

# High-temperature Inhibition of Flowering of *Phalaenopsis* and *Doritaenopsis* Orchids

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**Abstract.** *Phalaenopsis* orchids require a day temperature of 26 °C or less to initiate inflorescences, whereas the night temperature has little or no effect on inflorescence initiation. We determined the duration of high temperature required each day to prevent inflorescence initiation of four *Phalaenopsis* and *Doritaenopsis* clones. In Years 1 and 2, mature potted plants were grown in separate greenhouse sections with five daily durations at 29 °C: 0, 4, 8, 12, or 24 h. The high temperature was centered in the 16-h photoperiod (0600 HR to 2200 HR) and the remainder of the day was at 20 °C. Exposure to 29 °C for 8 h or longer inhibited inflorescence initiation of *Phalaenopsis* Miva Smartissimo × Canberra ‘Mosella’ and *Phalaenopsis* Brother Pink Mask × Brother Success ‘Explosion’, but *Phalaenopsis* Baldan’s Kaleidoscope ‘Golden Treasure’ and *Doritaenopsis* ‘Newberry Parfait’ required exposure to 29 °C for 12 h or longer to inhibit inflorescence initiation. Flowering was completely suppressed only when high-temperature exposure time was continual for *Doritaenopsis* ‘Newberry Parfait’ and *Phalaenopsis* Baldan’s Kaleidoscope ‘Golden Treasure’ and 12 h for *Phalaenopsis* ‘Mosella’. Plant leaf span generally increased as duration of exposure to 29 °C increased, but high-temperature exposure had few or no significant effects on flowering characteristics of flowering plants. These studies indicate that as few as 8 h of high temperature can prevent flowering of some *Phalaenopsis* hybrids, whereas others require greater than 12 h of high-temperature exposure.

Orchids have become a popular and economically important potted flowering plant in the past decade. In 2007, the U.S. Department of Agriculture (USDA) reported that 15.4 million potted orchids, with a total wholesale value of \$126 million, were sold in the United States (USDA, 2008a). An estimated 75% or more of orchids sold are potted flowering *Phalaenopsis*, *Doritaenopsis*, and their related hybrids (subsequently referred to only as *Phalaenopsis*; Griesbach, 2002). *Phalaenopsis* has become the most popular potted orchid partly because their flowers typically last for 2 to 4 months and plants are easily maintained at retail markets and by consumers (Wang and Lee, 1994).

Controlled production and flowering is a critical factor in ornamental plant production. Although orchid flowering is generally not a well-understood phenomenon, significant progress has been made in understanding the role of environmental factors, particularly for *Phalaenopsis*. Temperatures below 26 °C are

required for 3 to 7 weeks for a visible inflorescence (VI) to develop (Krizek and Lawson, 1974; Sakanishi et al., 1980). The day temperature, not the night temperature, primarily controls inflorescence induction (Blanchard and Runkle, 2006). Once plants have initiated inflorescences, they take 10 to 15 weeks to flower at 20 to 23 °C (Blanchard and Runkle, 2006; Sakanishi et al., 1980). The estimated base temperature for inflorescence development is 10.8 °C for *Phalaenopsis* Taisuco Smile, and anthesis is reached after 769 degree-days once the inflorescence is visible (Robinson, 2002). Commercial growers can use this information to assist scheduling of *Phalaenopsis* crops to bloom at peak periods of demand such as for Christmas, Valentine’s Day, and Mother’s Day.

Potted *Phalaenopsis* production can be divided into two general production stages: a vegetative stage, in which growth is promoted and flowering is inhibited, and a reproductive stage, in which inflorescences are initiated and flowers develop. The objective of this study was to determine how short or moderate periods of high temperatures each day influence flowering of mature *Phalaenopsis* orchids. By providing a high day temperature during the vegetative stage, commercial growers could theoretically provide a cooler night temperature and still inhibit flowering. If effective, this practice could reduce the amount of energy consumed for heating greenhouses at night, which is

when ≈80% of the heating energy is used in temperate locations (Bartok, 2001).

## Materials and Methods

### Plant material

*Year 1.* *Phalaenopsis* Brother Pink Mask × Brother Success ‘Explosion’ and *Phalaenopsis* Miva Smartissimo × Canberra ‘Mosella’ were potted on 1 Jan. 2006 and 19 Jan. 2006, respectively, in 11.4-cm (575-mL) pots with a medium composed of (by volume) 75% fine-grade douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark, 15% medium-grade perlite, and 10% sphagnum peat and grown at noninductive temperatures in a commercial greenhouse in California. Plants had been vegetatively propagated through tissue culture so that plants of each hybrid were all one clone. Plants were received at Michigan State University on 21 Nov. 2006. On arrival, plants were placed in a glass-glazed greenhouse with a temperature set point of 29 °C for 32 d before the experiment began. When treatments began, the mean leaf span (and leaf number) was 32 cm (4.4) for *P.* ‘Mosella’ and 37 cm (5.4) for *P.* ‘Explosion’.

Clones of *Doritaenopsis* ‘Newberry Parfait’ and *Phalaenopsis* Baldan’s Kaleidoscope ‘Golden Treasure’ were potted and grown in 11.4-cm pots as described previously. Plants were received at Michigan State University on 22 Nov. 2005 and were repotted in early June 2006 into 11.4-cm (725-mL) translucent pots with a medium consisting of 40% medium-grade douglas fir bark (Rexius Forest By-Products Inc., Eugene, OR), 30% medium-grade chopped coconut (*Coco nucifera* L.) coir (Millenniumsoils Coir, St. Catharines, Ontario, Canada), 15% long-fiber Canadian sphagnum peat (Mosser Lee Co., Millston, WI), and 15% coarse perlite (OFE Intl. Inc., Miami, FL). These plants were then grown at 29 °C for several months before being used in Year 1. Leaf span (the distance measured from the end of one leaf to the longest opposite leaf tip) and leaf number were recorded for each plant at the start of treatments and means were 42 cm and 5.7 for *P.* Baldan’s Kaleidoscope ‘Golden Treasure’ and 46 cm and 5.5 for *D.* ‘Newberry Parfait’, respectively.

