Photoperiod, Juvenility, and High Intensity Lighting Affect Flowering and Cut Stem Qualities of *Campanula* and *Lupinus*

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Abstract. *Campanula medium* L. 'Champion Blue' and 'Champion Pink' and *Lupinus hartwegii* Lindl. 'Bright Gems' were grown in 8- or 16-h initial photoperiods, transplanted when 2–3, 5–6, or 8–9 true leaves developed, and placed under 8-, 12-, or 16-h final photoperiods. The lowest flowering percentage for 'Champion Blue' (<1%) and 'Champion Pink' (16%) resulted from plants grown in the 8-h photoperiod continuously. One hundred percent flowering occurred when *Campanula* were grown in the 16-h final photoperiod, indicating that 'Champion Blue' and 'Champion Pink' are long-day plants. Plants grown initially in the 8-h and finished in the 16-h photoperiod had the longest stems. Stem diameter was generally thickest for plants grown in the 8-h compared with the 16-h initial photoperiod. However, the 8-h initial photoperiod delayed anthesis compared with the 16-h initial photoperiod. 'Champion Blue' and 'Champion Pink' plants transplanted at the 2–3 leaf stage from the 16 hour initial to the 8-h final photoperiod had flowering percentages of 64% and 63%, respectively; however, when transplanted at the 8–9 leaf stage, plants were fully mature and 100% flowering occurred indicating that all plants were capable of flowering. In year 2, plants receiving high intensity discharge (HID) supplemental lighting during the 16-h initial photoperiod reached anthesis in 11 fewer days compared with plants not receiving HID supplemental lighting. High profits were obtained from *Campanula* grown in the 8-h initial photoperiod and transferred at 5–6 true leaves into the 16-h final photoperiod. *Lupinus hartwegii* plants had a high flowering percentage (96% to 100%) regardless of photoperiod or transplant stage. The 16-h final photoperiod decreased days to anthesis compared with the 8- or 12-h final photoperiod indicating that *L. hartwegii* is a facultative long-day plant. Increasing length of final photoperiod from 8- to 16-h increased stem length. Juvenility was not evident for *Lupinus* in this study. In year 2, *Lupinus* cut stems were generally longer and thicker when given HID supplemental lighting, especially when grown in the 8- or 12-h final photoperiod. Supplemental lighting also reduced days to anthesis. Highest profits were generally produced from *Lupinus* plants grown with supplemental HID lighting (during the initial photoperiod) until 8–9 true leaves had developed.

The profitability of specialty cut flower production can depend on producers' ability to offer species and cultivars new to the industry. Two species that show promise as specialty cuts are *Campanula medium* L. and *Lupinus hartwegii* Lindl. *Campanula medium*, commonly known as Canterbury bells, is a pubescent plant with rosulate lower leaves and multiple 3.5-cm long bell-shaped flowers on terminal racemes (Griffiths, 1995). *Campanula medium* plants were previously biennials re-

quiring a lengthy cultivation time and cold or short days followed by long days for flowering (Wellensiek, 1985). However, two new cultivars, 'Champion Blue' and 'Champion Pink', now offer a production time as low as 19 weeks with no cold requirement for flower development (Sakata, personal communication). These new cultivars can produce multiple stems up to 25-cm long when spaced 25- to 30-cm apart or single stems of 65-cm when spaced 10- to 15-cm apart.

Lupinus hartwegii 'Bright Gems' is a popular cut flower because of its light blue, pink, lavender, and white flower colors, and large spike inflorescence. *Lupinus hartwegii* is an annual with pubescent stems up to 90-cm long and 1.5-cm florets (Griffiths, 1995). While no published information is available on the specific cultural requirements for *L. hartwegii*, many *Lupinus* species are long-day plants (Rahman and Gladstones, 1974).

A major factor in determining production cost is crop time. Extended production time increases labor, irrigation, fertilization, pest

management expenses, and the likelihood of climatic problems. Reducing production time while maintaining high quality would help assure a profitable crop for producers.

Two factors, juvenility and photoperiod, can be important in economical cut flower production. Determining the minimum age at which a plant is capable of responding to the photoperiod or other flower induction conditions may aid in reducing production time. Damann and Lyons (1995) reported that transferring *Chrysanthemum* × *superbum* Bergmans ex J. Ingram at the proper node count from a noninductive photoperiod to an inductive photoperiod reduced the time to flower from 123 to 77 d. The minimum number of leaves (nodes) which indicates the end of juvenility has been described for many plants including *Antirrhinum majus* L. at 18–22 leaves (Cockshull, 1985), *Coreopsis* L. 'Sunray' at 16 leaves (Cameron et al., 1996), and *Pericallis* D. Don. 'Cindy Blue' at 6–7 leaves (Yeh and Atherton, 1997).

