Night Temperature, Photosynthetic Photon Flux, and Long Days Affect *Gypsophila paniculata* Flowering

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Abstract. The effects of night temperature (NT) and photosynthetic photon flux (PPF) on time to flower and flower yield in 'Bristol Fairy' and 'Bridal Veil' *Gypsophila paniculata* L. (perennial baby's breath) were studied in controlled environments. Plants were grown with nights at 8, 12, 16, and 20°C and 450 or 710 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ photosynthetic photon flux (PPF). Days were at 20°C. In both cultivars, the times from the start of treatments to visible bud and from visible bud to anthesis were delayed at the lower PPF and at an NT <20°C. The delays in 'Bristol Fairy' were greater than those in 'Bridal Veil'. Failure of 'Bristol Fairy' plants to reach anthesis was common at SC NT and either 450 or 710 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PPF; whereas in 'Bridal Veil', nearly all plants flowered, regardless of environmental conditions. Flower yield (measured as fresh weight of inflorescences) decreased with NT in 'Bristol Fairy' but was highest at 8 or 12°C in 'Bridal Veil'. In a second experiment using the same cultivars, the effect of curtailing long-day (LD) conditions at various stages on stem elongation and flower yield was investigated. 'Bristol Fairy' required more LD cycles (>56) than 'Bridal Veil' for maximum stem elongation and flower yield. Terminating LD conditions before the start of inflorescence expansion resulted in lower yields and shorter plants in both cultivars.

Perennial baby's breath is grown worldwide as a floricultural crop and is used extensively in floral arrangements. Since its selection in 1935 (Weiler et al., 1983), 'Bristol Fairy' has dominated commercial production and remains highly favored among florists for its pure-white, double flowers. *Gypsophila* generally is grown as a protected crop, with night lighting supplied throughout the growth cycle during the winter to provide the long-day (LD) conditions necessary for flowering (Shillo and Halevy, 1982). In addition, winter culture of 'Bristol Fairy' at high latitudes requires either heating the greenhouse to maintain night temperature (NT) at 11°C (Shillo, 1985) or applying gibberellin (Shlomo et al., 1985) or benzylaminopurine (Doi et al., 1989) to ensure flowering. Even with these inputs, 'Bristol Fairy' flower quality and yield may be

inhibited by low ambient photosynthetic photon flux (PPF) (Hicklenton, 1986).

To address some of the problems involved in winter culture and to attempt to establish year-round production systems, attention has been focused on alternative *Gypsophila* selections and cultivars that differ in their temperature and light requirements for flowering (Doi et al., 1989). 'Bridal Veil' bears flowers that are similar in form and color to those of the popular 'Bristol Fairy' and has shown good potential for culture at low temperatures and low PPF (Hicklenton et al., 1993). To develop recommendations for year-round *Gypsophila* production, it is necessary to establish and quantify cultivar responses to a full range of cultural conditions. In this study we compared the growth and flowering responses of 'Bristol Fairy' and 'Bridal Veil' to NT, PPF, and, in a separate experiment, to the effect of terminating LD conditions before flower opening.

Rooted cuttings of 'Bristol Fairy' and 'Bridal Veil', obtained from a commercial propagator on 18 Nov. 1991 and 3 Feb. 1992, were potted into 4-liter plastic containers filled with a 5 peat : 3 pumice (v/v) medium.

NT and flowering (Expt. 1). Twelve containers each of 'Bristol Fairy' and 'Bridal Veil' were placed on trolleys in four controlled-environment rooms at the National Climate Laboratory, Palmerston North, New Zealand (Dept. of Scientific and Industrial Research, 1981). There were four plants per trolley (two of each cultivar), and six trolleys per room. Each room was lit by four 1000-W

