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# Temperature, Irradiance, Photoperiod, and Growth Retardants Influence Greenhouse Production of *Angelonia angustifolia* Benth. Angel Mist Series

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***Abstract*. The influence of temperature, irradiance, photoperiod and growth retardants on growth and flowering of *Angelonia angustifolia* Angel Mist series was evaluated. When temperature was increased from 15 to 30 °C, time to visible bud and time to flower decreased in a quadratic manner but total plant height and flower stem dry weight increased linearly. As irradiance increased, time to flower, time to visible bud, and height decreased quadratically. Changes in photoperiod had no effect on growth or flowering, suggesting that *A. angustifolia* is a day-neutral species with regards to height and flowering time. Daminozide, ancymidol, and paclobutrazol resulted in significant reduction of plant height compared with control plants but did not influence flowering time. Chemical names used: K-cyclopropyl-K-(4-methoxyphenyl)-5-pyrimidinemethanol (ancymidol); butanedioic acid mono (2,2-dimethylhydrazide) (daminozide); K-[(4-chlorophenyl)methyl]-K-(1,1-dimethyethyl)-1*H*-1,2,4-triazole-1-ethanol (paclobutrazol).**

*Angelonia angustifolia* Benth. (Scrophulariaceae) is native to Mexico and the West Indies. This genus has potential to become a major annual crop in floriculture due to its season-long color and ease of propagation. Plants in this genus are known for their heat tolerance (Bruggeman, 1957) and have recently been incorporated into active breeding programs in a number of major flower-breeding firms. Recently, companies have been successful in breeding resistance to various viruses, in particular the cucumber mosaic virus, which has further revived interest in *Angelonia* as a landscape plant. These efforts have led to the release of the Angel Mist series, a virus-free series of cultivars available in a range of colors. However, little is known about optimal temperature, irradiance level, photoperiod, and growth-retardant use for production of this species.

With the exception of *Antirrhinum majus* L. (snapdragon), little research has been conducted on ornamental plants in the Scrophulariaceae family. In general, *Antirrhinum* is a facultative long-day (LD) plant in which short days retard flowering in most cultivars (Hedley, 1974). Miller (1962) found that optimum temperature for growth of snapdragons decreased as plants matured. Tayama and Miller (1965) also determined that optimal temperature decreased from 21 °C for 4-week-old plants to 13 °C when plants were 24 weeks old. The growth retardant uniconizole was effective in reducing height, while gibberellic acid increased height (Holcomb and Rose, 1990; Rak and Nowak, 1989). Research with *Veronica longifolia* L., also in Scrophulariaceae, determined that plants were day-neutral (Ball, 1998).

Although little scientific information has been published on *Angelonia*, Haas (1996), Armitage (1997), and Oschmann (1999) suggested potential for the species as a pot plant, landscape subject, and cut-flower crop, respectively. Unpublished data on *A. angustifolia* (Ball FloraPlant, Elburn, Ill.) was conducted on a broad range of temperatures and photoperiods for growth. The company determined that plants grew well in temperatures >15 °C, but did not respond to different photoperiods. To confirm this and to extend information to other environmental variables, experiments were conducted to determine the optimal photoperiod, temperature, irradiance, and growth retardants for greenhouse production of *A. angustifolia* Angel Mist series.

## Materials and Methods

*Temperature*. Twenty-four rooted tip cuttings (4 weeks old) on each of five cultivars that make up the Angel Mist series of *Angelonia angustifolia* were received on 6 Feb. 1999. The cuttings were transplanted into 10-cm pots containing a commercial soilless medium (Fafard 6-M; Fafard Co., Anderson, S.C.) and were pinched to three nodes 1 week after transplanting. After 9 d, eight plants of each cultivar were placed in growth chambers (Conviron 3244; Conviron, Asheville, N.C.) at constant day and night temperatures of 15 ± 2, 22 ± 2, or 30 ± 3 °C. All plants received 800 ± 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of light from incandescent and fluorescent lamps as measured with a quantum sensor (LI-188B; LI-COR, Lincoln, Nebr.). Plants were rotated within each chamber weekly to ensure equal light exposure, at which time the distances between the plants and the lights were adjusted to maintain similar light levels. Plants were illuminated for 16 h because of preliminary work (Armitage et al., 2000; Ball FloraPlant, unpublished data) that showed no detrimental effect of that photoperiod. Pots were irrigated with constant liquid feed at 200 $mg \cdot L^{-1}$ N provided by 15–0–15 fertilizer (Peter's Dark Weather Feed; Scotts Co., Milpitas, Calif.) as needed. The pots were leached on every fifth irrigation to prevent soluble salt accumulation. Data were taken on days to visible bud (bud >1 mm), days to flower (two flowers open on the raceme), total height at flowering (height from soil to top of plant), and dry weight of the first flower stem. The flower stem was harvested for dry-weight measurement when about half the flowers on the raceme reached anthesis. The statistical design was completely randomized with eight single-plant replications.

