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The Effect of Day and Night Temperature and Irradiance on Development of *Catharanthus roseus* (L.) 'Grape Cooler'

Grace M. Pietsch[1], William H. Carlson[2], Royal D. Heins[2], and James E. Faust[1]
Department of Horticulture, Michigan State University, East Lansing, MI 48824

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Abstract. **The effects of day and night temperatures (15 to 35C) and three irradiance levels [50% of ambient, ambient, and ambient plus 12 mol·m^{-2}·day^{-1} of supplemental photosynthetic photon flux (PPF)] on development of *Catharanthus roseus* 'Grape Cooler' were determined. Time to flower decreased by 30 days and leaf-pair unfolding rate (LUR) increased linearly as average daily temperature increased from 18 to 35C. Flower size was greatest when plants were grown at 25C. Supplemental light decreased days to flower and increased flower size. Flowering occurred when nine leaf pairs were present on the plant. Using the inverse of the LUR curve, i.e., days per leaf pair, the number of days to flower could be predicted at any time during plant development based on plant leaf number.**

The U.S. bedding plant industry produces over 1.5 billion plug seedlings each year (Dill, 1993). One bedding plant species especially tolerant of high summer temperatures is *Catharanthus roseus*, or Madagascar vinca, which accounted for 3.6% of bedding plant flat sales in 1993 (Behe and Beckett, 1993).

When temperatures fall between the base temperature (temperature at which growth rate is zero) and the optimum temperature, development rate can be described by a linear function of average daily temperature (ADT) (Heins and Erwin, 1990; Ritchie and NeSmith, 1991). This linear relationship has been demonstrated in several flowering species, including poinsettia (Berghage and Heins, 1991; Berghage et al., 1990), Easter lily (Erwin et al., 1989), chrysanthemum (Karlsson et al., 1989), hibiscus (Karlsson et al., 1991), geranium (Armitage et al., 1981; Heins, 1979; White and Warrington, 1988), and impatiens (Lee et al., 1990).

The photosynthetic photon flux (PPF) a plant receives can influence flowering time and size. Karlsson et al. (1989) showed that, as PPF increased, time to flower decreased and inflorescence diameter increased in chrysanthemums. Carpenter and Beck (1973) found that 4 weeks of supplemental lighting caused earlier-flowering, shorter, more-compact impatiens, marigolds, petunias, and zinnias. Graper et al. (1990) showed that 5 to 10 days of supplemental lighting decreased time to flower in lo-day-old petunia seedlings. Earlier flowering of plants treated with supplemental lighting results from flower initiation occurring at a node that developed earlier or from warmer average plant temperatures as a result of the thermal radiation and heating from lamps (unpublished data).

The effects of supplemental PPF and the quantitative response of vinca to temperature have not been studied. The objective of this experiment was to quantify the effects of light and temperature on vinca development rate and flowering.

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[1]Former graduate research assistant.
[2]Professor of horticulture.

Materials and Methods

Experiment 1. Five 4.0 × 4.7-m greenhouse sections with three 0.9 × 2.7-m benches were maintained at constant 15, 20, 25, 30, or 35C. Plants on each bench were exposed to a different PPF level: ambient solar radiation (18 mol·m^{-2}·day^{-1} average), 50% of ambient as a result of shading with mesh shadecloth, and ambient plus 250 to 300 µmol·m^{-2}·s^{-1} for 12 h/day (10.8 to 13.0 mol·m^{-2}·day^{-1}) provided by two 400-W high-pressure sodium (HPS) lamps.

Plug trays of g-week-old *Catharanthus roseus* 'Grape Cooler' plants were transplanted into 804-cell packs (eight 150-cm^3 4-cell packs per 29 × 58-cm flat) filled with Baccto potting medium (Michigan Peat Co., Houston) on 5 Mar. 1992. There were three replications, each consisting of one flat. Each flat was assigned a day and night temperature, light level, and replication number. Flats were moved every 12 h among the five greenhouse sections to provide 25 day temperature (DT) and night temperature (NT) treatments. Plants under constant temperature were rearranged each time the other plants were moved. Days to first flower, to 50% of plants in flower per flat, and to 100% of plants in flower per flat were recorded.

Experiment 2. Plugs were received and transplanted 15 Mar. 1993 and were used as a verification of the 1992 experiment. Plants were given the same treatment as those used the previous year except that the supplemental PPF was 200 µmol·m^{-2}·s^{-1} (8.6 mol·m^{-2}·day^{-1}).