*Year 2.* *Phalaenopsis* ‘Mosella’, *Phalaenopsis* Baldan’s Kaleidoscope ‘Golden Treasure’, and *Doritaenopsis* ‘Newberry Parfait’ plants were grown in 11.4-cm (810-mL) containers with a potting mix of 80% coarse (2.5 cm) pine bark and 20% fine coir at noninductive temperatures in a commercial greenhouse in Florida. Plants were shipped to Michigan State University on 7 Sept. 2007 and 19 Oct. 2007 and were placed in a glass-glazed greenhouse with a set point of 29 °C and a 16-h photoperiod for 9.5 or 3.5 weeks before the second replication of the experiment began. At the onset of treatments, mean leaf span and leaf number were 52 cm and 6.5 for *P.* ‘Mosella’, 43 cm and 7.2 for *P.* Baldan’s Kaleidoscope ‘Golden Treasure’, and 50 cm and 5.9 for *D.* ‘Newberry Parfait’, respectively. *Phalaenopsis* ‘Explosion’ plants

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were not available in Year 2, so they were not included in experimentation.

### Temperature treatments

Five temperature treatments were used in both Year 1 and Year 2: constant 29 °C, 12 h at 29 °C, 8 h at 29 °C, 4 h at 29 °C, and constant 20 °C. For the remaining periods, a temperature of 20 °C was maintained. The hours at 29 °C were centered in the middle of the 16-h photoperiod (0600 to 2200 HR). Nine or 10 plants of each clone were moved from constant 29 °C to the temperature treatments on 22 Dec. 2006 in Year 1 and 14 Nov. 2001 in Year 2. Plants were grown at these temperature treatments for 20 weeks. Plants that had initiated an inflorescence but not yet flowered at the end of the 20-week treatment period remained at the appropriate temperature treatment until the first flower of each plant opened and the flowering data were collected.

To determine whether plant size influenced the response to temperature treatments, six to eight large *Phalaenopsis* 'Mosella' plants were placed at constant 29 °C, 8-h 29 °C, or constant 20 °C in Year 2 and were compared with the moderate-sized *P.* 'Mosella'. The large-sized plants, which had a mean of 9.5 leaves and a 65-cm leaf span, had been growing at constant 29 °C for more than 2 years and so were larger than the moderate-sized plants that had a mean of 6.5 leaves and leaf span of 52 cm.

### Greenhouse environment

Plants were maintained in glass greenhouses at the Michigan State University Plant Science Research Greenhouses in East Lansing, MI. Each temperature treatment was assigned to one greenhouse compartment in Years 1 and 2. Whitewash and shadecloth were used to keep the maximum instantaneous light intensity below 400  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . During periods without active ventilation, the vapor pressure deficit was maintained at 1.2 kPa by the addition of steam. A 16-h photoperiod (0600 to 2200 HR) was provided by sunlight and supplemental lighting from high-pressure sodium lamps, which provided 40 to 115  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  of light, depending on the presence or absence of shadecloth beneath the lamps, at plant canopy. Plants were individually watered as needed with reverse osmosis water containing water-soluble fertilizer that provided (in  $\text{mg}\cdot\text{L}^{-1}$ ) 125 nitrogen, 12 phosphorus, 100 potassium, 65 calcium, 12 magnesium, 1.0 iron, 1.0 copper, 0.5 manganese, 0.5 zinc, 0.3 boron, and 0.1 molybdenum (MSU Special; GreenCare Fertilizers, Inc., Kankakee, IL) at each watering.

Temperatures were maintained using a computerized environmental control system (Priva Computers Inc., Vineland Station, Ontario, Canada), which controlled the vents, fans, heaters, and the evaporative cooling system. Transitions between temperatures typically occurred within 15 min because of the small size of each greenhouse compartment. Temperature in each greenhouse compartment was measured every 10 s by

aspirated and enclosed thermocouples positioned at plant height, and a CR10 data logger (Campbell Scientific, Logan, UT) recorded hourly means. The actual mean temperatures for the constant 29 °C, 12-h 29 °C, 8-h 29 °C, 4-h 29 °C, and constant 20 °C treatments were 29.1, 24.7, 22.8, 22.6, and 20.0 °C, respectively, in Year 1 and 28.8, 24.6, 23.3, 21.4, and 20.2 °C, respectively, in Year 2 (Newton, 2008).

### Data collection and analysis

The dates of first macroscopic VI and first open flower were recorded for each plant. In addition, the number of flower buds per inflorescence was counted, and the diameter of the first flower, the length of the inflorescence to the first flower, and the total inflorescence length (to the tip of the inflorescence) were measured at first open flower. The effect of the temperature treatments on vegetative growth was determined by measuring the leaf span at both the beginning and the end of the experiment and counting the number of new leaves (1 cm long or greater) produced by each plant during the 20 weeks of the experiment.