*Irradiance*. Thirty cuttings of each cultivar were transplanted as previously described. The plants were placed in a glass greenhouse on 15 Feb. 1999 controlled by a Q-COM environmental control system (Q-COM Corp., Irvine, Calif.). Temperature set points were 20 °C day and night temperatures; however, actual temperatures ranged from 20 ± 5 °C day/19 ± 3 °C night. Ten cuttings of each cultivar were placed in natural day (ND); ND + 900 ± 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$; or ND +1200 ± 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$. ND photoperiod was 10 h 56 min on the first day of the experiment and 13 h 6 min on the last day of the experiment. Two high-intensity discharge (HID) lights (400-W metal halide) were used in each supplemental treatment. Light intensity was controlled by the distance between the lamps and the apices of the plants. Light intensity was measured using a quantum sensor (LI-188B; LI-COR) at night and lamps were adjusted every week. Lights were on 24 h each day. The average daily irradiance (*PPF*) for the duration of the study (weeks 5–15) was obtained from the Georgia Automated Environmental Monitoring Network at Watkinsville, ≈16 km from the Georgia campus (Fig. 1). Irrigation and data collection were as described in the temperature experiments. The statistical design was completely randomized, with 10 single-plant replications.

*Photoperiod*. Ninety tip cuttings of each cultivar were received on 10 Dec. 1999 and transplanted as previously described. The plants were pinched to two nodes on 20 Dec. 1999 and again on 14 Jan. 2000 to ensure no reproductive tissue was present. Ten plants of each cultivar were placed into nine treatments on 18 Jan. 2000. They were continuous ND, continuous short day (SD), and continuous long day (LD) with night break. Remaining treatments were 2 weeks SD, then LD; 4 weeks SD, then LD; 6 weeks SD, then LD; 2 weeks LD, then SD; 4 weeks LD, then SD; or 6 weeks LD, then SD. All plants were covered with blackcloth each day from 1700 to 0800 hr. Long-day treatments were provided by night interruption by 40-W incandescent bulbs

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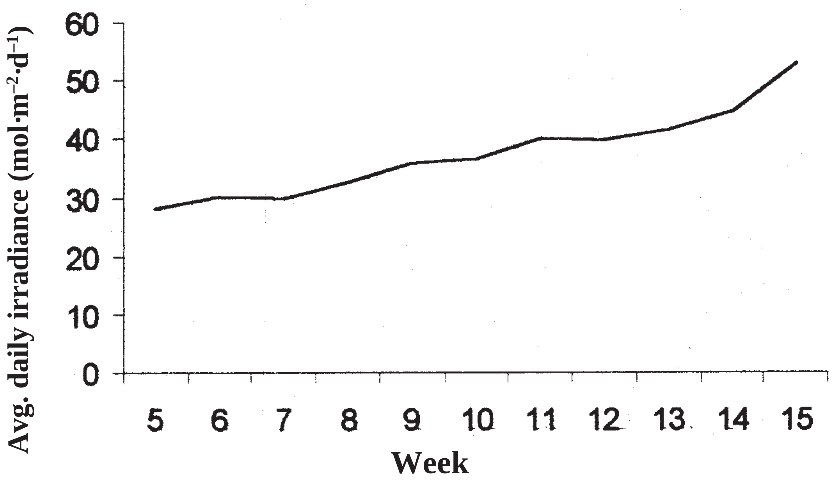


Fig. 1. Irradiance levels for Athens, Ga., weeks 5 to 15, 1999. Data obtained from the Georgia Automated Environmental Monitoring Network at Watkinsville, ≈16 km from the Georgia campus.

providing ≈µmol·m$^{-2}$·s$^{-1}$, from 2200 until 0200 hr, also under the cloth. Night temperatures under the cloth under LD and SD conditions were 20 ± 5 and 19 ± 3 °C, respectively. Day temperatures in the greenhouse were 20 ± 5 °C. Irrigation and data collection were as described in the temperature experiments. The statistical design was completely randomized, with 10 single-plant replications.