If a plant is prematurely exposed to reproductive conditions before sufficient plant mass has developed, the plant may not be able to support quality flowers. In addition, early exposure to reproductive conditions before the end of juvenility could decrease uniformity of flowering (Cameron et al., 1996).

In addition to photoperiod, light intensity is an important factor in plant development and quality. Low light levels increased plant height in *Anemone coronaria* L., *Centaurea americana* Nutt., *Echinops ritro* L., *Eryngium planum* L., *Oxypetalum caeruleum* (D. Don.) Decne, and *Zantedeschia* Spreng. (Armitage, 1991; Armitage et al., 1990). Plants may become taller or have longer stems under low light levels but may be markedly weaker. Weak stems would not properly support the flowers and would lower the cut stem quality.

Studies involving geranium (*Pelargonium* L. sp.) have illustrated the potential for reducing production time of floral crops using high intensity discharge (HID) supplemental lighting (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter and Rodriguez, 1971; Quatchak et al., 1986). In greenhouse cut rose (*Rosa* L.) production, time to anthesis was decreased 3–10 d with the use of HID lamps (Tsujita, 1987). In *Chrysanthemum morifolium* Ramat. production, Carpenter (1976) reported that height and fresh weight increased during the vegetative growth stage when plants were given supplemental lighting. The higher light intensity compared with ambient light intensity increased photosynthate production that increased carbohydrate levels for growth and development (Kinet et al., 1985).

The objectives of this study were to determine: 1) optimum photoperiods and transplant stages for *C. medium* 'Champion Blue', *C. medium* 'Champion Pink' and *L. hartwegii* 'Bright Gems'; and 2) if HID supplemental lighting can aid in producing high quality cut flowers with minimal production time.

Materials and Methods

Year 1—Campanula and Lupinus. *Campanula medium* 'Champion Blue' and 'Cham-

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pion Pink' and *L. hartwegii* seeds were direct sown into 1206 bedding plant flats (50 cm³/cell) using a peat-lite commercial root substrate (Redi Earth, Scotts-Sierra Company, Marysville, Ohio) on 12 Sept. 1997. Seedlings were placed into the respective photoperiods upon the appearance of the first true leaves. Two initial photoperiods of 8 and 16-h were used. The 8-h photoperiod received 8-h of natural light concurrent with 8-h of incandescent light. The 16-h photoperiod received 8-h of natural light and an additional 8-h of day extension provided by incandescent lights. Thus, both treatments received 8-h of natural daylight and 8-h of incandescent light [654 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux (PPF)].

Plants were transplanted into 1801 (260-cm³/cell) bedding plant flats with a commercial soilless media (BM1; Berger, Saint-Modeste, Quebec) at the appearance of 2–3, 5–6, or 8–9 true leaves and placed into the final 8-, 12-, or 16-h photoperiods. Each plant received 86 cm² area per plant, which was sufficient for single stem *Campanula* production (Sakata, personal communication). The 8- and 16-h photoperiods were lighted as described previously. The 12-h photoperiod received 8-h of natural light concurrent with 4-h incandescent light and 4-h day extension incandescent light.

Plants were grown in a corrugated polycarbonate-covered greenhouse set at an 18 °C day/15 °C night temperature. Plants were

fertigated with 250 mg·L⁻¹ N from a premixed commercial 20N–4.4P–16.6K fertilizer (Peter's Professional; Scotts Co., Marysville, Ohio).

The three crops were analyzed separately and data collected at harvest time included stem length, stem diameter, selling price, and number of flowering plants per replication (flat of 18 plants). Light levels (once a month at solar noon) and anthesis dates were recorded. Profit/loss was calculated based on: gross sales – production expenses. Production expenses were calculated as: {(seed, flat, and media expenses) + [\$0.322/m²/d * area in plug flat (m²) * d] + [\$0.322/m²/d * area in production flat (m²) * d]}*18. Seed, flat, and media expenses totaled \$0.144/cell. The \$0.322/m²/d was determined from Brumfield et al. (1982) for small growers servicing floral shops and adjusted by the consumer price index (U.S. Bureau of the Census, 1998). Plug flat area was 0.0022 m²/cell and production flat area was 0.0086 m²/cell (18 cells per flat). Based on sales to retail florist, \$0.65/stem was obtained for stems <38-cm long and \$0.75/stem for stems ≥38-cm long. Gross sales per flat = \$/stem*18*percentage of flat flowering.

