Unravelling the Role of Temperature and Photoperiod on Poinsettia Heat Delay

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Abstract. The effects of day temperature (DT), night temperature (NT), and night length (NL) were evaluated on the flowering responses of heat-tolerant and heat-sensitive poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) cultivars Orion Red and Prestige Red, respectively. Plants were placed under 60 DT × NT × NL treatments that consisted of three DT (20, 24, 28 °C), four NT (16, 20, 24, 28 °C), and five NL (10, 11, 12, 13, 14 hours) for the first 17 days of the experiment. After 17 days, all plants were consolidated to one greenhouse with an inductive environment (14-hour NL, 24 ± 2.0 °C DT and 21.2 ± 1.4 °C NT), and the timing of first color, visible bud, and anthesis were recorded. ‘Orion Red’ reached anthesis 8 to 10 days faster than ‘Prestige Red’ across all NLs; however, in both cultivars, days to anthesis decreased in a sigmoidal pattern as NL increased. The relative rate of progress to anthesis (1/days to anthesis) under a 12-hour NL was approximately half that of plants grown at a 13- or 14-hour NL. At a 12-hour NL, the relative rate of progress to anthesis decreased linearly as DT increased for both cultivars. At 13- to 14-hour NL, DT had relatively little effect on the relative rate of progress to anthesis. Thus, high DT delayed flowering of both heat-tolerant and heat-sensitive cultivars when flower initiation occurred under NL, typical of naturally occurring NLs in September and early October (i.e., 12-hour NL), whereas high DT did not delay flowering for either cultivar under a 14-hour NL, which is typically provided under black cloth systems. In contrast, the flowering responses to NT were quite different for the two cultivars. The heat-tolerant cultivar showed relatively little change in the relative rate of progress to anthesis as NT increased from 16 to 28 °C within each NL treatment; however, the heat-sensitive cultivar displayed a large decrease in the relative rate progress to anthesis as NT increased from 20 to 28 °C within each NL treatment. Although the delayed flowering that occurred at 28 °C and 14-hour NL was significant, the relative rate of progress to anthesis at this treatment was significantly higher than the 28 °C and 12-hour NL treatment. This suggests that artificially shortening NL to 14 hours with a black cloth system does not prevent heat delay of poinsettia, but it allows for more rapid flowering than if flower initiation took place under natural NL (≈12 hours). To summarize, high DT affected flowering when flower initiation took place at 12-hour NL for heat-tolerant and heat-sensitive poinsettia cultivars, whereas high NT uniquely delayed flowering of the heat-sensitive cultivar at NL from 12 to 14 hours.

Poinsettia is a short-day plant that begins to initiate flowers around the time of the autumnal equinox (21 Sept.) when NLs become sufficiently long and thereby inductive (Ecke et al., 2004). Flower initiation can be delayed by exposure to supra-optimal

temperatures; this phenomenon is termed “heat delay” (Ecke et al., 2004). Approximately one-third of all poinsettias produced in the United States are in regions that are considered especially prone to heat delay, i.e., states where average daily temperatures (ADTs) regularly exceed 27 °C during September (Cathey, 1997; USDA, 2019). Poinsettias that are delayed by high temperatures may mature too late to be shipped in time for the Christmas market. This can lead to a significant loss of revenue on a crop that is considered to be marginally profitable. The increasing global temperatures brought on by climate change are expected to amplify the magnitude of heat delay in susceptible regions and spread this problem to new areas previously unaffected by heat delay (Vose et al., 2017).

Numerous studies on poinsettia flowering have attributed heat delay to be a function of NT (Berghage et al., 1987; Kofranek and

Hackett, 1965; Langhans and Larson, 1959; Langhans and Miller, 1959; Roberts and Struckmeyer, 1938). Berghage et al. (1987) provided evidence that supra-optimal NT was the cause of heat delay. This study used a full factorial experiment consisting of 36 DT and NT treatments from six temperatures (14, 17, 20, 23, 26, and 29 °C) provided to ‘Annette Hegg Dark Red’ grown under 14-h NLs for the duration of the experiment. Results from this experiment clearly demonstrated that NT ≥26 °C delayed bract coloration and inhibited cyathia development regardless of DT. The researchers suggested that growers need to maintain NT of ≤23 °C to avoid heat delay.

