HortScience 47(6):745–750. 2012.

Development of *Euphorbia pulcherrima* under Reduced Finish Temperatures

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Additional index words. bract area, cold finish, poinsettia, time to anthesis, transplant week

Abstract. **The holiday poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch.) is the number two potted flowering crop sold in the United States with a reported wholesale value of $146 million in 2010. Profitability is increasingly threatened as the cost to heat greenhouses has increased by over 90% in the last 10 years. As energy costs continue to increase and poinsettia prices remain relatively constant, growers are seeking cultivars that can be finished under reduced temperatures. Our objectives were to quantify how reduced temperature finishing (RTF) 2 weeks after the start of short days influences height, bract area index, and time to anthesis of poinsettia. Eight red poinsettia cultivars were selected based on their early response attributes (initiate and finish within 6 to 8 weeks), moderate to high vigor, and naturally large bracts. Rooted cuttings were grown at day/night temperature set points (12 h/12 h) of 24/19 °C until 15 Oct. and under a 16-h photoperiod consisting of natural daylengths with day-extension lighting until 1 Oct. On 15 Oct., plants were transferred to day/night temperatures (12 h/12 h) of 20/14, 21/17, or 24/19 °C. Time to anthesis from the start of short days was 60 and 55 days at 24/19 °C and 76 and 68 days at a reduced finishing temperature of 20/14 °C for 'Prestige Early Red' and 'Early Orion Red', respectively. Final height was not significantly influenced by RTF in either cultivar. Our results indicate that RTF is a viable option that greenhouse growers can use to help reduce energy costs of carefully selected poinsettia cultivars.**

In response to rising energy costs over the past several years, greenhouse growers have implemented a variety of strategies to reduce costs, including lowering their air temperature set points, increasing insulation, starting production later in the season, consolidating production, installing thermal energy curtains, contracting fuel, purchasing energy-efficient heaters, or switching to alternative fuel sources (Hopkins, 2001). Today, energy for heating in Northern climates accounts for 10% to 30% of the total operating cost of commercial greenhouses (Brumfield, 2007; Langton et al., 2006). The cost to heat a greenhouse has increased in the past decade because the cost of fuel (e.g., natural gas, propane, and heating oil) has more than doubled. The average price of natural gas sold to commercial growers in the United States rose from $19.61 per 100 m^3 in 1998 to $45.82 per 100 m^3 in 2008 (Energy Information Administration, 2011). During the same time period, the average wholesale price received by U.S. greenhouse growers for 5″ or larger potted poinsettias has only increased by 14%, from $4.24 to $4.82 (U.S. Dept. of Agriculture, 1999, 2009).

The holiday poinsettia is the second most valuable potted flowering crop in the United States with a reported wholesale value of $146 million in 2010 for the 15-top producing states, representing 4% of the total wholesale value for floriculture crops (U.S. Dept. of Agriculture, 2011). Of the 36 million plants sold in 2010, the majority were red cultivars. Poinsettias are propagated from shoot-tip cuttings and grown in greenhouses from July to early December for sales in November through December. As energy costs continue to increase and poinsettia prices remain constant, poinsettia producers are lowering their greenhouse air temperatures (Faust and Kehoe, 2007; Lopez and Krug, 2009) without knowledge of cultivar-specific consequences.

Temperature controls the rate of plant development, including time to unfold a leaf and time to flower. In addition, if temperatures are at or below the species-specific base temperature (T_b, estimated to be 10 °C for poinsettia), developmental rate is zero (Berghage et al., 1990; Roberts and Summerfield, 1987). Research conducted by Liu and Heins (2002) on the moderate-vigor poinsettia 'Freedom' indicates that as the photothermal ratio [ratio of daily light integral (DLI) to temperature] decreases after the start of short days (SD), bract size and cyathia diameter decrease linearly. Therefore, it is imperative that the effects of RTF on scheduling and plant quality are quantified on moderate- to high-vigor and/or early-flowering poinsettia cultivars. Two red cultivars from each of the five major poinsettia breeding companies were selected for investigation based on their early response attributes (6-to 8-week response time), moderate to high vigor, and naturally large bracts because these attributes are essential for RTF.

RTF has the potential to reduce energy consumption and costs associated with production while increasing profitability (Faust and Kehoe, 2007). To our knowledge, no peer-reviewed studies have been published on the effects of RTF on a wide breeder selection of modern commercially available cultivars. The objectives of this study were to

Table 1. Mean daily air temperatures and daily light integral (DLI) during each month and for the entire experiment for Purdue University (PU) and the University of New Hampshire (UNH).[z]

		Day/night set point temp (°C)			
		Avg temp (°C)			
Month	Location	(20/13) (17)	(21/17) (19)	(24/19) (21.5)	Avg DLI ($mol \cdot m^{-2} \cdot d^{-1}$)
August	PU	—[y]	—	23.9	13.0
	UNH	—	—	25.8	14.9
September	PU	—	—	22.7	14.8
	UNH	—	—	23.2	14.6
1 to 14 Oct.	PU	—	—	21.3	8.2
	UNH	—	—	21.7	8.2
15 to 31 Oct.	PU	17.7	19.5	21.9	6.6
	UNH	17.5	19.0	22.0	8.8
November	PU	16.9	19.1	21.9	6.1
	UNH	16.5	18.3	21.6	7.1
December	PU	16.5	18.0	20.9	5.2
	UNH	16.5	18.0	21.3	5.9
Average	PU	17.0	18.9	22.1	9.0
Average	UNH	16.8	18.4	22.6	9.9

[z]The day and night temperature set points were (12 h/12 h) (Expt. 2).
[y]— = temperature treatments not used from August to 14 Oct.