high-pressure multivapor lamps (Sylvania Metalarc; Drummondville, Que., Canada) and four 1000-W quartz-halogen lamps providing 710 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PPF at the initial plant height on three open trolleys per room. Three other trolleys were fitted with neutral-density synthetic screening, resulting in 450 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PPF at plant height. Trolleys were placed randomly in each room, and the position of each trolley was changed within the room twice per week. Plants were grown under the established PPF for 9 h each day, conditions that resulted in daily PPF integrals of 23 and 14.6 $\text{mol}\cdot\text{m}^{-2}$. Total day length was extended to 18 h with lighting from a 1000-W quartz-halogen lamp for 4.5 h immediately before and after the main irradiance period. PPF during these day-extension periods was 15 or 8 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, open or screened, respectively. The temperature during the main irradiance period was constant at 20°C; NT was 8, 12, 16, or 20°C. Room air temperatures, vapor-pressure deficit (VPD), CO_2 concentration, and lamp function were monitored continuously during the experiment. Temperatures did not deviate by more than 0.5°C from set points. VPD was 0.5 kPa during the main irradiance period and 0.3 kPa during the rest of the diurnal period. PPF measured at the start and end of the experiment did not change from initial values. Each plant was supplied automatically with excess half-strength Hoagland's A solution twice daily (Brooking, 1976), and additional water was supplied as needed. Plants were examined daily for signs of flower buds. The number of days to visible bud and the number of days from visible bud to anthesis of the first inflorescence were noted. When about two-thirds of the florets on a plant had reached anthesis, all inflorescences [as defined by Shillo (1985)] were harvested and weighed. Development time and harvest data were subjected to analysis of variance according to the split-split plot experimental design, with temperature assigned to main plots, PPF to the subplots, and cultivar to the sub-subplots. Data were analyzed using general linear models procedures capable of dealing with design imbalance that occurs in cases in which plants fail to reach anthesis. All inflorescence weight data are expressed on a per-flowering-plant basis.

Possible room effects (plant responses specific to a controlled-environment room) were not considered in this experiment. Previous plant studies (e.g., Hardacre et al., 1986; Warrington and Kanemasu, 1983) conducted in the climate laboratory have shown negligible room effects, providing that environmental conditions do not deviate significantly from set points during the experiment.

Duration of LD treatment effects on shoot growth and flowering (Expt. 2). The experiment used two controlled-environment rooms, each maintained at 20°C. LD conditions were established in one room using the same protocol as described for Expt. 1, with a high-irradiance period PPF of 710 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ at initial plant height. The second room also was programmed to provide 9 h at 710 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$, but without photoperiod-extension lighting [short-day (SD) regime]. At 14, 28, and 56

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days, five plants were moved from the LD to the SD room. Five more plants remained constantly under LD conditions and five plants were grown only under SD. At weekly intervals, plant height from medium surface to the uppermost growing apex was recorded on each plant. Developmental stage at time of transfer was noted, and inflorescences were harvested as described for Expt. 1.

Experiment 1. NT and PPF influenced the percentage of 'Bristol Fairy' plants that flowered (Table 1). Underlow PPF ($450 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$), temperatures $<20^\circ\text{C}$ caused most plants to remain in a vegetative rosette or show only limited shoot elongation; the few flower buds that did form usually failed to develop to anthesis. Even at high PPF ($710 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$), a low NT (8°C) resulted in a proliferation of nonelongating vegetative shoots. This result is consistent with previous ones that indicate low flowering percentages of 'Bristol Fairy' with nights of $\leq 7^\circ\text{C}$, irrespective of prevailing day temperature (Shillo, 1985; Shlomo et al., 1985). In contrast, the percentage of 'Bridal Veil' plants that flowered was independent of PPF and NT.

In both cultivars, the days from the start of treatments to visible bud and the subsequent development of flower buds to anthesis increased as NT and PPF decreased. However, the delaying effects of low temperature were more severe in 'Bristol Fairy' (94-day increase in total time to anthesis as NT decreased from 20 to 8°C at $710 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PPF) than in 'Bridal Veil' (41-day increase over the same NT range). Overall, 'Bridal Veil' had significantly higher yield per flowering plant than 'Bristol Fairy'. Low PPF had similar effects on yield in both cultivars; total inflorescence weight was depressed by an average of 40% at

$450 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ relative to $710 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. The cultivars differed in their yield response to NT, however. In 'Bristol Fairy' grown at $710 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ PPF, maximum yield occurred at 16°C NT and decreased at a lower NT. In 'Bridal Veil', however, yield was higher when the NT was 12 or 8°C .

Experiment 2. *Gypsophila paniculata* is typical of many obligate LD plants that show rapid stem elongation (bolting) at, or shortly before, flower-bud initiation (Wellensiek, 1985). In these plants, bolting can indicate readiness to flower. Subsequent floral development, however, depends on a wide range of internal and external factors; e.g., genetic background (Kusey et al., 1981), temperature (Shlomo et al., 1985), PPF (Hicklenton, 1986), and the continuance of LD-inductive conditions (Shillo, 1985). 'Bristol Fairy' and 'Bridal Veil' plants remained as vegetative rosettes and failed to flower in continuous SD or with only 14 LD cycles (Figs. 1 and 2). Maintaining inductive conditions for 28 or 56 days promoted bolting, but curtailing LD after 28 cycles resulted in flowering only in 'Bridal Veil' (Fig. 2). In this case, flower yields were only 27% of those in plants subjected to continuous LD. After 56 LD cycles, 'Bridal Veil' plants were similar in height and had flower yields similar to those maintained under continuous LD conditions; 'Bristol Fairy' plants, however, were shorter than the LD controls and produced only 40% of maximum yield.

