Influence of Day/Night Temperatures on Containerized Production of Selected *Helleborus* Species©

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Seedlings of *Helleborus foetidus* L. (stinking hellebore), *H.* ×*hybridus* L. (Lenten rose), and *H. niger* L. (Christmas rose) were grown under long-day conditions in controlled-environment chambers for 95 days with 9-h days of 14, 18, 22, 26, or 30 °C (57, 64, 72, 79, or 86 °F) in factorial combination with 15-h nights of 10, 14, 18, 22, or 26 °C (50, 57, 64, 72, or 79 °F). Total dry weight of each species responded differently to day and night temperatures. Maximum total dry weight of *H. foetidus* occurred with days/nights of 18/14 °C (64/57 °F), whereas, total dry weight of *H. niger* was maximized with days/nights of 14/10 °C (57/50 °F). At days of 22 or 26 °C (72 or 79 °F), there were quadratic responses in total dry weight with maximum growth of *H.* ×*hybridus* at nights of 18 or 14 °C (64 or 57 °F), respectively.

INTRODUCTION

In 2005 the Perennial Plant Association named *Helleborus* ×*hybridus* (Lenten rose) the 2005 Perennial Plant of the Year (Perennial Plant Assoc., 2005). This recognition lead to immediate increased popularity of the genus *Helleborus* L. (hellebores) which includes many species with garden merit. A rainbow of colors aptly describes the extremely attractive winter to early spring flowers species of *Helleborus* exhibit in shade gardens in the southeastern United States (Burrell and Tyler, 2006; Rice and Strangman, 2003).

The genus *Helleborus* includes 17 species native to Europe and western Asia. *Helleborus* ×*hybridus* (Lenton rose) is a natural hybrid of several individual species spread throughout the aforementioned region and is found growing in mixed woodlands and the edges of meadows. Another species, *H. foetidus* (stinking hellebore), is widespread in western Europe, from Portugal east to Hungary, north to Great Britain and Germany, and occurs in a range of woodlands from sea level to 2134 m (7000 ft) (Burrell and Tyler, 2006). A third species, *H. niger* (Christmas rose), is widespread throughout the Alps of central and eastern Europe, from Croatia and Italy north to Switzerland and Germany. *Helleborus niger* grows at elevations from 305 m (1000 ft) to 1829 m (6000 ft) in mixed coniferous and deciduous forests to above the tree line (Woodard, 2006).

In the landscape, *H.* ×*hybridus* and *H. foetidus* are easy to cultivate having few disease and insect problems and tolerating a wide range of soils (Burrell and Tyler, 2006; Rice and Strangman, 2003). On the other hand, in the southeastern United States, cultivation of *H. niger* is difficult even under ideal landscape conditions. While *H. niger* requires careful site selection in the southern landscape, it is valued in breeding programs.

Containerized nursery production of all species of *Helleborus* can be very challenging. When grown in containerized production, *Helleborus* sp. exhibit mineral nutrient deficiencies and slow growth rates taking 5 to 7 years from seed to reach flowering size. The plants also appear to be very sensitive to high temperature (Richard and Judith Tyler, pers. commun.). Although some research has been reported on culture of *H.* ×*hybridus* (Kraus and Warren, 2006), it appears no research has been reported on the influence of temperature on this genus. Additionally, since the genus is native to varying geographic and climatic regions, it is likely individual species may require different temperature regimes during production to maximize growth. Therefore, the following research was conducted to study the influence of day/night temperatures on containerized culture of three species of *Helleborus*.

MATERIALS AND METHODS

On 5 June 2007, seedlings of *H. foetidus*, *H.* ×*hybridus,* and *H. niger* were transplanted into square 1-L (1.1-qt) plastic containers filled with a substrate of pine bark and sand (4 : 1, v/v) amended with 1.8 $kg{\cdot}m^{-3}$ (3 lb/yd^3) dolomitic lime. After transplanting, the plants were acclimated in a controlled-environment greenhouse at the Horticulture Field Laboratory, Raleigh, under natural photoperiod and irradiance with days/nights of 24/18 ºC (75/64 ºF). On 12 June 2007, seedlings were transferred to the North Carolina State University Phytotron and temperature treatments were initiated the following day using four controlled-environment A-chambers and one B-chamber (Thomas et al., 2007). Seedlings were arranged as a 3 × 5 × 5 factorial in a completely random design using four single-plant replications per temperature treatment per species. The two main factors were five day [(14, 18, 22, 26, or 30 ºC) (57, 64, 72, 79, or 86 ºF)] and five night temperatures [(10, 14, 18, 22, or 26 ºC) (50, 57, 64, 72, or 79 ºF)] provided to seedlings as 9/15-h thermoperiods. Temperatures were maintained within 0.25 ºC (0.45 ºF) of the set point. Plants were moved between chambers at 0730 and 1630 HR daily to maintain appropriate day/night temperatures. Plants exposed to the same day and night temperature were also moved daily to different areas of a chamber to simulate transient mechanical perturbations and to avoid possible gradient effects within chambers.

