Flowering Responses of Easter Cactus Clones at Optimal and Supraoptimal Temperatures

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Abstract. The effects of temperature and clonal genotype on flowering of Easter cactus (*Rhipsalidopsis* Britton & Rose) were investigated in two experiments. Plants of 'Crimson Giant', 'Evita', 'Purple Pride', and 'Red Pride' were exposed to 6 weeks of either 10C or 18C night temperature (NT) under 9- to 9.5-hour natural daylengths (ND), and afterwards were forced at 18C NT and long days (LD). All clones produced fewer flowers when exposed to 18C and ND as compared with 10C and ND; however, the clones varied significantly in their flowering responses. Relative to 10C NT and ND, exposure to 18C NT and ND resulted in an 84% to 95% decrease in the number of flower buds for 'Evita', 'Purple Pride', and 'Red Pride', but only a 50% decrease in the number of flower buds for 'Crimson Giant'. In another experiment, 23 clones were exposed to 18C NT and 8-hour short days for 6 weeks, then forced at 18C NT and LD. The clones exhibited differences in percentage of plants flowering, days to flowering, percentage of apical phylloclades flowering, and number of flower buds. 'Crimson Giant' outperformed all other clones. Further breeding and selection may yield genotypes that flower more prolifically at 18C minimum than current cultivars.

Easter cactus is a prominent flowering potted plant in northern Europe, but is a relatively new crop in North America (Boyle, 1991a; Nell, 1988). Plants cultivated as Easter cactus are clonally propagated selections of *Rhipsalidopsis gaertneri* (Regel) Moran, *R. rosea* (Lagerheim) Britton & Rose, and their interspecific hybrids [*R. ×graeseri* (Werdermann) Moran] (Barthlott, 1979; Liberty Hyde Bailey Hortorium, 1976).

Flowering in Easter cactus is controlled by temperature and photoperiod (Boyle, 1990, 1991b; Boyle et al., 1988; Peters and Rünger, 1971; Rünger, 1960). The optimum temperature for flower initiation is ≈10C (Peters and Rünger, 1971; Rünger, 1960). Easter cactus exhibits considerable clonal variation in the optimal duration at 10C for prolific flowering: *R. gaertneri* 'Crimson Giant' requires 6 to 8 weeks (Boyle, 1991b), *R. ×graeseri* requires 10 weeks (Rünger, 1960), and *R. rosea* requires 12 to 16 weeks (Boyle, 1990). Flowering is inhibited at temperatures >15C (Boyle, 1990, 1991b; Peters and Rünger, 1971; Rünger, 1960), but the degree of inhibition varies among

clones. At 18C minimum, flowering is only partially inhibited in *R. gaertneri* 'Crimson Giant' (Boyle, 1991b; Boyle et al., 1988) but is almost completely inhibited in *R. rosea* (Boyle, 1990). The flowering responses of *R. ×graeseri* at 18C minimum have not been reported, but flower initiation is suppressed completely or partially at 20C (Rünger, 1960). At 10C, *R. gaertneri* will initiate flowers under photoperiods ranging from 10 h to continuous irradiation (Peters and Rünger, 1971). At 18C, *R. gaertneri* responds as a short-long-day plant (SLDP) for flowering (Boyle et al., 1988); the critical daylength for the short-day (SD) phase is between 11 and 12 h (Boyle, 1991b), whereas the critical daylength for the long-day (LD) phase is ≈12 h (Boyle et al., 1988).

Currently, Easter cactus is marketed from February to May (Nell, 1988), but extending the marketing period to other times of the year would be desirable. For example, red-flowered cultivars would be useful if they could be scheduled as a Christmas crop. In many regions of North America, however, it may be difficult to produce Easter cactus for Christmas due to the inability to maintain greenhouses at 10C for flower initiation. This statement is based on the following assumptions: 1) budded plants would be marketed in early December; and 2) plants would require 6 weeks at 10C followed by 7 weeks of forcing under LDs and 18 to 22C before they were marketable (Boyle, 1991a). Therefore, cold treatments would have to begin by early September and end by mid-October, and would occur at a time of the year when average daily temperatures exceed 10C in many areas of North

America. An alternative would be to select clones that would set buds at supraoptimal temperatures (>10C). The present study was conducted to determine the influence of temperature and clonal genotype on flowering of Easter cactus.