The experiment was replicated in time: from Dec. 2006 to May 2007 (Year 1) and Nov. 2007 to Apr. 2008 (Year 2). Plants of each cultivar were randomly divided among

the temperature treatments. To analyze the percentage of plants developing VI and flowering, a binomial distribution with a logit transformation was used. Mean separation was performed on all other data with Tukey's honestly significant difference test at  $P \leq 0.05$  in PROC MIXED of SAS (SAS Institute, Inc., Cary, NC).

## Results

### Effects of high temperature duration on flowering

*Phalaenopsis* 'Mosella'. The temperature treatments of constant 29 °C, 12 h at 29 °C, and 8 h at 29 °C prevented or reduced flowering (Fig. 1A) compared with the constant 20 °C (control) treatment. In contrast, 29 °C for 4 h at midday did not affect flowering percentage compared with that of plants at constant 20 °C. However, in Year 1, but not in Year 2, 4 h at 29 °C at midday increased the number of days until the first flower opened (Fig. 1A).

The number of inflorescences, total flower bud number per plant, number of flowers per inflorescence, and flower diameter were unaffected by temperature treatment (Table 1). The total height of the first inflorescence was increased by 19% and 30% by the 4- or 8-h 29 °C treatments, respectively, compared

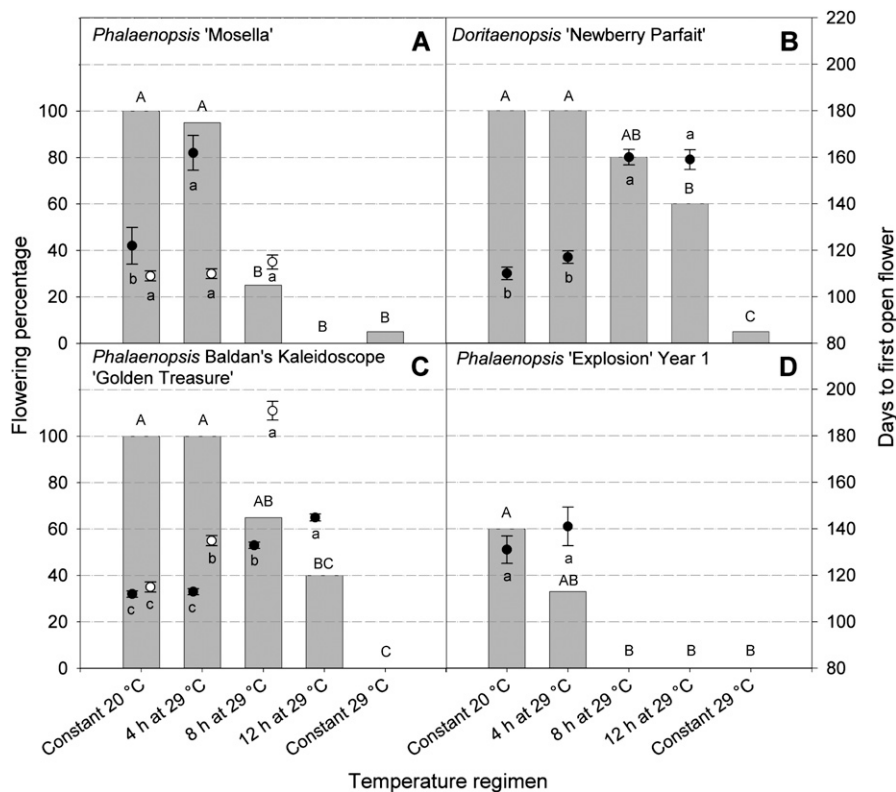


Fig. 1. (A–D) Effects of high-temperature (29 °C) duration on flowering percentage (bars) and mean days to first open flower (symbols) of *Phalaenopsis* and *Doritaenopsis* clone(s). For clones in which the temperature treatment by year interaction was significant for the days to first open flower, Year 1 is represented by closed circles (●) and Year 2 is represented by open circles (○). Flowering percentages within a clone with different uppercase letters are significantly different with a binomial distribution and logit transformation. Days to first open flower within a clone and year with different lowercase letters are significantly different with Tukey's honestly significant difference test at  $P \leq 0.05$ . Vertical bars represent the ses of the means.

Table 1. Effect of the duration of high temperature (29 °C) exposure on the visible inflorescence (VI) number per plant, total flower bud number per plant, flower bud number per inflorescence, first open flower diameter, length of the first inflorescence from the base to the first flower, and increase in leaf span after 20 weeks of treatments of *Phalaenopsis* 'Mosella'.<sup>z</sup>

Temperature treatment (TT)	VI no. per plant	Flower bud no. per plant	Flower bud no. per VI	Flower diam (cm)		VI length to first flower (cm)		Leaf span increase (cm)
				Year 1	Year 2	Year 1	Year 2	
Constant 20 °C	1.3 a <sup>y</sup>	12.2 a	9.4 a	8.2 a	8.8 a	28.6 b	41.8 a	0.1 b
4 h at 29 °C	1.2 a	10.8 a	8.8 a	8.5 a	8.3 a	37.3 a	45.4 a	0.3 b
8 h at 29 °C	1.0 a	11.0 a	11.0 a	— <sup>x</sup>	8.6 a	—	45.4 a	1.7 ab
12 h at 29 °C	—	—	—	—	—	—	—	3.4 a
Constant 29 °C	—	—	—	—	—	—	—	3.3 a
Significance								
TT	NS	NS	NS	NS	NS	***	***	***
Year	***	***	***	NS	NS	***	***	*
TT*year	NS	NS	NS	*	*	*	*	NS

<sup>z</sup>For parameters in which the interaction between temperature treatment and year was not significant, data were pooled; otherwise, mean separation was performed on each year separately.