Schnelle (2008) conducted a poinsettia heat delay study that seemingly contradicted those obtained by Berghage et al. (1987). Four poinsettia cultivars were grown under four DT/NT combinations (23/19, 26/22, 24/24, and 29/24 °C) that provided three ADT treatments (21, 24, and 27 °C), while the plants were grown under 12-h NLs for the duration of the experiment. The 27 °C ADT (29/24 °C) treatment was significantly delayed in time to first bract color, visible bud, and anthesis compared with the other three DT/NT treatments. As a result, the researcher suggested that growers need to maintain ≤24 °C ADT, although one could also have concluded that ≤26 °C DT would also avoid heat delay.

The apparent discrepancy among the research literature concerning whether supra-optimal NT, DT, or ADT causes heat delay has left poinsettia growers uncertain as to how to manage the greenhouse environment during flower initiation and development of poinsettias. The general consensus in the industry has been that the experimental differences were due to the different cultivars grown and that modern cultivars respond to temperature differently from older cultivars. Our hypothesis is that the photoperiodic flowering response of poinsettia is modified by temperature. Thus, the differing heat delay responses reported by Schnelle (2008) and Berghage et al. (1987) are due the different photoperiods provided in their studies (e.g., a 12-h vs. a 14-h NL).

The objective of this project was to examine the interaction of DT, NT, and NL on poinsettia flowering with the goal of improving our understanding of the environmental conditions that lead to poinsettia heat delay. We focused on the early stages of flowering (flower initiation) for two reasons. First, flower initiation is when poinsettias appear to be most sensitive to heat delay (Schnelle et al., 2006). Second, results from experiments that provide temperature treatments throughout the entire flowering period can be difficult to interpret; for example, high temperatures may delay flower initiation, but once initiation occurs, the same high temperatures may be optimal for flower development (Camberato et al., 2012).

Materials and Methods

Two poinsettia cultivars, Orion Red and Prestige Red, were selected for this experiment

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to evaluate heat-tolerant and heat-sensitive flowering responses, respectively. Three hundred cuttings of each cultivar were propagated in a foam medium (Oasis Rootcubes Plus Wedge, Smithers-Oasis, Kent, OH) in a greenhouse under long-day conditions that consisted of LED bulbs (9W LED A19 Light Bulb; Utilitech, West Lawn, PA) that delivered $1.2 \pm 0.2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from 1630 to 0000 HR daily. After 21 d, cuttings were transplanted into 1.33-L containers with a peat-based growing medium (Fafard 3B; Sun Gro, Anderson, SC) and provided long-day (8-h NL) conditions in a greenhouse equipped with metal halide lamps that delivered $175 \pm 25 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from 0800 to 0000 HR daily. Plants were grown with a constant liquid fertilization program consisting of a $150 \text{ mg}\cdot\text{L}^{-1}$ N solution made with 15N-2.2P-12.5K (Peters' Excel Cal-Mag Special; J.R. Peters, Allentown, PA). Ten days after transplant, plants were pinched to five nodes and vegetative growth continued for 4 weeks. The most uniform 240 plants from each cultivar were selected, thinned to three axillary shoots, and randomly assigned to each of 60 temperature $\times$ photoperiod treatments for 17 d. The treatments consisted of a factorial arrangement made up of three DTs (20, 24, or 28 °C), four NTs (16, 20, 24, or 28 °C), and five NLs (10, 11, 12, 13, or 14 h), and each of the 60 DT $\times$ NT $\times$ NL treatments were assigned four plants per cultivar.

To achieve the temperature $\times$ photoperiod treatments, four greenhouses (lat. 34.7° N) provided one of four temperatures (16, 20, 24, or 28 °C) throughout the experiment, and the 12 DT/NT combinations were achieved by moving plants among greenhouses at the beginning and the end of each photoperiod. A 16 °C, DT treatment was not provided because it was not possible to accurately maintain this temperature. Weather stations (Argus Controls, Surrey, B.C., Canada) continuously measured the temperatures within each greenhouse. For the purpose of calculating the greenhouse temperatures, the day was defined as the period from 0800 to 2000 HR, and the actual temperatures for the 20, 24, and 28 °C greenhouses were 19.7 ± 1.2 , 23.8 ± 0.7 , and 27.9 ± 1.9 °C, respectively. Night was defined as 2000 to 0800 HR, and the actual temperatures for the 16, 20, 24, and 28 °C greenhouses were 16.2 ± 0.9 , 19.9 ± 0.6 , 23.9 ± 0.2 , and 27.3 ± 1.0 °C, respectively.

