Effects of plant growth regulators on the plant height and quantitative properties of Narcissus tazetta

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Abstract: The effects of flurprimidol, paclobutrazol, and ethephon treatment as soil drench on plant height and quantitative and other properties of native narcissus (Narcissus tazetta L.) plants grown in pots were investigated. When the plants were 7–10 cm tall, flurprimidol and paclobutrazol at 0, 1, and 2 mg/pot and ethephon at 0, 37.5, and 75 mg/pot were applied as soil drenches. The effects of plant growth retardant treatments on plant height, leaf length, time of flowering, number of flowers, and flower life were determined. In addition, quantitative measurements (leaf area ratio, specific leaf area, leaf thickness, leaf weight ratio, and stem weight ratio) were analyzed in native narcissus. When narcissus grown in pots in the greenhouse reached the sale stage, the plants were taken to the laboratory at 20 °C to evaluate the postproduction life and quality of pot plants. Flurprimidol, paclobutrazol, and ethephon shortened plant height. The shortest plant height was obtained from 2 mg/pot paclobutrazol; plant height was 5.42 cm, 65% shorter than the untreated controls. Chemical applications also shortened leaf length. The shortest leaf length (13.25 cm) was obtained from the 2 mg/pot paclobutrazol treatment. The chemical treatment decreased the leaf area ratio and specific leaf area, but increased the leaf thickness and leaf weight ratio compared to the control plants. The effects of treatments on plant height continued in laboratory (home-office) conditions after production. The shortest plant height (9.5 cm) was obtained from the 2 mg/pot paclobutrazol treatment, whereas the height of untreated control plants was 24.25 cm during the postproduction life of pot plants.

Key words: Ethephon, flurprimidol, Narcissus, paclobutrazol, plant height, quantitative measurements

1. Introduction
Native narcissus (Narcissus tazetta L.) from the family Amaryllidaceae has 3–20 fragrant flowers in a stem. Narcissus flowers are of importance with their rich alkaloids used in the medical and cosmetics industries. They are also commonly used in parks, gardens, and refuges as ornamental plants (Kebeli and Çelikel, 2013). Narcissus flowers with long stems are used as cut flowers. In addition, Narcissus is also used as a potted plant indoors. However, their excessive elongation after production in consumer conditions with low light makes it difficult to use them as indoor plants. Elongation also causes downward curvature of the flower stem with heavy inflorescence. Therefore, plant height control is important for maintaining compactness and aesthetic appearance, as well as preventing damage during transportation and marketing due to stem elongation (Çelikel et al., 2016). We may control plant height either by physical methods with environmental factors (light, temperature, etc.) or by chemical methods with growth regulators, mostly gibberellin inhibitors (flurprimidol, paclobutrazol, ancymidol, and uniconazole) (Miller, 2012; Demir and Çelikel, 2013; Çelikel et al., 2016). Ethephon is also used to prevent increase in plant height (Miller and Olberg, 2016). Ethephon is a plant growth regulator that releases ethylene on application and can inhibit stem elongation and stimulate branching (Miller et al., 2012; Miller and Olberg, 2016).

Plant height of 'Tete a Tete' narcissus cultivar in the postproduction period was controlled by ethephon foliar spray at 1500 ppm and paclobutrazol substrate drench of 4 mg/pot concentration (Krug et al., 2006). A substrate drench of 100, 250, or 500 ppm ethephon was applied to different narcissus cultivars. Compared to untreated controls, ethephon reduced the plant height and the effect increased with increased concentration (Miller et al., 2012). Ethephon drenches are suggested to be a useful method of height control in narcissus in pots. A drench of 200 ppm ethephon provided excellent control for most narcissus cultivars with little effect as rates increased up to 500 ppm (Miller et al., 2013). Root zone ethanol concentrations of 1% and 5% (v/v) were effective..
in reducing the height of ‘Ziva’ paperwhite narcissus (*N. tazetta*) without visible phototoxicity to the roots. These plants were reported to be normal in other respects (Miller and Finan, 2006). Flurprimidol soil drench treatments showed excellent control of postharvest stem and leaf growth in different *Hyacinthus* cultivars (Miller, 2010). Soil drench of flurprimidol and paclobutrazol resulted in adequate height control of tulips (Krug et al., 2005).