Campanula flowers were harvested at full color of terminal flower bud and *Lupinus* when one-third of florets had reflexed petals. A split plot with a 3 × 3 × 2 factorial treatment combination was used with three final photoperiods as the main plots and two initial photoperiods and three transplant stages as sub-

plots. Four experimental units (1801 flats) of 18 plants per unit were used for each treatment combination. Data were analyzed by the general linear model procedure (SAS Institute, Cary, N.C.) with means separation by trend analysis. Percentage of flowering data analysis was based on arc-sin transformation.

Year 2—Campanula. 'Champion Blue' and 'Champion Pink' seed were sown on 2 Dec. 1998 and placed into 8- or 16-h initial photoperiods upon the appearance of the first true leaves as described in year 1. In addition, one half of plants were given 8-h of high-pressure sodium supplemental lighting (P.L. Light Systems, Beamsville, Ontario) concurrent with the 8-h of incandescent lighting for both photoperiods (740 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF). The other half of plants did not receive supplemental HID (654 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF). All plants were transplanted into the 16-h final photoperiod (incandescent lighting only) at 5–6 true leaves resulting in a split plot with a 2 × 2 factorial treatment combination with 2 initial photoperiods as the main plot and two light intensities from supplemental lighting as subplots. Four experimental units (1801 flats) with 18 plants per unit were used. All other procedures were the same as described for year 1.

Year 2—Lupinus. Seed were sown 14 Oct. 1998. Plants were placed into a 16-h initial photoperiod with or without 8-h of concurrent HID supplemental lighting upon appearance of the first true leaves. Plants were transplanted at

Table 1. Effect of 8-, 12-, and 16-h photoperiods and number of true leaves at transplanting on flower quality and production time for *Campanula medium* 'Champion Blue'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 64 to 72 plants per treatment. Year 1.

Initial photoperiod (h)	Transplant stage (no. true leaves)	Final photoperiod (h)	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Sowing to anthesis ^z (days)	Profit ^y (\$/replication)	
8	2–3	8	0	--- ^x	--- ^x	--- ^x	–12.68	
		12	90	42.3	9.4	193	2.03	
		16	100	40.2	3.7	135	6.29	
	5–6	8	0	--- ^x	--- ^x	--- ^x	–12.68	
		12	95	43.9	8.9	191	3.73	
		16	99	43.6	4.9	160	5.78	
	8–9	8	1	48.0	7.0	198	–7.80	
		12	94	45.5	7.9	198	3.75	
		16	100	40.8	7.0	178	5.59	
	16	2–3	8	64	25.7	4.9	148	–0.32
			12	94	27.8	4.7	132	4.19
			16	100	29.8	3.5	125	5.02
5–6		8	90	26.7	3.3	140	3.93	
		12	97	25.9	3.0	130	5.26	
		16	100	31.2	2.7	138	5.26	
8–9		8	100	27.2	4.2	149	5.21	
		12	100	26.9	2.8	134	5.94	
		16	100	30.3	3.0	138	5.76	
Initial photoperiod (I)			0.0001	0.0001	0.0001	0.0001		
Transplant (T)								
Linear (L)			0.0087	NS	NS	0.0001	0.0003	
Quadratic (Q)			NS	NS	0.0004	NS	NS	
Final photoperiod (F)								
L			0.0001	0.0001	NS	NS	0.0001	
Q			NS	0.0006	0.0001	0.0002	NS	
Significant interactions (<i>P</i> < 0.05)			I*FL	I*FL	I*TL	I*TL	I*TL	
					I*TQ	I*FL	I*TQ	
					I*FL	TL*FL	I*FL	
					TL*FL	TL*FQ	TL*FL	
					TL*FQ	TQ*FL	TQ*FL	
					I*TL*FL	I*TL*FL	I*TL*FL	
							I*TQ*FL	

²Seed were sown on 12 Sept. 1997.

³One replication = one flat = 0.1561 m², sales – production cost = profit or loss.

⁴Inflorescences did not reach anthesis prior to termination of experiment.

⁵NSNonsignificant.

the appearance of 2–3, 5–6, or 8–9 true leaves into the 8-, 12-, or 16-h final photoperiods using 1801 bedding plant flats as described previously for year 1 final photoperiods.

