Daylength, Light Quality, and Temperature Influence Growth and Development of *Achimenes*

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Abstract. The effects of supplementary irradiance (20 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 6 hours) with incandescent light (I) or fluorescent compact gas-discharge lamps (CF) vs. a basic irradiance (96 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for 12 h) with fluorescent (F) light at 17 or 25C was studied for *Achimenes* hybrids 'Flamenco', 'Hilda', and 'Rosenelfe'. The additional I increased leaf area (LA) and plant dry weight (DW) in 'Hilda' and 'Rosenelfe' and promoted stem elongation in all three cultivars. Additional F had no effect on DW. However, depending on cultivar, responses for LA varied. An increase in the number of flowers was promoted only in 'Rosenelfe' by I and CF compared with the control. In all cultivars, the supplementary CF, when compared with the I, reduced LA and DW. LA was significantly larger and DW higher at higher temperature, except for 'Rosenelfe', where DW was not influenced and LA was smaller at the higher temperature. All three cultivars produced a longer stem and more flowers at the higher temperature. Calculated growth responses were influenced by an interaction between temperature and cultivar.

Hybrids of the genus *Achimenes*, Gesneriaceae, are cultivated as potted plants in the United States and Europe. *Achimenes* will flower regardless of daylength after development of the third or fourth leaf whorl (Zimmer and Junker, 1985). Best vegetative and generative growth is achieved at 20C and 16 h light (Rohde, 1974). Recently, the influence of light and temperature on growth and development of several *Achimenes* cultivars was quantified. Higher temperatures (21 or 25C vs. 17C) increased the number of leaf whorls and favored flowering; however, responses varied among cultivars (Vlahos, 1990a). Extending natural daylength with high-pressure sodium lamps increased growth and flowering (Vlahos, 1989, 1990b). Low light intensities combined with long days (at the same daily light integral) increased growth and flowering in three cultivars of *Achimenes* due to an increase in relative growth rate (RGR) and net assimilation rate (NAR), which was attributed to more efficient light use at lower light intensity (Vlahos et al., 1991).

Apart from light intensity and light integral, it is well known that light quality influences plant growth and morphogenesis

(Healy et al., 1980; Smith, 1982). Most research on light quality refers to the effects of different light sources combined with different irradiance levels or photoperiods on growth and development. Incandescent light increases stem height, reducing plant quality in several pot plants. The fluorescent lamp, although it does not increase stem height as much as incandescent light, is not commonly used in commercial plant production (Andersen, 1986; Kristiansen, 1988). Red light promoted whereas far-red light suppressed rhizome formation in leaf or stem cuttings of *Achimenes* 'Major' (Deutch, 1974). We found no reports of other effects of light quality in *Achimenes*. The present experiment was designed to investigate the effect of supplementary light quality on growth and development in three *Achimenes* cultivars at two temperatures.

Design of experiment. 'Flamenco', 'Hilda Michelsen' ('Hilda'), and 'Rosenelfe' were obtained from a commercial grower in Mar. 1985 and grown in 10-cm (0.3-liter) plastic pots in a commercial potting medium (pH 5.5-5.8) consisting of 6 peat mold : 4 rough peat (v/v). Plants were grown for 10 days in a greenhouse at 21/18C (day/night) under natural daylength to establish the plants.

On 3 Apr. 1985, the plants were placed in six growth chambers (Controlled Environments Ltd., Winnipeg, Manitoba, Canada) (length $\times$ width $\times$ height = 185 $\times$ 77 $\times$ 137 cm) and grown for 9 weeks at 17 or 25C (constant day/night), each combined with three light regimes. At the start of the experiment, plants had an average height of 4 cm with three to four leaf whorls (nodes) with no flower buds visible, and with only axillary shoots emerging from the lower leaf axils. The light regime treatments were F:

12 h irradiance provided from fluorescent Philips TL33 tubes [96 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ photosynthetic active radiation (PAR); high R: FR ratio]; I: 12 h irradiance (same as F), extended for 6 h with incandescent Philips GLS lamps (20 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PAR; low R: FR ratio); CF: 12 h irradiance (same as F) extended for 6 h with Philips SL compact gas-discharge lamps (20 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PAR; high R: FR ratio). PAR encompassed 400 to 700 nm ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$). The CF lamp (miniature fluorescent) has the same spectral emission as the F, but is a more practical and energy-efficient lamp.