Leaf-pair number was counted at transplant. Flower diameter and number of leaf nodes were recorded as each plant came into flower. The uppermost leaf pair on plants that received constant temperature treatments were marked, and leaf-pair numbers were counted every other day,

Flowering data for both years were converted to rates, and linear regression lines were calculated. Slopes and intercepts were compared for statistical differences using the procedure by Snedecor and Cochran (1967). The inverse of each regression line was calculated and plotted to create a curve predicting days to flower.

Linear regression analysis was performed on leaf-pair numbers collected to determine leaf-pair unfolding rates (LURs) as a function of average daily temperature. The slope (b_1) and y intercept (b_0) of each line were used to calculate the base temperature ($-b_0/b_1$) and number of degree days required for one leaf pair to develop ($1/b_1$). The inverse of each LUR curve was calculated and plotted to create a predictive curve for days required for one leaf pair to unfold.

Results

Time to flower decreased as ADT increased (Fig. 1 a-c) without regard to the way temperature was delivered during the daily cycle, i.e., warmer days and cooler nights vs. cooler days and warmer nights. In both experiments, plants with au ADT of 15 or 17.5C under ambient or 50% shade conditions had not flowered when the experiments ended 8 weeks after transplant (15 weeks from seeding). Plants under supplemental light flowered earlier than those at the other two light levels, but also did not flower under an ADT of 15C by the end of the experiment. Flowering occurred in as few as 20 days from transplant at 35C.

There were no statistical differences between regression lines of flower development rate vs. temperature for plants grown under 50% shade when years were compared (Table 1). There was a significant difference (5% level) in the slope between years for plants grown under ambient light. While statistically significant, the difference between the slopes between the 2 years was judged horticulturally insignificant. Data for the 2 years were therefore pooled for the shade and ambient light treatments. However, the slope and intercept were significantly different for the supplemental lighting treatment between years; both years' data therefore were not pooled. Only data from 1993 are shown in Fig. 1.

LUR increased linearly as air temperature increased for all light levels (Fig. 2). LUR regression lines for ambient and supplemental light treatments were statistically parallel, although plants grown under supplemental light had a higher LUR than those under natural light at the same air temperature. LUR under 50% shade increased at a slower rate as temperature increased than LUR in the natural or supplemental light treatments.

Thermal time required for one leaf pair to develop varied from 82 to 127 degree days, with base temperatures varying from 10 to 11.9C (Table 2). Thermal time required for one leaf pair to develop decreased as irradiance increased.

The time required for one leaf pair to unfold decreased from 12 to 4 days as temperature increased from 20 to 35C (Table 3). There was an average of 9.3 leaf pairs on plants when flowering occurred, and the average number of leaf pairs unfolded at the time the plugs were transplanted was 4.9; therefore, about 4.4 leaf pairs developed after transplant and before flowering.

The LUR model (Fig. 2) was compared with that of time to flower (Fig. 1) by comparing the number of days required for 4.4

