Comparison of Flurprimidol to Ancymidol, Paclobutrazol, and Uniconazole for Tulip Height Control

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SUMMARY. **Preplant bulb soaks of ancymidol, flurprimidol, paclobutrazol, and uniconazole; foliar sprays of flurprimidol; and substrate drenches of flurprimidol, paclobutrazol, and uniconazole were compared for height control of 'Prominence' tulips (*Tulipa* sp.). Height control was evaluated at anthesis in the greenhouse and 10 days later under postharvest conditions. Substrate drenches of ancymidol, flurprimidol, and paclobutrazol resulted in adequate control using concentrations of 0.5, 0.5, and 1 mg/pot a.i. (28,350 mg = 1 oz), respectively. At these concentrations, ancymidol drenches cost $0.06/pot and paclobutrazol drenches $0.03/pot. Since flurprimidol is not yet available and no price is available, growers will need to assess the cost compared to ancymidol and paclobutrazol. Flurprimidol foliar sprays at <80 mg·L^{-1} (ppm) were ineffective in controlling height during greenhouse forcing, but during postharvest evaluation 80 mg·L^{-1} resulted in 14% shorter plants than the untreated control. Preplant bulb soaks of flurprimidol, paclobutrazol, and uniconazole at concentrations of 25, 50, and 10 mg·L^{-1}, respectively, effectively controlled plant height. Preplant plant growth regulator soaks are a cost-effective method of controlling plant height of tulips because of the limited amount of chemical required to treat a large quantity of bulbs.**

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Potted tulips are popular greenhouse crops due to their minimal spacing requirements and short benching time (Miller, 2002). DeHertogh (1996) suggested that an optimal height for pot tulips is 20 to 25 cm (7.9 to 9.8 inches), excluding the pot, to meet shipping requirements. A potential postharvest problem is the downward curvature of the flower scape due to excessive postharvest elongation of the stem and the heavy inflorescence. To control height, plant growth regulators (PGRs) are often required. Dole and Wilkins (1999) recommended an ancymidol (A-Rest; SePRO, Carmel, Ind.) drench of 0.125 to 0.5 mg/pot a.i. with higher concentrations being used for more vigorous cultivars, while Barrett (2002) recommended ancymidol drenches of 1 to 4 mg·L^{-1} per pot within the first 2 d of greenhouse forcing. Paclobutrazol (Bonzi; Syngenta, Greensboro, N.C.) label recommendations call for drenches of 0.31 to 2.5 mg/pot a.i. or 1-h preplant soaks in a 2 to 5 mg·L^{-1} solution. Tulips are listed on the uniconazole (Sumagic; Valent USA, Marysville, Ohio) label, but no recommended concentrations are provided. The recommendation for flurprimidol (Topflor; SePRO Corp., Carmel, Ind.) in Europe is two foliar applications of 0.25 to 0.5 mg·L^{-1}, 1 week apart (M. Bell, personal communication). Flurprimidol is available in Europe as a 1.5% concentrate, but the formulation being introduced into the U.S. will be a 0.38% concentrate. This study was conducted to compare the efficacy of flurprimidol preplant soaks, foliar sprays, and substrate drenches with the current commercial recommendations of ancymidol, paclobutrazol, and uniconazole for tulip height control.

Materials and methods

Noncooled *Tulipa* 'Prominence' bulbs were planted in standard 10.2-cm-diameter (4 inches) round plastic pots with a volume of 575 mL (0.6 qt) on 25 Oct. 2002 with three bulbs per pot. The root substrate was Berger BM 6 (Berger Peat Moss, St. Modeste, Que.), which contained 75% to 80% Canadian sphagnum peat and 20% to 25% perlite. For 10 weeks the cooler temperature set point was 5.0 °C (41 °F). On 4 Jan. 2003 the cooler temperature set point was reduced to 1.1 °C (34 °F) until 8 Feb. 2003. Greenhouse forcing began on 8 Feb. 2003 with day/night set points of 20.0/17.8 °C (68/64 °F). Plants were forced under natural day length. Pots were fertilized with nitrogen at 150 mg·L^{-1} using 15N–0P–12.5K once per week.

