Temperature Affects Leaf Unfolding Rate and Flowering of Cyclamen

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Abstract. The rate of leaf unfolding for *Cyclamen persicum* Mill. was determined at 8 to 24 °C. Temperature treatments started 9 weeks from seeding and after 8 weeks all plants were moved to 16 °C. The cultivars Miracle Salmon, Miracle Scarlet, and Miracle White produced leaves at a similar rate. The relationship of (leaves/d) = $-0.01727 - 0.02284 * ^\circ\text{C} + 0.005238 * (^{\circ}\text{C})^2 - 0.000162 * (^{\circ}\text{C})^3$ ($R^2 = 0.99$) best described the leaf unfolding rate in response to temperature. The maximum leaf unfolding rate was estimated to 0.329 leaves/day at 19.1 °C. Flower buds (2 mm diameter) developed within 60 days from the start of temperature treatments except at 8 °C. Thirty-five additional days at 16 °C were required for cyclamen initially grown at 8 °C for 8 weeks to produce flower buds. Despite similar conditions during bud development, flowering was delayed 14 to 18 days for plants initially grown at 24 °C compared to those grown at 12 to 20 °C. Plants initially at 8 °C did not flower within 70 days at 16 °C. Leaf and flower numbers at first open flower increased as initial temperature increased from 12 to 24 °C while dry weight and height only increased to 20 °C. No correlation between leaf unfolding and rate of flowering or flower number was detected. Recommendations for 20 °C during early cyclamen growth can be expected to support rapid rates of leaf unfolding and development, and large flower numbers.

In many plants, the rate of leaf production is controlled by temperature. Within the biological range, leaf appearance is expected to increase to a maximum and then decrease with increasing temperatures (Karlsson, 1992; Karlsson et al., 1991). Progression of leaf emergence may serve as a nondestructive measure of plant growth and development. For example, Easter lilies are routinely scheduled for flowering by adjusting the temperature to insure required progression of leaf development (Karlsson et al., 1988).

In some plants, the development of leaves is closely correlated with the initiation of flowers. A specific leaf number or physiological age may be required before flower buds are initiated, or continuous flower formation is dependent on leaf appearance. In *Hibiscus rosa-sinensis* L., flowers are first initiated after six or seven leaves have appeared depending on cultivar (Karlsson et al., 1991). Indeterminate plants such as tomato (*Lycopersicon esculentum* Mill.) and begonia (*Begonia x hiemalis* Fotsch) (Karlsson, 1992), which flower in leaf axils, require continuous growth and leaf formation for uninterrupted flowering.

The recommended temperature for cyclamen production from seeding to the appearance of flower buds is 20 °C (Anjou, 1986;

Ball, 1991; Hilding, 1999; Karlsson, 1997; Widmer, 1992). Seedlings are expected to be sufficiently large for transplanting 8 to 9 weeks from seeding and for flower buds to be visible after an additional 8 weeks of growth. Thereafter, Anjou (1986) suggested that 14 to 16 °C was more beneficial. The seed-propagated cyclamens produced today are expected to flower within 6 to 7 months from seeding. Prior to the initiation of flowers, as many as 10 to 13 leaves form on the plant (Stephens and Widmer, 1976; Sundberg 1981a, 1981b; Widmer and Lyons, 1985), and the first flower of a shoot initiates in the sixth vegetative leaf axil (Sundberg, 1981a, 1981b). However, the rate of leaf formation and its correlation with flower initiation is not well understood in cyclamen. This study was initiated to determine the effects of temperature on leaf unfolding and subsequent growth and flowering in seed-propagated cyclamen.

