Temperature and Photoperiodic Effects on Growth and Flowering of *Zygopetalum* Redvale 'Fire Kiss' Orchids

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Abstract

Flowering potted orchids have become the second most valuable floriculture flowering potted crop in the United States. However, little or no quantitative information exists on the flowering process of the majority of orchid species. We performed experiments to determine how temperature and photoperiod influence leaf development and flower induction of *Zygopetalum* Redvale 'Fire Kiss'. In the first experiment, plants were placed under photoperiods ranging from 10 to 24 h of continuous light or 9 h with a 4-h night interruption (NI). Sixty percent to 80% flowered when grown under every photoperiod except continual (24 h) light, and flowering was slightly hastened under photoperiods ≤14 h. In a separate experiment, plants were placed into environmental chambers with constant temperatures of 14, 17, 20, 23, 26 and 29 °C and 9-h photoperiods with or without a 4-h NI. Plants developed nodes faster as temperature increased from 14 to 26 °C; after 15 weeks, plants at 14 °C had developed an average of only 1.8 new nodes, while those at 26 °C had developed an average of 4.8. In the third experiment, plants were placed under 9- or 16-h pre-cooling photoperiods for 8 weeks, then were transferred to cooling temperatures of 11, 14, 17, 20, and 23 °C with 9- and 16-h photoperiods for 8 weeks. Plants grown under a 9-h pre-cooling photoperiod and then transferred to 11 or 14 °C had the highest flowering percentages and reached visible inflorescence in 17 to 22 days. Collectively, these studies indicate that *Zygopetalum* without a low temperature treatment is a quantitative short day plant. The most rapid, complete, and uniform flowering occurred when plants were grown under short days and then subjected to temperatures of 11 to 14 °C.

INTRODUCTION

In the United States, potted plants are commonly purchased for holidays such as Mother's Day, Easter, and Valentine's Day. Thus, greenhouse growers must be able to produce flowers (either for cut flowers or as potted plants) to meet specific market dates. Plants that do not have flowers, or have flowers that are too immature (e.g., only flower buds) or mature (e.g., flowers are all open), are often not sold or sold for a low price.

Potted flowering orchids are produced in vast quantities throughout the world. Orchids are the second most valuable flowering potted crop in the United States, with an estimated wholesale value of approximately $100 million (USDA, 2001). However, the flowering process of the majority of orchid species is understood poorly, or not at all. Some notable exceptions include *Phalaenopsis*, *Cattleya*, *Cymbidium*, and *Dendrobium*. In these genera, low temperatures, short photoperiods, or both, regulate the flowering process (Rotor, 1952; Sakanishi et al., 1980; Ichihashi, 1997).

The *Orchidaceae* includes over 30,000 species, many with considerable ornamental appeal. The commercial potential of the vast majority has not yet been explored. We are in the process of screening genera that show promise for commercial production as flowering potted plants. Important production factors include showiness of flower display, ease and length of production, uniformity, compact size, and flower longevity.

Zygopetalum is a South American genus of orchids that have fragrant flowers with lime-green and dark maroon flower petals and a white and magenta lip. Their exotic,

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attractive flowers and naturally compact habit (≈25- to 40-cm tall) make *Zygopetalum* appealing flowering potted plants. However, control of growth and flowering is not well understood, and to our knowledge, no scientific studies on flower induction have been published on this genus.

We have performed experiments to determine how temperature and light controls growth and development of *Zygopetalum* Redvale 'Fire Kiss'. Specifically, our objectives were to determine: 1) how temperature influenced the rate of plant growth; 2) if a period of cool temperatures influenced flowering; 3) if photoperiod alone controlled flowering; and 4) if photoperiod before and during cooling influenced flowering. Here, we present preliminary results after one year of experiments.