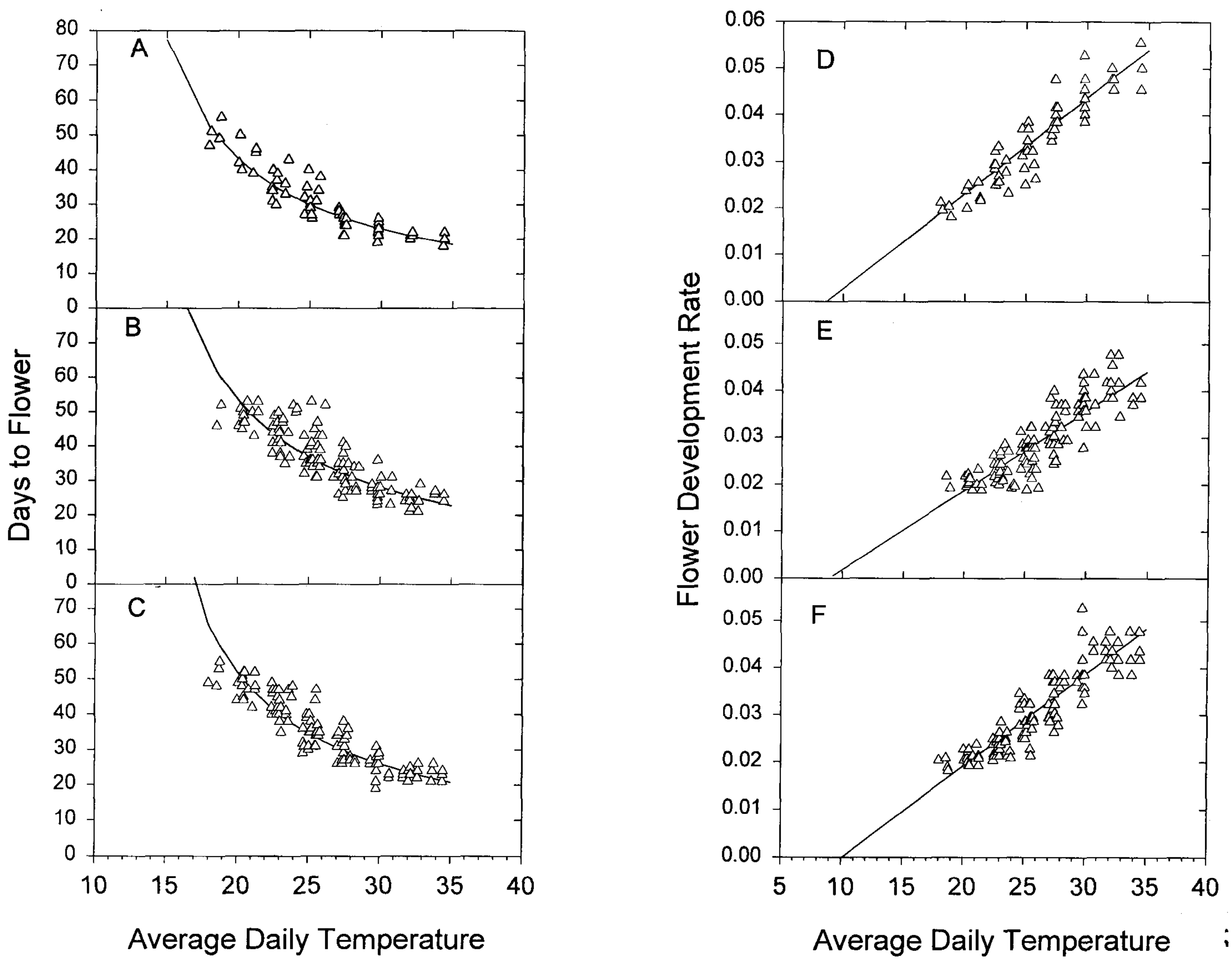

Fig. 1. Flower development rate and predicted days to flower. Supplemental lighting, where days to flower = 40178 + 0.002 * average daily temperature (ADT), and rate of progress to flower = l/(4.01 78 + 0.002 *ADT) **(A** and **D).** Ambient light, where days to flower = 4.0198 + 0.0019 * ADT and rate of progress to flower = l/(–0.0198 + 0.0019 * ADT) **(B** and **E).** Shade (50%), where days to flower = –0.0151 + 0.0017 * ADT, and rate of progress to flower = l/(–0.0151 + 0.0017 * ADT) **(C** and **F).**

Table 1. Regression analysis for 'Grape Cooler' vinca flower development rate between years. Flower development rate = $b_0 + b_1$[average daily temperature (ADT)].

Year	Variable	50% shade	Ambient	Supplemental
1992	b_0	–0.0155	–0.0206	–0.0094
	b_1	0.0017	0.0020	0.0017
1993	b_0	–0.0152	–0.0191	–0.0178
	b_1	0.0017	0.0019	0.0020
Comparison of slopes		$F = 0.0245^{NS}$	$F = 5.1235^{*}$	$F = 8.5223^{**}$
Comparison of intercepts		$F = 2.4157^{NS}$	$F = 3.0977^{NS}$	$F = 3.1543^{*}$

^{NS},*,**Nonsignificant or significant at P = 0.05 and 0.01, respectively.