<sup>y</sup>Mean separation within column by Tukey's honestly significant difference test at  $P \leq 0.05$  with the exception of the percentage of plants developing a VI, which was analyzed with a binomial distribution and logit transformation.

<sup>x</sup>Twenty percent or less of plants in treatment flowered, so data were not analyzed.

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

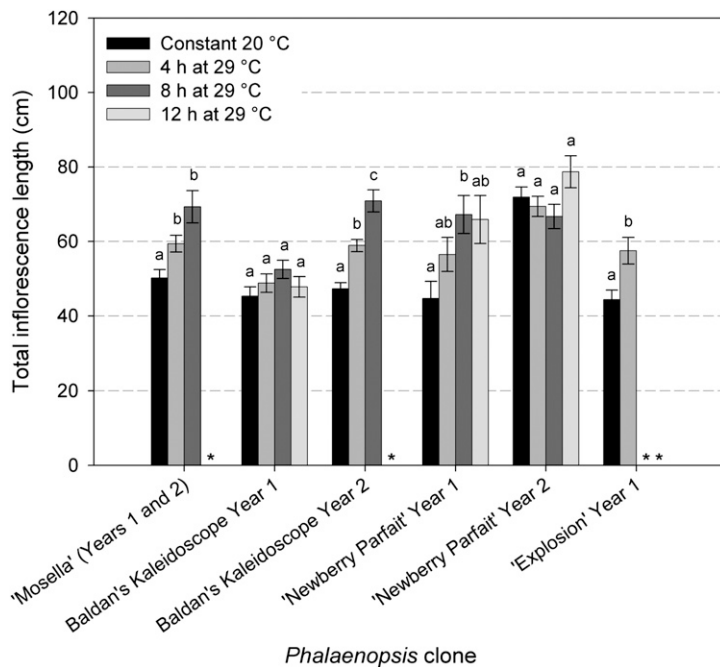


Fig. 2. Effects of high-temperature (29 °C) duration on total inflorescence height (from base to tip) of *Phalaenopsis* and *Doritaenopsis* clone(s). For clones in which the temperature treatment by year interaction was significant, the years were analyzed separately. Data were not analyzed for temperature treatments in which 20% or less of plants flowered (\*). Mean separation within each clone and year was performed with Tukey's honestly significant difference test at  $P \leq 0.05$ . Vertical bars represent the SEs of the means.

with the height of inflorescences at constant 20 °C (Fig. 2).

*Phalaenopsis Baldan's Kaleidoscope 'Golden Treasure'*. Constant 29 °C completely prevented flowering, whereas only 40% of the plants at 29 °C for 12 h flowered (Fig. 1C). The percentage of plants flowering was similar among plants grown at constant 20 °C and those exposed to 29 °C for 4 or 8 h at midday. However, exposure to 29 °C generally delayed flowering. The 4-h 29 °C treatment did not delay flowering in Year 1 compared with constant 20 °C, but it did delay flowering in Year 2 by 2 to 3 weeks. Exposure to 29 °C for 8 h at midday delayed flowering by 3 and 10 weeks in Years 1 and

2, respectively. The plants that flowered in the 12 h at 29 °C treatment in Year 1 did not flower until almost 5 weeks after plants at constant 20 °C.

The effect of the duration at 29 °C on number of inflorescences per plant and total flower bud number per plant varied by year (Table 2). In Year 1, none of the temperature treatments influenced the number of inflorescences, but in Year 2, plants at 29 °C for 8 h at midday developed fewer inflorescences than those at constant 20 °C. Total flower bud number of plants exposed to 29 °C for 12 h was lower in Year 1 and by 8 h of exposure to 29 °C in Year 2 compared with that of plants at constant 20 °C. Flower bud number

per inflorescence was similar among temperature treatments, but first flower diameter of plants at 8 and 12 h at 29 °C was 8% to 12% smaller than that at constant 20 °C. In Year 1, inflorescence length to the first flower was greater when plants were exposed to 29 °C for 8 h at midday compared with that at constant 20 °C, but there was no effect on total inflorescence length (Fig. 2). In Year 2, both 4 h and 8 h at 29 °C at midday increased the inflorescence length to the first flower by 18% and 50%, respectively, compared with that of plants at constant 20 °C.

*Doritaenopsis 'Newberry Parfait'*. The only temperature treatments that reduced flowering percentage were constant 29 °C and 12 h at 29 °C, which reduced the flowering percentage to 5% and 60%, respectively (Fig. 1B). At least 80% of the plants flowered in the other temperature treatments. Although the majority of plants exposed to 29 °C for 8 h at midday or 12 h flowered, the time to first open flower was 7 to 8 weeks later than that of plants at constant 20 °C.

Exposure to 29 °C did not influence the number of inflorescences per plant or the first flower diameter (Table 3). Although the effect of temperature treatment on total flower bud number per plant and the mean number of flower buds per inflorescence varied by year, none of the temperature treatments differed from the control in a given year. The inflorescence length to the first flower was greater for plants exposed to 29 °C for 8 or 12 h compared with that of plants at constant 20 °C in Year 1, but there was no effect of temperature treatment in Year 2. Similarly, total inflorescence length of plants in the 8-h 29 °C treatment was greater compared with that of plants at constant 20 °C in Year 1 but not in Year 2 (Fig. 2).