Results and Discussion

In year 1, differences were observed between *Campanula medium* 'Champion Blue' and 'Champion Pink' and the two cultivars are discussed separately (Tables 1 and 2). 'Champion Blue' reached anthesis significantly earlier than 'Champion Pink'. Although 'Champion Blue' had thinner stems than 'Champion Pink', stem lengths were similar.

A continuous 8-h photoperiod inhibited or greatly reduced flowering for 'Champion Blue' (<1%) and 'Champion Pink' (16%) plants, which is in agreement with Wellensiek (1985) (Tables 1 and 2). In the 16-h final photoperiod, 'Champion Blue' and 'Champion Pink' had high flowering percentages (99% to 100%) and reached anthesis in fewer days than the 12-h final photoperiod, except for 'Champion Pink' plants initially grown in the 16-h photoperiod and transplanted at either 5–6 or 8–9 true leaves. An interaction existed such that percent flowering increased from <1% for plants grown under the 8-h final photoperiod to 64% to 100% for plants grown under the 16-h photoperiod initially. *Campanula medium* Champion cultivars are long-day plants with a

critical photoperiod between 8 and 12 h. Wellensiek (1985) reported that *C. medium* (no cultivar specified) is a short-day/long-day plant that does not flower when given long-days unless plants previously received ≈4 weeks of short days. In our study, however, 99% to 100% of plants receiving continuous 16-h long-days flowered indicating that short days are not required for Champion cultivars to flower.

The 8-h initial photoperiod, a noninductive photoperiod for *C. medium* (Wellensiek, 1985), increased stem length and diameter for 'Champion Blue' and 'Champion Pink' when compared with the 16-h initial photoperiod (Tables 1, 2, and 3). The noninductive 8-h initial photoperiod allowed plants to continue to form leaf primordia; thus, more leaves were formed, stems were longer, and flowering was delayed compared with the 16-h initial photoperiod. An interaction existed such that 'Champion Blue' grown under the 8-h initial photoperiod had the thickest stems when transferred to the 12-h final photoperiod (Table 1). However, when plants were grown in the 16-h initial photoperiod, the thickest stems were obtained under the 8-h final photoperiods. Most plants continuously grown in the 8-h photoperiod never developed flowering stems.

For 'Champion Pink', an interaction existed such that plants grown continuously in the 8-h photoperiod and transplanted at the 2–3 leaf

stage had the thickest stems (Table 2). In contrast, plants grown continuously in the 16-h photoperiod and transplanted at the 8–9 leaf transplant stage resulted in the thinnest stems.

'Champion Blue' and 'Champion Pink' plants transplanted at the 2–3 leaf stage from the 16-h initial to the 8-h final photoperiod had flowering percentages of 64% and 63%, respectively (Tables 1 and 2). However, flowering percentage increased to 100% for both cultivars when plants were transplanted at the 8–9 leaf stage. Thus, juvenility existed and all plants were capable of flowering at 8–9 true leaves, 81 d from sowing, which is much shorter than the 120 to 160 d reported by Wellensiek (1985). Other species were mature at 18–22 leaves for *Antirrhinum majus* (Cockshull, 1985), 16 leaves for *Coreopsis* 'Sunray' (Cameron et al., 1996), and 6–7 leaves for *Pericallis* 'Cindy Blue' (Yeh and Atherton, 1997).

For *Campanula*, days to anthesis were reduced by the 16-h initial photoperiod (Tables 1, 2, and 3). An interaction existed such that *C. medium* grown continuously in the 16-h photoperiod and transplanted at the 2–3 leaf stage flowered in the fewest days. Plants receiving HID supplemental lighting during the 16-h initial photoperiod reached anthesis earlier than plants not receiving HID supplemental lighting (Table 3). These results are similar to those obtained with *Pelargonium* (Armitage and Tsujita, 1979; Armitage and Wetzstein,

Table 2. Effect of 8-, 12-, and 16-h photoperiods and transplant stage on flower quality and production time for *Campanula medium* 'Champion Pink'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 71 or 72 plants per treatment. Year 1.

