Forcing Temperature Affects Postproduction Quality, Dark Respiration Rate, and Ethylene Responsiveness of Pelargonium × domesticum

Kathleen B. Evensen and Karen M. Olson
Department of Horticulture, Penn State University, University Park PA 16802

Abstract. Postproduction quality, net C exchange, and petal abscission in response to ethylene were compared following forcing at 21(day)/16C(night) or 18/13C(18-hour photoperiod) of two cultivars of Pelargonium × domesticum L.H. Bailey. Fewer petals of 2- to 6-day-old florets abscised in response to 60 minutes of 0.7 µl ethylene/liter on plants forced at low temperature than on plants forced at 3C higher temperature. Forcing temperature did not affect floret longevity or the number of florets opening during forcing, but the floral display under simulated consumer conditions was prolonged in low-temperature plants by the continued development of buds. Dark respiration rates at 21C were lower in leaves from plants forced at low temperature than in leaves of plants forced at the higher temperature. Differences in postproduction quality between plants forced at high and low temperatures may have been related to the reduced rate of carbohydrate depletion in low-temperature plants.

Materials and Methods

Plant material. Two genetically related cultivars of P. × domesticum were chosen for study: ‘Virginia’, a commercial cultivar, and ‘Majestic’, a progeny of ‘Virginia’ × ‘Lavender Grand Slam’, previously referred to as ‘PSU-1’ (Olson and Evensen, 1990). Stock plants, started from culture-virus-indexed cuttings (Oglevee Assocs., Connellsville, Pa.) were maintained in the Penn State horticulture greenhouses. Cuttings harvested from stock plants were cut to 8 cm, dipped in a rooting powder containing 1-naphthaleneacetic acid, and rooted in cell packs filled with Metromix 215 (Grace Horticultural Products, Cambridge, Mass.) for 4 weeks in a greenhouse equipped with bottom heat and intermittent mist.

Floral initiation was promoted by exposing rooted cuttings to high irradiance and low temperature for 4 weeks in a controlled-environment room. An irradiance of 250 ± 15 µmol·s−1·m−2 for an 18-h photoperiod was provided by metal halide lamps (High Intensity Discharge Super Metalarc 400 R, Sylvania-GTE, Manchester, N.H.). The temperature was maintained at 16(day)/11C (night) ± 1C. Plants were fertilized with each subirrigation by use of a solution of 190 mg N/liter made from 15N-7P-14.1K fertilizer (Peter’s Fertilizer Products, Fogelsville, Pa.).

Floral-initiated plants were selected for uniformity and transplanted one per 1.5-liter (15.2-cm) azalea pot in Metromix 350 (Grace Horticultural Products). Pots were randomly placed in one of two controlled-environment growth chambers (Model CEL 5122-27, Sherer/Gillett, Marshall, Mich.) for forcing. The temperature cycles were 21(day)/16C (night) ± 1C (high) and 18(day)/13C (night) ± 1C (low). The irradiance was 350 ± 15 µmol·s−1·m−2, provided by cool-white fluorescent and incandescent lamps (Philips Lighting Co., Somerset, N.J., 14% incandescent on a wattage basis), with an 18-h photoperiod. Plants were fertilized with each drip irrigation with a solution of 250 mg N/liter using two applications of 15N-7P-14.1K for every one application of 20N-0P-16.6K fertilizer (Peter’s Fertilizer Products). Foliar sprays of insecticidal soap were used before anthesis to control whitefly populations.

Environmental monitoring and instrumentation. Photosynthetic photon flux was measured at midshoot height with a solar monitor equipped with a quantum sensor (Model LI-185B, LI-COR, Lincoln, Neb.) at the beginning and end of the growth period in each of the controlled environments (floral initiation,
forcing, and postproduction). During forcing, irradiance was also measured at 2-week intervals. Air temperatures were measured at midshoot height by maximum-minimum thermometers (Model 5458, Taylor Scientific Consumer Instruments, Arden, N.C.), with an ethanol thermometer calibrated against an NBS standard thermometer, and by recording hygrothermographs (Model 594, Friez/Bendix Co., Baltimore).

Evaluation of ethylene responsiveness. The ethylene responsiveness of randomly selected plants was evaluated 16 ± 3 days after first anthesis. Plants were treated with ethylene in darkness at 25 ± 1°C in a sealed, modified controlled-environment chamber (Model 4005-0, Sherer/Gillet) equipped with four additional fans to improve circulation. Ethylene from source gas of 21 to 25 µl·liter⁻¹ was added continuously to the chamber to maintain 0.7 µl ethylene/liter. Gas samples were taken at 2-min intervals, and ethylene concentration was determined using a Hewlett Packard 5840A gas chromatography equipped with a flame ionization detector and a column of activated alumina. The desired concentration of ethylene was reached within 8 to 14 min and remained ±0.1 µl·liter⁻¹ for the duration of the treatment. Ethylene samples taken at six locations in the chamber indicated that within 10 min from the start of treatment, the ethylene concentration varied only ±0.05 µl·liter⁻¹ within the chamber. To keep ethylene exposure consistent between treatments, the dose of ethylene was determined as parts per billion-hours (ppb-h), the product of concentration and duration in hours (Barden and Hanan, 1972). Ethylene exposure was complete when the total dose reached 700 ppb-h as determined by 2-min interval gas sampling. The duration of treatment was 68 ± 6 min. Control plants were placed in the chamber for 68 min with addition of air instead of ethylene.