The effects of flurprimidol, paclobutrazol, and ethephon have been investigated in narcissus cultivars and other species before but there was no previous study on *N. tazetta* L. naturally growing in the Black Sea Region of Turkey. The effects of treatments on the quantitative properties of flowers also have not been studied before. Therefore, we investigated the effects of flurprimidol, paclobutrazol, and ethephon treatments as soil drench on plant height and quantitative and other properties of native *N. tazetta* L. grown in pots.

2. Materials and methods

Native narcissus bulbs with circumference of 12 cm from Ünye District in Ordu were used. The bulbs were planted in 15-cm-diameter plastic pots (1.6-L volume) containing soil, peat, and perlite (1:1:1), one bulb per pot, on 7 October 2013. The plants were grown in a polyethylene-covered greenhouse and irrigated as needed with tap water. Soil drench of flurprimidol (Sigma-Aldrich) and paclobutrazol (25% Cultar; Syngenta) at 0, 1, and 2 mg/pot and ethephon (48% a.i., Efhun; Agrobest, Turkey) at 0, 37.5, and 75 mg/pot were applied 150 mL per pot when the shoots were 7–10 cm (10 November 2013). Ethanol (141 mg/pot) was used as a solvent of flurprimidol. Therefore, a control for the solvent was included in these experiments.

2.1. Postproduction evaluation

When they reached the sale stage (one open flower in a stem with buds), four replicate plants randomly selected from each treatment were taken to the laboratory on 14 February 2014 (130 days after planting) (Figure 1). Postproduction life and quality of pot plants were evaluated in this laboratory at 20 °C illuminated with cool white fluorescent light of 1000 lux at bench level, under a diurnal cycle of 12 h day/12 h night as standard conditions (Çelikel and Karaçalı, 1991, 1995; Çelikel, 1993; Çelikel et al., 2011).

2.2. Flowering time, number of flowers, and flower life

Flowering time was determined as number of days from planting time to opening of the first flower. *Narcissus* started to open their flowers in the greenhouse. When the first flower opened, it was recorded as flowering time and then they were taken to the lab for postproduction evaluation. Therefore, flowering time was determined in the greenhouse, but number of flowers and flower life were determined in the laboratory (during the postproduction period). Numbers of flowers were determined for each stem. Flower life was calculated as the number of days from the opening of the first flower to the wilting of the last flower.

2.3. Leaf length

The longest leaves for each plant were measured weekly. Leaf length measurement started 21 days after planting (28 October 2013), when they started to emerge.

2.4. Plant height

The plant heights were measured from the pot rim to the uppermost point of the inflorescence. Plant height measurement started 91 days after planting (6 January 2014), when the flower shoots started to emerge.

When narcissus reached the sale stage (one open flower in a stem with buds) greenhouse measurements were completed, and leaf length and plant height measurements continued in the lab (14 February 2014, 130 days after from planting). The plants stayed in the laboratory 2 weeks. The first week started on 14 February 2014 and the second on 21 February 2014.

Figure 1. *N. tazetta* L. in the laboratory for postproduction evaluation.
2.5. Quantitative measurements (leaf area ratio, specific leaf area, leaf thickness, leaf weight ratio, and stem (bulb) weight ratio)

The plant growth parameters (Uzun and Kar, 2004) investigated were dry weights of leaves, stems, and roots of the plants with 3 replications for each treatment in order to determine leaf area ratio (LAR), specific leaf area (SLA), leaf thickness (LT), leaf weight ratio (LWR), and stem (bulb) weight ratio (SWR). After all narcissus flowers wilted in the lab (17 March 2014), the bulb (modified stem), leaves, and roots were separated from each plant. Fresh leaves were placed on paper and leaf area was measured with a planimeter ('Koizumi Placom') on photocopies of these papers. Drying of different plant parts was implemented at 80 °C over 3 days in an oven ('Ecocell'). The growth parameters were calculated according to the formulas given in Table 1.