Received for publication 19 Jan. 2012. Accepted for publication 6 Apr. 2012.
We gratefully acknowledge Landon Young, Rob Eddy, Dan Hahn, Shannon Goldknopf, David Goudreault, and Russell Norton for greenhouse assistance and data collection; and funding from The Fred C. Gloeckner Foundation and The American Floral Endowment. Thanks to Dümmen USA, Florema Young Plants, Paul Ecke Ranch, Selecta First Class, and Syngenta Flowers, Inc., for plants and financial support. We thank Fafard, The Scotts Co., and L.S. Svensson for donating growing substrate, fertilizer, and black cloth, respectively.
Use of trade names in this publication does not imply endorsement by Purdue University and The University of New Hampshire of products named nor criticism of similar ones not mentioned.
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quantify how RTF influences time to anthesis, plant height, bract area index, and bract area-to-height ratio of eight modern poinsettia cultivars.

Materials and Methods

Plant material (Expt. 1). Rooted cuttings of 'Advent Red', 'EarlyGlory', 'Prestige Early Red', and 'Viking Red' were received in weekly intervals at Purdue University (PU), West Lafayette, IN (lat. 40° N) and the University of New Hampshire (UNH), Durham, NH (lat. 43° N) and transplanted into 16.5-cm diameter (1.25-L) round plastic containers (Landmark Plastics, Akron, OH) on 30 July (Week 31), 6 Aug. (Week 32), 13 Aug. (Week 33), and 19 Aug. 2008 (Week 34; UNH only). In addition, 'Alreddy Red', 'Christmas Eve Red', 'Christmas Feelings Red', 'Early Orion Red', 'Orion Red', and 'Saturnus Red' were received (Weeks 31 to 33; PU only). A commercial soilless substrate composed of 20% perlite and 80% sphagnum peatmoss (Fafard Custom 1P Mix; Conrad Fafard, Inc., Agawam, MA) was used.

Plant material (Expt. 2). 'Advent Red', 'Christmas Eve Red', 'Christmas Feelings Red', 'EarlyGlory', 'Prestige Early Red', 'Early Orion Red', 'Orion Red', and 'Viking Red' were transplanted as mentioned previously on 27 July (Week 31), 3 Aug. (Week 32), and 10 Aug. 2009 (Week 33) at both locations.

Greenhouse environment (Expts. 1 and 2). A 16-h photoperiod (0600 to 2200 HR) consisting of natural daylengths with day-extension lighting provided from high-pressure sodium (HPS) lamps was maintained until 1 Oct. 2008 and 2009. The HPS lamps delivered a supplemental photosynthetic photon flux of 42 ± 2 μmol·m^{-2}·s^{-1} [as measured with a quantum sensor (LICOR Biosciences, Lincoln, NE)] from 1700 to 2200 HR. An 8-h SD photoperiod was created with blackout cloth that covered plants from 1600 to 0800 HR beginning on 1 Oct. at the PU location only. Plants at UNH received natural SD. The greenhouse day/night temperature set point (12 h/12 h) was 24/19 °C until 15 Oct. 2008 and 2009.

Reduced temperature finishing (Expt. 1). Six plants of each cultivar and from each planting date were transferred to greenhouse compartments with day/night temperature (12 h/12 h) set points of 17/17, 20/13, and 24/19 °C on 15 Oct. 2008 at PU and 16/13, 19/19, 21/17, and 24/19 °C on 15 Oct. 2008 at UNH.

Reduced temperature finishing (Expt. 2). Data collected in Expt. 1 indicated that constant temperatures of 17/17 and 19/19 or 16/13 °C did not produce a commercially acceptable poinsettia and were not used in Expt. 2. Six plants of each cultivar and from each planting date were transferred to greenhouse compartments with day/night temperature (12 h/12 h) set points of 20/13, 21/17, and 24/19 °C on 15 Oct. 2009 at both locations. The actual mean temperatures and DLI for each month of the experiment were calculated (Table 1).