Petal abscission was evaluated 1 h after completion of ethylene treatment, since it had been determined in previous experiments that abscission was complete within that time. The percent of petals with ≥50% abscised petals was calculated for each floret age. Two experiments were conducted, with a total of seven plants of each cultivar, temperature, and ethylene treatment.

Evaluation of postproduction longevity. To evaluate duration of floral display, plants that were not treated with ethylene were moved (16 ± 3 days after first anthesis) to a SCE. The SCE was maintained at 50% ± 15% relative humidity (using a dehumidifier). 21 ± 1°C, with lighting from fluorescent lamps at 32 ± 5 µmol·s⁻¹·m⁻² for 12 h daily. Constant, uniform moisture was provided to the growing medium by a capillary mat system. Air scrubbers containing KMnO₄ (Purafil, Atlanta) were used to prevent ethylene accumulation. Individual floret longevity was determined from the dates of floral anthesis and senescence. Petals were considered senescent if they wilted or if ≥50% of the petals had abscised. The duration of the floral display was defined as the number of days from placement in the SCE until five or fewer healthy petals remained on the plant. Six plants of each cultivar and forcing temperature combination were evaluated in each of two experiments for floret longevity and duration of floral display.

Measurement of net CO₂ flux. Net CO₂ flux of the youngest fully expanded intact leaves was determined with a LICOR LI-6200 Photosynthesis System using a 0.25-liter leaf chamber. Measurements were made at 21 ± 1°C in the forcing growth chambers at four irradiance levels: 0, 15, 30, and 60 ± 5 µmol·s⁻¹·m⁻², achieved by using curtains of cheesecloth and black cloth. Plants were held at the test irradiance for at least 2 h before measurement.

Results

Floral development and longevity. Plants forced at 21(day)/16°C (night) flowered 5 to 6 days earlier than plants forced at 18(day)/13°C (night) (Table 1). Plants of ‘Virginia’ reached first anthesis 7 days earlier than plants of ‘Majestic’ forced at the same temperature. After first flowering, the number of open florets per plant increased steadily to a peak of ≈60 on ‘Virginia’ and ≈50 on ‘Majestic’. The peak floral display (maximum number of open florets per plant) occurred 13 to 15 days after transfer to the SCE in ‘Virginia’ plants and 6 to 8 days after transfer to the SCE in ‘Majestic’.

Forcing temperature did not affect the number of florets per plant that opened during the forcing period (up to the 16th day after first anthesis) (Table 1). However, the number of florets that opened after transfer to the SCE was significantly higher for low-temperature plants of both cultivars. More florets opened during forcing and fewer in the SCE on ‘Majestic’ than on ‘Virginia’ (Table 1). Forcing temperature did not affect the number of inflorescences per plant or the number of florets per inflorescence, but ‘Virginia’ produced about twice as many inflorescences and ≈20% more florets than ‘Majestic’.

The floral display on low-temperature plants was significantly longer than on high-temperature plants (Table 2). However, the longevity of individual florets that opened either during forcing or in the SCE did not differ between temperature treatments. Floral display and floret longevity lasted longer for ‘Virginia’ than for ‘Majestic’ plants grown at the same temperature, both in the forcing environment and in the SCE.

Individual floret longevity remained constant during the forcing period but declined after transfer to the SCE (data not shown). The mean floret longevity of all florets that opened in the SCE was shorter than the longevity of all florets that opened in the forcing environment (Table 2).

Petal abscission. Petal abscission following ethylene treatment of whole plants increased sharply as florets aged (Fig. 1). Ethylene-induced petal abscission of florets 2 to 6 days old was significantly higher in plants forced at high temperature. Petals on control plants did not abscise during the course of the experiment. There was no significant difference between cultivars in the abscission response.

Net carbon exchange. The dark respiration rate (net C flux at zero irradiance) of leaves of high-temperature plants was significantly higher (more negative net CO₂ exchange) than that of low-temperature plants of both cultivars (Fig. 2). In all treatments, the light compensation point (LCP, net C exchange = 0) was between 15 and 30 µmol·s⁻¹·m⁻². There were no obvious differences in vegetative morphology between low- and high-temperature plants.