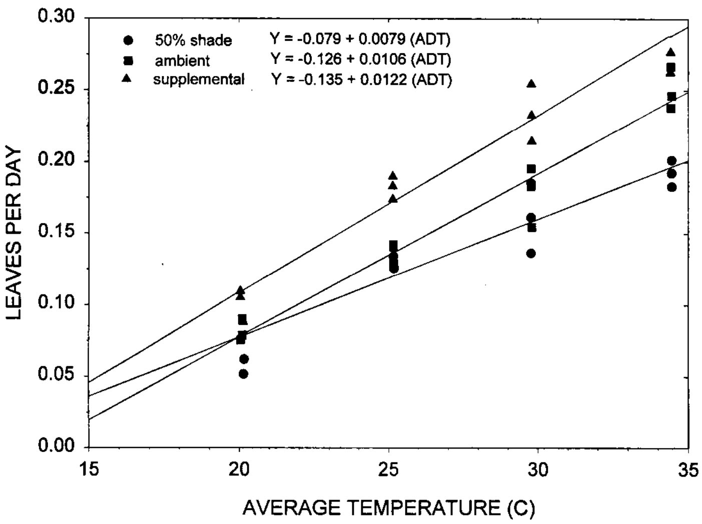

Fig. 2. Relationship between average daily temperature (ADT) and *Catharanthus roseus* L. 'Grape Cooler' leaf-pair unfolding rate (LUR) for 50% shade (●), ambient(∇), and supplemental light(▼). The regression lines are $LUR_{(50\%\ shade)}$ –0.078 + 0.0078 (ADT), $LUR_{(ambient)}$ =-0.128 + 0.0106 (ADT), and $LUR_{(supplemental)}$ = -0.136 + 0.0122 (ADT).

Table 2. Calculated values for degree days/leaf pair and base temperature using leaf unfolding rate regression lines for 'Grape Cooler' vinca. Irradiance levels were equivalent to photosynthetic photon flux daily light integrals of about 9, 18, and 30 $mol \cdot m^{-2} \cdot day^{-1}$ for the 50% shade, ambient, and supplemental irradiance treatments, respectively.

Irradiance	Degree days/leaf	Base temp
50% Shade	127	10.0
Ambient	94	11.9
Supplemental	82	11.1

Table 3. Calculated days required for one leaf pair to unfold based on leaf unfolding rate regression lines for 'Grape Cooler' vinca. Irradiance levels were equivalent to photosynthetic photon flux daily light integrals of about 9, 18, and 30 $mol \cdot m^{-2} \cdot day^{-1}$ for the 50% shade, ambient, and supplemental irradiance treatments, respectively.

	Irradiance		
Temp	50% Shade	Ambient	Supplemental
18	16	15	12
20	13	12	9
25	8	7	6
30	6	5	4
35	5	4	3

leaf pairs to unfold with the predicted number of days to flower from transplant. Both models showed a similar number of days (Table 4). Therefore, the LUR model can be used to predict days to flower. Figure 3 shows predicted number of days to flower for plants with three (top line) to eight (bottom line) leaf pairs. The days to flower for a plant can be predicted from Fig. 3 by subtracting the current number of leaf pairs on a plant from 9.3 and selecting an average daily temperature.

Flower diameter was influenced by DT and irradiance level, but not by NT (Fig. 4). Flowers were largest at a day setting of 25C under supplemental light.

Discussion

The leaf development rate in vinca increased and time to flower decreased as temperature increased from 15 to 35C (Fig. I), indicating that vinca is more responsive to and tolerates continuous high temperatures (30 to 35C) (Scullin, 1991; Thomas and Gilbertz, 1992) better than many other ornamental species, such as poinsettia (Berghage et al., 1990; Faust and Heins, 1994), chrysanthemum (Karlsson et al., 1989), dahlia (Brøndum and Heins, 1993), hibiscus (Karlsson et al., 1991), Easter lily (Erwin and Heins, 1990), and African violet (Faust and Heins, 1993). Vinca plants grown at 35C in these experiments were of quality equal to those grown at lower temperatures.