*Phalaenopsis 'Explosion'*. The only plants that developed open flowers (Fig. 1D) were those grown at 29 °C for 4 h or less per day. None of the plants exposed to 29 °C for 8 h or longer flowered. There was no difference in days to first open flower, number of inflorescences, total flower bud number per

Table 2. Effect of the duration of high temperature (29 °C) exposure on visible inflorescence (VI) number per plant, total flower bud number per plant, flower bud number per inflorescence, first open flower diameter, length of the first inflorescence from the base to the first flower, and increase in leaf span after 20 weeks of *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure'.<sup>z</sup>

Temperature treatment (TT)	VI no. per plant		Flower bud no. per plant		Flower bud no. per VI	Flower diam (cm)	VI length to first flower (cm)		Leaf span increase (cm)
	Year 1	Year 2	Year 1	Year 2			Year 1	Year 2	
Constant 20 °C	1.3 ab <sup>y</sup>	2.0 b	10.4 ab	14.0 ab	7.6	7.8 a	29.6 b	32.9 c	-0.1 c
4 h at 29 °C	1.8 a	2.1 b	11.3 a	18.2 a	7.7	7.4 ab	33.0 ab	38.8 b	0.3 bc
8 h at 29 °C	1.6 ab	1.0 a	11.4 a	8.3 b	8.0	7.2 b	36.9 a	49.6 a	2.7 a
12 h at 29 °C	1.1 b	— <sup>x</sup>	7.1 b	—	6.4	6.9 b	34.7 ab	—	2.5 a
Constant 29 °C	—	—	—	—	—	—	—	—	1.7 ab
Significance									
TT		***		***	NS	**		***	***
Year		NS		*	NS	NS		***	NS
TT*year		**		***	NS	NS		*	NS

<sup>z</sup>For parameters in which the interaction between temperature treatment and year was not significant, data were pooled; otherwise, mean separation was performed on each year separately.

<sup>y</sup>Mean separation within column by Tukey's honestly significant difference test at  $P \leq 0.05$  with the exception of the percentage of plants developing a VI, which was analyzed with a binomial distribution and logit transformation.

<sup>x</sup>Twenty percent or less of plants in treatment flowered, so data were not analyzed.

NS, \*, \*\*, \*\*\*Nonsignificant or significant at  $P \leq 0.05, 0.01, \text{ or } 0.001$ , respectively.

Table 3. Effect of the duration of high temperature (29 °C) exposure on visible inflorescence (VI) number per plant, total flower bud number per plant, flower bud number per inflorescence, first open flower diameter, length of the first inflorescence from the base to the first flower, and increase in leaf span after 20 weeks of *Doritaenopsis* 'Newberry Parfait'.<sup>z</sup>

Temperature treatment (TT)	VI no. per plant	Flower bud no. per plant		Flower bud no. per VI		Flower diam (cm)	VI length to first flower (cm)		Leaf span increase (cm)
		Year 1	Year 2	Year 1	Year 2		Year 1	Year 2	
Constant 20 °C	1.0	4.8 a <sup>y</sup>	10.4 a	4.8 a	10.4 a	8.2 a	31.9 a	50.5 a	-0.6 a
4 h at 29 °C	1.2	7.3 a	9.0 a	6.6 a	7.7 a	8.4 a	39.3 ab	47.4 a	1.4 a
8 h at 29 °C	1.0	7.2 a	8.1 a	7.2 a	8.1 a	8.5 a	46.3 b	46.1 a	1.0 a
12 h at 29 °C	1.0	6.3 a	8.0 a	6.3 a	8.0 a	8.6 a	48.3 b	57.0 a	0.9 a
Constant 29 °C	— <sup>x</sup>	—	—	—	—	—	—	—	1.0 a
Significance									
TT	NS		NS		NS	NS		*	NS
Year	NS		***		***	*		***	**
TT*year	NS		*		**	NS		*	NS

<sup>z</sup>For parameters in which the interaction between temperature treatment and year was not significant, data were pooled; otherwise, mean separation was performed on each year separately.

<sup>y</sup>Mean separation within column by Tukey's honestly significant difference test at  $P \leq 0.05$  with the exception of the percentage of plants developing a VI, which was analyzed with a binomial distribution and logit transformation.

<sup>x</sup>Twenty percent or less of plants in treatment flowered, so data were not analyzed.

NS, \*, \*\*, \*\*\*Nonsignificant or significant at  $P \leq 0.05, 0.01, \text{ or } 0.001$ , respectively.

plant, flower bud number per inflorescence, first flower diameter, or length of inflorescence to the first flower between plants at constant 20 °C or at 29 °C for 4 h. However, total inflorescence length of plants at 29 °C for 4 h was 30% greater than inflorescences at constant 20 °C (data not shown).

#### Effects of plant size on flowering

The size of *Phalaenopsis* 'Mosella' plants at the onset of the experiment did not influence the percentage of plants that developed open flowers in any of the three temperature treatments tested (data not shown). All plants of both sizes flowered at constant 20 °C and no plants of either size flowered at constant 29 °C. In the 8-h 29 °C treatment, 100% of large plants flowered and 50% of the moderate-sized plants flowered, but there was no statistical difference (data not shown). Plant size also did not affect time to first open flower. The moderate-sized plants flowered in 109 or 115 d at constant 20 °C or in the 8-h of 29 °C treatment, respectively, whereas the large plants took 115 or 123 d to flower (data not shown). At both constant 20 °C and 8 h at 29 °C, the larger plants developed a greater number of VI and total flowers (Table 4). Large plants developed a greater number of

flowers per inflorescence than moderate-sized plants only at constant 20 °C. The moderate-sized plants had larger flowers at constant 20 °C, but not at 8 h at 29 °C. Although inflorescence length to the first flower of large plants was greater than that of moderate-sized plants in the 8-h 29 °C treatment, total inflorescence length was unaffected by plant size.