We used a split-plot design, where the six combinations of temperature and light regime were applied in the whole plots (growth chambers), with cultivars as subplots (16 plants per cultivar in each growth chamber). The combinations of temperature and light regime were not replicated. The experiment involved a total of 288 plants.

Leaf area (LI-COR model 3100 area meter; LI-COR, Lincoln, Neb.) and leaf, stem, root, and rhizome fresh and dry weights (60C, forced-air oven for at least 5 days) were determined on four plants for each cultivar at 0, 21, 42, and 63 days after the start of the experiment. At the final harvest, plant height, number of leaf whorls, and number of axillary shoots were also measured. The number of days to first flower anthesis was recorded by daily observations. Data were subjected to an analysis of variance with least significant difference (LSD) mean separation.

Growth analysis. Growth analysis was conducted according to the functional approach (Hunt, 1982). The best-fitting polynomial (up to the sixth degree) relating the natural logarithms of plant dry weight (DW), leaf dry weight (DW_L), and leaf area (LA) with time was calculated (Nilwik, 1981). The degree of the polynomials was chosen by using the "stepwise" F test ($P < 0.001$) described by Draper and Smith (1981). In most cases a quadratic function provided the most satisfactory fit to the data. Therefore, a quadratic relationship was fitted to all the plots of the natural logarithms of DW, DW_L, and LA against time.

Since growth rate is size dependent (ontogenetic effect), it is necessary to take this into account. Terry (1968) used DW as an index of ontogenetic state. This approach has also been applied here. Therefore, mean values of RGR (per day), NAR (milligrams per square centimeter per day), leaf area ratio (LAR; LA/DW; square centimeters/milligram), specific leaf area (SLA; LA/DW_L; square centimeters/milligram), and leaf weight ratio (LWR; DW/DW_L) were compared on the basis of a DW interval instead of a time interval. This DW interval was 107-508 mg (lnDW = 4.68-6.23), where the lower limit equals the maximum fitted DW at the first harvest and the upper limit equals the minimum fitted DW at the last harvest. Thus, no extrapolation of the measured data is required.

Instantaneous values for RGR, NAR, LAR, SLA, and LWR were calculated by means of the described polynomials, relating DW,

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Table 1. Effect of light regime and cultivar on plant height, number of flowers, leaf area, and total dry weight of *Achimenes*.

Cultivar	Plant ht (cm)			No. flowers			No. axillary shoots			Leaf area (cm ²)			Total dry wt (mg)		
	Light regime														
	F	I	CF	F	I	CF	F	I	CF	F	I	CF	F	I	CF
Flamenco	9.8 ^a	18.7	11.5	7.2	8.8	9.9	1.7	1.3	1.9	154	120	86	1068	119	1088
Hilda	10.2	16.5	12.5	7.1	7.9	8.8	1.1	1.4	0.9	173	256	220	938	1658	1255
Rosenelfe	20.0	28.5	23.9	17.8	28.4	35.4	5.8	4.3	5.5	325	342	274	1765	2183	1971
LSD at <i>P</i> = 0.05		6.9			12.0			1.0			30.1			371	

^aValues are means of two temperature regimes and 16 plants per cultivar.

Table 2. Effect of temperature and cultivar on plant height, number of flowers, leaf area, and total dry weight of *Achimenes*.