Within each greenhouse, two benches (7.3 m $\times$ 1.5 m) were subdivided into three sections (2.43 m $\times$ 1.5 m $\times$ 0.9 m) and separated with aluminized radiant barriers (Double Reflective Insulation; Reflectix Inc., Markleville, IN) to prevent light pollution from neighboring treatments. Five bench sections within a greenhouse were randomly assigned an NL treatment (10, 11, 12, 13, or 14 h) with one of the six sections not being used. Within each of the five bench sections, four white LED bulbs were hung above the plants to provide day-length-extension lighting. The white LED bulbs were controlled with timers that turned on daily at 1730 HR, and black cloth was pulled over the benches

at the same time. Each evening the white LED bulbs turned off at 1800, 1900, 2000, 2100, or 2200 HR in each of the five photoperiod sections to provide the 14-, 13-, 12-, 11- or 10-h NL treatments, respectively. The black cloth was pulled off the benches at 0800 HR daily. Sunrise occurred before 0800 HR throughout the experimental period, so the photoperiod treatments started promptly at 0800 HR daily when the black cloth was removed.

The plants were transported on carts between greenhouses in lit corridors $\approx$ 20 min before the termination of daylight extension periods so that the photoperiod treatments were uninterrupted and the NLs were precise. At 0800 HR, black cloth was removed from all greenhouse benches and plants were moved to their assigned DT treatment. Moving plants back to the appropriate DT treatment took 20 to 30 min. Thus, the plants were exposed to the setpoint DT or NT for their respective temperature treatment for the entire duration of their photoperiod/NL treatment. After 17 d, all plants were consolidated to one greenhouse with an inductive environment (14-h NL, 24 ± 2.0 °C DT, and 21.2 ± 1.4 °C NT) and grown to anthesis.

Data were collected when plants reached first color, visible bud, and anthesis. First color was determined on each stem when a green leaf had a distinctive blush of red pigmentation. Visible bud was identified when the primary cyathium was clearly visible ($\approx$ 2 mm in diameter). Anthesis was identified on the first stamen to bear pollen from the primary cyathium. Progress to anthesis was calculated as the reciprocal of days to anthesis, and data were scaled between 0 and 1. A tag was hung on the most recently mature expanded leaf on each stem at the beginning of temperature $\times$ photoperiod treatments, and the number of nodes on each stem above the tag was counted at anthesis. The experiment was performed twice with replications beginning on 14 Sept. 2018 and 1 Feb. 2019; these dates are the first day that the poinsettias

were placed under the temperature $\times$ photoperiod treatments. Both replications followed the same procedures except that plants were grown nonpinched (i.e., with a single stem per plant during the second replication).

Statistical analysis of data was performed using JMP Pro (v. 14.0; SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) tests were conducted to evaluate the significance of each factor and their interactions on each of the three flowering responses. Each flowering response was transformed by taking the reciprocal of the number of days to reach a given response to estimate the amount of progress made during the 17 d when treatments were applied. Least squares means were calculated for each of the 60 photoperiod $\times$ temperature treatments, and then these treatment means were scaled between 0 and 1. For example, the rate of progress to anthesis was calculated as the reciprocal of days to anthesis, and the calculated least squares means for each photoperiod $\times$ temperature treatment were scaled between 0 and 1. The treatment with the fastest progress to anthesis rate (fewest days to anthesis) was set equal to 1 and the treatment with the slowest progress to anthesis rate (greatest days to anthesis) was set equal to 0. Data for 'Orion Red' and 'Prestige Red' were transformed independent of each other.

Results and Discussion

The ANOVA of the full experimental factorial demonstrated large differences in time to anthesis across cultivars and NLs (Table 1; Fig. 1). Although the four-way interaction (cultivar $\times$ NL $\times$ DT $\times$ NT) is statistically significant, the main effects of NL and cultivar have extremely large F-ratios for time to anthesis (750 and 1675, respectively), so Fig. 1 displays these main effects. 'Orion Red' reached anthesis 8 to 10 d faster than 'Prestige Red' across all NLs; however, in both cultivars, days to anthesis decreased in a sigmoidal pattern as NL increased. Both

Table 1. Analysis of variance table demonstrating the significance of each main effect, including cultivar (Cvr), night length (NL), day temperature (DT), and night temperature (NT), and their interactions across all three floral responses: days from start of the experiment to first color, visible bud, and anthesis.