#### Effects of high-temperature duration on vegetative growth

Overall, the mean number of new leaves that developed during the 20 weeks of the experiment increased with increasing daily duration at 29 °C and, hence, with mean daily temperature (Fig. 3). Except for *Phalaenopsis* Baldan's Kaleidoscope in Year 1, plants at 29 °C for 8, 12, or 24 h developed more leaves than plants at constant 20 °C. The effect of varying durations at 29 °C on the change in leaf span was more variable among clones. Leaf span of *Doritaenopsis* 'Newberry Parfait' and *Phalaenopsis* 'Explosion' was similar in all temperature treatments (Table 3 and data not shown). In contrast, 12 h at 29 °C and constant 29 °C increased leaf span compared with that of plants at constant 20 °C in both *Phalaenopsis* 'Mosella'

and Baldan's Kaleidoscope 'Golden Treasure' (Tables 1 and 2). The 8-h 29 °C treatment also increased leaf span in *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure'.

#### Discussion

Eight and 12 h at 29 °C either prevented or delayed flowering in the *Phalaenopsis* and *Doritaenopsis* clones studied. Twelve hours at 29 °C completely prevented flowering of all the *Phalaenopsis* clones except Baldan's Kaleidoscope 'Golden Treasure' in Year 1 and 'Newberry Parfait' in both Year 1 and 2. Plants that flowered and were exposed to an 8- or 12-h high-temperature period had a delay in flowering of 6 to 50 d. Sakanishi et al. (1980) reported a high-temperature inhibition of the emergence of a VI on *P. amabilis* (L.) Blume; only 84% of plants exposed to 28 °C for 12 h developed an inflorescence. When the high temperature was extended by 2 h (for a total of 14 h), inflorescence emergence was delayed and VI percentage was reduced to 46%. By comparison, 12 h at 29 °C was more effective at inhibiting flowering in *Phalaenopsis* Brother Goldsmith '720' and *Phalaenopsis* Miva Smartissimo × Canberra '450' (Blanchard

Table 4. Effect of duration of high temperature (29 °C) exposure and plant size in Year 2 on visible inflorescence (VI) number per plant, total flower bud number per plant, flower bud number per inflorescence, first open flower diameter, total length and length to the first flower of the inflorescence, increase in leaf span, and the number of new leaves developed after 20 weeks of *Phalaenopsis* 'Mosella'.

Temperature treatment (TT)	Plant size	VI no. per plant	Flower bud no. per plant	Flower bud no. per VI	Flower diam (cm)	VI length to first flower (cm)	Total VI length (cm)	Leaf span increase (cm)	No. of new leaves
Constant 20 °C	Moderate	1.5 bc <sup>z</sup>	18.4 bc	13.1 b	8.8 a	41.8 b	58.6 b	-0.1	0.1 c
	Large	2.5 a	53.3 a	20.4 a	7.5 b	44.1 b	60.5 ab	1.4	0.5 bc
8 h at 29 °C (1000–1800 HR)	Moderate	1.0 c	11.0 c	11.0 b	8.6 a	45.4 b	65.3 ab	2.3	1.0 bc
	Large	1.8 b	26.0 b	14.4 ab	8.3 a	49.4 a	69.1 a	0.9	0.8 bc
Constant 29 °C	Moderate	— <sup>y</sup>	—	—	—	—	—	2.2	2.2 a
	Large	—	—	—	—	—	—	3.8	1.4 ab
Significance									
TT		**	***	NS	NS	**	**	NS	***
Plant size		***	***	*	***	*	NS	NS	NS
TT*plant size		NS	*	NS	*	NS	NS	NS	NS

<sup>z</sup>Mean separation within column by Tukey's honestly significant difference test at  $P \leq 0.05$  with the exception of the percentage of plants developing a VI, which was analyzed with a binomial distribution and logit transformation.

<sup>y</sup>Twenty percent or less of plants in treatment flowered, so data were not analyzed.

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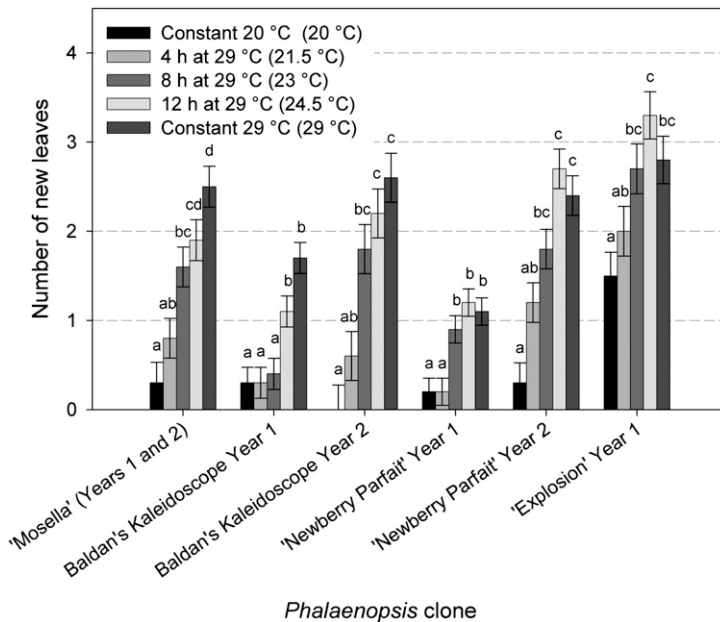


Fig. 3. Effects of high-temperature (29 °C) duration (and mean daily temperature) on number of new leaves of *Phalaenopsis* and *Doritaenopsis* clone(s). For clones in which the temperature treatment by year interaction was significant, the years were analyzed separately. Mean separation within each clone and year was performed with Tukey's honestly significant difference test at  $P \leq 0.05$ . Vertical bars represent the SES of the means.

and Runkle, 2006). After 20 weeks at a day/night temperature (12 h each) of 29/17 and 29/23 °C, none of the plants had developed a VI. Similarly, Wang (2007) reported that none of the *Doritaenopsis* 'Lava Glow' plants grown at a day/night temperature of 30/20 °C (12 h each) flowered. Apparently, the daily duration of high temperature required to prevent flowering depends on the *Phalaenopsis* or *Doritaenopsis* clone and the actual temperature. Twelve hours at 29 or 30 °C is long enough to prevent inflorescence initiation in some, but not all, *Phalaenopsis* clones.

