Growth and Development Responses of Ornamental Gingers to Photoperiod

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ADDITIONAL INDEX WORDS. *Curcuma alismatifolia*, *C. cordata*, *C. petiolata*, *C. thorelii*, *Kaempferia*, *Siphonichilus decora*, *S. kirkii*, dormancy, photoperiod, rhizomes, t-roots

SUMMARY. Rhizomes of *Curcuma alismatifolia* 'Chiang Mai Pink' and tissue cultured plants of *C. cordata*, *C. petiolata* 'Emperor', *C. thorelii*, *Kaempferia* sp. 'Grande', *Siphonichilus decora* and *S. kirkii* were grown in a greenhouse under 8-, 12-, 16-, and 20-hour photoperiods. All plants grown under the 8-hour photoperiod became dormant over a 15 week time period. After 90 days, most ginger species grown under the 16- and 20-hour photoperiods were taller than those grown under 8 and 12 hours. A larger number of unfolded leaves was indicated for all ginger species grown under 16- and 20-hour photoperiods compared to those grown under 8- and 12-hour photoperiods except for *C. thorelii*. The percentage of unfolded leaves as determined by quartile indicated similar results. The number of underground rhizomes of *C. alismatifolia*, *C. cordata*, and *C. petiolata* increased when plants were grown at 16 and 20-hour photoperiods. The number of tuberous-roots (t-roots) increased as photoperiod decreased below 16 hours for *C. alismatifolia*, *C. cordata*, *C. petiolata*, *Kaempferia* sp. and *S. kirkii*. *Siphonichilus decora* produced no t-roots while *C. thorelii* produced the most t-roots at 16 hours. Vegetative growth of gingers grown in this study, except for *C. thorelii*, was maintained and increased at photoperiods of 16 and 20 hours.

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Photoperiods of 8 and 12 hours induced dormancy and t-root production of most of these gingers.

Gingers are a member of the Zingiberaceae family with attractive flowers that make them useful as potted plants. These tropical and subtropical perennials are native to areas with small changes in daylength and temperature throughout the year (Zhang et al., 1995). Popularity of gingers as ornamental plants has continued to increase, and they are now commonly grown in containers under protected conditions in temperate and subtropical regions that present significant variation in daylength throughout the year (Lekawatana and Pituck, 1998). To control growth and flowering of ginger, it is necessary to understand the effects of photoperiod on vegetative and reproductive growth.

In general, gingers become dormant in winter in response to short days (≤ 12 h) and low temperatures. *Curcuma alismatifolia*, a ginger native to Thailand, flowers during the summer and the fall in Israel, and in winter growth is reduced (Hagiladi et al., 1997a). Studies have demonstrated that short days and low temperatures (not specified) promote shoot dormancy in *C. alismatifolia* (Zhang et al., 1995). Other species of *Curcuma* tend to respond to short days (not specified) by becoming dormant (Lekawatana and Pituck, 1998). *Globba winitii*, another member of the Zingiberaceae, senesces in winter as a short-day response (Kuack, 1998).

Curcuma alismatifolia, along with most *Curcuma* species, has two underground storage organs: a rhizome and a spherical tuberous root designated as a t-root, attached to the rhizome by a connecting root (Hagiladi et al., 1997b). Tuberous roots (t-roots) have been indicated to have an important role in growth and flowering of the plant. Two or more t-roots per propagule reduced time to bloom by 18 d, and produced more inflorescences per plant with longer scapes (Hagiladi et al., 1997b).

The objectives of this experiment were to determine the effect of photoperiod on plant growth and development of *Curcuma alismatifolia* 'Siam Tulip White', *C. cordata*, *C. petiolata* 'Emperor', *C. thorelii* 'Chiang

Mai Dwarf', *Kaempferia* 'Grande', *Siphonichilus decora*, and *S. kirkii*.