Factor	First color		Visible bud		Anthesis	
	F ratio	Significance	F ratio	Significance	F ratio	Significance
Cvr	4762.5	***	657.9	***	1675.2	***
NL	1252.0	***	873.3	***	750.8	***
DT	18.6	***	57.4	***	10.8	***
NT	54.6	***	59.1	***	43.5	***
Cvr $\times$ NL	11.8	***	6.9	***	2.8	*
Cvr $\times$ DT	6.7	**	0.3	NS	0.1	NS
Cvr $\times$ NT	46.7	***	30.1	***	19.6	***
NL $\times$ DT	17.2	***	17.6	***	15.4	***
NL $\times$ NT	8.0	***	4.1	***	4.8	***
DT $\times$ NT	0.9	NS	1.0	NS	0.5	NS
Cvr $\times$ NL $\times$ DT	0.7	NS	2.1	*	2.9	**
Cvr $\times$ NL $\times$ NT	6.2	***	3.1	**	3.4	***
Cvr $\times$ DT $\times$ NT	1.2	NS	1.6	NS	1.4	NS
NL $\times$ DT $\times$ NT	1.2	NS	2.3	**	1.5	NS
Cvr $\times$ NL $\times$ DT $\times$ NT	0.9	NS	1.8	**	1.8	*

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Fig. 1. Poinsettia 'Orion Red' and 'Prestige Red' were placed under night lengths (NL) of 10, 11, 12, 13, and 14 h for 17 d and then consolidated to a fully inductive environment (14-h NL, 24/20°C day/night temperature). Data points in each night length treatment represent the mean value associated with the 12 d/night temperature combinations applied during the 17 d of treatments. Error bars represent ± 1 SE.

cultivars showed a slight decrease in days to anthesis when NL increased from 10 to 11 h and from 13 to 14 h, whereas a large decrease occurred between 11 and 13 h. 'Orion Red' had the largest decrease in days to anthesis (8 d) when NL increased from 11 to 12 h, whereas time to anthesis decreased in 'Prestige Red' by 5 d when NL increased from 11 to 12 h and from 12 to 13 h. The center of poinsettia biodiversity occurs in the state of Guerrero, Mexico (lat. $\approx 18.6^\circ$ N) (Trejo et al., 2012). At this latitude, NL measured by the U.S. Naval Observatory (2007) from civil twilight to civil twilight ranges from 10 h 59 min to 13 h 01 min. The interaction of NL $\times$ cultivar is also significant (F ratio = 2.8) and can be seen by the shift in the inflection point from 11.8 h for 'Orion Red' to 12.0 h for 'Prestige Red'. At lat. 34.7° N, NL increases at a rate of ≈ 2 min per night in September and October, thus this shift in the inflection point represents a 12-min shift in the NL required to reach 50% of the optimal flowering response time,

which represents a 6-d difference between cultivars at this latitude and season.

The difference in the number of days from first color to anthesis and from visible bud to anthesis were evaluated to determine if the timing of anthesis could be predicted once first color or visible bud occurs (Table 2). The time from first color to anthesis was affected only by cultivar; 'Orion Red' reached anthesis 32.0 ± 0.23 d after first color, whereas 'Prestige Red' reached anthesis 30.3 ± 0.33 d after first color across all treatments. Thus, when first color is observed and moderate temperatures are expected through the remainder of the crop time, commercial growers can expect that anthesis will occur ≈ 30 to 32 d later. Similarly, the time from visible bud to anthesis was also affected by cultivar; Orion Red reached anthesis 21.4 ± 0.35 d after visible bud, whereas Prestige Red reached anthesis 25.4 ± 0.36 d later. The interaction of cultivar $\times$ NT $\times$ NL was statistically significant with regard to the time from visible bud to anthesis. For 'Orion Red', no clear trends occurred and the

difference in time from visible bud to anthesis was ≤ 2 d across all treatments (i.e., all treatments reached anthesis between 20 to 22 d after visible bud). For 'Prestige Red', time from visible bud to anthesis was 24 to 26 d except for the 16°C NT treatments where the time from visible bud to anthesis decreased from 27 to 21 d as NL increased from 11 to 14 h.

