Substrate Drenches Containing Flurprimidol Suppress Height of 'Nellie White' Easter Lilies

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SUMMARY. The objective of this research was to quantify how flurprimidol substrate drenches applied to 'Nellie White' easter lilies (*Lilium longiflorum*) affected height at flowering, time to flower, and flower number. In Expt. 1, size 9/10 'Nellie White' easter lilies were treated with a 4-fl oz drench applied to the surface of the substrate when shoots were ≈ 3 inches tall providing 0.0, 0.02, 0.04, 0.08, 0.16, or 0.24 mg flurprimidol per pot or 0.03 or 0.06 mg uniconazole per pot. In Expt. 2, size 10/12 'Nellie White' easter lilies were treated with 4-fl oz drenches applied to the surface of the substrate when shoots were ≈ 3 inches tall providing 0.0, 0.01, 0.02, 0.04, 0.06, or 0.08 mg flurprimidol per pot. In Expt. 1, plants treated with flurprimidol or uniconazole were up to 38.9 cm (59%) shorter than untreated plants, while time to flower and flower number remained unaffected by plant growth retardant (PGR) treatments. In Expt. 2, as the amount of flurprimidol increased from 0.01 to 0.08 mg/pot, plant height was suppressed linearly ($r^2 = 0.63$), by up to 23.2 cm (28%), while time to flower and flower number remained unaffected. Additionally, the chemical cost for drenches containing flurprimidol is less than the cost of uniconazole required to achieve comparable height control. Flurprimidol substrate drenches appear to be an effective and economical alternative to control easter lily height.

Easter lilies are an important flowering potted crop in the United States with a wholesale value over \$26.8 million for the 15 largest-producing states in 2010 (U.S. Department of Agriculture, 2011). Plant height can reach up to 1 m and must be controlled to produce plants for aesthetic value that are also amenable to packing, shipping, and retailing (Miller, 1992, 1993).

Easter lily height control may be achieved environmentally or culturally by manipulating the difference between the day and night air

temperature, increasing light, enhancing plant spacing, minimizing exposure to far-red light, or using cold water in overhead irrigation (Blom et al., 1995, 2004; Erwin et al., 1989). However, chemical PGR applications may be used to produce compact potted easter lilies (McAvoy, 2001). Though foliar sprays and bulb dips are effective PGR application methods for bulb crops, substrate drenches provide more uniform height control over a longer duration (Boldt, 2008; Gent and McAvoy, 2000). Substrate drenches containing ancymidol, paclobutrazol, or uniconazole have been shown to successfully control easter lily height (Bailey and Miller, 1989; Gianfagna and Wulster, 1986; Jiao et al., 1986, 1990; Larson et al., 1987; Sanderson et al., 1975; Wilfret, 1987; Wilfret and Reiser, 1996).

Flurprimidol (Topflor; SePRO Corp., Carmel, IN) is available in the U.S. market as a 0.38% liquid formulation. In addition to ancymidol, paclobutrazol, and uniconazole, flurprimidol inhibits the conversion of *ent*-kaurene into *ent*-kaurenoic acid in the gibberellin biosynthesis pathway (Rademacher, 2000) and is active when applied as a foliar spray, bulb dip, and substrate drench (Currey and Lopez, 2010). Flurprimidol substrate drenches effectively suppressed the height of bulb crops such as tulip [*Tulipa gesneriana* (Krug et al., 2005b)], narcissus [*Narcissus pseudo-narcissus* (Krug et al., 2006)], and lilies including Asiatic lily (*Lilium × asiatica*), oriental lily (*L. auratum* × *L. speciosum*), and tiger lily (*L. lancifolium*) (Krug et al., 2005a; Pobudkiewicz and Nowak, 1992; Pobudkiewicz and Treder, 2006). While flurprimidol has been shown to have height-suppressing activity on easter lily when applied as a foliar spray (Whipker, 2004) and bulb dips (Whipker et al., 2011), we have found no reports of using flurprimidol substrate drenches to control height of easter lilies. Therefore, the objective of this research was to quantify how flurprimidol substrate drenches applied to 'Nellie White' easter lilies affect height at flowering, time to flowering, and flower number.