PLANT GROWTH REGULATOR TREATMENTS. On 25 Oct. 2002, preplant bulb soaks applied for 10 min included: flurprimidol (0.38%) at 25, 50, 100, 200, or 400 mg·L^{-1}; paclobutrazol at 25, 50, 100, 200, or 400 mg·L^{-1}; and uniconazole at 5, 10, 20, 40, or 80 mg·L^{-1}. The PGR substrate drenches were applied within 24 h of when forcing began (9 Feb.); plants were between 7.6 and 10.2 (3 to 4 inches) cm tall at application time. Substrate drenches were applied at 59.1 mL (2 fl oz) per pot and included: flurprimidol at 0.25, 0.5, 1, 2, or 4 mg/pot a.i.; paclobutrazol at 0.25, 0.5, 1, 2, or 4 mg/pot a.i.; and ancymidol at 0.0625, 0.125, 0.25, 0.5, or 1 mg/pot a.i.. A foliar spray of flurprimidol at 5, 10, 20, 40, or 80 mg·L^{-1} was also applied based on the application rate of 203.7 mL·m^{-2} (0.5 gal/100 ft^2). An untreated control was also included. The experiment was a completely randomized design with six pot replications with three plants per pot for each of the 36 treatments. At anthesis (all petals fully colored and beginning to separate), plant height (measured from the soil line to the uppermost part of the inflorescence), was recorded.

POSTHARVEST. Four pots, randomly selected, from each treatment were placed in a growth chamber at 20.0 °C after anthesis. Light was provided by fluorescent bulbs at 24 to 75 µmol·m^{-2}·s^{-1}. Plant height was recorded 10 d after anthesis.

DATA ANALYSIS. Data were tested by analysis of variance (ANOVA) using general linear model (SAS Institute, Cary, N.C.) and means were separated by least significant differences (LSD) at $P \leq 0.05$. Plant heights at the end of forcing and postharvest were regressed using the PROC REG to determine the best-fit, linear or quadratic, model. Terms of the model were evaluated for significance based on a comparison of F values at $\alpha = 0.05$. PROC NLIN in SAS, as modified by

Cox (1992), was used to calculate linear-plateau functions (model IV) relating forcing and postharvest plant height to flurprimidol, paclobutrazol, and uniconazole preplant bulb soaks as well as ancymidol, paclobutrazol, and flurprimidol substrate drenches. The quadratic and the linear-plateau models were compared to determine the best fit based on r^2 values.

Results and discussion

Substrate drenches. Substrate drenches ≥0.45 mg/pot ancymidol, during forcing, resulted in the shortest plants at 21.6 cm (8.50 inches) tall (Fig. 1A). No further increases in height control occurred at higher concentrations. Plants treated with ancymidol at 0.45 mg/pot were 24% shorter than the untreated control at the end of forcing. At the end of postharvest, the shortest plants were 33.4 cm (13.15 inches) tall, 27% shorter than the untreated control, resulting from treatment with concentrations ≥0.40 mg/pot (Fig. 1A). No further increases in control occurred at higher concentrations. An ancymidol drench provided commercially acceptable control at a concentration of 0.5 mg/pot. At a concentration of 0.5 mg/pot, plants were 27% shorter during forcing and 34% shorter at postharvest evaluation than the untreated control. Concentrations <0.5 mg/pot resulted in control which varied from pot to pot. Anthesis was delayed by <2 d at a concentration of 1 mg/pot (data not shown). An ancymidol drench of 0.5 mg/pot is in agreement with recommendations by Dole and Wilkins (1999). A concentration of 0.5 mg/pot is equivalent to 8 mg·L^{-1}, which is at least twice the rate recommended by Barrett (2002); however, no volume recommendations were provided, which may account for the difference in recommended concentrations.