Table 2. Purdue University: bract area index was determined by using the formula for an ellipse [(widest diameter × shortest diameter × π)/(4)], final plant height at anthesis, bract area-to-height ratio, and time to anthesis of poinsettia 'Prestige Early Red', 'Advent Red', 'Early Orion Red', 'Orion Red', 'Viking Red', 'EarlyGlory', 'Christmas Feelings Red', and 'Christmas Eve Red' transplanted during grower Week 31, 32, or 33 and placed in reduced temperature finishing temperatures of 24/19, 21/17, and 20/13 °C on 15 Oct. 2009 (Expt. 2).[z]

Transplant week	Day/night temp (°C)	Bract area index (cm^2)	Ht (cm)	Bract area:ht ratio	Time to Anthesis
		'Prestige Early Red'			
31	24/19	1075 ab	48.5 ab	22.2 bc	56.8 c
	21/17	1170 a	49.5 a	23.6 abc	68.3 b
	20/13	850 b	49.3 a	17.4 c	76.0 a
32	24/19	1034 ab	46.6 abc	22.2 bc	55.6 c
	21/17	1070 ab	44.2 cd	24.3 ab	71.0 ab
	20/13	970 ab	44.2 bcd	22.0 bc	75.6 a
33	24/19	1124 ab	38.6 e	29.1 a	58.3 c
	21/17	967 ab	40.5 de	23.9 ab	74.0 a
	20/13	910 ab	38.1 e	23.9 abc	74.8 a
Significance					
Week (WK)		NS	***	***	NS
Temperature		**	NS	**	***
WK × temp.		NS	NS	*	**
		'Advent Red'			
31	24/19	1065 abc	66.8 a	17.7 cd	52.5 f
	21/17	1060 abc	60.1 b	17.4 cd	67.7 bc
	20/13	913 bc	60.8 b	13.8 d	65.6 c
32	24/19	1229 a	58.8 b	23.0 b	53.5 ef
	21/17	1089 abc	53.4 cd	19.4 bc	62.3 cd
	20/13	859 c	55.9 bc	14.6 d	73.6 a
33	24/19	1124 ab	38.6 e	29.1 a	58.3 de
	21/17	1082 abc	40.5 e	23.9 b	74.0 a
	20/13	967 bc	49.2 d	21.9 bc	72.0 ab
Significance					
Week (WK)		NS	***	***	***
Temperature		*	***	**	***
WK × temp.		***	***	***	***
		'Early Orion Red'			
31	24/19	1053 a	53.3 ab	19.7 bc	50.8 d
	21/17	1071 a	53.1 ab	20.5 abc	57.1 c
	20/13	978 a	53.9 a	18.3 bc	65.1 ab
32	24/19	971 a	48.4 bc	20.1 abc	51.7 d
	21/17	971 a	45.6 c	21.4 abc	63.5 b
	20/13	844 a	48.1 bc	17.6 c	69.1 a
33	24/19	972 a	40.2 d	24.6 ab	51.4 d
	21/17	1014 a	39.5 d	26.1 a	62.3 b
	20/13	863 a	40.0 d	22.0 ab	69.4 a
Significance					
Week (WK)		NS	***	***	***
Temperature		NS	NS	*	***
WK × temp.		NS	NS	NS	NS
		'Orion Red'			
31	24/19	1036 ab	54.9 a	19.0 cd	53.3 c
	21/17	1051 ab	52.1 a	20.2 bcd	65.3 b
	20/13	1049 ab	51.6 a	28.0 a	68.4 a
32	24/19	854 b	43.0 b	16.6 d	53.2 c
	21/17	1158 a	50.3 a	23.0 abc	62.3 b
	20/13	859 b	49.3 a	17.5 cd	71.8 a
33	24/19	880 b	37.7 b	20.6 bcd	51.7 c
	21/17	968 ab	38.9 b	24.9 ab	64.2 b
	20/13	875 b	37.7 b	23.3 abc	68.4 a
Significance					
Week (WK)		**	***	***	NS
Temperature		***	NS	***	***
WK × temp.		*	***	***	NS
		'Viking Red'			
31	24/19	862 b	51.6 a	16.8 d	56.3 d
	21/17	959 b	49.0 ab	19.5 cd	70.2 b
	20/13	991 b	46.6 b	21.2 bcd	70.3 ab
32	24/19	898 b	49.1 ab	18.3 cd	55.3 d
	21/17	1260 a	45.4 b	27.8 a	62.7 c
	20/13	967 b	47.1 b	20.5 cd	76.3 a
33	24/19	1021 b	38.2 c	26.7 ab	55.2 d
	21/17	955 b	35.9 c	26.6 ab	72.8 ab
	20/13	836 b	35.3 c	23.8 abc	75.3 a

(*Continued on next page*)

Table 2. (*Continued*) Purdue University: bract area index was determined by using the formula for an ellipse [(widest diameter × shortest diameter × π)/(4)], final plant height at anthesis, bract area-to-height ratio, and time to anthesis of poinsettia 'Prestige Early Red', 'Advent Red', 'Early Orion Red', 'Orion Red', 'Viking Red', 'EarlyGlory', 'Christmas Feelings Red', and 'Christmas Eve Red' transplanted during grower Week 31, 32, or 33 and placed in reduced temperature finishing temperatures of 24/19, 21/17, and 20/13 °C on 15 Oct. 2009 (Expt. 2).[z]