Materials and Methods

Three cyclamen cultivars in the Miracle series ('Salmon', 'Scarlet', and 'White') were selected for the study. The seed was germinated in 50-plug trays at 20 ± 2 °C in darkness. As the seed germinated 4 weeks following seeding, irradiance was provided for 16 h at 5.8 mol·d⁻¹·m⁻² (≈100 ± 20 μmol·m⁻²·s⁻¹). Five weeks after germination (9 weeks from seeding), plants with uniform size (two expanded leaves and 3 to 4 cm in height) were transplanted into 10-cm-diameter pots (520 cm³) filled with Premier Pro-Mix BX (Premier Horticulture; Premier Brands, Red Hill, Pa.). Plants were placed in growth chambers (Conviron model E15; Controlled Environ-

ments, Pembina, N.Dak.) at constant 8, 12, 16, 20, or 24 ± 1 °C. The daylength was 16 h at 10 mol·d⁻¹·m⁻² (≈175 ± 20 μmol·m⁻²·s⁻¹) measured at canopy height and provided by cool-white fluorescent (GE, F48T12, CW1500) and incandescent lamps (GE, 40 W) on a 80:20 input wattage basis.

Twenty-five plants of each cultivar were placed at each temperature in a completely randomized design with a spacing of ≈185 cm²/pot. After 8 weeks, all plants were moved to 16 °C until termination of the experiment 10 weeks later. The length of the temperature treatments (8 weeks) was selected based on the production guidelines, which call for maintaining 20 °C for 8 weeks following transplanting and then dropping the temperature to 16 °C (Anjou, 1986; Karlsson, 1997). Plants were watered with fertilizer solutions of 3.5N–0.7P–1.2K (mm) from the cotyledon stage and 7.1N–1.5P–2.4K (mm) from transplant using Peters' 15–16–17 (Scotts-Sierra Horticultural Products, Marysville, Ohio). Plants were watered once a day, allowing for some drainage.

Expanded leaves (≥1 cm in length) were counted weekly during the 8 weeks of temperature treatment. Times to visible bud (VB, 2-mm-diameter flower buds) and to flower (first reflexed petal) were recorded. Morphological data (leaf number, plant height, plant width, flower number, and dry weights of aboveground tissues, roots, and the expanded hypocotyl) were collected as individual plants reached flower. Leaf height was measured from the surface of the growing medium to the top of the leaf canopy and flower height to the tallest point of the plant. Plant width was determined as the average of two measurements across the plant 90° apart. The leaf canopy volume was considered cylinder-shaped and calculated using plant height and plant width as the diameter of a circle. The medium was washed off roots and the expanded hypocotyl. Dry weights were determined after 3 d of drying at 70 ± 2 °C. Data were analyzed using analysis of variance (ANOVA), single degree of freedom polynomial tests, and linear regression (SPSS, 1997).

Results

Leaf unfolding rate did not differ among the cultivars in the Miracle series. Leaf unfolding increased with increasing temperature from 8 to 20 °C and then decreased at 24 °C (Fig. 1A). Polynomial tests showed significant linear, quadratic and cubic responses and leaf unfolding rate was best described by

$$\text{Rate (leaves/d)} = -0.01727 - 0.02284 * ^\circ\text{C} + 0.005238 * (^{\circ}\text{C})^2 - 0.000162 * (^{\circ}\text{C})^3$$

$$R^2 = 0.99$$

This relationship suggests an average of 19 d for leaf appearance at 8 °C, 3 d at 20 °C, and 5 d at 24 °C. Maximum leaf unfolding rate for the Miracle series was estimated to 0.329 leaves/d at 19.1 °C.

The only observed significant difference among cultivars was the number of leaves at

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Fig. 1. (A) Leaf unfolding rate and (B) number of leaves at flowering as a function of temperature for *Cyclamen persicum* 'Miracle Salmon', 'Miracle Scarlet' and 'Miracle White'. The photoperiod was 16 h at 10 mol·d⁻¹·m⁻². Temperature treatments began 9 weeks after seeding and continued for 8 weeks. All plants were grown at 20 °C before and at 16 °C after the 8 weeks.

flowering. 'Miracle Salmon' consistently had more, and 'Miracle White' fewer, leaves than did 'Miracle Scarlet'. The increase in number of leaves with temperature and the developed functional relationships are shown in Fig. 1B. Polynomial tests indicated significant linear and quadratic temperature responses for leaves in 'Miracle Salmon' and 'Miracle White'. For 'Miracle Scarlet', the response was linear.