Substrate drenches ≥1.51 mg/pot paclobutrazol during forcing produced the shortest plants at 20.7 cm (8.15 inches) (Fig. 1B). No further increases in height control occurred at higher concentrations. During postharvest evaluation the smallest plants were 32.4 cm (12.76 inches) tall resulting from treatment with ≥1.58 mg/pot paclobutrazol (Fig. 1B). No further increases in height control occurred at higher concentrations. Although the joinpoints were 1.51 and 1.58 mg/pot for forcing and postharvest

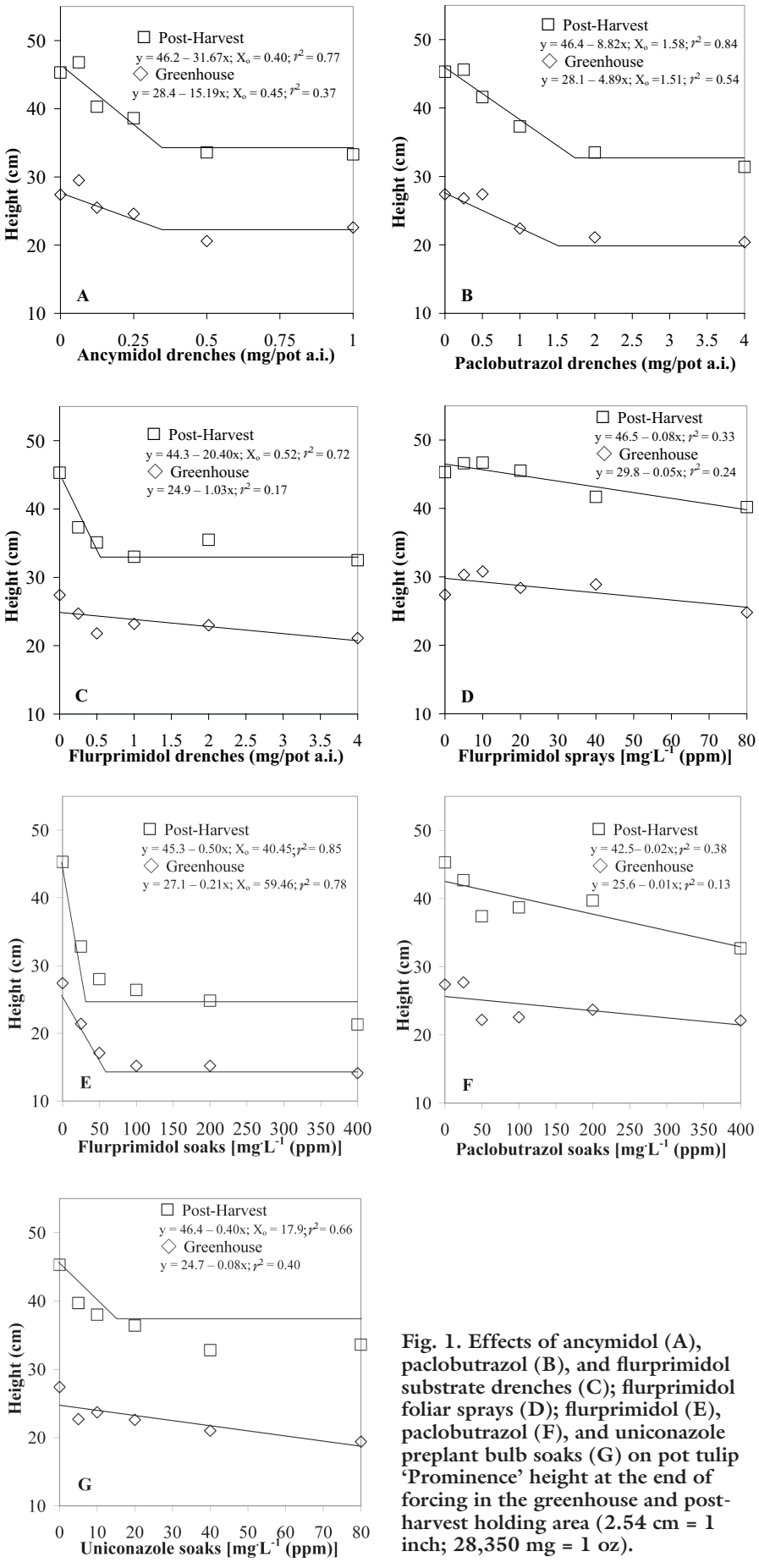

Fig. 1. Effects of ancymidol (A), paclobutrazol (B), and flurprimidol substrate drenches (C); flurprimidol foliar sprays (D); flurprimidol (E), paclobutrazol (F), and uniconazole preplant bulb soaks (G) on pot tulip 'Prominence' height at the end of forcing in the greenhouse and postharvest holding area (2.54 cm = 1 inch; 28,350 mg = 1 oz).

evaluation, respectively, a concentration of 1 mg/pot provided adequate growth control with higher concentrations being excessive. At the concentration of 1.0 mg/pot, plants were 17% shorter during forcing and 19% shorter at postharvest evaluation than the untreated control. Concentrations lower than 1 mg/pot resulted in height control which varied from pot to pot. Paclobutrazol at a concentration of 1 mg/pot is within the range stated on the product label (0.31 to 2.5 mg/pot). No delay of anthesis occurred at any concentration trialed (data not shown).

Tulip growth was controlled ($P \leq 0.05$) during forcing by substrate drenches ≥0.5 mg/pot flurprimidol resulting in at least 2% shorter plants than the control (Fig. 1C). After postharvest evaluation the shortest plants were 33.6 cm (13.23 inches) tall resulting from treatment with ≥0.52 mg/pot flurprimidol (Fig. 1C). No further increases in height control occurred at higher concentrations. Plants were 23% shorter than the control. No delay of anthesis occurred with substrate drenches of flurprimidol (data not shown). Although 0.5 mg/pot flurprimidol resulted in plants 2% shorter; greater control (24%) was provided during postharvest and would be useful for commercial operations, despite the minimal control provided during forcing.