Differences between cultivars in growth and flower yield after transfer to SD conditions are attributable to differences in developmental rate. Shillo (1985) reported that 'Bristol Fairy' plants responded to LD conditions until the start of inflorescence expansion; thereafter, development proceeded similarly, and fi-

nal yields were similar under either LD or SD conditions. In the present study, 'Bristol Fairy' plants did not show visible buds at the 14- or 28-day transfers. At 56 days, however, shoots were elongated with tight buds. 'Bridal Veil', in contrast, showed elongated shoots with tight buds. at 28 days and partly expanded inflorescences at 56 days. Evidently, processes that determine the extent of shoot elongation and flower bud initiation or development in either clone are not complete until inflorescences begin to expand.

In summary, our results indicate that 'Bridal Veil' may be grown successfully at NTs that are unsuitable for culturing 'Bristol Fairy'. In 'Bridal Veil', an NT as low as 8°C produces a maximum flowering response; whereas the number of flowering plants and potential yields of 'Bristol Fairy' decrease markedly under these conditions. Reducing PPF decreases total yield in both cultivars, but 'Bridal Veil' produced more flowers than 'Bristol Fairy' under all conditions. Flower development proceeded more rapidly in 'Bridal Veil', especially at a low NT. To develop maximum stem height and yield, both cultivars require maintained LD conditions until inflorescences begin to expand. Since 'Bridal Veil' grows more rapidly, LDs may be terminated safely earlier than would be desirable for 'Bristol Fairy'. In commercial production, this earlier termination would allow earlier curtailment of photoperiod-extension lighting. 'Bridal Veil' may be useful particularly for winter greenhouse production at high latitudes.

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Table 1. Effect of photosynthetic photon flux (PPF) and night temperature (NT) on flowering in *Gypsophila paniculata* 'Bristol Fairy' (BF) and 'Bridal Veil' (BV).

PPF ($\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$)	NT ^a ($^\circ\text{C}$)	Flowering plants (%)		Days to VB ^b		Days VB to anthesis		Inflorescence yield (g/plant) ^a	
		BF	BV	BF	BV	BF	BV	BF	BV
710	8	33	100	96	50	54	41	52	176
	12	83	100	71	45	39	35	80	181
	16	100	100	51	38	29	30	102	116
	20	100	100	32	26	24	24	82	110
450	8	33	83	121	50	52	42	26	83
	12	0	100	---	45	---	39	0	130
	16	33	100	52	49	39	37	15	40
	20	100	100	49	35	29	28	13	56
<i>Statistical analysis</i>									
NT				**		**			NS
Linear (L)				**		**			
Quadratic (Q)				NS		NS			
Deviation (D)				NS		NS			
Cultivar (C)				**		NS			*
PPF				**		*			**
NT $\times$ C				*		*			**
L $\times$ C				*		*			*
Q $\times$ C				NS		NS			NS
D $\times$ C				NS		NS			*
NT $\times$ PPF				*		NS			NS
L $\times$ PPF				*					
Q $\times$ PPF				NS					
D $\times$ PPF				NS					

^a20C maintained during the 9-h high-irradiance period in each treatment.

^bVB = visible bud.

*Only flowering plants were incorporated in the calculation of mean yield.

NS, **Nonsignificant or significant at $P \leq 0.01$ or 0.05 , respectively. Only effects significant for one or more traits are shown.

Fig. 1. Stem elongation of *Gypsophila paniculata* 'Bristol Fairy' (BF) and 'Bridal Veil' (BV) in relation to time of transfer from long-day (LD) to short-day (SD) conditions. Bars indicate $\pm$ SE at final plant height.

Fig. 2. Yield of *Gypsophila paniculata* 'Bristol Fairy' (BF) and 'Bridal Veil' (BV) transferred at various times from long-day (LD) to short-day (SD) conditions, or grown continuously under SDs, expressed as a percentage of yield of LD-grown plants. Where bars are absent, all plants failed to flower.

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