Materials and methods

Tissue culture plants of *C. petiolata* 'Emperor', *C. thorelii* and *Kaempferia* 'Grande' *S. decora*, *S. kirkii* were planted one per 15.2-cm-diameter (6-inch) container in the greenhouse on 16 Aug. 1999. Tissue culture plants of *C. cordata* were planted two per 15.2-cm-diameter container on 9 Sept. 1999. Rhizomes of *Curcuma alismatifolia* 'Siam Tulip White' (lacking t-roots) were planted one per 12.7-cm (5-inch) container on 27 Aug. 1999. The substrate consisted of 50% peatmoss, 30% pine bark, and 20% perlite (v/v), amended with 5.1 kg·m⁻³ (0.32 lb/yd³) dolomite limestone and triple superphosphate 2.7 kg·m⁻³ (0.17 lb/yd³) 0N-18P-0K. Plants were watered immediately after planting and drenched with a tank mix of metalaxyl (Subdue 2E; Novartis, Greensboro, N.C.) and PCNB quinazone (Terraclor 75% WP; Uniroyal Chemical, Middlebury, Conn.). Containers were spaced 20.3 × 20.3-cm (8 inches) centers and fertigated with 24N-3.5P-13.3K (Peters 24-8-16 Tropical Foliage; Scotts Co., Marysville, Ohio) at 150 mg·L⁻¹ (ppm) N.

Photoperiod treatments were initiated 17 d after transplanting for *S. decora*, *S. kirkii*, *C. thorelii*, *C. petiolata* and *Kaempferia* 'Grande', 18 d after transplanting for *C. cordata* and 6 d after planting for *C. alismatifolia*. There were 12 experimental units (plants) per treatment for *S. decora*, 16 per treatment of *C. cordata* and 3 per treatment for *S. kirkii*, *C. thorelii*, *C. petiolata* and *Kaempferia* 'Grande'. Plants in each photoperiod treatment were arranged in a complete randomized design. Plants received 8 h of natural light from 0900 to 1700 HR; 0, 4, 8, and 12 h of supplemental light were provided for the 8-, 12-, 16-, and 20-h photoperiod, respectively. Light source was 100-W incandescent light bulbs at an irradiance of 11 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (50.0 fc) at plant height. Temperature set points in the greenhouse from planting date to 18 Oct. 1999 were 29 °C day/24 °C night (84.2 °F day/75.2 °F night). From 19 Oct. to the end of the experiment, temperature set points were 27 °C day/21 °C night (80.6 °F day/69.8 °F night).

Each week, the number of newly unfolded leaves was counted as a

Table 1. Effect of photoperiod on plant height for *Curcuma alismatifolia* 'Siam Tulip White', *C. cordata*, *C. petiolata*, *C. thorelii*, *Kaempferia* 'Grande', *Siphonichilus decora*, and *S. kirkii* after 61 and 90 d of photoperiod treatment.

Plant species	Day	Ht (cm ^a)			
		Photoperiod (h)			
		8	12	16	20
<i>Curcuma alismatifolia</i>	61	20.5 a ^z	30.0 b	31.6 b	31.5 b
	90	20.7 a	30.0 b	38.8 c	35.6 bc
<i>Curcuma cordata</i>	61	42.5 a	44.0 a	45.3 a	46.8 a
	90	D ^y	42.7 a	50.2 b	49.0 b
<i>Curcuma petiolata</i>	61	35.3 a	42.3 ab	56.3 bc	69.8 c
	90	35.6 a	41.6 a	65.3 b	70.3 b
<i>Curcuma thorelii</i>	61	31.3 a	33.0 ab	35.3 ab	37.3 b
	90	D	32.0 a	37.3 b	38.0 b
<i>Kaempferia</i> 'Grande'	61	25.3 a	30.3 ab	38.0 b	39.3 b
	90	D	31.6 a	46.6 a	46.6 a
<i>Siphonichilus decora</i>	61	27.4 a	29.8 a	37.0 b	41.8 c
	90	27.7 a	29.9 a	48.0 b	53.8 c
<i>Siphonichilus kirkii</i>	61	29.0 a	29.8 a	34.0 a	36.3 a
	90	30.3 a	29.3 a	39.6 ab	47.8 b

^aMean separation of photoperiods by Tukey's studentized range test, $P = 0.05$. Means within rows with different letters are significantly different.

^yD = dormant. Plants were dormant before measurement.

^z1.0 cm = 0.39 inches.

measurement of plant growth. On 2 Nov. and 1 Dec. 1999, plant height was measured vertically from the top of the pot to the tip of the longest leaf. The photoperiod treatments ended on 1 Feb. 2000 or after ≈ 17 to 20 weeks of treatment. Plants that did not go dormant during the course of the experiment were forced into dormancy by terminating irrigation. After all plants were dormant, weight of underground organs (rhizomes and t-roots together) was measured and number of rhizomes and t-roots per plant was counted. Data was analyzed using PROC GLM (SAS Institute, Inc. Cary, N.C.). Comparisons between means was conducted by Tukey's studentized range test. Quartiles of new leaves were generated using PROC UNIVARIATE. Distribution in new leaves on quartiles was analyzed by chi-square and Fisher's exact test. The quartiles resulted from the division of the relative frequency of the data (number of unfolded leaves) into four intervals with each containing 25% of the measurements.