Each data point in the DT figures for the two cultivars (Figs. 2A, C, E and 3A, C, and E) represents the relative rate of progress made to first color, visible bud, or anthesis during the 17 d across the four NTs and vice versa for the NT figures (Figs. 2B, D, and F and 3B, D, and F). Thus, all 60 temperature $\times$ photoperiod treatments are represented in each DT and NT figure. The actual days to each of the three flower development measurements can be calculated with the following equation: $17 - (\text{relative progress to flower} \times 17) + \text{minimum days to each event}$, where the minimum days to first color, visible bud, and anthesis were 18, 28, and 48 for 'Orion Red', and 26, 32, and 55, for 'Prestige Red', respectively.

At the 10-h NL, the heat-tolerant cultivar, Orion Red, made significantly more progress to visible bud and anthesis at a DT of 20°C compared with 24 and 28°C (Fig. 2C and E) during the first 17 d of treatments, whereas no DT response was noted for first color (Fig. 2A). At the 11-h NL, progress to all three flowering responses increased if DT was 20°C compared with 24 and 28°C . At the 12-h NL, 'Orion Red' showed a linear decrease in progress to all three flowering responses as DT increased from 20 to 28°C . At the 13-h NL, little change occurred in progress made to the three flowering responses compared with the 12-h NL if DT was 20°C ; however, at 24 and 28°C , increasing NL from 12 to 13 or 14 h resulted in a significant increase in progress made to all three flowering responses.

The flowering responses of 'Orion Red' to NT demonstrated relatively small responses from 16 to 28°C ; however, NT from 20 to 24°C tended to be optimal at NL from 11 to 14 h (Fig. 2B, D, and F). In general, the relative rate of progress to first color, visible bud, and anthesis showed a significant increase as NL increased from 11 to 13 h, whereas little to no difference was observed between NLs of 13 and 14 h at NT of 20 and 24°C .

For the heat-sensitive cultivar, Prestige Red, no differences in progress to first color, visible bud, and anthesis were observed for the different DT treatments at the 10-h NL (Fig. 3A, C, and E). At the 11-h NL, progress to each of the three flowering responses increased at 20°C DT compared with the 10-h NL treatments. At the 12-h NL, 'Prestige Red' showed a linear decrease in progress to each of the three flowering responses as DT increased. No differences in progress to the three flowering responses across the DT treatments were observed at 13-h NL, whereas 14-h NLs resulted in a greater relative rate of progress to anthesis at 24 and 28°C DT.

Table 2. Analysis of variance table demonstrating the significance of each main effect, including cultivar (Cvr), night length (NL), day temperature (DT), and night temperature (NT), and their interactions on the number of days from first color to anthesis and from visible bud to anthesis.

Factor	Days from first color to anthesis		Days from visible bud to anthesis	
	F ratio	Significance	F ratio	Significance
Cvr	12.6	**	63.9	***
DT	0.4	NS	0.5	NS
NT	0.0	NS	0.2	NS
NL	0.7	NS	4.9	*
Cvr $\times$ DT	0.0	NS	0.0	NS
Cvr $\times$ NT	0.0	NS	0.5	NS
Cvr $\times$ NL	0.1	NS	0.0	NS
DT $\times$ NT	0.3	NS	3.0	NS
DT $\times$ NL	2.8	NS	0.9	NS
NT $\times$ NL	0.0	NS	1.1	NS
Cvr $\times$ DT $\times$ NT	0.0	NS	0.2	NS
Cvr $\times$ DT $\times$ NL	0.4	NS	0.5	NS
Cvr $\times$ NT $\times$ NL	0.4	NS	6.9	**
DT $\times$ NT $\times$ NL	1.1	NS	0.1	NS
Cvr $\times$ DT $\times$ NT $\times$ NL	0.0	NS	0.0	NS

NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.01, and 0.0001, respectively.

Fig. 2. Poinsettia 'Orion Red' plants were placed under night lengths (NL) of 10, 11, 12, 13, or 14 h for 17 d and then consolidated to a fully inductive environment (14-h NL, 24/20 °C day/night temperature) until anthesis. The relative rate of progress to first color, visible bud, and anthesis are reported for each day temperature (A, C, E) and night temperature (B, D, F) treatment. Each data point in the day temperature figures represents the average time to reach a flowering response across the four night temperatures and vice versa for the night temperature figures. Error bars represent ± 1 SE.

Fig. 3. Poinsettia 'Prestige Red' plants were placed under night lengths (NL) of 10, 11, 12, 13, or 14 h for 17 d and then consolidated to a fully inductive environment (14-h NL, 24/20°C day/night temperature) until anthesis. The relative rate of progress to first color, visible bud, and anthesis are reported for each day temperature (A, C, E) and night temperature (B, D, F) treatment. Each data point in the day temperature figures represents the average time to reach a flowering response across the four night temperatures and vice versa for the night temperature figures. Error bars represent ± 1 SE.