Materials and Methods

General procedures. Plants were propagated and grown in glasshouses at the Univ. of Massachusetts, Amherst (lat. 42°22.5'N). Unrooted phylloclades of 'Evita', 'Purple Pride', and 'Red Pride' were received from J. de Vries Potplantencultures bv (Aalsmeer, The Netherlands) and were stored at 10 ± 2.0C and 90% relative humidity until propagation (Expt. 1). All other clones were propagated from stock plants maintained at the Univ. of Massachusetts.

A commercial medium composed of sphagnum peat, perlite, and vermiculite (Fafard Growing Mix No. 2; Conrad Fafard, Springfield, Mass.) was used for propagation and growing. The medium was kept evenly moist by irrigating plants every 2 to 5 days. Plants were fertilized weekly with 20N–4.3P–16.6K (12% NO₃–N, 8% NH₄–N) at 200 mg N/liter. Fertilization began after phylloclades were rooted and continued until the experiments ended.

Air temperatures and photosynthetic photon flux (PPF) were monitored with a LI-1000 datalogger (LI-COR, Lincoln, Neb.) equipped with an aspirated LI-1000-16 thermistor and a LI-190SA quantum sensor. The datalogger was configured with a sampling interval of 60 sec and recorded mean PPF and temperature values at 1-h intervals. Shading compound (Kool Ray; Continental Products Co., Euclid, Ohio) was applied to the glass to maintain the PPF below 650 μmol·m⁻²·s⁻¹. Plants were grown under natural daylengths (ND) and 18 ± 2.0C minimum from propagation until the start of experiments, and plants remained vegetative throughout this period.

Clones and night temperatures. 'Crimson Giant', 'Evita', 'Purple Pride', and 'Red Pride' were propagated on 14 Apr. 1989 in 60-cell plastic trays, using two phylloclades per 70-cm³ cell. In mid-July, rooted phylloclades were planted, two plants (one cell) per pot, into 520-cm³ (10 cm in diameter) plastic pots. Each plant consisted of three or four tiers of mature phylloclades by late November. On 24 Nov., pots were transferred to either 1) 10 ± 2.0C nights/12 ± 2.0C days and ND (10/ND), or 2) 18 ± 2.0C nights/21 ± 2.0C days and ND (18/ND). Plants remained in 10/ND or 18/ND for 6 weeks. ND ranged from 9 to 9.5 h during the 6-week period (List, 1951). On 5 Jan. 1990, plants were transferred to 18 ± 2.0C nights/21 ± 2.0C days and LDs (18/LD). LDs were achieved by supplementing ND with 25 to 35 μmol·m⁻²·s⁻¹ (400 to 700 nm) irradiance from 400-W, high-pressure sodium lamps (LU400; Canadian General Electric Co., Toronto, Ont.) from 1600 to 2200 hr (Boyle, 1991b). Plants remained under 18/LD until the experiment ended (15 Apr. 1990). There were 10 pots per clone per initial environment (10/ND or 18/

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ND). Pots were completely randomized within initial environments and were re-randomized when transferred to the final environment (18/LD). Pots were spaced on 25-cm centers throughout the experiment.

Data were collected when the first flower reached anthesis in each pot or when the experiment ended. Days to flowering (from the start of 18/LD), number of apical phylloclades, percentage of apical phylloclades flowering, and number of flower buds were recorded. Data were analyzed by SAS's (1985) General Linear Model (GLM) procedure. Initial environments were not replicated, and therefore were analyzed separately. Values for percentage of apical phylloclades flowering were arcsin-transformed ($\sin^{-1} \sqrt{\%}$) before analysis. Analysis of covariance was performed on the number of flower buds per pot, with number of apical phylloclades per plant as the covariate. The percentage of plants flowering was calculated for each clone, and chi-square tests were used to test for differences among clones.