Results and discussion

All plants became dormant when grown under the 8-h photoperiod, except *S. decora*. The number of weeks required for plants to go dormant under the 8-h photoperiod was 12 weeks for *C. alismatifolia*, 9 weeks for *C. cordata*, 15 weeks for *C. petiolata* 'Emperor', 11.6 weeks for *C. thorelii*, 12 weeks for *Kaempferia* 'Grande', and 15.6 weeks for *S. kirkii*. Some plants of each species grown under the 12-h

photoperiod became dormant before the end of the 17 weeks of treatment. None of the plants however, became dormant under the 18 and 20-h photoperiod.

Photoperiod affected height of all ginger species evaluated. Plants grown under 20- and 16-h photoperiods were taller than those grown under 12- or 8-h photoperiods. After 61 d, plant height of *C. alismatifolia*, *C. petiolata*,

C. thorelii and *S. decora* grown at 20 h was taller than those plants grown at 8 h (Table 1). At 90 d all ginger grown at 20 h were taller than those grown at 8 h, while *Kaempferia* 'Grande', *C. cordata* and *C. thorelii* had gone dormant and produced no more leaves. Similar results were found for orchid pansy (*Achimenes* spp.) a rhizomatous plant native from Mexico to Brazil, where a 16-h photoperiod produced

Fig. 1. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Curcuma alismatifolia* 'Siam Tulip White' after 20 weeks of photoperiod treatment.

Fig. 2. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Curcuma cordata* after 17 weeks of photoperiod treatment.

Fig. 3. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Curcuma petiolata* after 20 weeks of photoperiod treatment.

significantly taller plants than an 8-h photoperiod (Vlahos, 1990).

Photoperiod affected the number of unfolded leaves of all plants, except for *C. thorelii* (Figs. 1–7); 16- and 20-h photoperiod increased the number of leaves unfolded compared to 12 and 8 h. For example, *C. alismatifolia* grown at 8- and 12-h photoperiods unfolded 0 to 2 leaves (84% and 72% respectively) during the 17-week study (Fig. 1). Of the plants grown at a 16-h photoperiod, 60% unfolded >4 to 8 leaves; 43% of those grown at 20 h unfolded >4 to 8 leaves, and 48% unfolded more than 8 leaves. The percentage of unfolded leaves of *Kaempferia* 'Grande' in the >3 to 4.5 quartile was 33% for the 12-h photoperiod (Fig. 5). The 16-h photoperiod had the largest percentage in the >10.5 quartile (67%). At 20 h the largest percentage unfolded was in the >4.5 to 10.5 quartile. *Siphonichilus decora* plants grown at 8 h (75%) and all plants grown at 12 h unfolded 0-2 leaves during the 21-week study (Figure 6). Two thirds of the plants grown under 16-h photoperiod unfolded >5 to 9 leaves and one third unfolded more than 9 leaves. Most plants grown at 20 h (58%) unfolded more than 9 leaves, and 41% unfolded >5 to 9 leaves. Similar results were found for tuberous begonias (*Begonia × tuberhybrida*), another geophytic plant, where a 16-h photoperiod (9 h natural light + 7 h supplemental) or interrupted nights (9 h natural light + 3 h supplemental light from 2300 to 0200 HR) increased the number of leaves and top fresh weight (Fonteno and Larson, 1982).

Effect of photoperiod on fresh weight of underground storage organs, number of rhizomes and number of t-roots depended on the ginger species. More t-roots per plant were produced when grown under 8- or 12-h than 20- or 16-h photoperiods with as many as 1.5 more for *C. alismatifolia* 'Siam Tulip White', 5.9 more for *C. cordata*, 5.7 more for *C. petiolata*, 8.3 more for *Kaempferia* 'Grande' and one more for *S. kirkii* (Table 2). These results are similar to those found for dahlia (*Dahlia variabilis*), where tuberization in the roots was promoted by short days (8-h photoperiod) (Moser and Hess, 1968). Also, in tuberous begonias, tuber formation was enhanced on plants grown at short days (9 h) (Fonteno and Larson, 1982). The exception was *C. thorelii*, where more t-roots were produced on the plants growing at a 16-h photoperiod.

riod than at 8 h. *Siphonichilus decora* did not produce t-roots under any of the four photoperiods.

