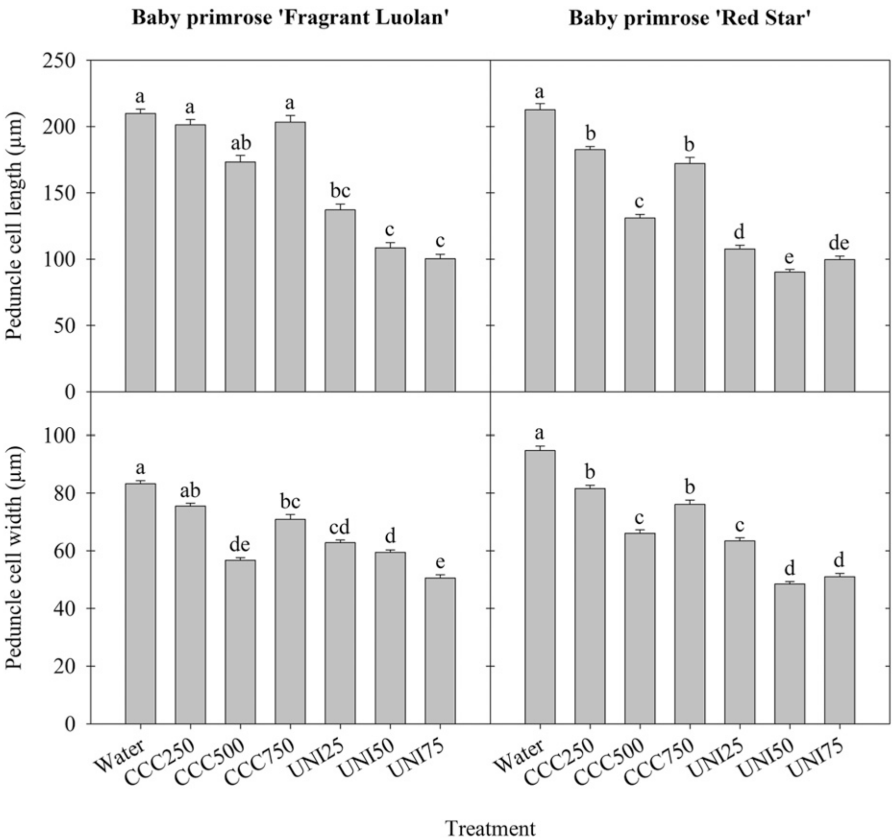

Fig. 5. Peduncle cell length and width of two cultivars of baby primrose treated with water, chlormequat chloride (CCC) at 250, 500, and 750 ppm, and uniconazole (UNI) at 25, 50, and 75 ppm. All data were pooled from three replications with 20 subsamples each (n = 60). A pairwise comparison was performed within each cultivar. Means sharing the same letter are not statistically different by Tukey's honestly significant difference test at $P \leq 0.05$. Error bars indicate SE; 1 ppm = 1 mg·L^{-1}, 1 µm = 1 micron.

that they can be profitable. González-Gómez and Morini-Marrero (2009) found that cost elements involved in commercial ornamental production included direct costs, indirect costs, stay costs, greenhouse activity costs, and plant activity costs. As PGR applications comprise a common and important technique for the production of select ornamental crops, the cost of the PGRs needs to be considered to decide the ideal concentration to achieve the desired height target and flower traits. In this study, the market costs of two PGRs were $18.5/100 g for CCC and $113.5/100 g for UNI. Approximately 25 mL was used as the foliar spray for each pot. Both 500 ppm CCC and 25 ppm UNI applications effectively controlled plant height while maintaining the desired flower traits (Figs. 2 and 3, Table 1). The amounts of CCC and UNI used for each pot were 12.5 and 0.625 mg, respectively, and were associated with PGR costs of $0.0023/plant and $0.0007/plant, respectively. We concluded that a foliar spray of 25 ppm UNI at the emergence of the primary inflorescence and 20 d later would effectively control baby primrose height and lead to the desired flowering traits at a lower cost than CCC. These findings provide critical information regarding the efficient and effective use of two common PGRs for producers of baby primrose.

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