2.6. Data analysis

The data were tested by one way analysis of variance (ANOVA) using a completely randomized design. The study was conducted with 10 replications except for 3 replications for quantitative analyses and 4 replications for postproduction evaluation. The obtained data were analyzed statistically by SPSS. The mean and standard error (X ± Sx) values were determined. Differences between means were separated by Duncan’s multiple range test (P ≤ 0.01).

3. Results

3.1. Flowering time, number of flowers, and flower life

There was a significant difference (P ≤ 0.01) among the applications (Table 2). The effects of flurprimidol, paclobutrazol, and ethephon applications on the number of days from planting to flowering are given in Table 2 for native narcissus. The earliest flowering was obtained from ethanol and the control with 106 and 109 days, respectively, and all plant growth regulators delayed flowering. The latest flowering was obtained from 75 mg/pot ethephon with 123 days. Number of flowers and flower life were determined in the postproduction period.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Flowering time (days to flowering)</th>
<th>Number of flowers</th>
<th>Flower life (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>109.25 ± 2.14 c</td>
<td>7.00 ± 0.41 a</td>
<td>17.67 ± 0.65 a</td>
</tr>
<tr>
<td>Ethanol</td>
<td>106.25 ± 2.11 c</td>
<td>5.80 ± 0.75 b</td>
<td>17.50 ± 0.28 a</td>
</tr>
<tr>
<td>1 mg flurprimidol</td>
<td>118.00 ± 0.58 b</td>
<td>6.00 ± 0.71 b</td>
<td>16.50 ± 0.82 ab</td>
</tr>
<tr>
<td>2 mg flurprimidol</td>
<td>119.86 ± 1.74 ab</td>
<td>5.70 ± 0.52 b</td>
<td>16.00 ± 0.76 ab</td>
</tr>
<tr>
<td>1 mg paclobutrazol</td>
<td>121.67 ± 1.23 ab</td>
<td>6.00 ± 0.71 b</td>
<td>17.00 ± 0.52 a</td>
</tr>
<tr>
<td>2 mg paclobutrazol</td>
<td>122.14 ± 1.33 ab</td>
<td>5.70 ± 0.76 b</td>
<td>16.17 ± 0.47 ab</td>
</tr>
<tr>
<td>37.5 mg ethephon</td>
<td>121.53 ± 1.86 ab</td>
<td>5.70 ± 0.80 b</td>
<td>15.17 ± 0.17 ab</td>
</tr>
<tr>
<td>75 mg ethephon</td>
<td>123.16 ± 1.02 a</td>
<td>5.60 ± 0.62 b</td>
<td>15.38 ± 0.53 ab</td>
</tr>
</tbody>
</table>

*Different letters in the same column indicate differences among treatments according to Duncan’s multiple range test (1%).

Table 1. Determination methods for plant growth parameters for quantitative analysis (Uzun and Kar, 2004).

<table>
<thead>
<tr>
<th>Plant growth parameter</th>
<th>Calculation models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf area ratio (LAR)</td>
<td>Total leaf area (cm²)/total plant dry weight (g)</td>
</tr>
<tr>
<td>Specific leaf area (SLA)</td>
<td>Total leaf area (cm²)/total leaf dry weight (g)</td>
</tr>
<tr>
<td>Leaf thickness (LT)</td>
<td>1/specific leaf area (cm² g⁻¹)</td>
</tr>
<tr>
<td>Leaf weight ratio (LWR)</td>
<td>Total leaf dry weight (g)/total plant dry weight (g)</td>
</tr>
<tr>
<td>Stem weight ratio (SWR)</td>
<td>Total stem dry weight (g)/total plant dry weight (g)</td>
</tr>
</tbody>
</table>
paclobutrazol, ethephon, and ethanol treatments reduced flower numbers compared to the control (Table 2). The results showed that plant growth regulator applications shortened flower life by 2 days compared to the control.