*Growth Retardants*. Cuttings of all cultivars were received and transplanted into 10-cm pots in a glass greenhouse on 15 Dec. 1999. The cuttings were transplanted in a commercial soilless medium (Fafard 6-M) and were pinched to two nodes 1 week after transplanting, similar to the previous experiment. Ten plants of each cultivar received one of the following treatments: ancymidol at 50 or 100 mg·L$^{-1}$; paclobutrazol at 50 or 100 mg·L$^{-1}$; daminozide at 2500 or 5000 mg·L$^{-1}$; or control. On 5 Jan. 2000, ≈10 mL of ancymidol and daminozide were sprayed on each plant, resulting in some spray runoff. About 8 mL/plant of paclobutrazol was applied in order to minimize runoff. Night/day temperatures, fertilization, irrigation, and data collection were as previously described. The statistical design was completely randomized, with 10 single-plant replications.

*Statistical analysis*. Data were tested by analysis of variance using the SAS General Linear Model (SAS Institute, Cary, N.C.), and means separated with Duncan's multiple range test, or trend analysis where appropriate.

## Results and Discussion

All cultivars responded similarly to all experiments; therefore, only the data from 'Angel Mist Pink' are presented.

*Temperature*. Increasing the temperature from 15 to 22 °C decreased time to visible bud and flowering; however, no additional decreases occurred when the temperature was raised above 22 °C, resulting in a quadratic response to temperature (Table 1). Total height of the flowering plant increased linearly as temperature rose. Shoot dry weight also increased in a linear manner as temperature increased. The results show that increasing the temperature significantly influences flowering and growth of *Angelonia*. This response is similar to that of other tropical species, such as *Hamelia patens* Jacq., which flowered faster at 25 or 30 °C than at 20 °C (Armitage, 1995) and *Aseschynanthus* Jack 'Koral', which also flowered faster as temperatures increased (Whitton and Healy, 1991). In contrast, although snapdragons are closely related, they are a cool-tolerant species and show little flower delay when soil temperatures decreased from 24 to 20 °C (Seeley, 1965). Visually, plants in the 22 °C chamber were of higher quality than plants in the other chambers. The foliage was obviously greener, the internodes were shorter than those in the 30 °C chamber, and the stems were obviously stouter. Plants in the 15 °C chamber were shorter than plants in other temperatures (Table 1) but the foliage exhibited chlorosis throughout, with stunted leaves and some marginal necrosis. Plants in the 30 °C chamber were taller than plants in the other chambers, and the stems were thin and brittle, and easily broken.

In general, the flowering time and flower stem dry weight were negatively affected by the 15 °C treatment. Plants were stunted, perhaps from the inability to absorb nutrients at cooler temperatures and overall slower biological activity. The plants grew more slowly at 15 °C than at other temperatures, and were smaller and weighed less at anthesis. Based on the data presented, an optimum day/night temperature of ≈22 °C is suggested.

*Irradiance*. As irradiance levels increased, days to visible bud and days to flower decreased. The greatest decrease in time for both occurred between ND and ND + 900 µmol·m$^{-2}$·s$^{-1}$. A further increase in intensity to ND + 1200 µmol·m$^{-2}$·s$^{-1}$ resulted in less response, thus a significant quadratic trend (Table 2). Total height of the plant also showed a quadratic decrease at higher irradiance intensities, with the highest light level resulting in the shortest plants. Dry weight of the flower

Table 1. Influence of temperature on growth and flowering of *Angelonia angustifolia* 'Angel Mist Pink'. Plants were grown in growth chambers and illuminated with 800 ± 50 µmol·m$^{-2}$·s$^{-1}$ of light from incandescent and fluorescent lamps for 16 h each day.

| | Chamber temp | | | |
|---|---|---|---|---|
| | 15 °C | 22 °C | 30 °C | Significance |
| Days to visible bud | 54 | 42 | 44 | L,Q[z] |
| Days to flower | 58 | 47 | 50 | L,Q |
| Total ht (cm) | 31.4 | 51.5 | 68.2 | L |
| Flower shoot dry wt (g) | 4.6 | 8.1 | 9.3 | L |

[z]Linear (L) or quadratic (Q) response at $P \leq 0.05$.