Materials and methods

EXPT. 1. On 13 Dec. 2005, 200 case-cooled 9 to 10-cm-diameter 'Nellie White' easter lily bulbs were delivered from the Easter Lily Research Foundation (Harbor, OR) to North Carolina State University in Raleigh (lat. 35°N) in pressboard cases filled with peatmoss. Each bulb was planted individually into 6-inch-diameter round containers (1.6 L) containing soilless substrate comprised of (v/v) 75% to 80% Canadian sphagnum peatmoss and 20% to 25% perlite (Berger BM 6; Berger Peat

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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
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
28,350	oz	mg	3.5274×10^{-5}
1	ppm	mg·L ⁻¹	1
0.7646	yard ³	m ³	1.3080

Moss, St. Modeste, QC, Canada). When shoots were ≈ 3 inches above the substrate surface (Miller, 1992), a 4-fl oz drench providing 0.03 or 0.06 mg uniconazole per pot (Sumagic; Valent U.S.A., Walnut Creek, CA) (McAvoy, 2001) or 0.0, 0.02, 0.04, 0.08, 0.16, or 0.24 mg flurprimidol per pot (Topflor) was applied to the surface of the substrate. The range of flurprimidol concentrations was selected based on results of a preliminary study (B. Whipker, unpublished data).

Plants were grown in a glass-glazed greenhouse with exhaust fan and evaporative-pad cooling, radiant hot-water heating, and retractable shade curtains controlled by an environmental computer (Maximizer Precision 6; Priva Computers, Vine-land Station, ON, Canada). The day and night greenhouse air temperature set points were 20 ± 1 °C and 18 ± 1 °C, respectively, with natural daylengths and ambient photosynthetic photon flux (PPF). Plants were irrigated as necessary with water supplemented with 13N–1P–10.8K water-soluble fertilizer (Cal-Mag; Scotts, Marysville, OH) to provide the following (in $\text{mg}\cdot\text{L}^{-1}$): 150 nitrogen (N), 10 phosphorous (P), 125 potassium (K), 69 calcium (Ca), 35 magnesium (Mg), 0.75 iron (Fe), 0.38 manganese (Mn) and zinc (Zn), 0.19 copper (Cu) and boron (B), and 0.1 molybdenum (Mo).

The experiment was conducted in a completely randomized design with six replications (individual plants) for each drench treatment. On the date the first flower opened, plant height from the surface of the substrate to the top of the plant and flower number (flower buds and open flower) were recorded. Time to flower from shoot emergence was calculated. Analyses of variance and pairwise comparisons between treatments using Tukey's honestly significant difference test at $P \leq 0.05$ were performed using SPSS 17.0 (IBM Corp., Armonk, NY).

EXPT. 2. On 29 Oct. 2009, two hundred 10 to 12-cm-diameter 'Nellie White' easter lily bulbs were delivered from the Easter Lily Research Foundation to Purdue University in West Lafayette, IN (lat. 40°N) in pressboard cases filled with peatmoss. The cases were immediately placed in a walk-in environmental cooler set at 5 °C for a 6-week vernalization

treatment. On 10 Dec. 2009, each bulb was planted individually into 6-inch-diameter round plastic containers (1.6 L) containing soilless substrate comprised of (v/v) 80% sphagnum moss and 20% perlite (Fafard 1P Mix; Conrad Fafard, Agawam, MA). When shoots were ≈ 3 inches above the substrate surface, a 4-fl oz drench providing 0.0, 0.01, 0.02, 0.04, 0.06, or 0.08 mg flurprimidol per pot (Topflor) was applied to the surface of the substrate. The range of flurprimidol concentrations was selected based on results of Expt. 1.

Plants were grown in a glass-glazed greenhouse with exhaust fan and evaporative-pad cooling, radiant hot-water heating, and retractable shade curtains controlled by an environmental computer (Maximizer Precision 10, Priva Computers). The day and night greenhouse air temperature set point was 18 ± 1 °C with natural daylengths and ambient PPF. Plants were irrigated as necessary with acidified water supplemented with 15N–1.3P–13.3K water-soluble fertilizer (Greencare Fertilizers, Kankakee, IL) to provide the following (in $\text{mg}\cdot\text{L}^{-1}$): 200 N, 17 P, 176 K, 40 Ca, 27 Mg, 1.0 Fe, 0.5 Mn and Zn, 0.24 Cu and B, and 0.1 Mo. Irrigation water was supplemented with 93% sulfuric acid (Ulrich Chemical, Indianapolis) at 0.08 $\text{mL}\cdot\text{L}^{-1}$ to reduce alkalinity to 100 $\text{mg}\cdot\text{L}^{-1}$ and pH to a range of 5.8 to 6.2.

The experiment was conducted in a completely randomized design with 10 replications (individual plants) for each drench concentration. When the first flower opened, data were collected and calculated as outlined in Expt. 1. Regression analyses were performed using SPSS 17.0.