Substrate drenches of ancymidol, flurprimidol, and paclobutrazol at concentrations of 0.5, 0.5, and 1 mg/pot, respectively, provided similar and adequate growth control. Paclobutrazol drenches appeared to have produced a more uniform plant to plant response, within the pot, when compared to flurprimidol or uniconazole drenches at concentrations trialed. A substrate drench of 0.5 mg/pot ancymidol costs $0.06/pot which may be cost prohibitive as compared to a of 1 mg/pot paclobutrazol drench at $0.03/pot. Flurprimidol has not yet been released for sale in the U.S. Growers will need to assess the cost of a 0.5 mg/pot flurprimidol substrate drench to compare with ancymidol and paclobutrazol costs.

FOLIAR SPRAYS. Flurprimidol foliar sprays did not control height during greenhouse forcing (Fig. 1D). Concentrations of 5 and 10 mg·L^{-1} resulted in heights taller than the control, $P \leq 0.05$. During postharvest evaluation, the highest concentration applied (80 mg·L^{-1}) resulted in 14% shorter plants than the control. The lack of response to foliar sprays during greenhouse forcing contradicts the commercial practice in Europe of applying foliar sprays. This suggests that multiple sprays should be trialed or a foliar spray of ≥80 mg·L^{-1} may be used to improve postharvest quality of shorter cultivars which do not require height control during greenhouse forcing.

Foliar sprays of flurprimidol were ineffective at concentrations trialed during greenhouse forcing. Only a small amount of leaf area was present at the time of treatment, which may have limited absorption. Delaying application or the use of a spreader/sticker may be beneficial. Higher concentrations did give minimal postharvest control on 'Prominence' plants. Growers who want to improve postharvest quality on shorter cultivars may consider using flurprimidol foliar sprays at concentrations >80 mg·L^{-1}.