The event of VB was observed within 60 d in the 12 to 24 °C range. Plants grown at 8 °C required 35 d at 16 °C in addition to the experimental 56 d to reach VB (Table 1). Despite similar growing conditions during flower development, significant differences were observed for the VB to flower progression. Plants initially grown at 12 °C flowered slightly earlier than those grown at 16 or 20 °C (Table 1). Although flowering was delayed 14 to 18 d, the plants grown at 24 °C had the largest number of flower buds. The response was linear and quartic and increased from six flower buds at 8 °C to 53 at 24 °C (Table 1). Since flowering was not observed in plants grown at 8 °C, flower buds indicate the number at termination of the experiment.

Plants grown at 20 °C following transplanting had the largest dimensions at flower-

ing, with an estimated leaf canopy volume of 4031 cm³ (Table 1). Leaf height was similar for plants grown at 16 or 24 °C while those grown at 16 °C were narrower (data not shown). The leaf canopy volume was therefore smaller for plants at 16 than at 24 °C. Flower height above the foliage was proportional at all growing conditions, adding about two-thirds to the total plant height at flowering. Top and root dry weights (Table 1) continued to increase above 20 °C although plant height and width were reduced. Total plant dry weight at flowering varied from a minimum of 3.8 g at 8 °C to a maximum of 13.0 g at 24 °C. As temperature increased to 20 °C, the proportion of dry weight partitioned to below-ground tissues decreased from 45% to 30%. For the plants initially grown at 24 °C, the proportion of dry weight in roots and the expanded hypocotyl was 37%.

Discussion

Leaf unfolding in cyclamen is similar to the response found in many other plants. The peak rate of one leaf every 3 d is within earlier observed magnitudes of leaf emergence rates for other greenhouse-grown ornamentals.

Easter lily has been reported to unfold leaves at a maximum rate of 2.7 leaves/d (Karlsson et al., 1988) while maximum rate for *Begonia xhiemalis* Fotsch was much slower at 0.12 leaves/d (Karlsson, 1992).

Sundberg (1981a) followed the development of *C. persicum* 'F-1 Rosemunde' and measured a leaf unfolding rate of 1.3 leaves/week at 21 to 27 °C day/18 °C night. Estimating the average temperature to 21 °C, the rate reported by Sundberg (1981a) is about half the rate suggested by the relationship in Fig. 1A. Flowering at 240 d from seeding (Sundberg, 1981a) was also slower than the 174 d at initial 20 °C in this study (Table 1). Rapidly growing seed-propagated cultivars like the Miracle series appear to have rapid leaf unfolding accompanying the increased rate of flower development.

The leaf unfolding response in the 8 to 16 °C range can be approximated with a linear function of 0.029 slope (Fig. 1A). The change in the rate is smaller per 1 °C increase between 17 to 19 °C than in the 8 to 16 °C range. Between 19 and 20 °C, the estimated decrease in the rate (0.0034 leaves/d) is without practical significance. The recommended 20 °C (Anjou, 1986; Ball, 1991; Hilding, 1999; Karlsson, 1997; Widmer, 1992) for early vegetative development of cyclamen can therefore be considered optimal for fast leaf unfolding. On the other hand, flower initiation did not appear to be strongly correlated with leaf number. The number of leaves longer than 1 cm at VB varied from 11 to 18 (data not shown) and, as would be expected, plants at temperatures promoting rapid unfolding had more leaves. At 8 °C, the plants had three leaves after 56 d and another 10 leaves had developed by the time VB was reached at 16 °C. Ten to 13 leaves have earlier been reported (Stephens and Widmer, 1976; Sundberg, 1981a, 1981b; Widmer and Lyons, 1985) to have been initiated, but not necessarily expanded, by the time cyclamen flowers are formed.