Results and discussion

In Expt. 1, every PGR application resulted in shorter 'Nellie White' easter lilies compared with the untreated control (Fig. 1). As the amount of flurprimidol increased from 0.02 to 0.24 mg/pot, plants were 6.1 cm (9%) to 38.9 cm (59%) shorter than untreated plants, respectively (Fig. 1). Similarly, plants treated with 0.03 or 0.06 mg uniconazole per pot were 5.1 cm (8%) or 23.7 cm (36%) shorter than untreated plants, respectively (Fig. 1). Neither flurprimidol nor uniconazole applications had a significant effect on time to flower or flower number (Fig. 1).

Trends observed in Expt. 2 were very similar to those observed in Expt. 1. Height of 'Nellie White' easter lilies exhibited a strong linear relationship ($r^2 = 0.63$) to flurprimidol concentration (Fig. 2). For example, height at flowering was reduced by 1.3 cm (2%) to 23.2 cm (28%) compared with untreated plants as flurprimidol increased from 0.01 to 0.08 mg/pot. Time to flower and flower number were unaffected by flurprimidol drenches (Fig. 2). We did observe some lower leaf yellowing on plants treated with the higher flurprimidol concentrations in Expt. 2. However, we attribute the leaf yellowing to slight overwatering of smaller plants because all easter lilies were on drippers with the same irrigation program, and not a direct consequence of flurprimidol applications.

While we have found no literature reporting the use of flurprimidol substrate drenches for controlling height of easter lily, previous reports have demonstrated the effectiveness of flurprimidol using a variety of application methods on lilies (Krug et al., 2005a; Pobudkiewicz and Nowak, 1992; Pobudkiewicz and Treder, 2006; Whipker, 2004; Whipker et al., 2011). Krug et al. (2005a) reported that applying 0.5 mg flurprimidol per pot provided commercially acceptable height control for 'Star Gazer' oriental lilies with no significant effect on time to anthesis or flower bud number. However, as the amount of flurprimidol applied increased above 2.0 mg/pot, height control was excessive, while a delay in time to anthesis and reduction in flower bud number were observed as the amount of flurprimidol increased to 4 mg/pot (Krug et al., 2005a). Alternatively, 'Mona Lisa' oriental lilies treated with 0.1125 to 0.45 mg flurprimidol per pot were 10.6 to 13 cm shorter than untreated plants with no delay in time to flower or flower bud number (Pobudkiewicz and Treder, 2006). It appears that the amount of flurprimidol required to control stem elongation of 'Nellie White' easter lilies is less than that required for height control of other oriental hybrid lilies.

Flurprimidol sprays have also been reported to control height of easter and oriental lilies (Krug et al., 2005a; Pobudkiewicz and Nowak, 1992; Pobudkiewicz and Treder, 2006; Whipker, 2004). Whipker

Fig. 1. (A) Height, (B) time to flower, and (C) number of flowers of size 9/10 'Nellie White' easter lilies treated with 4-fl oz (118.3 mL) drenches providing 0.0, 0.02, 0.04, 0.08, 0.16, or 0.24 mg flurprimidol per pot or 0.03 or 0.06 mg uniconazole per pot applied to the surface of the substrate when shoots were ≈ 3 inches (7.6 cm) above the substrate surface. Each symbol represents the mean of 10 plants, and error bars represent SE. Different letters are significantly different by Tukey's honestly significant difference test at $P \leq 0.05$; $1 \text{ mg} = 3.5274 \times 10^{-5} \text{ oz}$, $1 \text{ cm} = 0.3937 \text{ inch}$.

(2004) reported that foliar sprays containing $80 \text{ mg}\cdot\text{L}^{-1}$ flurprimidol controlled height of easter lily, while sprays containing $160 \text{ mg}\cdot\text{L}^{-1}$ flurprimidol resulted in similar height control with some lower-leaf yellowing. Although foliar sprays containing 80 to $160 \text{ mg}\cdot\text{L}^{-1}$ flurprimidol applied to 'Star Gazer' oriental lilies when shoots were 7.6 to 10.2 cm tall resulted in plants that were 6% to 13% shorter than control plants, the overall efficacy of foliar sprays containing flurprimidol was considered minimal and not an effective method for controlling

height of 'Star Gazer' lilies (Krug et al., 2005a). Pobudkiewicz and Nowak (1992) reported that while height of 'Prima' asiatic hybrid lilies was 12.3 to 16.5 cm shorter than control plants as flurprimidol spray concentration increased from 10 to $50 \text{ mg}\cdot\text{L}^{-1}$, they observed a delay in time to anthesis (2 to 7 d) and flower bud abortion (8% to 58%) with spray concentrations of 30–50 and 20–50 $\text{mg}\cdot\text{L}^{-1}$, respectively. Similarly, height of 'Mona Lisa' oriental lilies was less than untreated plants when flurprimidol was applied as a foliar spray once or

twice at concentrations ranging from 10 to $40 \text{ mg}\cdot\text{L}^{-1}$ when shoots were 7 or 14 cm tall (Pobudkiewicz and Treder, 2006).