Curcuma alismatifolia 'Siam Tulip White' (1.3 more rhizomes), *C. cordata* (1.1 more rhizomes) and *C. petiolata* (2 more rhizomes) produced more rhizomes under the long day photoperiods (20 and 16 h) than under 12 and 8 h (Tables 4–7). The greater numbers of t-roots and rhizomes of those plants grown under 20- and 16-h photoperiods were also reflected in increased underground organ weight with differences between 8 and 20 h of 8.7 g (0.31 oz) for *C. alismatifolia*, 28.8 g (1.02 oz) for *C. thorelii*, 41.3 g (1.46 oz) for *S. decora* and 36.4 g (1.28 oz) for *S. kirkii*. *Curcuma cordata* grown under 12 and 16 h produced heavier underground organs than at 8 h. Photoperiod did not have an effect on the weight of underground organs of *Kaempferia* 'Grande'.

A number of tropical plants (not specified) have been shown to be sensitive to day length (Rees, 1987). Photoperiodically responsive plants near the equator are more sensitive to small changes in daylength because of the very small seasonal day-to-day differences in daylength that occur in low latitudes. Variations in physiological response to photoperiod was observed for the different species of Zingiberaceae evaluated in this study. This was true for dormancy, weight of underground organs, number of t-roots and number of rhizomes. Such variation may be attributed to the different origin of the gingers studied. *Siphonichilus* originated in southern and eastern Africa (Huxley et al., 1992). *Curcuma* and *Kaempferia* originated in tropical Asia, where a great diversity in temperature (caused by latitude and altitude) and photoperiod (caused by latitude) occurs. In Thailand, where 30 of the 65 species of *Curcuma* are found, latitude varies from 5° to 21° N and longitudes 97° to 106°E, with average temperatures from 24 to 33 °C (74.7 to 90.5 °F) (Lekawatana and Pituck, 1998). Thus, although growth and development stages have been established by Hagiladi et al. (1997b) for *C. alismatifolia*, they cannot be applied to all gingers in the Zingiberaceae family.

The effect of incandescent lights used to manipulate photoperiod in this experiment may have had a confounding effect on shoot height. A 4-h light interruption using 100-W incandescent

Fig. 4. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Curcuma thorelii* after 20 weeks of photoperiod treatment.

Fig. 5. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Kaempferia* sp. after 20 weeks of photoperiod treatment.

Fig. 6. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Siphonichilus decora* after 20 weeks of photoperiod treatment.

Fig. 7. Effect of photoperiod on percent of leaves unfolded as grouped by quartile of new leaves for *Siphonichilus kirkii* after 20 weeks of photoperiod treatment.

lamps (0.39 red to far-red ratio) from 2200 to 0200 HR significantly increased plant height, node number and days to flowering of chrysanthemum (*Chrysanthemum × morifolium*) 'Improved Indianapolis White' and 'Golden Yellow Princess Anne' (Cathey, 1974). The increase in leaf unfolding at 16- and 20-h photoperiods and ensuing dormancy of those plants grown at an 8-h photoperiod however, indicates that despite the differences in the amount of red to far-red light these gingers received, the photoperiods were significant factors in affecting continued or increased shoot growth, or dormancy. The effect of photoperiod on flowering was not evaluated because those plants that continued to produce vegetative growth under the longer photoperiods, failed to bloom during the 17-week treatment period. Results from a photoperiod experiment conducted by Hagiladi et al. (1997a) indicated that *C. alismatifolia* plants began to flower after 12 weeks of growth under day lengths of 10 or 20 h. The number of t-roots each rhizome had before the experiment was not reported and photoperiod treatments were not initiated until after 11 weeks of growth. In another study on *C. alismatifolia* by Hagiladi et al. (1997b), results indicated that rhizomes without t-roots required up to 180 d (≈26 weeks) from planting to flower. Therefore, in this study where *C. alismatifolia* rhizomes had no t-roots when planted and the remaining ginger species were from tissue culture, a longer time period may have been required to initiate flowering under long days.

Vegetative growth of most of the ornamental ginger species used in this study was optimized when plants were grown under 16- and 20-h photoperiods. An 8-h photoperiod promoted dormancy and for most species an increased number of t-roots. These results correspond to the results of Hagiladi et al. (1997a) and Zhanget al. (1995) both of which reported that vegetative growth of *C. alismatifolia* was maintained by long days and dormancy was induced by short days. There was some variation in response to photoperiod by species of ginger in this study, for example *C. thorelii* and *Kaempferia*, and therefore the affect of photoperiod on vegetative shoot growth and development of underground storage organs is not the same for all ginger species.