Rapid leaf formation would be expected to result in plants with a large number of leaves. However for the three cultivars in this study, more leaves (Fig. 1B) and flowers (Table 1) developed in plants initially grown at 24 °C than at 20 °C. Leaf unfolding was followed during 8 weeks of vegetative growth and leaves and flowers were counted at first open flower without distinguishing their origin on the plant. The higher temperature may have supported more efficient initiation of branches and leaves while limiting expansion. During finishing at 16 °C, the leaves already initiated increased in size, resulting in the higher number at flowering.

The final leaf number at flowering also varied among cultivars (Fig. 1B). Although more leaves would be expected to provide additional nodes for flower initiation, the flower number was similar for the three cultivars. To compensate for the fewer leaves and nodes, the first flower may be initiated at a lower node in 'Miracle White' and 'Miracle Scarlet' than in 'Miracle Salmon', as reported for cultivars of *H. rosa-sinensis* (Karlsson et al., 1991).

Table 1. Time to visible bud (2 mm diameter) and first open flower, number of flower buds, plant height and flower height at first open flower, canopy volume, dry weights of top (above ground), roots, and the expanded hypocotyl at first flower for *Cyclamen persicum* 'Miracle Salmon', 'Miracle Scarlet', and 'Miracle White'. All plants were grown at 20 °C for 9 weeks prior to exposure to the test temperatures for 8 weeks and then at 16 °C for 8 weeks. The photoperiod was 16 h at 10 mol·d⁻¹·m⁻² throughout the study. Days are counted from start of treatments (63 d from seeding).

Temp. (°C)	Days to:		No. flower buds	Height (cm)		Leaf canopy volume (cm ³)	Dry wt (g)		
	visible bud	flower		Plant	Flower		Top	Root	Hypocotyl
8	91	---	6	7.0	---	1270	2.09	0.46	1.25
12	57	107	20	8.2	13.6	1928	3.45	0.64	1.51
16	54	109	27	9.4	15.8	2527	4.08	0.65	1.68
20	54	111	42	11.0	18.4	4031	6.85	0.98	1.97
24	60	125	53	9.3	15.8	3130	8.20	1.30	3.54
Linear	***	***	***	***	***	***	***	***	***
Quadratic	***	***	NS	***	***	***	***	***	***
Cubic	***	**	NS	***	***	***	*	NS	***
Quartic	***	---	***	***	---	***	***	**	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively

Temperatures below 20 °C following transplanting can delay production (Anjou, 1986; Karlsson, 1997). In this study, initial temperatures of 12 or 16 °C did not slow VB or flowering compared with 20 °C (Table 1). A 4 degree decrease from 12 to 8 °C, however, greatly reduced growth (Table 1) and at 6 °C, leaf unfolding was estimated to be zero. Stephens and Widmer (1976) and Widmer (1992) suggested that an air temperature of 10 °C in combination with a 20 to 21 °C root temperature adequately supports early cyclamen development. We do not know if a 20 °C root temperature can prevent the poor leaf and flower initiation noted here at 8 °C.

Although final development took place at 16 °C, plant appearance and rate of flowering varied significantly (Table 1). Height increased with initial temperature to 20 °C. The more compact plants at 24 °C were unexpected, since

the number of leaves and flowers and the dry weight increased more than in plants initially at 20 °C. Leaf area was not measured in this study. Smaller, less expanded leaves may explain the reduced plant size at 24 °C. The variation in height was relative to other morphological characteristics, and under all experimental conditions plants had proportional dimensions at the time the experiment was terminated.

Bud abortion, with overall poor plant and keeping quality, can be expected if development is completed at temperatures higher than 20 °C (Karlsson, 1997). Such effects have also been reported when temperature during the final stage of growth is below 14 °C (Hilding, 1999). To determine the most favorable conditions for the final stages of plant and flower development, additional studies are required, since only the recommended 16 °C was used in this study.

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