Clonal comparison. Twenty-three clones (genotypes) were evaluated in this study. Stem cuttings, consisting of one to five phylloclades each, were propagated on 3 Mar. 1992 in 72-cell plastic trays, using two cuttings per 65-cm³ cell. Phylloclade size varied substantially among the 23 clones (data not presented), and therefore the number of phylloclades per cutting was adjusted from one to five to equalize propagule size. For example, clones with small phylloclades were propagated by cuttings consisting of up to five phylloclades each, whereas clones with the largest phylloclades were propagated by cuttings consisting of one phylloclade each. Each plant consisted of two to four tiers of mature phylloclades by late September. On 21 Sept., all plants were transferred to 18 ± 2.0C nights/21 ± 2.5C days and

8-h SDs (18/SD). SDs were provided by covering plants with black sateen cloth from 1600 to 0800 HR. Six weeks later (2 Nov.), plants were transferred to 18/LD (as described in Expt. 1). Plants remained under 18/LD until the experiment ended (10 Feb. 1993). The experiment was a completely randomized design with 12 cells per clone and two plants per cell. Before the start of 18/SD, cells were completely randomized in 72-cell trays and were placed on 9.0-cm centers.

Data were collected on the same variables described in Expt. 1. Values for percentage of apical phylloclades flowering were arcsin-transformed before statistical analysis. Data were analyzed by the GLM procedure (SAS Institute, 1985). A hierarchical classification was used to separate clonal effects, experimental error (variation among cells within clones), and sampling error (variation among plants within cells) (Steel and Torrie, 1980). Covariance analysis was performed on the number of flower buds per plant, using the number of apical phylloclades per plant as the covariate. The percentage of plants flowering was calculated for each clone, and chi-square tests were used to test for differences among clones.

Results

Clones and night temperatures. All plants of 'Crimson Giant', 'Evita', and 'Red Pride' flowered, but flowers developed on only 50% of the 'Purple Pride' plants exposed to 18/ND (Table 1). For both initial environments, there were significant differences between clones for number of apical phylloclades, percentage of apical phylloclades flowering, and number of flower buds. Generally, 'Crimson Giant' exhibited the highest percentage of apical phyl-

loclades flowering and the most flower buds. 'Crimson Giant' produced the most flower buds, regardless of initial environment, when the number of buds was adjusted to an equivalent number of apical phylloclades by covariance analysis. Time to flowering was not significantly influenced by clonal genotype, but plants exposed to 18/ND for 6 weeks flowered 11 to 14 days later than those given 10/ND for an equivalent span.

Increasing the NT from 10 to 18C for 6 weeks inhibited flowering of all clones, but to different degrees. Exposure to 18/ND decreased the percentage of apical phylloclades flowering more for 'Evita', 'Purple Pride', and 'Red Pride' than for 'Crimson Giant' (Table 1). Relative to 10/ND, exposure to 18/ND resulted in an 84% to 95% decrease in the number of flower buds for 'Evita', 'Purple Pride', and 'Red Pride', but only an ≈50% decrease in the number of flower buds for 'Crimson Giant'. These responses indicate the existence of a strong genotype × environmental interaction for flowering in Easter cactus.

Clonal comparison. The 23 clones differed significantly in percentage of flowering plants, days to flowering, number of apical phylloclades, percentage of apical phylloclades flowering, and number of flower buds (Table 2). All 'Crimson Giant' plants produced flowers, but ≤75% of the plants flowered for the other 22 clones. Furthermore, 'Crimson Giant' exhibited the highest percentage of apical phylloclades flowering and the most flower buds among the 23 clones. The clones also differed in the number of flower buds when adjusted for an equivalent number of apical phylloclades by covariance analysis (Table 2). 'Crimson Giant' yielded the most flower buds, followed by CLU1, R891-11, CL32, and 'Yvonne Pelham', among the adjusted means.

Table 1. Influence of initial environment [10 ± 2.0C nights/12 ± 2.0C days and natural daylengths (10/ND) or 18 ± 2.0C nights/21 ± 2.0C days and natural daylengths (18/ND)] on flowering of four Easter cactus clones (Expt. 1). Plants were exposed to 10/ND or 18/ND for 6 weeks, then transferred to 18 ± 2.0C nights/21 ± 2.0C days and long days (18/LD).