During the 9-h portion of a thermoperiod, chamber irradiance was provided by a combination of cool-white fluorescent lamps and incandescent bulbs resulting in a photosynthetic photon flux (PPF) of 642 $\mu mol{\cdot}m^{-1}{\cdot}s^{-1}$ (Thomas et al., 2007). Incandescent bulbs providing a PPF of 44 $\mu mol{\cdot}m^{-1}{\cdot}s^{-1}$ were used as a dark interruption between 2300 and 0200 HR daily. Plants were fertigated every other day with the standard Phytotron nutrient solution providing N, P, and K at 106, 10, and 111 $mg{\cdot}L^{-1}$ (ppm), respectively (Thomas et al., 2007).

On 14 Sept. 2007, 95 days after initiation, the experiment was terminated. Plants were separated into roots and shoots. Roots were washed to remove substrate. Roots and shoots were then dried at 70 ºC (158 ºF) for a minimum of 72 h and weighed. Data were subjected to analysis of variance (ANOVA) procedures and regression analyses (SAS Inst., Inc., 1990).

RESULTS

ANOVA procedures revealed a significant species × day temperature × night temperature interaction (data not presented). Therefore, data were reanalyzed and are presented by species. Additionally, the day temperature × night temperature interaction was significant for total dry weight of *H.* ×*hybridus*. As such, day and night temperature main effects are only discussed for *H. foetidus* and *H. niger* and additional statistical analyses were conducted and treatment comparisons were made within each day temperature and within each night temperature for *H. ×hybridus*.

Total dry weight of *H. foetidus* responded quadratically as day and night temperatures increased (Table 1). Maximum total dry weight of *H. foetidus* occurred with days/nights of 18/14 ºC (64/57 ºF). In contrast, total dry weight of *H. niger* decreased linearly with increasing day and night temperatures. Total dry weight of *H. niger* was maximized with days/nights of 14/10 ºC (57/50 ºF).

Table 1. Effect of day temperature averaged over all night temperatures and the effect of night temperature averaged over all day temperatures on total dry weight of *Helleborus foetidus* and *Helleborus niger*.[z]

Day temperature (ºC)	*H. foetidus* (g)	*H. niger* (g)
14	16.0	5.4
18	19.1	4.6
22	17.7	4.6
26	12.8	3.6
30	6.0	2.1
Linear	***	***
Quadratic	***	NS
Night temperature (ºC)	***H. foetidus* (g)**	***H. niger* (g)**
10	16.4	4.6
14	18.8	5.3
18	17.7	4.3
22	11.2	3.5
26	7.5	2.5
Linear	***	***
Quadratic	***	*

[z] Data are means of 20 observations. There was a nonsignificant day × night temperature interaction for each species.
NS, *, *** Nonsignificant or significant at $P < 0.05$ or 0.001, respectively.

Total dry weight of *H. ×hybridus* differed between each day and night temperature combination. For all night temperatures except 14 ºC (57 ºF), total dry weight decreased linearly as day temperature increased (Table 2). At nights of 14 ºC (57 ºF) there was a quadratic response to total dry weight with maximum total dry weight at days of 18 ºC (64 ºF).

DISCUSSION

Growth of each species of *Helleborus* was optimized with different day/night temperatures. *Helleborus foetidus*, native to wider geographical and climatic regions than *H. niger*, grew better with warmer day and night temperatures than *H. niger* whose geographic range is restricted to higher elevations. With cool nights (14 ºC), *H. ×hybridus* grew well under higher day temperatures than the other

Table 2. Effect of day and night temperatures on total dry weight of *Helleborus* ×*hybridus.* [z]

	Night temperature (°C)						
	10	14	18	22	26		
Day temp. (°C)	(g)					Linear[y]	Quadratic
14	7.9	7.7	12.3	11.2	9.4	NS	NS
18	8.5	14.4	8.8	10.2	6.5	NS	NS
22	6.0	9.4	10.4	9.9	5.3	NS	***
26	5.6	8.9	8.1	8.5	3.9	NS	***
30	4.6	3.5	4.6	5.4	2.7	NS	NS
Linear[x]	**	*	***	**	***		
Quadratic	NS	**	NS	NS	NS		

[z] Data are means of four observations. There was a significant day × night temperature interaction.
[x] Effect of night temperature.
[y] Effect of day temperature.
NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

species. The broader genetic make-up and native climatic range of *H. ×hybridus* appears to enable it to tolerate higher day-time temperatures than the other two species. *Helleborus niger* is often used in breeding programs as a bridge between *Helleborus* sp. that cannot be hybridized to incorporate different leaf and flower forms and colors into the *H. ×hybridus* complex (Burrell and Tyler, 2006). However, *H. niger* does not appear to have the genetic potential to expand the climatic range of *H. ×hybridus*.

In conclusion, containerized production of *H. foetidus, H. ×hybridus,* and *H. niger* is feasible for the southeastern United States. Temperature management, however, of each species is important to optimize growth, particularly night temperatures.

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