Plants grown under the supplemental lighting treatment required fewer days to flower than those grown under the 50% shade and the ambient irradiance treatments. The beneficial developmental responses observed with HPS lamp treatments may be a result of increased plant temperatures. HPS lamps mounted above a plant canopy deliver about 0.74 $W \cdot m^{-2}$ (300 to 100,000 nm) per $\mu mol \cdot m^{-2} \cdot s^{-1}$ (400 to 700 nm) (Bubenheim et al., 1988). If this extra energy absorbed by the plant canopy is not dissipated by transpiration or convection, then plant temperatures increase. Measurement of vinca shoot-tip temperatures showed that those of plants under HPS lamps (200 $\mu mol \cdot m^{-2} \cdot s^{-1}$) were generally 2 to 3C higher than those under shadecloth and ambient light (data not shown). Similarly, Faust and Heins (unpublished data) observed a 1.5C increase in shoot-tip temperatures of vinca plants grown under HPS lamps that delivered 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Graper and Healy (1991) showed that petunia leaf temperatures under HPS lamps delivering 167 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were 4 to 5C higher than those of plants under ambient irradiance.

A comparison of the regression of leaf-pair unfolding rate of the supplemental lighting treatment with that of the other two irradiance treatments showed that the slopes were similar, but the y intercepts were different. This relationship suggests that the faster flowering under the HPS lamps was a result of higher plant temperature as a result of the increased absorbed radiation. If we

Table 4. Comparison of predicted days to flower from transplant and predicted days required for 4.4 leaf pairs to unfold for 'Grape Cooler' vinca. Irradiance levels were equivalent to photosynthetic photon flux daily light integrals of about 9, 18, and 30 $mol \cdot m^{-2} \cdot day^{-1}$ for the 50% shade, ambient, and supplemental irradiance treatments, respectively.

	50% Shade		Ambient		Supplemental	
Temp	4.4 Leaf pairs to unfold	Days to flower	4.4 Leaf pairs to unfold	Days to flower	4.4 Leaf pairs to unfold	Days to flower
20	54	54	48	52	41	43
25	37	37	31	35	27	30
30	29	28	22	26	20	23
35	23	23	18	21	16	19

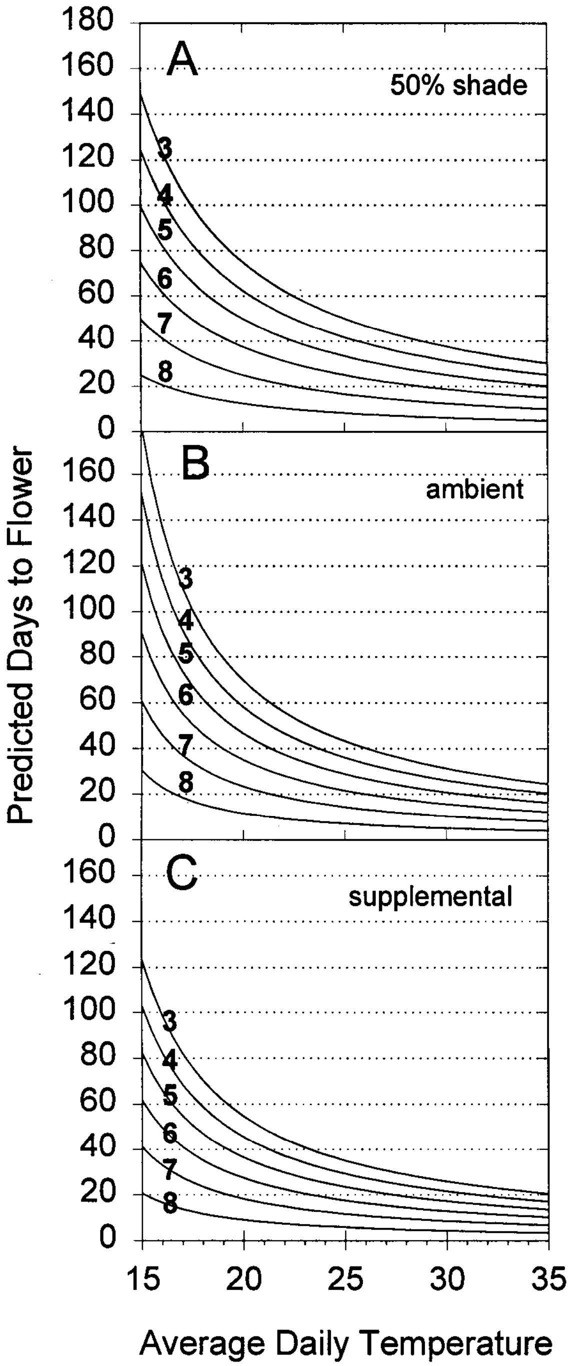

Fig. 3. Curves of predicted days to flower using predicted days required for one leaf pair to unfold. The numbers above each line represent the number of leaf pairs already on the plant.

assume that the average daily plant temperature under the HPS lamps increased 2C and recalculate the supplemental lighting regression line in Fig. 2, then the regression line is identical to that of the ambient and 50% treatments. Therefore, we believe that the increased leaf and flower development rates observed under the supplemental irradiance treatment were a result of increased shoot-tip temperatures, not increased irradiance alone.