3.2. Leaf length
There was a significant difference ($P \leq 0.01$) among the applications for leaf length (Table 2). The shortest leaf length (13.25 and 13.60 cm) was obtained from 2 mg/pot paclobutrazol and 2 mg/pot flurprimidol, respectively, while the control was 18.4 cm (Table 3; Figure 2). The longest leaf length was 21.8 cm, in the ethanol application. The continuing effects of chemical application on leaf length during postproduction in lab (home-office) conditions are given in Figure 3. The shortest leaf length was obtained from 2 mg/pot paclobutrazol application with 11.75 cm, while the control was 24.25 cm (Figure 3). The differences in leaf lengths among the applications were maintained in the postproduction period.

3.3. Plant height
The treatments significantly affected ($P \leq 0.01$) plant height. Chemicals reduced plant height. The shortest plant height was 5.4 cm in the plants to which 2 mg/pot paclobutrazol was applied, while the control was 15.6 cm and ethanol was 13.4 cm (Table 3; Figure 4). The effects of applications on plant height during postproduction lab (home-office) conditions are given in Figure 5. The shortest plant height was obtained from 2 mg/pot paclobutrazol application with 9.5 cm, while the control was 24.25 cm in the postproduction period. The narcissus plants treated with different concentrations of flurprimidol and ethephon were also shorter than the untreated control in lab conditions (Figure 5). The effects of chemicals on plant height are given in Figures 6–8. These pictures were taken 134 days after planting (18 February 2014, fifth day in lab).

3.4. Quantitative analysis
According to the results of the quantitative analysis of native narcissus treated with flurprimidol, paclobutrazol, and ethephon, mean values of LAR, SLA, LT, LWR, and SWR are given in Tables 4 and 5.

3.4.1. Leaf area ratio (LAR)
Plant growth regulators affected LAR significantly ($P \leq 0.01$). While 2 mg/pot paclobutrazol application gave the lowest LAR (4.69 cm$^2$/g) and the highest LAR (10.25 cm$^2$/g) was obtained from ethanol application, the control was 8.06 cm$^2$/g (Table 4).

3.4.2. Specific leaf area (SLA)
The difference among the applications was significant ($P \leq 0.01$). While 75 mg/pot ethephon provided the lowest SLA, 69.8 cm$^2$/g, the control was 101.2 cm$^2$/g (Table 4). The highest SLA (103.83 cm$^2$/g) was obtained from ethanol treatment. Flurprimidol and paclobutrazol applications also decreased SLA.

3.4.3. Leaf thickness (LT)
Flurprimidol, paclobutrazol, and ethephon increased LT, but there was no significant difference ($P > 0.05$) among the applications. The highest LT was 0.016, 0.015, and 0.014 g/cm$^2$ in 2 mg/pot paclobutrazol, 75 mg/pot ethephon, and 2 mg/pot flurprimidol, respectively, while the control was 0.010 g/cm$^2$ (Table 4).

3.4.4. Leaf weight ratio (LWR)
The treatments affected LWR significantly ($P \leq 0.01$). The lowest LWR (0.08 g) was obtained from the control; the highest LWR (0.12 g) was from the plants treated with 2 mg/pot paclobutrazol (Table 5).

Table 3. The effects of flurprimidol, paclobutrazol, and ethephon on leaf length and plant height of *N. tazetta* L. (at the end of greenhouse production). Mean ± standard error ($X \pm S\bar{E}$).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Leaf length (cm)</th>
<th>Plant height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>18.40 ± 0.80 b</td>
<td>15.63 ± 0.43 a</td>
</tr>
<tr>
<td>Ethanol</td>
<td>21.80 ± 0.99 a</td>
<td>13.38 ± 1.75 a</td>
</tr>
<tr>
<td>1 mg flurprimidol</td>
<td>15.10 ± 0.63 cd</td>
<td>7.25 ± 0.60 bc</td>
</tr>
<tr>
<td>2 mg flurprimidol</td>
<td>13.60 ± 0.70 d</td>
<td>7.06 ± 0.88 bc</td>
</tr>
<tr>
<td>1 mg paclobutrazol</td>
<td>15.75 ± 1.27 c</td>
<td>6.20 ± 1.33 bc</td>
</tr>
<tr>
<td>2 mg paclobutrazol</td>
<td>13.25 ± 0.56 d</td>
<td>5.42 ± 0.64 c</td>
</tr>
<tr>
<td>37.5 mg ethephon</td>
<td>15.05 ± 0.64 cd</td>
<td>9.44 ± 1.16 b</td>
</tr>
<tr>
<td>75 mg ethephon</td>
<td>14.55 ± 0.75 cd</td>
<td>7.67 ± 1.33 bc</td>
</tr>
<tr>
<td>Significance</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Different letters in the same column indicate differences among treatments according to Duncan’s multiple range test (1%).