The increase in net CO₂ exchange with increased irradiance
Table 1. Influence of forcing temperature on floral development. Data shown are means ± SE.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Forcing temp (°C) (day/night)</th>
<th>Time to first anthesis (days)</th>
<th>Florets opening during forcing (no./plant)</th>
<th>Florets opening after transfer to SCE* (no./plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>21/16</td>
<td>31.0 ± 1.2 c</td>
<td>30.4 ± 3.1 b</td>
<td>61.6 ± 4.4 b</td>
</tr>
<tr>
<td></td>
<td>18/13</td>
<td>36.2 ± 0.1 b</td>
<td>28.2 ± 2.7 b</td>
<td>69.1 ± 6.3 a</td>
</tr>
<tr>
<td>Majestic</td>
<td>21/16</td>
<td>38.2 ± 0.6 b</td>
<td>39.9 ± 2.4 a</td>
<td>35.3 ± 2.6 d</td>
</tr>
<tr>
<td></td>
<td>18/13</td>
<td>43.8 ± 0.6 a</td>
<td>39.4 ± 1.9 a</td>
<td>43.9 ± 2.9 c</td>
</tr>
</tbody>
</table>

*SCE = simulated consumer environment.
†Mean separation within columns by Duncan’s multiple range test, \( P < 0.05, N = 12 \) plants.

Table 2. Influence of forcing temperature on duration of floral display and floret longevity. Data shown are means ± SE.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Forcing temp (°C) (day/night)</th>
<th>Duration of floral display in the SCE* (days)</th>
<th>Floret longevity in the forcing environment (days)</th>
<th>Floret longevity in the SCE (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>21/16</td>
<td>28.2 ± 1.1 b</td>
<td>18.6 ± 0.2 a</td>
<td>17.4 ± 0.2 a</td>
</tr>
<tr>
<td></td>
<td>18/13</td>
<td>33.0 ± 0.9 a</td>
<td>17.7 ± 0.2 a</td>
<td>16.4 ± 0.2 a</td>
</tr>
<tr>
<td>Majestic</td>
<td>21/16</td>
<td>21.2 ± 0.7 c</td>
<td>14.2 ± 0.2 b</td>
<td>12.8 ± 0.2 b</td>
</tr>
<tr>
<td></td>
<td>18/13</td>
<td>28.2 ± 1.2 b</td>
<td>13.5 ± 0.2 b</td>
<td>11.4 ± 0.2 b</td>
</tr>
</tbody>
</table>

*Duration of floral display was the number of days from placement in the SCE (simulated consumer environment) until five or fewer healthy florets remained on the plant.
†Mean separation within columns by Duncan’s multiple range test, \( P < 0.05, N = 12 \) plants.

Fig. 1. Percent of florets exhibiting at least 50% petal abscission following treatment of whole plants with 0.7 µl ethylene/liter for 68 min at 25°C. There were 14 plants per treatment, each bearing at least 18 florets of each age ≤6 days. Forcing temperature significantly affected ethylene-induced abscission in florets 2 to 6 days old (ANOVA, \( P < 0.05 \)). Data for the two cultivars were pooled.

Discussion

The extent of petal abscission in response to ethylene strongly depended on floret age (Fig. 1; Denke et al., 1990; Evensen, 1991; Olson and Evensen, 1990). In this paper, we have shown that forcing at low temperature reduces this ethylene responsiveness (Fig. 1). However, this did not account for the superior postproduction quality of low temperature-forced plants, since individual floret longevity was similar between the temperature treatments in the absence of exogenous ethylene (Table 2). During shipping, when exogenous ethylene may be present, plants grown at relatively low temperatures would abscise fewer petals than plants grown at higher temperatures.

The major factor contributing to the prolonged floral display in plants forced at 18/13°C was the number of new florets that low temperature-grown plants continued to develop and support. The improved bud development of low-temperature plants was related to metabolic rates. The LCP of all plants was near the irradiance level in the SCE (32 µmol·s⁻¹·m⁻²). Since the photoperiod in the SCE was 12 h, the daily C balance of all plants was negative and carbohydrates were continually depleted. Low-temperature plants exhibited a lower dark respiration rate and, therefore, would metabolize carbohydrate reserves more slowly than high-temperature plants. Decreased production temperature has been associated with increased carbohydrate levels in leaves of *P. × hortorum* (White and Warrington, 1984) and poinsettia (*Euphorbia pulcherrima* Willd. ex KL) (Senecal et al., 1989). In our study, the low-temperature plants probably had higher carbohydrate reserves at the onset of the postproduction period.

The relationship between metabolic rates and postproduction quality is further supported by comparison of the two cultivars: ‘Majestic’, which had a higher dark respiration rate than ‘Virginia’ at both forcing temperatures (Fig. 2), also had a shorter floral display (Table 2). However, the dark respiration rate did not seem to be related to floret longevity, since there were no significant differences in floret longevity between forcing temperatures (Table 2). Longevity of florets that opened in the SCE, which had lower irradiance and a higher mean daily temperature than the forcing environments, was less than that of florets that opened earlier (Table 2). While this relationship could be interpreted as a result of faster carbohydrate depletion in the SCE, it is also possible that the longevity of florets reaching anthesis...
late in the flowering cycle would have been shorter, regardless of the environment in which the plants were held. Greater floret longevity, in addition to continued bud development, contributed to the longer floral display in ‘Virginia’ than in ‘Majestic’.