These data clearly demonstrate that when DT are relatively cool (20°C), the greatest increase in progress to anthesis occurs as NL increases from 11 to 12 h, whereas at the warmest DT (28°C) the greatest increase in progress to all three flowering responses occurs as NL increases from 12 to 13 h.

For 'Prestige Red', no differences in progress to first color, visible bud, and anthesis were observed for the different NT treatments at the 10-h NL (Fig. 3B, D, and F), whereas at the 11-h NL, progress to the three flowering responses increased if NT was 20 and 24°C. At the 11-h NL, no increase in progress to flower was observed compared with the 10-h NL if the NT was 16 or 28°C. At the 12-h NL, progress to flower increased significantly at all temperatures compared with the 11-h NL; however, progress to flower decreased significantly as NT increased from 24 to 28°C. Similarly, at the 13- and 14-h NLs, progress to flower continued to occur at a faster rate at all NT, but progress was much slower when NT increased from 20 to 28°C NT.

It is commonly observed that heat-delayed poinsettias are taller than those grown at moderate temperatures. In this experiment, the number of nodes formed during the experiment increased linearly as the days to visible bud increased. For example, days to visible bud for 'Orion Red' increased from 31 to 45 d, whereas the number of nodes increased from 8 to 19 across all treatments, and days to visible bud for 'Prestige Red' increased from 35 to 51 d, whereas the number of nodes increased from 8 to 19. This suggests that taller plants resulting from heat delay conditions are a result of additional node formation before flower initiation in the shoot apex.

The results from this study demonstrate that poinsettia flowering response to temperature depends on NL. For both the heat-sensitive cultivar, Prestige Red, and the heat-tolerant cultivar, Orion Red, flowering occurred more rapidly at short NLs (10–12 h) when the DT was relatively cool (20°C), whereas longer NLs (13–14 h) were required when DT was warm (28°C). This suggests that when poinsettias are grown under natural NL conditions in early September through early October, cool DT will result in earlier flower initiation for both heat-tolerant and heat-sensitive cultivars.

Our temperature treatments were provided for only 17 d before plants were consolidated into a 24°C DT, 20°C DT, and 14-h NL environment. We expect that once the initial stages of flower initiation occur, warmer temperatures (e.g., 24°C and possibly 28°C) increase the rate of flower development. For example, poinsettias grown continuously at 20°C will stimulate early flower initiation due to the interaction of temperature and photoperiod, but 20°C is not optimal for flower development, so the fastest flowering may not occur when 20°C is provided continuously (Grueber and Wilkins, 1994). Future studies focusing on flower initiation of poinsettia may consider providing treatments for

just 10 to 14 d to minimize the potential to confound flower initiation and development responses.

The flowering responses of 'Prestige Red' were dramatically slower at high NT (28°C), whereas 'Orion Red' showed relatively little change in flowering across NT. High NT caused slower flower development of 'Prestige Red' for all NL from 11 to 14 h. This suggests that if high NT cannot be avoided due to prevailing temperatures, using blackout curtains to create longer NL will not entirely alleviate heat delay, but flowering will occur faster at a 14-h NL than if the plants were receiving natural NL (≈ 12 h) in the fall. For example, when the NT was 28°C, the relative progress to anthesis of 'Prestige Red' occurred at a rate of 0.56 (days of progress to flower per day of treatment) at the 14-h NL compared with a rate of 0.29 at the 12-h NL, which represents a 93% increase by changing from a natural NL (≈ 12 h) to a black cloth situation (≈ 14 -h NL). For this reason, black clothing poinsettias is an effective method for reducing the magnitude of heat delay in heat-sensitive cultivars. It should also be noted that the number of hours that the plants were exposed to the high NT temperatures increased as NL increased, thus the 14-h NL $\times$ 28°C NT treatment experienced 2 additional hours of high temperature compared with the 12-h NL $\times$ 28°C NT treatment. Despite this, the 14-h NL treatment flowered faster, thus underscoring the benefit of longer NL to compensate for heat delay.