MATERIALS AND METHODS

Plant Material

In June 1999, *Zygopetalum* Redvale 'Fire Kiss' plants were received and grown in vitro by a commercial greenhouse (California, U.S.), transplanted into 38-cell plug trays in June 2000, and into 10-cm pots in April 2001. In California, plants were grown at 16 to 26 °C under natural photoperiods (lat. 37°N) with a maximum photosynthetic photon flux (*PPF*) of 300 μmol·m^{-2}·s^{-1}. Five hundred plants in 10-cm pots in a bark and perlite-based media were received in East Lansing, Michigan, USA on 6 May 2001. All plants were maintained at 23 °C in a glass-glazed greenhouse until experiments began. The photoperiod was a constant 16 h, consisting of natural daylengths (lat. 42°N) with day-extension lighting from high-pressure sodium (HPS) lamps, which delivered a supplemental *PPF* of ≈50 μmol·m^{-2}·s^{-1} at plant height [as measured with a LI-COR quantum sensor (model LI-189; LI-COR, Inc., Lincoln, Nebr.)]. Each plant had at least one mature and two immature pseudobulbs at the onset of experiments.

Photoperiod Treatments (Expt. 1)

On 31 May 2001, ten plants were placed under each of seven photoperiods: 10, 12, 13, 14, 16 or 24 h of continuous light or 9 h with a 4-h (2200 to 0200 HR) night interruption (NI). Continuous photoperiods consisted of 9-h days completed by day extension lighting; lamps were turned on at 1700 HR and turned off after each photoperiod was completed. Day-extension and NI lighting (≈3 μmol·m^{-2}·s^{-1} at canopy level) was provided by incandescent lamps. Plants were grown in a glass greenhouse with a constant temperature setpoint of 20 °C. Opaque black cloth was pulled at 1700 HR and opened at 0800 HR everyday on all benches so plants received a similar daily light integral. From 0800 to 1700 HR, HPS lamps provided a supplemental *PPF* of ≈25 μmol·m^{-2}·s^{-1} at plant level when the ambient greenhouse *PPF* was less than 400 μmol·m^{-2}·s^{-1}. To provide uniform night temperatures of 20 °C, a data logger controlled a 1500-W electric heater, which provided supplemental heat under each bench as needed.

Temperature and Photoperiod Treatments – Environmental Chamber (Expt. 2)

Ten plants were assigned randomly to walk-in controlled-environment chambers on 12 June 2001 with constant temperature setpoints of 14, 17, 20, 23, 26, and 29 ºC. Each chamber was divided in half with black plastic and two photoperiods were created: 9-h of light without or with NI lighting (≈3 μmol·m^{-2}·s^{-1} from 2200 to 0200 HR) from incandescent lamps. The 9-h base photoperiod was provided by a combination of cool-white fluorescent (VHOF96T12, Philips, Bloomfield, NJ.) and incandescent lamps from 0800 to 1700 HR at 150 μmol·m^{-2}·s^{-1}. Plants were grown for 20 weeks, except for those at 29 ºC, in which observations were terminated after 13 weeks due to declining growth and plant mortality. The average daily air temperature recorded in the chambers was 13.4, 16.7, 19.5, 22.4, 25.5, and 28.6 °C. At the beginning of the experiment, one immature pseudobulb was identified and node development was recorded weekly by counting the number of leaves from the soil level to the terminal end of the shoot.

Temperature and Photoperiod Treatments – Greenhouse (Expt. 3)

Two hundred *Zygopetalum* were grown at 23 ºC for 8 weeks under photoperiods of 9 or 16 h (pre-cooling photoperiods) beginning on 01 September 2001. Photoperiods were created by pulling opaque blackout cloth over plants between 1700 and 0800 HR, and for the 16-h photoperiod, light from incandescent lamps (delivering ≈3 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was provided between 1700 and 2400 HR. After 8 weeks, plants were transferred to greenhouses with temperature setpoints of 11, 14, 17, 20, and 23 ºC (cool temperatures) with 9- and16-h photoperiods (provided as described above with incandescent lamps), also for 8 weeks. Actual average daily air temperature in each chamber was 12.0, 14.2, 17.3, 20.7, and 23.5 ºC. Vapor pressure deficit during the temperature treatments was maintained around 0.7 kPa by the injection of water vapor as needed. Following the cool temperatures, plants were grown in a common greenhouse at 23 °C with 16-h photoperiods using the HPS lamps. Plants that did not flower after 15 weeks of forcing were considered nonflowering.