Transplant week	Day/night temp (°C)	Bract area index (cm^2)	Ht (cm)	Bract area:ht ratio	Time to Anthesis
Significance					
Week (WK)		*	***	***	***
Temperature		**	***	***	***
WK × temp.		***	NS	***	***
		'EarlyGlory'			
31	24/19	913 b	48.4 b	18.8 c	56.8 d
	21/17	959 b	49.0 b	19.5 c	70.2 b
	20/13	1011 ab	48.8 b	20.7 bc	72.0 ab
32	24/19	1061 ab	52.4 a	20.2 c	56.7 d
	21/17	1218 a	48.4 b	25.2 ab	65.0 c
	20/13	984 ab	46.7 b	21.1 bc	77.3 a
33	24/19	1005 ab	36.2 cd	27.7 a	56.8 d
	21/17	884 b	39.0 c	22.6 bc	78.0 abc
	20/13	839 b	35.2 d	23.8 abc	76.0 ab
Significance					
Week (WK)		***	***	***	NS
Temperature		NS	**	NS	***
WK × temp.		*	***	***	***
		'Christmas Feelings Red'			
31	24/19	966 ab	47.5 ab	20.5 a	56.3 e
	21/17	1110 a	50.2 a	22.1 a	63.5 d
	20/13	931 ab	49.8 a	18.8 a	69.4 bc
32	24/19	871 b	47.9 ab	18.2 a	55.7 e
	21/17	775 b	42.0 cd	18.4 a	69.0 c
	20/13	782 b	44.3 bc	17.8 a	73.6 abc
33	24/19	873 ab	41.9 cd	20.8 a	56.5 e
	21/17	915 ab	39.6 de	23.1 a	73.8 ab
	20/13	811 b	36.8 e	22.0 a	76.0 a
Significance					
Week (WK)		**	***	**	***
Temperature		NS	*	NS	***
WK × temp.		NS	***	NS	***
		'Christmas Eve Red'			
31	24/19	628 a	51.9 a	12.1 b	55.7 e
	21/17	714 a	49.5 abc	14.4 ab	64.3 d
	20/13	666 a	50.3 ab	13.3 ab	70.0 b
32	24/19	692 a	47.4 bc	14.6 ab	54.3 e
	21/17	674 a	46.2 cd	14.6 ab	68.2 bc
	20/13	565 a	43.5 de	12.9 ab	75.0 a
33	24/19	626 a	42.9 e	14.6 ab	55.5 e
	21/17	697 a	41.9 ef	16.7 a	66.0 cd
	20/13	596 a	39.0 f	15.3 ab	71.2 ab
Significance					
Week (WK)		NS	***	**	**
Temperature		NS	***	*	***
WK × temp.		NS	NS	NS	**

[z]Values within columns with the same letter are not significantly different by Tukey's honest significant difference test at $P \leq 0.05$.

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

Plant culture (Expts. 1 and 2). Plants were irrigated as necessary with acidified water (PU only) supplemented with water-soluble fertilizer to provide the following ($mg \cdot L^{-1}$): 200 nitrogen, 29 phosphorus, 167 potassium, 67 calcium, 28 magnesium, 1.0 iron, 0.5 manganese and zinc, 0.2 boron and copper, and 0.1 molybdenum (Peters Excel© Cal-Mag© 15N-2.2P-12.5K; The Scotts Co., Marysville, OH).

Two weeks after planting, plants were manually pinched to leave 6 to 7 nodes. Throughout the study, pH and electrical conductivity were measured weekly using the pour-through method to ensure that pH remained in the range of 5.7 to 6.2.

Data collection and analysis (Expts. 1 and 2). Plant height from the base of the container to the top of the apical meristem was measured weekly and plotted in a graphical tracking program (Fisher and Heins, 1995). Anthesis was determined as the point at which pollen was visible on two branches. At visible anthesis of two branches, bract length and width of the two flowering stems (widest diameter across and diameter 90° across) were recorded. Bract area index of each of the flowering stems was determined by using the formula for an ellipse [(widest diameter × shortest diameter × π)/(4)] and averaged as a representation of bract area. The bract area-to-height ratio was calculated by dividing bract area index by final plant height as a measure of the aesthetic ratio of "color" to height (Currey and Lopez, 2011). Time to anthesis was calculated by subtracting the date SD were initiated from the date of anthesis. Plants were randomly assigned to each temperature treatment and temperature treatments were randomized among greenhouses. Data were analyzed using SAS (SAS Institute, Cary, NC) mixed model procedure (PROC MIXED) and pairwise comparisons between treatments were performed using Tukey's honest significant difference test.

Results

Expt. 1. Data collected in Expt. 1 were considered preliminary and only used to determine which RTF treatments were suitable for Expt. 2. At both locations, quality parameters (height, bract area index, and bract area-to-height ratio) were reduced when plants were finished at constant temperatures of 17/17 and 19/19 °C or when the day/night temperature set point (12 h/12 h) was 16/13 °C. For example, bract area index of 'EarlyGlory' was reduced by 216, 333, and 570 cm^2 when finishing temperature was lowered from 24/19 to 17/17, 19/19, and 16/13 °C, respectively, for plants transplanted Week 33 (data not presented). Time to anthesis (TTA) significantly increased across cultivars when poinsettia cultivars were finished at 16/13 °C. For example, average TTA of 'Prestige Early Red', 'Viking Red', and 'EarlyGlory' occurred after 15 Dec. (data not presented).