Figure 2. Effects of flurprimidol (FP), paclobutrazol (PB), and ethephon (EP) treatments on leaf length of *N. tazetta* L. during greenhouse production. Leaf length measurement started 21 days after planting (28 October 2014).
3.4.5. Stem weight ratio (SWR)
No significant difference (P > 0.05) was found among the applications (Table 5).

4. Discussion
4.1. Flowering time, number of flowers, and flower life
The plant growth regulators delayed the flowering time of narcissus. The latest flowering was obtained from 75 mg/
Figure 6. The effects of flurprimidol (FP) soil drench on *N. tazetta* L. (134 days after planting, fifth day in the lab).

Figure 7. The effects of paclobutrazol (PB) soil drench on *N. tazetta* L. (134 days after planting, fifth day in the lab).

Figure 8. The effects of ethephon (EP) soil drench on *N. tazetta* L. (134 days after planting, fifth day in the lab).
pot ethephon with 123 days, while ethanol and the control were 106 and 109 days, respectively. The gibberellin inhibitors also delayed flowering time about 9–11 days. It was reported that ethephon drench delayed the flowering time of bedding plants (Miller et al., 2012). A delay was observed in some Iris cultivars in the visible appearance buds in plants treated with paclobutrazol (Francescangeli, 2009). The application of paclobutrazol delayed the appearance of the flower color in Petunia (Francescangeli and Zagabria, 2009). Flurprimidol application caused flowering delay and reduced the inflorescence and flower diameter of Ornithogalum saundersiae (Salachana and Zawadzińska, 2013). Flowering time was not affected by lower rates of flurprimidol, but it was slightly delayed when flurprimidol was applied at higher doses in the ‘Mona Lisa’ lily cultivar (Pobudkiewicz and Treder, 2006). It is well known that exogenous ethylene applications affect various aspects of flower development, including delay in floral initiation, flower bud abortion and senescence of flower buds, wilting of petals, or failure of the bud to open (Reid, 1987; Miller et al., 2012). In our study ethephon and gibberellin inhibitors decreased the number of flowers. Blázquez et al. (1998) reported that the gibberellin class of plant hormones has been implicated in the control of flowering in several species. It was reported by Wilson et al. (1992) that exogenous GA₃ promoted the switch from vegetative growth to flowering in a variety of plants. Therefore, the gibberellin inhibitors used in our study affected flowering. Treatments affected the duration of the cycle.

The longest flower life in native narcissus (N. tazetta L.) was 17.7 days in the control and the shortest flower life was 15.2 days in the 37.5 mg/pot ethephon treatment (Table 2). It was found that the flower life in native narcissus varied between 2 and 3 weeks (Acarsoy and Özzambak, 2006). The higher doses of flurprimidol and paclobutrazol applications shortened flower life only 1 day, while ethephon treatment shortened it 2 days. Ethephon similarly shortened the flower life in other cultivated varieties of narcissus before (Miller et al., 2012). The higher doses of these plant growth regulators also significantly reduced plant height.