Light and Temperature

Light transmission through the greenhouses (Expts. 1 and 3) was reduced using permanent woven shade curtains that reduced light by ≈55% (OLS 50; Ludvig Svensson, Charlotte, N.C.) and by applying whitewash (up to 50%) to the glass as needed. Air temperatures on each bench were monitored with 36-gauge (0.127-mm-diameter) type E thermocouples connected to CR10 dataloggers (Campbell Scientific, Logan, Utah). The datalogger collected temperature data every 10 s and recorded the hourly average. For each experiment, actual average daily air temperatures from the beginning of treatments until the average date of flowering were calculated.

Plant Culture

Plants were irrigated as necessary with well water (containing 95, 34, and 29 $mg \cdot L^{-1}$ Ca, Mg, and S, respectively) supplemented with water-soluble fertilizer to provide the following ($mg \cdot L^{-1}$): 125 N; 12 P; 125 K; 13 Ca; 1.0 Fe, B, and Mo; and 0.5 Mn, Zn, and Cu (MSU Special, Greencare Fertilizers, Chicago, IL). Water was acidified with H_2SO_4 to a titratable alkalinity of 140 $mg \cdot L^{-1}$ $CaCO_3$.

Data Collection and Analysis

A randomized design was used in all experiments. The date at which the first inflorescence was visible (visible inflorescence, or VI) without dissection and the date of the first flower opened (anthesis) were recorded for each plant. At flowering, the number of VI and nodes on the immature pseudobulb below the inflorescence were counted and inflorescence height was measured. The percentage of plants that had VI, the percentage of plants that flowered, days to VI, days from VI to flower, days to flower, and the weekly rates of node development (Expt. 2 only) were calculated. The few plants that died during the experiments were discarded and not included in the results. Data were analyzed using SAS' (SAS Institute, Cary, N.C.) mixed model procedure (PROC MIXED).

RESULTS

Sixty to eighty percent of plants flowered when grown under every photoperiod except continual (24 h) light (Table 1). However, average flowering occurred >150 days after plants were placed under the various photoperiods. Plants reached VI earlier when grown under photoperiods ≤14 hours, but there was no effect of photoperiod on time from VI to anthesis. Flower inflorescences under continuous light had a low flower count and were shorter than under all other photoperiods.

Photoperiod also influenced vegetative growth of *Zygopetalum*. As photoperiod increased from 10 to 24 h, the number of leaves (nodes) per pseudobulb decreased from 12.2 to 7.0 (Table 1). Plants under continual light, however, developed more pseudobulbs per pot compared to those under shorter photoperiods.

Only one of the 120 plants grown in the growth chambers (Expt. 2) flowered (data not shown). Plants developed nodes faster as temperature increased from 14 to 26 °C (Fig. 1). Plants grown at 29 °C developed smaller leaves and at a similar or slower rate than plants at 26 °C. After 15 weeks, plants at 14 °C developed an average of only 1.8 new nodes, while those at 26 °C developed an average of 4.8.

Flowering of *Zygopetalum* was primarily influenced by photoperiod before cooling and by cool temperatures (Expt. 3), and not by photoperiod during the cooling treatment (Fig. 2). Plants grown under a 9-h photoperiod before cooling and then transferred to 11 or 14 °C for eight weeks had the highest flower inflorescence and flowering percentages (Fig. 2A). These plants also flowered rapidly, reaching VI in 17 to 22 days after the end of the cooling period. None of the plants grown under a 9-h photoperiod followed by temperatures ≥17 °C flowered within the duration of the experiment.