Exposure to 29 °C for 4 h did not delay or inhibit flowering in most cases. These results support those of Sakanishi et al. (1980), who reported that 6 h at 28 °C did not inhibit or delay inflorescence initiation of *P. amabilis*

compared with temperatures less than 25 °C. The one exception in our study was *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure', for which 4 h at 29 °C midday delayed inflorescence initiation.

In addition to the duration of high temperature, the time of day the high temperature is delivered can also influence flowering characteristics of *Phalaenopsis*. The treatments used in the study, which were centered in the middle of a 16-h photoperiod, have been compared with three additional temperature treatments (Newton, 2008). The additional treatments were two treatments with 4 h at 29 °C, with the 29 °C delivered either early in the day (0800 to 1200 HR) or late in the day (1600 to 2000 HR) and one additional treatment of 8 h at 29 °C late in the day (1400 to 2200 HR). For each of these treatments, the

temperature was 20 °C during the remaining periods of the day. Although the time of day during which the 4 or 8 h at 29 °C was delivered did not influence the flowering percentage, it did affect the time to flower in *Doritaenopsis* 'Newberry Parfait' and *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure'. In both of these clones, the plants exposed to 29 °C for 8 h during the end of the day flowered 4 to 5 weeks earlier than plants exposed to 29 °C for 8 h during the middle of the day. However, the later in the day that the 4-h at 29 °C treatment was delivered, the greater the delay in flowering of *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure'.

Two factors could have contributed to the differing responses of a particular clone between years: temperature control and plant size. In Year 1, outside temperature during Weeks 7 through 9 was so cold that 29 °C could not be adequately maintained as desired inside the greenhouses. In Year 2, greenhouse temperature was maintained closer to the set points during the entire experiment. This temperature difference could explain why 45% of *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure' plants initiated flowers in Year 1 in the 12-h 29 °C treatment. The periods of lower temperatures in Year 1 could also have contributed to the fewer new leaves that developed in *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure' and *Phalaenopsis* 'Newberry Parfait' compared with Year 2.

Differences in plant responses of the same clone between years could also be attributed to differences in plant size at the onset of the experiments. *Phalaenopsis* 'Mosella' plants used in Year 2 had a leaf span 20 cm greater than the plants used in Year 1. Smaller plants require a cooler temperature, longer exposure to cool temperatures, or both to initiate inflorescences and flower (Yoneda et al., 1992). Thus, the larger plants used in Year 2 could have been more sensitive to temperature with respect to flowering. The smaller *Phalaenopsis* 'Mosella' plants used in Year 1 took 13 and 52 d longer to flower at constant 20 °C and 4 h at 29 °C, respectively, compared with the larger plants used in Year

2. However, the time to VI did not vary by size.

There was little effect of the duration of 29 °C on inflorescence characteristics of flowering plants, although inflorescence height generally increased with increasing duration at 29 °C. Other researchers have reported an increase in inflorescence length with increasing temperature. For example, the mean total inflorescence length of a *Phalaenopsis* hybrid grown at a day/night temperature of 30/25 °C was 68% longer than the inflorescences of plants at 20/15 °C (Lee and Lin, 1984). However, 1 week at 30 °C preceded or followed by a day/night of 25/20 °C did not have an effect on flowering characteristics of *Phalaenopsis* Taisuco Swan (Tsai et al., 2008).

The duration of 29 °C had no effect on number of inflorescences, number of flower buds per plant, number of flower buds per inflorescence, or diameter of first open flower on three of the four *Phalaenopsis* clones tested. However, exposure to 29 °C for 8 h reduced both the number of inflorescences and number of flower buds per plant of *Phalaenopsis* Baldan's Kaleidoscope 'Golden Treasure' in Year 2. In Year 1, the number of flower buds per plant was decreased only by exposure to 29 °C for 12 h. Additionally, both the 4- and 8-h 29 °C treatments decreased the diameter of the first flower of this clone.

In Year 2, the 12 h at 29 °C treatment caused small pitted spots on the leaves, which resembled chilling injury (McConnell and Sheehan, 1978). All three clones exhibited some damage, but *Doritaenopsis* 'Newberry Parfait' was more susceptible than the other two clones. We speculate that these symptoms developed from the use of passive ventilation through top vents used in Year 2, which allowed heat to escape rapidly as the temperature set point changed from 29 to 20 °C. In Year 1, active ventilation was used when the temperature was lowered to 20 °C, which drew air in from a heated hallway. Furthermore, we speculate that these symptoms occurred only in this temperature treatment because the transition from 20 to 29 °C occurred at the very end of the day, when outdoor temperatures were generally coldest.