Table 2. Effect of photoperiod on fresh weight of underground storage organs, number of rhizomes per plant, and number of tuberous roots (t-roots) per plant for *Curcuma alismatifolia* 'Siam Tulip White', *C. cordata*, *C. petiolata*, *C. thorelii*, *Kaempferia* spp. 'Grande', *Siphonichilus decora*, and *S. kirkii* after 20 weeks of photoperiod treatment.

Plant species and response variable	Photoperiod (h)			
	8	12	16	20
<i>Curcuma alismatifolia</i>				
wt (g ^y)	3.6 a ^z	6.9 b	13.7 c	12.3 c
rhizomes (no.)	1.0 a	1.0 a	1.9 b	2.3 c
t-roots (no.)	2.1 b	2.1 b	1.9 b	0.6 a
<i>Curcuma cordata</i>				
wt (g)	13.2 a	29.9 b	20.3 b	15.9 ab
rhizomes (no.)	1.0 a	1.0 a	1.9 b	2.1 b
t-roots (no.)	5.9 b	5.3 b	0.0 a	0.0 a
<i>Curcuma petiolata</i>				
wt (g)	25.6 a	35.6 ab	47.2 b	44.2 ab
rhizomes (no.)	1.0 a	1.0 a	1.6 ab	3.0 b
t-roots (no.)	6.3 b	6.3 b	0.3 a	0.6 a
<i>Curcuma thorelii</i> wt				
wt (g)	13.4 a	19.3 a	36.2 b	42.2 b
rhizomes (no.)	1.0 a	1.0 a	1.0 a	1.0 a
t-roots (no.)	6.0 a	8.3 ab	11.6 b	10.6 ab
<i>Kaempferia</i> 'Grande'				
wt (g)	18.1 a	25.2 a	22.6 a	20.2 a
rhizomes (no.)	1.0 a	1.0 a	1.0 a	1.3 a
t-roots (no.)	8.3 c	4.6 b	0.0 a	0.0 a
<i>Siphonichilus decora</i>				
wt (g)	15.7 a	17.6 a	45.1 b	57.0 c
rhizomes (no.)	1.0 a	1.0 a	1.0 a	1.0 a
t-roots (no.)	0.0 a	0.0 a	0.0 a	0.0 a
<i>Siphonichilus kirkii</i>				
wt (g)	22.6 a	19.2 a	55.5 b	55.6 b
rhizomes (no.)	1.0 a	1.0 a	1.3 a	1.6 a
t-roots (no.)	1.0 b	0.6 ab	1.0 b	0.0 a

^aMean separation of photoperiods by Tukey's studentized range test, $P = 0.05$. Means within rows with different letters are significantly different.

^y28.35 = 1.0 oz.

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Efficacy of Ethephon on Vegetative Annuals

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ADDITIONAL INDEX WORDS. Florel, (2-chloroethyl) phosphonic acid, height reduction, internode elongation

SUMMARY. Plant response to ethephon treatment was tested on 27 cultivars of vegetative annuals that have spreading and trailing growth habits. A control treatment was compared to 500 and 1000 mg·L⁻¹ (ppm) foliar spray treatments of ethephon. Plant height and/or width index were significantly reduced for 81% of the cultivars tested. Responsive cultivars were alternanthera (*Alternanthera dentata*), brachyscome (*Brachyscome iberidifolia*) 'Toucan Tango'; calibrachoa (*Calibrachoa* hybrids) 'Colorburst Red', 'Million Bells Cherry Pink', and 'Trailing Pink'; diascia (*Diascia × hybrida*) 'Sunchimes Rose' and 'Red Ace'; double impatiens (*Impatiens wallerana*) 'Tioga Red' and 'Tioga White'; sweetpotato vine (*Ipomoea batatas*) 'Sweet Caroline Bronze'; lantana (*Lantana camara*) 'Patriot Cherry' and 'Samantha'; nemesia (*Nemesia × hybrida*) 'Aromatica Dark Lavender', 'Blue Bird', and 'Blueberry Sachet'; nolana (*Nolana paradoxa*) 'Blue Eyes'; ivy geranium (*Pelargonium hybrida*) 'King of Balcon'; petunia (*Petunia × hybrida*) 'Cascadia Pink', 'Mini Bright Pink', and 'Supertunia Mini Purple'; bacopa (*Sutera cordata*) 'Bridal Showers'; and vinca vine (*Vinca minor*) 'Illumination'. Ethephon was not effective on monopsis (*Monopsis unidentata*) 'Royal Flush',

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