When plants were exposed to 16-h photoperiods before cooling, flowering percentage was generally low and flowering was delayed (Fig. 2). However, flowering percentage was greatest and flowering was rapid when plants were cooled at 11 °C. Several of the plants cooled at 14 °C or higher that developed flower inflorescences did not develop to anthesis. In addition, for plants that were reproductive, the average time to VI when cooled at 17 °C or higher was ≥50 days. Regardless of pre-cooling photoperiod and cool temperatures and photoperiod, time from VI to anthesis was 30 to 39 days at ≈23 °C (data not shown).

DISCUSSION

Without exposure to cool temperatures (<20 °C), *Zygopetalum* showed a quantitative short-day photoperiodic flowering response. However, regardless of photoperiod, time to VI was long (>117 days) and relatively nonuniform. Compared with plants grown under long days, those under short photoperiods (14 hours or less) developed fewer pseudobulbs per plant but each pseudobulb developed more nodes. Plant growth was most rapid when grown at temperatures near 26 °C, but at this temperature and higher, leaves developed numerous necrotic spots, ≈1 to 2 mm in diameter. Despite several attempts by plant pathologists, no pathogens could be isolated from these necrotic leaf regions.

The most rapid, complete, and uniform flowering occurred when plants were grown under short days and then cooled at 11 to 14 °C. Photoperiod before cooling also influences flowering in the tropical epiphyte *Hatiora* spp. (Easter cactus) (Rünger, 1960; Rohwer, 2002). In both *Hatiora* and *Zygopetalum*, a period of short days before cooling increased flowering percentage and uniformity. Another similarity between the genera is that the maximum effective temperature for induction is around 14 to 15 °C (Rohwer, 2002).

Flowering in several other orchid genera is also at least partially controlled by exposure to cool temperatures, short days, or both. Flower induction in *Phalaenopsis* follows exposure to temperatures below 28 °C and may be promoted by short days (Sakanishi et al., 1980; Wang and Lee, 1994). Exposure to short photoperiods, sometimes in combination with low temperatures, induces flowering in a number of *Cattleya* species (Rotor, 1952). Diurnal temperature fluctuations that include cool nights induce flowering in the temperate *Cymbidium* Astronaut ‘Rajah’ (Powell et al., 1988) and in other members of the genus (Ichihashi, 1997). Mature pseudobulbs of *Dendrobium* produce flower buds in response to low temperature, with effective temperatures varying between 10 and 20 °C depending on cultivar (Ichihashi,1997).

Essentially none of the plants grown in the growth chambers reached VI, despite that some plants were exposed to cool temperatures (13.4 °C). The lack of flowering can be at least partially attributed to the noninductive pre-cooling photoperiod (16-h) prior to transfer to the growth chambers. A low light intensity could have also contributed to the lack of flowering, as it was lower in the growth chambers (150 $\mu mol \cdot m^{-2} \cdot s^{-1}$) compared to the greenhouse (<400 µmol·m^{-2}·s^{-1}). One other difference between experiments was light quality, which could also have played a role.

We are currently repeating these experiments and are performing additional studies with *Zygopetalum* as well as several other orchid genera, including *Brassia*, *Degarmoara*, and *Miltoniopsis*.

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Tables

Table 1. The effect of photoperiod on days to visible inflorescence (VI), days from VI to flowering, flower number, spike height, initial number of nodes per shoot, initial shoot height, final number of nodes per shoot, initial shoot height, final number of pseudobulbs and final number of shoots of *Zygopetalum* Redvale 'Fire Kiss.'