### 4.2. Leaf length
Plants treated with 2 mg/pot paclobutrazol (13.25 cm) and 2 mg/pot flurprimidol (13.60 cm) were 28% and 26%
shorter than the control plants (Table 3; Figure 2). The longest leaf length was 21.8 and 18.4 cm in the ethanol application and untreated control, respectively. It was reported that ethephon treatment shortened the leaf length of ‘Primeur’ and ‘Tete a Tete’ narcissus cultivars (Miller and Olberg, 2016). Uniconazole foliar spray caused a reduction in leaf length and width of *Fuchsia x hybrida* (Kim, 1995). The tepal size, leaf size, and pedicel length of plants treated with flurprimidol were smaller than the control plants in the ‘Mona Lisa’ lily cultivar (Pobudkiewicz and Treder, 2006). The use of flurprimidol resulted in shorter leaves in *Ornithogalum saundersiae* (Salachana and Zawadzińska, 2013) and *Zantedeschia aethiopica* (Gonzalez et al., 1999). Similarly in our study flurprimidol and the other chemicals were effective in shortening the leaf length of narcissus during both the greenhouse and postproduction periods.

**4.3. Plant height**

The shortest plant height (5.4 and 6.2 cm) was obtained from 2 mg/pot and 1 mg/pot paclobutrazol treatments, respectively, whereas the control plants (15.6 cm) were the longest ones (Table 3). Plants treated with 2 mg/pot paclobutrazol were 65% shorter than the controls. Flurprimidol and ethephon also shortened plant height. Plants treated with 2 mg/pot flurprimidol and 75 mg/pot ethephon were 55% and 51% shorter than the untreated controls. It was reported that flurprimidol was an effective growth retardant in reducing stem extension of the ‘Mona Lisa’ lily cultivar without adverse side effects (Pobudkiewicz and Treder, 2006). Paclobutrazol substrate drenches controlled the plant height of the ‘Tete a Tete’ narcissus cultivar during greenhouse forcing (Kruger et al., 2006). Ethephon drench at 500 ppm similarly shortened the plant height of ‘Ice Follies’ narcissus before (Miller et al., 2012). Ethephon at 500 and 1000 ppm applied as gas to *Hyacinthus orientalis* had no significant effect (Acarsoy and Özzambak, 2006). Plumbago plants with the use of ethephon drench at 125 to 250 mg L⁻¹ were shorter and had higher aesthetic appeal due to increased flowering (Barker et al., 2016). Soil drenches of uniconazole retarded shoot and petiole elongation of *Brassia actinophylla* (Wang et al., 1990). In another study, flurprimidol, paclobutrazol, and uniconazole suppressed the height of ‘Divine Cherry Red’, ‘Divine Scarlet Bronze Leaf’, and ‘Divine White Blush’ *Impatiens hawkeri* cultivars (Currey et al., 2016). *Narcissus* plants treated with plant growth regulators in the present study were shorter than the control plants during the postproduction evaluation (Figure 5). Our results clearly indicated that the effect of plant growth regulator applications on plant height and leaf length continued in the laboratory (home-office) conditions during the postproduction period (Figures 3 and 5). The height differences between control and treated plants were maintained in the postproduction period. ‘Tete a Tete’ narcissus plants treated with 0.69 mg/pot flurprimidol were 15% shorter than the controls at the end of the postproduction evaluation (Krug et al., 2006). We found that flurprimidol, paclobutrazol, and ethephon effectively controlled plant height not only during production in the greenhouse but also after production and there was no significant difference between low and high doses of chemicals (Figures 4 and 5).

**4.4. Quantitative analysis**

There was a significant difference (P ≤ 0.01) among the applications. According to the results of quantitative analysis in native narcissus, the highest LAR was 8.06 cm²/g, in the control plants, while the lowest LAR was 4.69 cm²/g, in the 2 mg/pot paclobutrazol application (Table 4). Flurprimidol and ethephon also decreased LAR. The LAR is the ratio of total leaf area to total plant dry weight (Uzun and Kar, 2004). Therefore, plants treated with plant growth retardants showed a more compact appearance and a shorter structure with a smaller area (Table 4). As a result of compactness, both the leaf areas and the LAR decreased (Table 4). Ethephon at 100 and 200 ppm concentration similarly decreased the leaf area of *Diospyros kaki* (Kim et al., 2004).