Initial photoperiod (h)	Transplant stage (no. true leaves)	Final photoperiod (h)	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Sowing to anthesis ² (days)	Profit ³ (\$/replication)
8	2–3	8	17	46.0	12.4	229	–9.65
		12	88	40.4	9.5	198	1.53
		16	100	37.1	3.9	144	5.87
	5–6	8	19	53.6	11.4	229	–7.99
		12	81	39.2	9.2	198	1.46
		16	100	39.2	4.9	165	5.70
	8–9	8	11	51.5	10.3	241	–9.65
		12	96	40.8	8.3	204	3.97
		16	100	47.5	7.5	188	5.04
	2–3	8	63	37.9	8.8	198	–3.85
		12	94	37.3	8.1	191	0.53
		16	100	31.9	4.0	141	4.34
16	5–6	8	82	24.7	3.8	144	2.48
		12	89	22.8	3.2	139	4.32
		16	100	19.9	3.3	145	5.11
	8–9	8	100	24.5	3.1	150	5.15
		12	97	20.6	3.1	143	5.20
		16	100	24.4	3.1	148	5.35
Initial photoperiod (I)			0.0369	0.0053	0.0004	0.0002	0.0003
Transplant (T)							
Linear (L)			NS	0.0249	0.0012	0.0256	0.0015
Quadratic (Q)			NS	NS	0.0130	0.0001	NS
Final photoperiod (F)							
L			0.0003	NS	0.0156	0.0171	0.0001
Q			NS	NS	0.0131	0.0357	NS
Significant interactions ($P < 0.05$)			None	I*TL TL*FL	I*TL I*TQ IL*FL TL*FL TL*FQ I*TQ*FL	I*TL I*TQ I*FL TL*FL TL*FQ TQ*FL I*TL*FL I*TQ*FL I*TQ*FQ	I*TL I*FL TL*FL I*TL*FL

²Seed were sown on 12 Sept. 1997.

³One replication = one flat = 0.1561 m², sales - production cost = profit or loss.

^{NS}Nonsignificant.

Table 3. Effect of initial photoperiod and 8-h supplemental light intensity on flower quality and production time for *Campanula medium* 'Champion Blue' and 'Champion Pink'. Plants were transplanted at the appearance of 5–6 true leaves and placed in 16-h final photoperiod. Means are an average of data from 64 to 72 plants per treatment. Year 2.

Initial photoperiod (h)	Supplemental lighting ^a	Stem length (cm)	Stem diameter (mm)	Sowing to anthesis ^c (days)	Profit ^b (\$/replication)
<i>Campanula</i> 'Champion Blue'					
8	Yes	63.3	6.8	127	7.34
	No	62.9	6.5	129	7.67
16	Yes	39.8	4.8	108	8.28
	No	42.7	5.4	122	7.99
Initial photoperiod (I)		0.0001	0.0001	0.0001	0.0001
Light intensity (H)		NS	NS	0.0001	NS
I*H		0.0001	0.0004	0.0001	0.0001
<i>Campanula</i> 'Champion Pink'					
8	Yes	58.0	6.9	132	7.47
	No	56.8	7.3	132	7.47
16	Yes	46.5	6.5	122	7.56
	No	55.0	6.4	129	7.62
Initial photoperiod (I)		0.0001	0.0011	0.0001	0.0458
Light intensity (H)		0.0098	NS	0.0057	NS
I*H		0.0004	NS	0.0039	NS

^aSeed were sown on 2 Dec. 1998.

^bOne replication = one flat = 0.1561 m², sales - production cost = profit or loss.

^cPresence or absence of high intensity supplemental lighting.

^{ns}Nonsignificant.

1984; Carpenter and Rodriguez, 1971; Quatchak et al., 1986) and Rosa (Tsujita, 1987)

In year 1, *Campanula* grown in the 8-h initial photoperiod and transferred to the 16-h final photoperiod when plants had 5–6 true leaves produced high profits due to long stems and longer duration of production time in the plug flat which used less area per plant as compared with plants transplanted at the 2–3 leaf stage (Tables 1 and 2). Lower profits

occurred for plants grown in the 8-h initial, transplanted at the 8–9 leaf stage, and 16-h final photoperiod than when plants were grown in the 8-h initial, transplanted at the 5–6 leaf stage, and 16-h final photoperiod due to the delay in flowering caused by later transplanting into an inductive photoperiod and larger substrate area. While *Campanula* grown in the 16-h initial photoperiod had short stems, high profits were obtained due to short crop times,

except for plants transferred at 2–3 true leaves to the 8- or 12-h final photoperiod or at 5–6 true leaves to the 8-h final photoperiod which had low flowering percentages. While all stems were sold due to high demand, the market for short stems would likely be limited with sufficient supply of long stems. In year 2, 'Champion Blue' was most profitable when grown in the 16-h initial photoperiod with supplemental lighting due to decreased production time (Table 3). 'Champion Pink' highest profits were from plants grown in the 16-h continuous photoperiod (Table 3).