Expt. 2:'Prestige Early Red'. Bract area index generally decreased at lower reduced temperatures and at later transplant weeks at UNH; no trends were observed at PU (Tables 2 and 3). In both locations, transplant week significantly influenced height at anthesis regardless of finishing temperature. For example, regardless of temperature, plant height decreased by 9 to 10 cm as transplant week increased from Week 31 to 33. Bract area-to-height ratio decreased from 23.9 to 16.9 at UNH as finishing temperature decreased. As finishing temperature was reduced, TTA increased at both locations. For example, at transplant Week 31, average TTA at 24/19 and 20/13 °C was 57 and 76 d, respectively at PU.

Expt. 2: 'Advent Red'. As finishing temperature was reduced, bract area index decreased at both locations (Tables 2 and 3). Height at anthesis decreased by 19.8 cm (32%) and 10.2 cm (17%) at PU and UNH, respectively, as transplant week increased from Week 31 to 33. As transplant week and finishing temperature increased, the bract area-to-height ratio increased at both locations. As finishing temperature was reduced from 24/19 to 20/13 °C, TTA increased by 23 and 16 d at UNH and PU, respectively.

Expt. 2: 'Early Orion Red'. Neither finishing temperature or transplant week had a significant influence on bract area index at either location (Tables 2 and 3). As transplant week increased from Week 31 to 33, height at anthesis decreased by 13.5 cm (25%) and 13.0 (23%) at PU and UNH, respectively. No trends in bract area-to-height ratio were observed at either location. At PU and UNH, both temperature and transplant week influenced TTA. As finishing temperatures were reduced from 24/19 to 20/13 °C and transplant week increased from Week 31 to 33, TTA increased by 17 d at PU and 20 d at UNH, respectively.

Expt. 2: 'Orion Red'. Transplant week and finishing temperature both had a significant effect on bract area index and bract area-to-height ratio; however, no trends were observed (Tables 2 and 3). In both locations, transplant week significantly influenced height at anthesis regardless of RTF. For example, at PU and UNH, plant height decreased by 15 and 11 cm, respectively, as transplant week increased from Week 31 to 33. TTA was influenced by RTF at both locations. As finishing temperature was reduced from 24/19 to 20/13 °C, TTA increased from 53 to 70 d and 50 to 70 d at PU and UNH, respectively, regardless of transplant week.

Expt. 2: 'Viking Red'. As finishing temperature was reduced from 24/19 to 20/13 °C, bract area index decreased from 1099 to 761 cm^2 at UNH (Tables 2 and 3). Height at anthesis decreased by 13.6 (37%) and 11.5 cm (21%) at PU and UNH, respectively, as transplant week increased from Week 31 to 33. Transplant week and finishing temperature influenced bract area-to-height ratio at both locations. For example, as transplant week increased from Week 31 to 33, bract area ratio increased from 19.2 to 25.7 at PU. The TTA at PU increased from 56 to 70 d and from 55 to 75 d as transplant week increased from Week 31 to 33 and as finishing temperatures were reduced from 24/19 to 20/13 °C.

Expt. 2: 'Early Glory'. Transplant week and RTF at PU and UNH influenced bract area index; however, no trends were observed (Tables 2 and 3). Height at anthesis decreased by 11.9 cm (24%) and 9.1 cm (17%) at PU and UNH, respectively, as transplant week increased from Week 31 to 33. No trends in bract area-to-height ratio were observed at either location. However, RTF significantly influenced TTA at both locations. For example, as finishing temperature was reduced from 24/19 to 20/13 °C, TTA increased from 57 to 75 d at PU.

Expt. 2: 'Christmas Feelings Red'. No trends in bract area index or bract area-to-height ratio were observed at either location (Tables 2 and 3). As transplant week increased from Week 31 to 33, height at anthesis decreased by 9.8 cm (20%) and 5.7 (11%) cm at PU and UNH, respectively. At both locations, RTF and transplant week influenced TTA. As finishing temperatures were reduced from 24/19 to 20/13 °C and transplant week increased from Week 31 to 33, TTA increased by 17

Table 3. University of New Hampshire: bract area index was determined by using the formula for an ellipse [(widest diameter × shortest diameter × π)/(4)], final plant height at anthesis, bract area-to-height ratio, and time to anthesis of poinsettia 'Prestige Early Red', 'Advent Red', 'Early Orion Red', 'Orion Red', 'Viking Red', 'EarlyGlory', 'Christmas Feelings Red', and 'Christmas Eve Red' transplanted during grower Week 31, 32, or 33 and placed in reduced temperature finishing temperatures of 24/19, 21/17, and 20/13 °C on 15 Oct. 2009 (Expt. 2).[z]