PREPLANT BULB SOAKS. Flurprimidol preplant bulb soaks ≥59.4 mg·L^{-1} during forcing produced the shortest plants at 14.8 cm (5.83 inches) tall (Fig. 1E), 46% shorter than the untreated control. No further increases in height control occurred at higher concentrations. During the postharvest evaluation flurprimidol preplant bulb soaks ≥40.4 mg·L^{-1} produced the shortest plants at 25.1 cm (9.88 inches) tall (Fig. 1E). No further increases in height control occurred at higher concentrations. Plants were 45% shorter than the untreated control. Although joinpoints for forcing and postharvest evaluation were 59.4 and 40.4 mg·L^{-1}, respectively, concentrations >25 mg·L^{-1} resulted in excessive growth control. Commercially acceptable plants were produced with 25 mg·L^{-1} resulting in plants 19% shorter during forcing and 28% shorter at postharvest evaluation than the untreated control. Flurprimidol preplant soaks at 25 mg·L^{-1} resulted in some leaf distortion and flowering appeared to be uneven within the pot (personal observation). A delay of anthesis ≤3 d occurred at concentrations of flurprimidol ≥25 mg·L^{-1}, but the delay would not be considered commercially significant (data not shown).

Plant height linearly (negative) correlated with increased paclobutrazol preplant soaks during forcing and at postharvest evaluation (Fig. 1F). Concentrations ≥50 mg·L^{-1} controlled height with plants ≥1.9% shorter than the untreated control. At postharvest evaluation, 50 mg·L^{-1} resulted in plants 2% shorter than the untreated control. Although plants were only minimally shorter than the untreated control when treated with 50 mg·L^{-1}, it was statistically significant ($P \leq 0.05$). Based on our observations, 50 mg·L^{-1} paclobutrazol provided adequate height control, which is much greater than the labeled recommendation (2 to 5 mg·L^{-1}). However, the label recommends soaking bulbs for 1 h, while in this experiment, the bulbs were soaked for only 10 min, which may account for differences between our findings and the label recommendations. Individual growers will need to assess chemical costs vs. application time required for soaking to determine if high concentration and short duration soaks are more economical than low concentration and longer soaks. Anthesis was delayed by <2 d with concentrations of 25 and 400 mg·L^{-1} paclobutrazol, but the delay would not be considered commercially significant.

Uniconazole preplant bulb soaks controlled plant height during forcing at concentrations ≥5 mg·L^{-1} resulting in plants at least 2% shorter than the control (Fig. 1G). Commercially acceptable height control was provided at a concentration of 10 mg·L^{-1}. Plants during forcing and postharvest evaluation were 3% and 9%, respectively, shorter than the untreated control when treated with 10 mg·L^{-1} uniconazole. Uniconizole preplant bulb soaks ≥17.9 mg·L^{-1} during postharvest produced plants at 39.2 cm (15.43 inches) tall (Fig. 1G). No further increases in height control occurred at higher concentrations. Uniconazole concentrations ≥17.9 mg·L^{-1} resulted in plants with an unacceptable variation in individual plant heights within the pot. Therefore, 10 mg·L^{-1} uniconazole should be used for commercial production. Delayed anthesis of <2 d occurred at concentrations of uniconazole ≥20 mg·L^{-1} (data not shown).

Flurprimidol, paclobutrazol and uniconazole preplant bulb soaks at concentrations of 25, 50, and 10 mg·L^{-1}, respectively, provided similar and commercially acceptable growth control. Additional trials to confirm optimal concentrations and cultivar response to flurprimidol preplant bulb soaks should center around the 25 mg·L^{-1}

concentration range. Preplant soaks are an efficient method of controlling plant height of tulips because of the limited amount of chemical required to treat a large amount of bulbs. For example, using 59.1 mL of solution per pot (three bulbs per pot), approximately 85 pots containing 250 bulbs could be treated using a substrate drench with 5 L (1.3 gal) of solution. Although it has not been determined how many bulbs can be effectively treated with a preplant soak using a given volume of solution, it is foreseeable that more than 250 bulbs could be soaked with 5 L of solution.

Conclusions

Flurprimidol is suitable for height control as a substrate drench at 0.5 mg/pot or a preplant bulb soak at 25 mg·L^{-1} with 'Prominence' tulip. Further work is required to determine the suitability of foliar sprays. Growers will need to determine if a preplant bulb soak or a substrate drench is the preferred method of controlling plant height, depending on individual production practices and labor costs.

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