The recommended greenhouse temperature for growing vinca is 15 to 18C NT (Nau, 1991); however, the predicted number of days required for one leaf pair to unfold decreases as temperature increases from 18 to 35C (Table 3). Thus, by increasing the air temperature from 18C to 35C, the number of days required for one leaf pair to unfold decreases by 11 days, meaning that time to flower decreases by 55 days if five leaf pairs must unfold. A more realistic situation would be au increase from 20 to 25C NT, at which time to flower decreases by 2 to 3 weeks.

The prediction curves in Fig. 3 can be used by growers to determine temperatures necessary for flowering vinca for specific market dates. Their use requires a knowledge of plant leaf-pair number. Leaf-pair number subtracted from nine leaf pairs indicates how many leafpairs must develop before flowering. All days to flower and temperature combinations associated with that leaf-pair number are shown in Fig. 3 and can be used to determine greenhouse temperature setpoint.

In conclusion, optimal temperature for vinca production is about 25C. Temperatures below 25C result in increased time to flower, and, while those above 25C result in faster leaf and flower development rates, flower size decreases.

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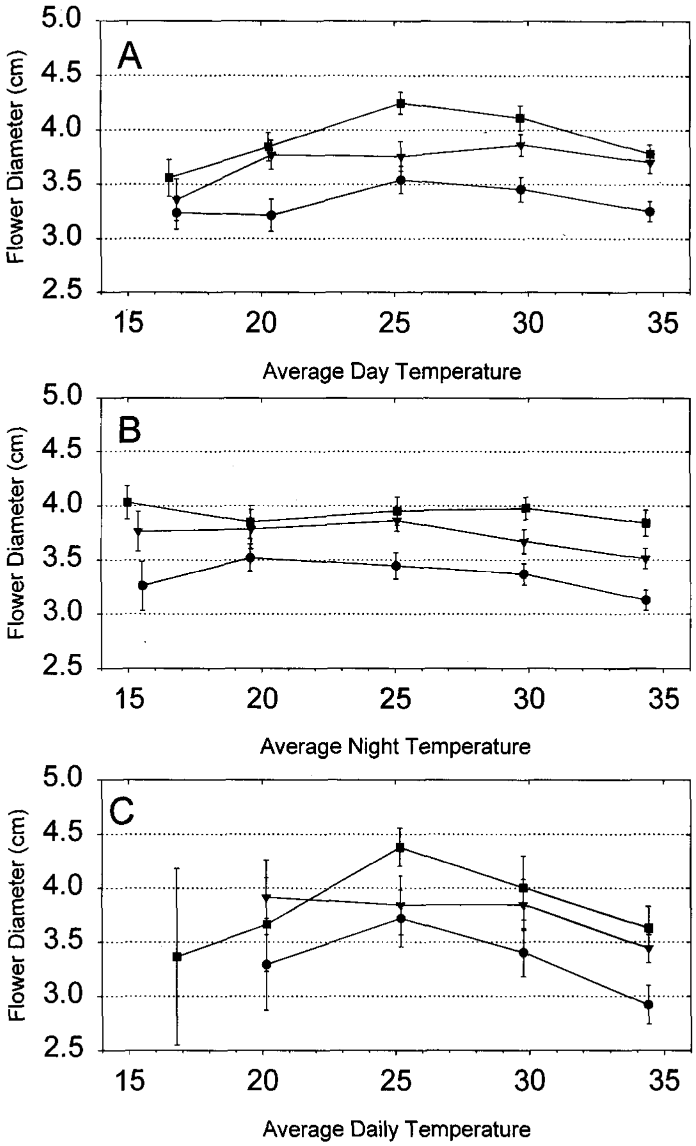

Fig. 4. Comparison of flower diameter under **(a)** average day temperature, **(b)** average night temperature, and **(c)** constant temperature. Error bars represent 95% confidence intervals. Symbols: (●) 50% shade, (▼) ambient light, (■) supplemental light.

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