Transplant week	Day/night temp (°C)	Bract area index (cm^2)	Ht (cm)	Bract area:ht ratio	Time to anthesis
		'Prestige Early Red'			
31	24/19	1347 a	51.3 ab	26.3 a	53.7 b
	21/17	1026 bc	55.4 a	18.6 bc	68.7 a
	20/13	908 bcd	53.3 ab	17.0 c	—[y]
32	24/19	1143 ab	50.6 b	22.7 ab	51.3 b
	21/17	913 bcd	49.9 b	18.4 bc	69.0 b
	20/13	815 cd	49.2 bc	16.6 c	–
33	24/19	920 bcd	45.0 cd	22.6 abc	54.7 b
	21/17	886 cd	45.0 cd	19.8 bc	68.0 b
	20/13	730 d	42.8 d	17.1 c	—
Significance					
Week (WK)		***	***	NS	NS
Temperature		***	NS	***	***
WK × temp.		NS	NS	*	*
		'Advent Red'			
31	24/19	1060 ab	59.6 a	17.8 bc	51.2 c
	21/17	1013 ab	58.4 a	17.4 bc	61.8 b
	20/13	912 ab	58.2 a	15.8 c	73.7 a
32	24/19	1090 a	57.8 a	18.9 abc	51.8 c
	21/17	1077 ab	57.0 a	19.0 abc	63.2 b
	20/13	922 ab	55.3 a	16.7 bc	73.3 a
33	24/19	1140 a	49.3 b	23.1 a	51.5 c
	21/17	975 ab	46.5 b	21.1 ab	65.3 b
	20/13	826 b	49.7 b	16.7 bc	76.0 a
Significance					
Week (WK)		NS	***	**	NS
Temperature		***	NS	***	***
WK × temp.		NS	NS	NS	NS
		'Early Orion Red'			
31	24/19	1129 a	55.4 a	20.3 a	49.3 d
	21/17	898 a	56.6 a	15.8 a	54.3 cd
	20/13	944 a	57.0 a	16.7 a	65.0 ab
32	24/19	1016 a	47.8 b	21.4 a	50.2 d
	21/17	849 a	46.0 b	18.6 a	59.6 bc
	20/13	862 a	47.6 b	18.2 a	70.4 a
33	24/19	960 a	44.1 b	22.0 a	49.2 d
	21/17	918 a	42.9 b	21.5 a	60.8 bc
	20/13	841 a	42.9 b	17.4 a	71.8 a
Significance					
Week (WK)		NS	***	NS	**
Temperature		NS	NS	*	***
WK × temp.		NS	NS	NS	NS
		'Orion Red'			
31	24/19	1074 bc	60.1 a	17.9 c	49.7 c
	21/17	977 bcd	53.5 abc	18.5 c	60.3 b
	20/13	1009 bc	56.2 ab	17.9 c	68.8 a
32	24/19	1398 a	47.2 cd	29.6 a	48.3 d
	21/17	929 bcd	48.9 cd	19.1 c	65.2 b
	20/13	896 cd	49.3 bcd	17.1 c	68.0 a
33	24/19	1147 b	46.5 d	24.8 ab	51.7 c
	21/17	905 cd	45.1 d	20.1 bc	63.3 b
	20/13	767 d	44.8 d	17.1 c	72.4 a
Significance					
Week (WK)		**	***	***	NS
Temperature		***	NS	***	***
WK × temp.		***	NS	***	NS
		'Viking Red'			
31	24/19	1133 a	54.1 ab	21.0 abc	54.0 b
	21/17	954 abc	54.5 ab	17.6 bcd	66.3 a
	20/13	804 bc	55.5 a	14.5 d	—
32	24/19	1089 ab	49.9 bc	21.8 ab	53.3 b
	21/17	1023 ab	47.3 cd	21.7 abc	70.7 b
	20/13	814 bc	49.6 ab	16.5 cd	—
33	24/19	1076 ab	45.2 cde	23.9 a	54.2 b
	21/17	1001 ab	43.9 de	22.8 a	70.0 a

(*Continued on next page*)

Table 3. (*Continued*) University of New Hampshire: bract area index was determined by using the formula for an ellipse [(widest diameter × shortest diameter × π)/(4)], final plant height at anthesis, bract area-to-height ratio, and time to anthesis of poinsettia 'Prestige Early Red', 'Advent Red', 'Early Orion Red', 'Orion Red', 'Viking Red', 'EarlyGlory', 'Christmas Feelings Red', and 'Christmas Eve Red' transplanted during grower Week 31, 32, or 33 and placed in reduced temperature finishing temperatures of 24/19, 21/17, and 20/13 °C on 15 Oct. 2009 (Expt. 2).[z]