Cultivar	Plant ht (cm)		No. flowers		No. leaf whorls		Leaf area (cm ²)		Total dry wt (mg)	
	Temp (°C)									
	17	25	17	25	17	25	17	25	17	25
Flamenco	11.2 ^a	15.5	6.6	10.7	7.7	9.5	91	149	920	1310
Hilda	9.5	16.7	3.6	12.4	7.8	10.6	166	267	902	1665
Rosenelfe	20.3	28.0	12.8	41.6	10.0	13.3	334	294	1818	2068
LSD at <i>P</i> = 0.05	2.8		9.8		0.8		24.6		303.4	

^aValues are means of three light regimes and 16 plants per cultivar.

Table 3. Effect of temperature and cultivar on mean values of RGR, NAR, LAR, SLA, and LWR over the DW interval 107–508 mg.^{a,b}

Cultivar	RGR/day		NAR (mg·cm ⁻² ·day ⁻¹)		LAR (cm ⁻² ·mg ⁻¹)		SLA (cm ⁻² ·mg ⁻¹)		LWR	
	Temp (°C)									
	17	25	17	25	17	25	17	25	17	25
Flamenco	0.0633 ^a	0.0653	0.532	0.449	0.121	0.166	0.228	0.288	0.529	0.571
Hilda	0.0406	0.0622	0.228	0.345	0.182	0.183	0.269	0.286	0.677	0.644
Rosenelfe	0.0651	0.0728	0.338	0.463	0.223	0.167	0.365	0.314	0.611	0.530
LSD at <i>P</i> = 0.05	0.017		0.14		0.076		0.148		0.083	

^aRGR, relative growth rate; NAR, net assimilation rate; LAR, leaf area ratio; SLA, specific leaf area; LWR, leaf weight ratio; DW, dry weight.

^bValues are means of three light regimes and 16 plants per cultivar.

DW₀ and LA with time. Average RGR, NAR, LAR, SLA, and LWR values were calculated by taking the mean of daily instantaneous values over the DW interval. Results were statistically analyzed with analysis of variance followed by an LSD test.

Light regime. The design did not provide for a test of an interaction between light regime and temperature. Significant interactions between light regime and cultivar were found for plant height, number of flowers, leaf area, and total dry weight (Table 1). Additional lighting for 6 h with I lamps increased plant height in all three cultivars; however, this effect was significant only in 'Flamenco' and 'Rosenelfe'. The number of leaf whorls was unaffected (data not shown), which means that increased plant height was a result of elongation (longer internodes). This elongation reduces plant quality. Low R : FR ratio (incandescent light), compared with high R : FR ratio (fluorescent light), is known to promote stem elongation in a wide range of ornamental plants (Cathey and Campbell, 1975; Smith, 1986). Additional CF light (high R : FR ratio) had no significant effect on plant height (Table 1). Kristiansen (1988) reported similar results for *Campanula*. Incandescent light is known to retard or inhibit lateral branching in several plants (Cathey and Campbell, 1975; Grimstad, 1987). In the present investigation, only 'Rosenelfe' responded with reduced branching, ex-

pressed as number of axillary shoots, to the low R : FR ratio of incandescent (I) light (Table 1). Wilkins (1985) and Grimstad (1987) reported for *Fuchsia* and *Gloxinia* that flower development was not influenced by light source or photoperiod. Results in 'Flamenco' and 'Hilda' are similar to these findings, as the total number of flowers was not significantly affected by the light regime. In 'Rosenelfe', however, supplementary lighting with CF increased the number of flowers compared with FL light regime (Table 1).

Flower development in several day-neutral plants is strongly influenced by the light integral (Kinet and Sachs, 1984). In 'Rosenelfe' the increased light integral (by 10%) may have promoted flowering, since day-length extension with I had a positive effect on the number of flowers. The number of days to first flower anthesis was not significantly affected by light regime (data not shown) for any of the cultivars studied.