Clone	Plants flowering (%)	Days to flowering (no.)	Apical phylloclades (no./pot)	Apical phylloclades flowering ^z		Flower buds (no./pot)	
				(%)	[AT]	Actual means	Adjusted means ^y
<i>Initial 10/ND—Final 18/LD^x</i>							
Crimson Giant	100	62	25	91	[74]	67.7	78.3
Evita	100	62	39	72	[58]	51.8	36.4
Purple Pride	100	62	29	68	[56]	52.3	55.2
Red Pride	100	65	30	90	[73]	59.8	61.7
LSD _{0.05}			4		[7]	10.9	7.5
Significance							
Clones		NS	***		***	*	***
Apical phylloclades		---	---		---	---	***
<i>Initial 18/ND—Final 18/LD^x</i>							
Crimson Giant	100	76	21	72	[59]	34.2	38.0
Evita	100	73	41	18	[24]	8.2	3.1
Purple Pride	50 ^w	75	30	6	[9]	2.7	2.4
Red Pride	100	78	26	22	[27]	6.7	8.3
LSD _{0.05}			4		[8]	5.1	4.9
Significance							
Clones		NS	***		***	***	***
Apical phylloclades		---	---		---	---	NS

^zPercentage (%) and arcsin-transformed [AT] data.

^yMeans calculated using number of apical phylloclades per plant as the covariate.

^x10 or 18C nights, 9- to 9.5-h ND, or ≈14-h LD.

^wClone significantly different from 100% flowering by chi-square test, $P = 0.05$. Chi-square = 3.841 for 1 df.

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

Table 2. Flowering responses of 23 Easter cactus clones grown at 18C minimum temperature (Expt. 2). Plants were exposed to 18 ± 2.0C nights/21 ± 2.5C days and 8-h short days for 6 weeks, then transferred to 18 ± 2.0C nights/21 ± 2.0C days and long days.

Clone	Source ^y	Plants flowering (%) ^x	Days to flowering (no.) ^w	Apical phylloclades (no./plant)	Apical phylloclades flowering ^z		Flower buds (no./plant)	
					(%)	[AT]	Actual means	Adjusted means ^v
Annika	PM	0	---	10	0	[0]	0	0.1
Cassiopeia	PM	4	106	9	<1	[1]	0.1	0.2
Crimson Giant	MD	100	73 ± 1	9	47	[44]	4.3	4.4
CL 16	CL	0	---	15	0	[0]	0	-0.1
CL 32	CL	29	71 ± 1	11	13	[14]	1.5	1.6
CL U1	CL	75	71 ± 1	15	21	[23]	3.2	3.1
CL U3	CL	0	---	16	0	[0]	0	-0.1
Evita	JV	0	---	9	0	[0]	0	0.1
Flash	RG	0	---	11	0	[0]	0	0
Hatherton Star	RG	0	---	8	0	[0]	0	0.1
Leo's Pink	RG	0	---	16	0	[0]	0	-0.1
Monarch	RG	0	---	11	0	[0]	0	0.1
Pink Perfection	RG	0	---	14	0	[0]	0	0
Purple Pride	JV	4	79	7	<1	[<1]	<0.1	0.2
<i>Rhipsalidopsis rosea</i>	MD	4	62	23	<1	[<1]	<0.1	-0.3
R891-4	MA	0	---	14	0	[0]	0	0
R891-9	MA	21	64 ± 2	12	5	[6]	0.5	0.6
R891-11	MA	46	73 ± 1	13	14	[16]	1.9	1.9
R891-13	MA	8	77 ± 1	9	1	[2]	0.1	0.2
Shocking Pink	RG	8	86 ± 3	11	1	[2]	0.1	0.2
Sutter's Gold	RG	0	---	15	0	[0]	0	-0.1
Thor-Anne	GT	17	96 ± 2	5	4	[5]	0.2	0.4
Yvonne Pelham	RG	50	67 ± 1	25	5	[8]	1.1	0.7
LSD _{0.05}			---	2	---	[4]	0.5	0.6
Significance								
Clones			***	***	---	***	***	***
Cell (within clone)			NS	NS	---	***	***	---
Apical phylloclades			---	---	---	---	---	*

^zPercentage (%) and arcsin-transformed [AT] data.

^yCL = Crystal Lake Greenhouses, Carver, Mass.; GT = Gartneriet Thoruplund, Odense, Denmark; JV = J. de Vries Potplantencultures bv, Aalsmeer, The Netherlands; MA = Univ. of Massachusetts, Amherst; MD = Univ. of Maryland, College Park; PM = Gartneriet PKM, Odense, Denmark; RG = Rainbow Gardens, Vista, Calif.

^xAll clones, except 'Crimson Giant', significantly different from 100% flowering by chi-square test, $P = 0.05$. Chi-square = 3.841 for 1 df.