Transplant week	Day/night temp (°C)	Bract area index (cm^2)	Ht (cm)	Bract area:ht ratio	Time to anthesis
	20/13	665 c	40.4 e	19.9 abc	—
Significance					
Week (WK)		NS	***	***	NS
Temperature		***	NS	***	***
WK × temp.		NS	NS	NS	NS
		'EarlyGlory'			
31	24/19	1173 a	52.9 ab	22.3 abc	55.2 b
	21/17	1008 ab	53.8 ab	18.8 abc	64.8 a
	20/13	951 ab	54.4 a	17.6 bc	—
32	24/19	1244 a	49.0 bc	25.3 a	53.2 b
	21/17	1109 ab	44.7 cd	24.9 ab	68.6 b
	20/13	792 b	48.9 bc	16.2 c	—
33	24/19	1115 ab	43.1 d	25.8 a	53.5 b
	21/17	961 ab	45.8 cd	21.1 abc	71.3 a
	20/13	897 ab	44.8 cd	20.2 abc	—
Significance					
Week (WK)		NS	***	NS	NS
Temperature		***	NS	***	***
WK × temp.		NS	NS	NS	NS
		'Christmas Feelings Red'			
31	24/19	1109 a	52.2 ab	21.3 a	54.2 d
	21/17	945 abc	50.2 abc	18.9 a	63.5 c
	20/13	887 abc	53.4 a	16.6 a	72.3 ab
32	24/19	883 abc	51.2 abc	17.7 a	56.8 d
	21/17	820 abc	50.3 abc	16.3 a	64.8 c
	20/13	667 bc	48.6 abc	13.7 a	72.5 abc
33	24/19	963 ab	47.5 abc	20.7 a	56.5 d
	21/17	766 bc	46.2 bc	16.7 a	67.3 bc
	20/13	610 c	44.8 c	13.8 a	76.5 a
Significance					
Week (WK)		**	***	NS	*
Temperature		***	NS	**	***
WK × temp.		NS	NS	NS	NS
		'Christmas Eve Red'			
31	24/19	792 a	60.7 a	13.1 ab	55.3 c
	21/17	643 a	54.0 bcd	12.0 ab	63.7 b
	20/13	571 a	57.3 ab	10.0 b	72.4 a
32	24/19	725 a	54.8 abc	13.3 ab	55.5 c
	21/17	687 a	51.3 cde	13.3 ab	65.3 b
	20/13	634 a	48.0 def	13.2 ab	74.5 a
33	24/19	843 a	49.4 cdef	17.1 a	54.8 c
	21/17	789 a	44.5 f	17.5 a	66.5 b
	20/13	568 a	45.5 ef	12.6 ab	75.0 a
Significance					
Week (WK)		NS	***	**	**
Temperature		NS	***	*	***
WK × temp.		NS	NS	NS	NS

[z]Values within columns with the same letter are not significantly different by Tukey's honest significant difference test at $P \leq 0.05$.
[y]— = treatments never reached anthesis by 20 Dec.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

or 18 d and 4 or 5 d, respectively (Tables 2 and 3).

Expt. 2: 'Christmas Eve Red'. Bract area index was not influenced by transplant week or RTF at either location (Tables 2 and 3). Transplant week and RTF at PU and UNH influenced final height. For example, as transplant week increased from Week 31 to 33, final height decreased from 51 to 41 cm and 57 to 47 cm at PU and UNH, respectively. No trends in bract area-to-height ratio were observed at either location. As finishing temperatures were reduced from 24/19 to 20/13 °C, TTA increased from 55 to 72 d and 55 to 74 d at PU and UNH, respectively, regardless of transplant week.

Discussion

Successful and economically viable RTF of poinsettia requires cultivars with early response time to SD, moderate to high vigor, and naturally large bracts so that height, bract area index, and TTA or marketability are not as adversely affected as other less vigorous, later response group, and smaller bract cultivars.

For the red poinsettia cultivars tested in this study, TTA increased by 2 to 15 d and 15 to 22 d as finishing temperature was reduced during the day/night by 3/2 and 4/6 °C (12 h/12 h), respectively, beginning on 15 Oct. Depending on the cultivars selected, growers using RTF would have to begin production anywhere from a few days to 2 weeks earlier than normal to meet their market window. Previous work with randomly selected poinsettia cultivars reported that TTA increased by up to 49 d when finishing temperatures were reduced during the day/night by 6/5 °C from 24/19 °C on the start of SD (Lopez, 2008). Therefore, in the current study, we began RTF 2 weeks after the start of SD. Langhans and Larson (1960) reported that poinsettia 'Barbara Ecke Supreme' produced salable flowers when finished at 15 °C, whereas 'Ecke White' and 'Ecke Pink' were not marketable. Therefore, careful cultivar selection is essential for RTF to be economically viable for greenhouse growers.

Poinsettia is generally classified as a SD plant with a critical daylength of ≈12.5 h; this is dependent on the cultivar and ambient temperature (Kristoffersen, 1969). Larson and Langhans (1963) reported that the optimum temperature for rapid floral initiation and development of poinsettia is between 15 and 21 °C. For example, in previous studies they had determined that TTA of poinsettia 'Barbara Ecke Supreme' was 61, 81, and 96 d under day/night finishing temperatures of 27/21, 21/15, and 15/10 °C, respectively. No stamens were visible and plants were not marketable under finishing temperatures of 27/27 and 15/10 °C, respectively (Langhans and Larson, 1960).