Table 2. Influence of irradiance on growth and flowering of *Angelonia angustifolia* 'Angel Mist Pink'. Temperatures were 20 ± 5 °C day/19 ± 3 °C night.

| | Irradiance treatment | | | |
|---|---|---|---|---|
| | ND[z] | ND + 900[y] | ND + 1200[x] | Significance |
| Days to visible bud | 46 | 39 | 35 | L,Q |
| Days to flower | 57 | 49 | 45 | L,Q |
| Total height (cm) | 32.1 | 34.0 | 29.0 | L,Q |
| Flower shoot dry weight (g) | 7.8 | 7.4 | 6.9 | NS |

[z]ND = Natural day.
[y]Natural day + 900 µmol·m$^{-2}$·s$^{-1}$ photon irradiance level.
[x]Natural day + 1200 µmol·m$^{-2}$·s$^{-1}$ photon irradiance level.
[NS]Nonsignificant, linear (L), or quadratic (Q) response at $P \leq 0.05$.

Table 3. Influence of growth retardants on growth and flowering of Angelonia 'Angel Pink Mist', with temperatures of 20 ± 5 °C day/19 ± 3 °C night.

| | | Chemical applied (mg·L$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ancymidol | | Paclobutrazol | | Daminozide | |
| Criterion | Control | 50 | 100 | 50 | 100 | 2500 | 5000 |
| Days to visible bud | 46 bc | 44 c[z] | 44 c | 46 bc | 45 c | 48 ab | 50 a |
| Days to flower | 57 a | 54 b | 55 ab | 57 a | 57 a | 56 ab | 57 a |
| Total ht (cm) | 47.5 a | 35.7 b | 33.3 bc | 37.0 b | 34.7 b | 32.6 bc | 30.1 c |
| Flower shoot dry wt (g) | 7.7 b | 8.5 b | 8.6 b | 8.3 b | 9.8 a | 6.5 c | 5.4 d |

[z]Means separated by Duncan's multiple range test, $P \leq 0.05$.

stem was unaffected by irradiance. The reduction in days to flower and days to visible bud has been noted in many crops, including snapdragons (Stefanis and Langhans, 1982) and *Gypsophila paniculata* Per. (Hicklenton et al., 1993). Crop production time of *Angelonia* could be shortened by almost 2 weeks with supplemental lighting.

*Photoperiod*. The application of SD or LD affected no parameters measured (data not shown), nor did any significant differences occur in the remaining six treatments (2 weeks SD, then LD; 4 weeks SD, then LD; 6 weeks SD, then LD; 2 weeks LD, then SD; 4 weeks LD, then SD; or 6 weeks LD, then SD) (data not shown). These results are similar to those obtained for *Veronica longifolia* (Ball, 1998), a species in the same taxonomic family. Since the days to visible bud and days to flower were unaffected by photoperiod, plants could be produced without regard to daylength and season across the country. No differences in height and flowering time due to photoperiod were observed in any cultivars in the series, suggesting all cultivars would respond similarly in a common greenhouse range.

*Growth retardants*. Compared to the control, only daminozide at 5000 $mg\cdot L^{-1}$ delayed days to visible flower bud (Table 3). Except for plants treated with 50 $mg\cdot L^{-1}$ of ancymidol, anthesis was not delayed by any plant growth retardants. Total height was reduced by all growth retardants. The greatest reduction in height resulted from the application of daminozide at 5000 $mg\cdot L^{-1}$; however, both concentrations of daminozide decreased flower shoot dry weight (Table 3).

The primary function of a growth retardant is to reduce the height of the plant, and make it more manageable in a container. However, loss of plant volume, as reflected by dry-weight measurement, is not a positive outcome, regardless of height control. All growth retardants tested reduce plant height; however, the reduction in stem dry weight with daminozide may not be acceptable. Both ancymidol and paclobutrazol resulted in significant height reduction without increasing flowering time or resulting in phytotoxicity.

With regard to crop production, the data suggest that *Angelonia* Angel Mist series has potential as a bedding or potted flower crop. The lack of photoperiod response suggests that plants can be produced in all seasons, throughout the country. Flowering times from rooted pinched cuttings were as early as 45 d with supplemental light to 57 d with natural light in 20 to 22 °C greenhouses, a crop time that will not deter growers from producing this crop. In areas with low winter light, supplemental irradiance in winter months can hasten growth and flowering and can be recommended if economically feasible. All cultivars responded similarly to 'Angel Mist Pink' to temperature, irradiance, photoperiod, and growth retardants, making the entire series amenable to greenhouse scheduling.

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