Photoperiod (h)	VI percentage	Flowering percentage	Days to VI	Days from VI to flowering	Flower and bud no.	Spike height (cm)	Initial node no.	Initial pseudobulb height (cm)	Final node no.	Final pseudobulb height (cm)	Final mature pseudobulb no.	Final immature pseudobulb no.
10	70	70	122	34	3.9	28.0	4.2	4.2	12.2	23.7	2.9	1.1
12	80	80	133	29	3.5	25.6	3.9	4.4	10.5	23.3	3.0	1.4
13	70	70	117	33	2.8	23.5	4.3	4.2	11.4	23.5	3.2	2.0
14	70	70	126	30	2.4	18.7	3.7	3.2	11.3	22.3	3.1	1.5
16	90	60	152	35	3.7	26.7	3.9	4.2	8.7	24.5	3.9	1.7
24	50	40	142	24	1.8	13.1	4.1	4.2	7.0	24.6	5.4	1.0
NI[z]	70	70	158	25	2.3	20.3	3.6	3.4	9.0	26.5	4.5	0.8
Significance:												
Photoperiod			**	NS	***	**	NS	NS	***	NS	***	NS

[z] NI = 9-h photoperiod plus 4-h night interruption.

NS, **,*** Nonsignificant or significant at P≤ 0.01 or 0.001, respectively.

Figures

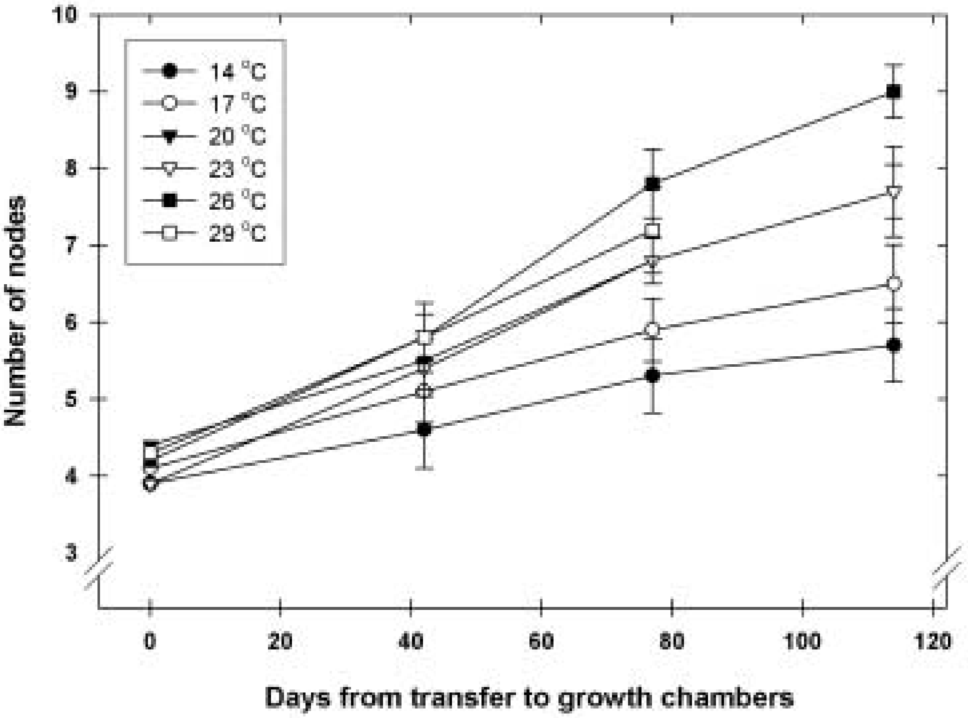

Fig. 1. Node development of *Zygopetalum* Redvale ‘Fire Kiss’ following 42, 77 and 114 days in growth chambers with temperature setpoints of 14, 17, 20, 23, 26, and 29 ºC and a 9-h photoperiod.