The physiological mechanism of high-temperature inhibition of flowering in *Phalaenopsis* is not well understood. It has been postulated that the synthesis or interconversion of plant hormones such as cytokinins and gibberellins is involved (Chou et al., 2000; Su et al., 2001). Low temperatures could increase the concentrations of the com-

pounds required for inflorescence initiation, whereas high temperatures could inhibit their accumulation. The results of this research support this hypothesis; plants exposed to 29 °C for 8 h showed an intermediate flowering response in which inflorescence initiation was either delayed or prevented in a portion of the *Phalaenopsis* plants.

The results of this study have practical applications for growers of *Phalaenopsis*. Because 12 h at 29 °C is sufficient to prevent flowering of some *Phalaenopsis* clones, growers may not need to heat a greenhouse to 26 °C or greater all night to prevent inflorescence initiation. Reducing the temperature of the greenhouse at night, when exterior temperatures are generally the coldest, could result in considerable energy savings. The energy savings of heating a double-layer polyethylene greenhouse to a 12-h day/12-h night temperature of 29/20 °C instead of constant 29 °C in Grand Rapids, MI, is estimated to be 14% for January and 74% for July. In the more moderate climate of San Francisco, CA, the estimated energy savings is 26% in January and 50% in July (USDA, 2008b).

In summary, there is a tradeoff between flowering and vegetative growth in *Phalaenopsis*. As the duration of high temperature increases, the percentage of flowering plants decreases and vegetative growth increases. A majority of the *Phalaenopsis* clones we studied required at least 12 h at 29 °C to completely prevent inflorescence initiation. Intermediate durations of high temperature partially inhibited inflorescence initiation, but 4 h at 29 °C did not inhibit flowering in the clones studied.

A better understanding of the duration required to prevent inflorescence initiation of *Phalaenopsis* could be obtained through additional studies of a wider range of clones and smaller intervals between the durations of high temperature tested. Durations longer than 12 h need to be tested for clones such as *Doritaenopsis* 'Newberry Parfait' that flower even when exposed to 29 °C for 12 h during the day. In addition, the effectiveness of a range of temperatures between 26 and 32 °C on inhibiting inflorescence initiation should be compared.

#### Literature Cited

Bartok, J.W., Jr. 2001. Energy conservation for commercial greenhouses. Natural Resource Agriculture and Engineering Service, Ithaca, NY.

Blanchard, M.G. and E.S. Runkle. 2006. Temperature during the day, but not during the night,

controls flowering of *Phalaenopsis* orchids. J. Expt. Bot. 57:4043–4049.

Chou, C.C., W.S. Chen, K.L. Huang, H.C. Yu, and L.J. Liao. 2000. Changes in cytokinin levels of *Phalaenopsis* leaves at high temperatures. Plant Physiol. Biochem. 38:309–314.

Griesbach, R.J. 2002. Development of *Phalaenopsis* orchids for the mass-market, p. 458–465. In: Janick, J. and A. Whipkey (eds.). Trends in new crops and new uses. ASHS Press, Alexandria, VA.

Krizek, D.T. and R.H. Lawson. 1974. Accelerated growth of *Cattleya* and *Phalaenopsis* under controlled-environment conditions. Amer. Orchid Soc. Bul. 43:503–510.

Lee, N. and G.M. Lin. 1984. Effect of temperature on growth and flowering of *Phalaenopsis* White Hybrid. J. Chinese Soc. Hort. Sci. 30: 223–231.

McConnell, D.B. and T.J. Sheehan. 1978. Anatomical aspects of chilling injury leaves of *Phalaenopsis* Bl. HortScience 13:705–706.

Newton, L.A. 2008. Effects of high temperature and plant growth regulators on vegetative growth and flowering of potted orchids. Dept. of Horticulture, Michigan State Univ., East Lansing, MI. MS Thesis.

Robinson, K.A. 2002. Effects of temperature on flower development rate and morphology of *Phalaenopsis*. Mich. State Univ., East Lansing, MI. MS Thesis.

Sakanishi, Y., H. Imanishi, and G. Ishida. 1980. Effect of temperature on growth and flowering of *Phalaenopsis amabilis*. Bul. Univ. Osaka. Ser. B: Agr. Biol. 32:1–9.

Su, W.R., W.S. Chen, M. Koshioka, L.N. Mander, L.S. Hung, W.H. Chen, Y.M. Fu, and K.L. Huang. 2001. Changes in gibberellin levels in the flowering shoot of *Phalaenopsis hybrida* under high temperature conditions when flower development is blocked. Plant Physiol. Biochem. 39:45–50.

Tsai, W.-T., Y.-T. Wang, and H.-L. Lin. 2008. Alternating temperature affects spiking of a hybrid *Phalaenopsis*. Acta Hort. 766:307–314.

U.S. Department of Agriculture. 2008a. Floriculture crops 2007 summary. Agr. Stat. Board, Washington, DC.

U.S. Department of Agriculture. 2008b. Virtual Grower 2.0. Agr. Res. Serv., Washington, DC. 4 Sept. 2008. <<http://www.ars.usda.gov/services/software/download.htm?softwareid%3d108>>.

Wang, Y.-T. 2007. Average daily temperature and reversed day/night temperature regulate vegetative and reproductive responses of a *Doritis pulcherrima* Lindley Hybrid. HortScience 42: 68–70.

Wang, Y.-T. and N. Lee. 1994. Another look at an old crop: Potted blooming orchids—Part 2. Greenhouse Grower 12:36–38.

Yoneda, K., H. Momose, and S. Kubota. 1992. Comparison of flowering behavior between mature and premature plants of *Phalaenopsis* under different temperature conditions. Jpn. J. Trop. Agr. 36:207–210.