The highest SLA was 103.8 and 101.2 cm²/g, in the ethanol and control treatments, respectively, while the lowest SLA was 69.8 cm²/g, in the 75 mg/pot ethephon application (Table 4). Paclobutrazol and flurprimidol treatments also decreased SLA (Table 4). The SLA of a plant is calculated according to the formula given in Table 1 as the ratio of the leaf area to the leaf dry weight (Uzun and Kar, 2004). Thus, plants treated with plant growth retardants were more compact with smaller SLA than the controls (Table 4). Uniconazole decreased SLA and increased LT and mesophyll density of longan (Nie et al., 2001). Uniconazole is also a gibberellin inhibitor like paclobutrazol and flurprimidol.

The results showed that all chemical treatments increased LT. The highest LT was 0.016 g/cm², in the plants treated with 2 mg/pot paclobutrazol, while the lowest LT was 0.010 g/cm², in the control plants (Table 4). However, the difference between the applications was not significant (P > 0.05). LT was calculated as 1/specific leaf area (Uzun and Kar, 2004). LT is dry mass in the unit area of leaves. It was found that the dry weight of the leaves increased in the unit area. Thus, the leaves of these plants were thicker and shorter than those of the controls (Table 4). This increase is probably due to the increase in dry mass per unit area as a result of chlorophyll increasing in the unit area of leaves. It was reported that chlorocholine chloride increased the biomass of leaves in *Lilium* Oriental hybrids ‘Sorbonne’ (Zheng et al., 2012). Chlorocholine chloride is an antigibberellin growth retardant. This
kind of gibberellin inhibitor has been extensively used to manipulate growth in plants (Wang et al., 2009; Zheng et al., 2012). In a study of *Chrysanthemum* it was shown that different concentrations of paclobutrazol increased LT and the leaves of treated plants were a darker green than the untreated controls (Burrows et al., 1992). It was reported that the increased thickness was due to increases in spongy and palisade mesophyll thickness (Burrows et al., 1992). In another study paclobutrazol treatment increased the thickness of the palisade and spongy layer, leaf epidermis, and cuticle in *Catharanthus roseus*. This increase caused an increase in LT (Jaleel et al., 2007).

The highest LWR was 0.12 g, in the 2 mg/pot paclobutrazol treatment, while the lowest LWR was 0.08 g, in the untreated control plants (Table 5). The LWR of a plant is the ratio of leaf weight to the whole plant dry weight (Uzun and Kar, 2004). As a result of the applications, the leaf weight per unit area increased compared to the control.

There was no difference (P > 0.05) in SWR among the applications (Table 5). Modified stem (bulb) weight ratio is the ratio of total dry stem weight to whole plant dry weight (Uzun and Kar, 2004). In *Narcissus*, bulbs were considered the stem and thus the SWR was calculated as the ratio of bulb dry weight to the whole plant dry weight. In another study uniconazole and daminozide gibberellin inhibitor treatments reduced stem dry weight compared to the control in *Chrysanthemum* (Schuch, 1994). Dry weights of leaves and stem decreased with increasing concentration of paclobutrazol and uniconazole in *Kalanchoe* (Lee et al., 2003), but SWR has not been studied. Paclobutrazol, uniconazole, and daminozide treatments commonly controlled plant growth by inhibiting gibberellin biosynthesis.

In conclusion, both gibberellin inhibitors and ethephon applications reduced plant height and leaf length. The effects of these treatments on *N. tazetta* continued during the postproduction period. Moreover, ethephon, flurprimidol, and paclobutrazol also affected LT, SLA, and LAR. The plant growth regulators increased the dry weight of leaves in unit area. We found that lower doses of these plant growth regulators also controlled the plant height of *Narcissus* in both greenhouse and postproduction conditions. In addition, the number of flowers and flower life of the plants treated with lower doses were higher compared to the other concentrations. Therefore, we suggest 37.5 mg/pot ethephon or 1 mg/pot flurprimidol or paclobutrazol treatments, the lower concentration, as soil drench when shoots are about 7–10 cm in height in order to provide plant height control and maintain postproduction quality of *N. tazetta* grown in pots.

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