Our results show that the data presented by Schnelle (2008) and Berghage et al. (1987) are not actually in conflict. Schnelle (2008) conducted experiments under 12-h NLs and reported that time to flower increased with ADT, and our data in the 12-h NL treatments are in agreement. DT and progress to anthesis were inversely proportional at the 12-h NL in both cultivars. Berghage et al. (1987) conducted their study under 14-h NLs and reported that time to flower increased with NT alone, and our data in the 14-h NL treatments are also in agreement. Increasing NT delivered to 'Prestige Red' from 20 to 28°C decreased progress to anthesis at the 14-h NL. 'Orion Red' showed a significant decrease in progress to anthesis under 13-h NLs at the 28°C NT relative to the 20 and 24°C NT treatments; however, increasing the NL to 14 h reduced the adverse effect of the 28°C NT.

Poinsettia cultivars have traditionally been classified by their response time, which is defined as the number of weeks of continuous inductive NL required to reach anthesis. 'Orion Red' is considered an "early season" cultivar with a response time of 7.5 to 8 weeks, whereas 'Prestige Red' is considered a "late season" cultivar with a response time of 9 weeks. Our data demonstrate that increasing NLs decreased the overall time to flower in both cultivars, but a difference of 8 to 10 d to anthesis between cultivars was maintained across all NLs. The overall cultivar response time from initiation to anthesis

does not necessarily correlate with enhanced tolerance to supra-optimal temperatures during flower initiation. For example, cultivars such as Prestige Early Red and Christmas Glory Red have similar response times to Orion Red, but both cultivars are considered to be heat-sensitive (personal communication).

Cultivar selection is one of the most critical steps for poinsettia growers to consider when attempting to avoid heat delay, and these decisions could be improved if breeders evaluate new cultivar introductions for susceptibility to heat delay. The current study provides guidelines for poinsettia breeders to evaluate the effect of high temperatures on flower initiation and early development in new cultivars. To achieve this, we recommend using two DT $\times$ NT regimens of 24/20 and 28/28°C under both 12- and 14-h NLs to assess the temperature sensitivity of a cultivar under NL that reflect both natural days and black cloth situations. For example, at the 12-h NL, 'Orion Red' flowered 4 d faster when initiating under DT/NT of 24/20°C relative to 28/28°C, which demonstrates that this cultivar is slightly susceptible to delay under NLs similar to natural photoperiod conditions in September. 'Orion Red' did not demonstrate a delay in flowering at these two temperature regimens when provided a 14-h NL. At the 12-h NL, 'Prestige Red' flowered ≈ 10.5 d faster when initiating under DT/NT of 24/20°C relative to 28/28°C. 'Prestige Red' grown at a 14-h NL flowered 8.5 d faster at DT/NT of 24/20°C relative to 28/28°C. Furthermore, despite the observed delay at a 14-h NL on 'Prestige Red' grown under a DT/NT of 28/28°C, this treatment actually flowered faster than the 24/20°C treatment at 12 h. Thus, growers located in regions where high temperatures are expected during September could produce heat-sensitive varieties if a black cloth system is available to provide 14-h NLs.

Poinsettia is often described as an obligate short-day plant and several studies have identified a critical NL for poinsettia to be between 11.5 and 12.5 h depending on cultivar (Ecke et al., 2004; Grueber, 1985; Kristofferson, 1969; Larson and Langhans, 1962; Langhans and Miller, 1959). However, our data show that a low rate of relative progress toward flowering occurs at 10- to 11-h NLs under certain temperatures. For example, 'Orion Red' demonstrated significant differences in relative progress to anthesis under a DT of 20°C under 10-h NLs; both cultivars showed significantly higher rates of relative progress to anthesis at NT of 20 and 24°C relative to 16 and 28°C at 11-h NLs. Furthermore, Evans et al. (1992) demonstrated that poinsettia will initiate a cyathium under long days (natural-day photoperiods at lat. 44°57'N with daylight extension lighting from 1700 to 2200 HR) once a cultivar-specific long-day leaf number has been achieved; however, this cyathium fails to develop to anthesis. Thomas and Vince-Prue (1997) described the facultative floral response as when flowering eventually occurs regardless of photoperiod; thus, technically speaking, poinsettia should be

characterized as a facultative short-day plant with regard to flower initiation. However, flower development does not occur under long-day conditions, which indicates that poinsettia is an obligate short-day plant with regard to flower development. A similar phenomenon has been reported in the short-day plant chrysanthemum (*Dendranthemum × grandiflorum*) in which flower buds initiate under long days but fail to develop unless short days are provided (Cockshull, 1976).

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