Previous research on poinsettia and temperature has primarily focused on high temperature or heat delay effects on flowering. Barrett (2004) placed 10 modern cultivars for 4 weeks at day/night temperatures of 23/21, 25/22, and 29/23 °C under an 11- or 12-h photoperiod to determine the effect of temperature on TTA. Under a 12-h photoperiod, TTA of 'Orion Red' occurred within 5 d across all temperature treatments. On the other hand, TTA of 'Prestige Red' placed at 29/23 °C was delayed by 18 d compared with the other temperature treatments. Schnelle (2008) reported that floral initiation of 'Prestige Red' was delayed by 19 d when plants were transferred from 26/21 to 29/24 °C day/night temperature for 28 d.

The slight differences in TTA between PU and UNH may be attributed to the use of black cloth to achieve an 8-h SD at PU as opposed to natural SD at UNH. Langhans and Larson (1960) reported that plants under a 9-h photoperiod created with black cloth reached anthesis before plants under natural daylengths.

The influence of temperature on stem elongation of poinsettia and other plant species has been extensively studied (Berghage and Heins, 1991; Erwin et al., 1989). Berghage and Heins (1991) reported that poinsettia stem

elongation was a function of the difference (DIF) between the day (DT) and night (NT) temperature (DIF = NT – DT) and as DIF becomes more positive, stem elongation increases. In our study, temperature had a significant influence on final plant height at anthesis across most cultivars at PU and only one cultivar at UNH. However, no significant trends were observed between the various DIFs resulting from our temperature treatments. Under a positive DIF of 6 (20/13 °C), 5 (24/19 °C), and 4 °C (21/17 °C), final height of 'Viking Red' transplanted Week 31 at PU was 46.6, 51.6, and 49.0 cm, respectively (Table 2). However, a reduction in final plant height was observed in certain cultivars as finishing temperatures were reduced from 24/19 to 20/13 °C. Similarly, Odula (2011) reported that final plant height of 'Prestige Red', but not 'Freedom Red', grown under constant temperatures (0 DIF) was 5.1 cm shorter at 15.5 °C than at 18 °C.

Transplant week had a significant effect on final plant height at both locations. For example, as transplant week increased from Week 31 to 33, final plant height decreased across cultivars (Tables 2 and 3). Regardless of RTF, average plant height of 'Orion Red' transplanted on Week 33 was 14.7 and 11.5 cm shorter than plants transplanted on week 31 at PU and UNH, respectively (Tables 2 and 3). Therefore, plant height may have to be regulated with plant growth regulators or nonchemical means if the crop is transplanted early (i.e., transplant Week 31 for a controlled photoperiod).

Odula (2011) reported that total bract area of poinsettia 'Freedom Early Red' and 'Prestige Red' was reduced by 53.8 and 29.5 cm^2, respectively, as temperatures decreased from constant 18 to 15.5 °C. At PU, no clear trends on the influence of RTF or transplant week were observed for bract area index, a representation of total bract area for any cultivar. However, at UNH, bract area index was generally reduced for 'Prestige Early Red', 'Advent Red', 'Orion Red, 'EarlyGlory', 'Viking Red', and 'Christmas Feelings Red' under RTF and plants were generally shorter at later transplant weeks. Additionally, the bract area-to-height ratio, a measure of aesthetic quality using the bract area index and plant height, was also reduced in these cultivars. For example at UNH, the bract area-to-height ratio of 'Advent Red' was 15.8 and 23.1, respectively, for plants transplanted on Week 31 (early) and placed under RTF of 20/13 °C (cool) compared with those transplanted on Week 33 (late) and placed under RTF of 24/19 °C (warm). However, there were no significant differences in bract area index for 'Advent Red' planted early and finished cool or planted later and finished warm. Therefore, this would suggest that a prolonged vegetative growth phase may counteract any negative influence of RTF on bract area. However, the use of antigibberellin plant growth regulators may be necessary to suppress excessive stem extension from an extended vegetative phase.

Conclusions

To meet target market heights, we can categorize the poinsettia cultivars in the study into transplant Week 32 or 33 if a controlled photoperiod is used based on their final height at anthesis. Assuming a target final height of 40 to 50 cm (16 to 20 inches) for florist quality poinsettias, rooted 'Prestige Early Red', 'Viking Red', 'EarlyGlory', 'Early Orion Red', 'Orion Red', 'Christmas Eve Red', and 'Christmas Feeling' should be transplanted during Week 32 and 'Advent Red' should be transplanted during Week 33.

Time to anthesis of 'Early Orion Red', 'Orion Red', 'Advent Red', 'Christmas Eve Red', 'Christmas Feeling Red', 'Viking Red', 'EarlyGlory', and 'Prestige Early Red' under RTF of 21/17 °C was on average 60, 63, 66, 66, 67, 69, 70, and 70 d, respectively, across locations and transplant week under controlled photoperiod conditions. Therefore, we can categorize cultivars based on their TTA response to RTF. For example, under natural SD, 'Early Orion Red' and 'Orion Red' can be categorized as reduced temperature-tolerant cultivars that growers can market after 20 Nov. 'Advent Red', 'Christmas Eve Red', 'Christmas Feeling', 'Viking Red', 'Early Glory', and 'Prestige Early Red' could be categorized as moderately tolerant to RTF that growers can market after 27 Nov.

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