^wMean ± 1 SE. The LSD_{0.05} could not be estimated due to missing values.

^vMeans calculated using number of apical phylloclades per plant as the covariate.

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

Discussion

The results of Expts. 1 and 2 demonstrate that clones of Easter cactus vary significantly in their flowering responses at 18C minimum. The diversity of flowering responses may be attributed to physiological differences between *R. gaertneri* and *R. rosea*. Both species are native to the southeastern Brazilian states of Minas Gerais, Parana, and Santa Catarina (Scheinvar, 1985). However, *R. gaertneri* grows at altitudes from 350 to 850 m, whereas *R. rosea* is found at higher elevations, i.e., from 1000 to 2000 m (Scheinvar, 1985). The obligate low-temperature requirement for flowering displayed by *R. rosea* may be an adaptation to lower temperatures found at higher altitudes, whereas the ability of *R. gaertneri* ('Crimson Giant') to flower at 18C minimum may have evolved in response to higher temperatures found at lower altitudes. With the exception of *R. gaertneri* 'Crimson Giant' and *R. rosea*, the clones used in Expts. 1 and 2 conform taxonomically to *R. xgraeseri*, as judged from the morphology of the flowers and phylloclades (Barthlott, 1979; Liberty Hyde Bailey Hortorium, 1976). When grown at 18C, most *R. xgraeseri* clones responded like *R. rosea* and produced few or no flowers (Table 2). However, a few *R. xgraeseri* clones (CL U1, R891-11, CL 32, and 'Yvonne

Pelham') displayed flowering responses that were intermediate between 'Crimson Giant' and *R. rosea* (Table 2). Flowering at high temperatures is a complex physiological trait that probably is controlled by numerous genes. The diverse flowering responses observed among the *R. xgraeseri* clones (Table 2) may be due to segregation of genes controlling flowering.

A 6-week exposure to 18C NT resulted in more flowers in Expt. 1 than Expt. 2 for 'Crimson Giant', 'Evita', and 'Purple Pride' (Tables 1 and 2). In both experiments, plants were grown in NDs and at ≈18C minimum before the start of treatments. However, treatments began on 24 Nov. in Expt. 1 and on 21 Sept. in Expt. 2. At 18C, 'Crimson Giant' responds as a SLDP for flowering (Boyle et al., 1988), and the critical daylength for the SD phase is between 11 and 12 h (Boyle, 1991b). It is feasible that 'Evita' and 'Purple Pride' also respond as SLDPs at 18C. At lat. 42°N, the duration of daylight is ≤11 h between 17 Oct. and 25 Feb. (List, 1951). Hence, plants in Expt. 1 received natural SDs for at least 5 weeks before the start of treatments (24 Nov.), whereas plants in Expt. 1 received natural LDs before treatments started (21 Sept.). The supplementary exposure to natural SDs for plants in Expt. 1 may account for their greater flowering compared to plants in Expt. 2.

In Easter cactus, nearly all flower buds develop on apical phylloclades (Boyle et al., 1988; Peters and Rünger, 1971; Rünger, 1960). Therefore, the number of flower buds per plant is functionally related to the number of apical phylloclades per plant. Clonal differences in the number of apical phylloclades were significant in both experiments (Tables 1 and 2), and these differences can be attributed primarily to genetic variation in branching and, in Expt. 2, to variation in number of phylloclades per cutting. Treatments that enhance branching, i.e., pinching or spraying with the growth regulator benzyladenine (BA) (Boyle, 1992), were not practiced in either experiment. Covariance analysis was used to adjust the numbers of flower buds in each experiment to an equivalent number of apical phylloclades, thus permitting a clone's flowering potential to be assessed independently from clonal differences in propagule size or growth habit. For commercial production, however, it would be desirable to obtain clones that are self-branching and capable of flowering at supraoptimal temperatures.

Considerable genotypic variation exists in Easter cactus for flowering at supraoptimal temperatures. However, it is important to note that none of the clones examined in Expt. 2 exhibited prolific flowering (Table 2), indicating that further selection and breeding will be

required to obtain genotypes that are suitable for commercial production at 18°C minimum. Introduction of Easter cactus cultivars that are capable of flowering at supraoptimal temperatures would extend the marketing period and allow production of flowering plants in warmer climates.

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