Whipker et al. (2011) reported that while preplant bulb soaks in flurprimidol solutions were effective in suppressing stem elongation of 'Nellie White' easter lilies, however variation in responses year-to-year and among different bulb lots made it difficult to identify a recommendation for bulb soak concentration for commercial production. However, flurprimidol bulb soaks have been reported to be a viable PGR application to control height of other lily species and cultivars (Krug et al., 2005a, Whipker et al., 2011). For instance, soaking 'Star Gazer' bulbs in solutions containing $25 \text{ mg}\cdot\text{L}^{-1}$ produced commercially acceptable plants that were 14.2 cm shorter than control plants (Krug et al., 2005a), while solutions containing ≥ 50 , 200, or $400 \text{ mg}\cdot\text{L}^{-1}$ flurprimidol resulted in excessive height suppression, delayed time to emergence and anthesis, or reduced flower bud number, respectively, compared with untreated plants (Krug et al., 2005a). Whipker et al. (2011) reported that while PGR solutions containing 10–20 $\text{mg}\cdot\text{L}^{-1}$ flurprimidol resulted in desirable height control of 'Orange Tiger', 'Pink Tiger', and 'Yellow Tiger' tiger lilies, 'White Tiger' was more sensitive and soak solutions containing $< 10 \text{ mg}\cdot\text{L}^{-1}$ flurprimidol are required; flurprimidol had no effect on time to anthesis or flower bud number for any tiger lily cultivar (Whipker et al., 2011).

Our data from Expt. 1 indicate comparable height control may be obtained by applying flurprimidol at a similar rate as uniconazole (Fig. 1). We determined the cost for making a 4-fl oz substrate drench containing 0.04 to 0.08 mg flurprimidol per pot or 0.06 mg uniconazole per pot using PGR CALC (Krug and Whipker, 2010). Using the average wholesale price for name-brand chemicals, it would cost \$1.17 to \$2.34 or \$11.12 per thousand 6-inch containers to apply flurprimidol or uniconazole, respectively, for the chemicals used in a drench application. Though the total amount of a.i. of flurprimidol and uniconazole required to achieve similar height control is similar, flurprimidol (\$0.03/mg a.i.) is more affordable compared with uniconazole

Fig. 2. (A) Height, (B) time to flower, and (C) number of flowers of size 10/12 'Nellie White' easter lilies treated with 4-fl oz (118.3 mL) drenches providing 0.0, 0.01, 0.02, 0.04, 0.06, or 0.08 mg flurprimidol per pot applied to the surface of the substrate when shoots were ≈ 3 inches (7.6 cm) above the substrate surface. Each symbol represents the mean of six plants, and error bars represent SE. Regression lines are presented for significant correlations only with corresponding r^2 . *** indicates significant at $P \leq 0.001$; 1 mg = 3.5274×10^{-5} oz, 1 cm = 0.3937 inch.

(\$0.18/mg a.i.) when the cost per milligram of a.i. of the two chemicals is taken into consideration. However, the price for chemicals may vary based on bulk discounts received when large quantities are purchased or if a generic formulation of uniconazole is used.

Producers may want to conduct on-site trials to determine the appropriate concentration of a.i. for their location and production schedule. This is especially important with easter lilies, where variation year-to-year among bulb lots (Larson et al., 1987) and bulb producers (Zlesak and Anderson, 2007) has been reported. Using lower

drench rates of flurprimidol to provide initial height control with subsequent spray applications containing uniconazole on an as-needed basis may be a viable strategy to maintain desired height and accommodate yearly variation in the forcing environment and bulbs.

Conclusions

Flurprimidol is effective in controlling stem length of 'Nellie White' easter lilies when applied in substrate drenches without adversely affecting time to flowering or flower number. Additionally, though we observed

comparable height suppressing activity of flurprimidol and uniconazole on a milligram per milligram basis, flurprimidol appears to be an economical alternative to uniconazole for drench applications because of a reduced chemical cost. While our data indicate applying a drench providing 0.04 to 0.08 mg flurprimidol per pot resulted in desirable height suppression, the flurprimidol concentration required to achieve desired height suppression will depend on the target final height and will vary among producers. Therefore, producers may want to conduct on-site trials to determine appropriate flurprimidol concentrations.

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