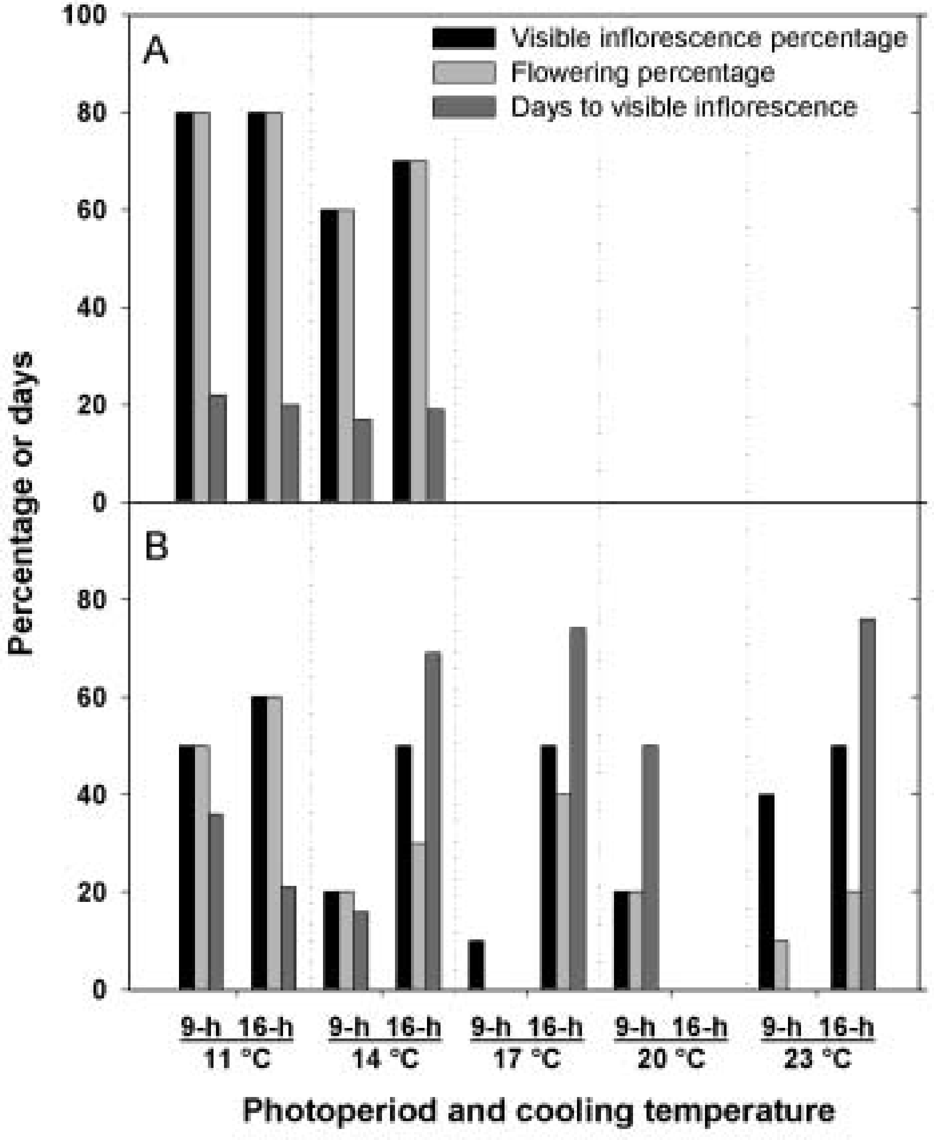

Fig. 2. Visible flower inflorescence and flowering percentages and days to visible inflorescence of *Zygopetalum* Redvale ‘Fire Kiss’ placed under a 9-h (A) and 16-h (B) pre-cooling photoperiod. Plants were subsequently transferred to greenhouses with temperature setpoints of 11, 14, 17, 20, and 23 ºC with 9- and16-h photoperiods for 8 weeks. Plants were then grown at 23 ºC with a 16-h photoperiod. Days to visible inflorescence is not presented if flowering percentage was <20%.