Lighting by either I or CF reduced LA in 'Flamenco' and increased it in 'Hilda' (Table 1). In 'Rosenelfe' LA was reduced only by CF. Additional I light significantly increased LA in all cultivars when compared with CF. In 'Hilda' and 'Rosenelfe' DW was increased by additional incandescent light (I) compared to the other light regimes, whereas 'Flamenco' was not affected. Dry weight in several species increases when incandescent irradiance supplements fluorescent irradi-

ance (Dijak and Ormrod, 1985; Knight and Mitchell, 1988). Our results for 'Hilda' and 'Rosenelfe' agree with these findings. Mortensen and Stromme (1987) reported that blue light, containing a high R : FR ratio [R : FR ratio = ratio of number of photons in the 655–665 nm band (red) to that in the 725–735 nm band (far red) (Bjorn, 1986)], reduced dry weight and leaf area in several plant species. Results for 'Hilda' agree with the above findings, since under both F and CF light (high R : FR ratio) LA and DW decreased compared with that associated with I. The other cultivars varied in their response. The R : FR ratio of the three lamp types used in this experiment was not measured, but according to Hart (1988), this ratio might be as much as 20 times higher in fluorescent light than in incandescent light. Considering that equal PAR (400–700 nm) was maintained in I and CF light regimes, the differences observed are due to light quality.

Deutch (1974) found that far red light suppressed and red light promoted rhizome formation in leaf cuttings in *Achimenes* 'Major', yet light regimes had no significant effect on the number of rhizomes formed by plants in this study (data not shown).

Temperature. Significant interactions between temperature and cultivar existed for plant height, number of leaf whorls, number of flowers, LA, and DW (Table 2). Higher temperature stimulated plant height and increased number of leaf whorls in all cultivars. Time to first flower anthesis was shortened in 'Rosenelfe' and 'Hilda' (data not shown). At 25C, the number of flowers was higher than at 17C in 'Rosenelfe'. Higher temperature is known to promote growth and flowering in many species (Djurhuus, 1985; Gertsson, 1984; Kristiansen, 1988). 'Rosenelfe' produced more flowers than the other two cultivars, since each leaf axil was capable of developing three to nine flowers (Vlahos, 1990a).

Both 'Flamenco' and 'Hilda' showed a significantly higher LA and DW at 25 than at 17C. However, for 'Rosenelfe', LA was smaller at 25C, yet DW was not significantly affected by temperature in this cultivar (Table 2). Dry weight of rhizomes was not significantly affected by temperature in any of the three cultivars (data not shown). 'Hilda' developed no rhizomes until the end of the experiment.

Growth analysis. No significant interaction between light regime and cultivar was found for any of the calculated growth characteristics. However, supplementary lighting

provided with I or CF ($20 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$) for 6 h-day⁻¹ appeared to be high enough to give higher values for NAR (27% and 43%, respectively) than the basic irradiance (data not shown). This result is as expected, because *Achimenes* is a "shade plant" (van Raalte, 1969) and, therefore, is adapted to use low light intensity. Significant interactions ($P < 0.05$) between temperature and cultivar were found for RGR and LWR (Table 3). Differences between cultivars were greater at 17C, than at 25C. RGR was lowest for 'Hilda' and increased 53% with temperature; for 'Flamenco' and 'Rosenelfe' this increase with temperature was smaller (3% and 12%, respectively). LWR for 'Hilda' and 'Rosenelfe' was lower (5% and 13%) at 25C than at 17C, whereas in 'Flamenco' it increased with temperature (8%).

The low RGR for 'Hilda' was the result of the lowest value for NAR, compared with that of the other two cultivars, combined with an intermediate value for LAR, whereas the high RGR for 'Rosenelfe' resulted from the highest LAR and intermediate NAR (Table 3). Therefore, NAR, the photosynthetic component of growth, and LAR, the morphological component, both appeared to be important factors in determining the differences in growth among the cultivars.

Our results indicate that, depending on cultivar, a 6-h daylength extension, providing as little light energy as $20 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ from either fluorescent or incandescent lamps, affects growth and development in *Achimenes*. However, the CF lamp is to be preferred as it does not cause stem elongation.

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