All *L. hartwegii* had high flowering percentages (96% to 100%) regardless of photoperiod (data not presented). The 16-h final photoperiod decreased days to anthesis in year 1 compared with the 8- or 12-h final photoperiod indicating that *L. hartwegii* is a facultative long-day plant (Table 4). Rahman and Gladstones (1974) also noted that *L. albus* L., *L. angustifolius* L., *L. consentini* Guss., and *L. luteus* L. were facultative long-day plants. However, *L. hartwegii* plants grown under 16-h initial photoperiod and transferred at 8–9 true leaves to the final photoperiod had similar days to anthesis regardless of final photoperiod. Increasing final photoperiod increased stem length and decreased stem diameter in both years (Tables 5 and 6). Thus, while long-days may hasten flower initiation, stem diameter will be decreased.

Lupinus did not exhibit juvenility in the parameters tested in this study as 96% to 100% of plants flowered regardless of transplant stage (data not presented). In year 1, transplants with

Table 4. Effect of 8-, 12-, and 16-h photoperiods and transplant stage on flower quality and production time for *Lupinus hartwegii* 'Bright Gems'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 51 to 59 plants per treatment. Year 1.

Initial photoperiod (h)	Transplant stage (no. true leaves)	Final photoperiod (h)	Sowing to anthesis ^c (days)
8	2–3	8	170
		12	188
		16	160
	5–6	8	178
		12	185
		16	169
	8–9	8	187
		12	175
		16	170
16	2–3	8	177
		12	193
		16	154
	5–6	8	188
		12	175
		16	167
	8–9	8	175
		12	176
		16	177
Initial photoperiod (I)			NS
Transplant (T)			
Linear (L)			NS
Quadratic (Q)			NS
Final photoperiod (F)			
L			0.0002
Q			0.0013
Significant interactions ($P < 0.05$)			TL*FQ I*TL*FL

^aSeed were sown on 12 Sept. 1997.

^{ns}Nonsignificant.

Table 5. Effect of 8- or 16-h initial photoperiod, transplant stage^a, and 8-, 12-, or 16-h final photoperiod main effects on stem length, diameter, and profit for *Lupinus hartwegii* 'Bright Gems'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 306 to 531 plants per treatment. Year 1.

Treatment	Stem length (cm)	Stem diameter (mm)	Profit ^b (\$/replication)
<i>Initial photoperiod</i>			
8 h	53.4	7.5	3.69
16 h	55.9	8.0	3.68
Significance	NS	0.0233	NS
<i>Transplant stage</i>			
2–3	54.6	7.8	2.72
5–6	57.3	8.0	3.22
8–9	52.0	7.4	5.10
Significance			
Linear (L)	0.0369	NS	0.0030
Quadratic (Q)	NS	NS	0.0202
<i>Final photoperiod</i>			
8 h	48.2	8.4	3.54
12 h	56.3	7.4	3.53
16 h	59.4	7.4	3.98
<i>Significance</i>			
L	0.0001	0.0002	0.0156
Q	0.0188	0.0152	NS

^aSeed were sown on 12 Sept. 1997.

^bOne replication = one flat = 0.1561 m², sales - production cost = profit or loss.

^{ns}Nonsignificant.

Table 6. Effect of 8-, 12-, and 16-h final photoperiods, supplemental light intensity, and transplant stage on flower quality and production time for *Lupinus hartwegii* 'Bright Gems'. Plants were transferred from a 16-h initial photoperiod to final photoperiod at the time of transplanting. Means are an average of data from 62 to 72 plants per treatment. Year 2.

Transplant stage (no. true leaves)	Supplemental lighting ^x	Final photoperiod	Stem length (cm)	Stem diameter (mm)	Sowing to anthesis ^z (days)	Profit ^y (\$/replication)
2-3	Yes	8	64.0	9.7	156	4.32
		12	78.9	8.6	148	4.67
		16	79.2	8.0	152	4.44
	No	8	61.1	9.2	160	4.05
		12	77.5	8.9	153	4.38
		16	84.7	7.9	146	4.73
5-6	Yes	8	61.1	9.3	149	5.07
		12	77.1	8.5	147	5.11
		16	79.6	8.5	144	5.29
	No	8	54.9	8.6	165	4.24
		12	75.5	7.6	156	4.68
		16	78.7	7.3	157	4.65
8-9	Yes	8	63.7	9.2	153	5.65
		12	78.9	8.8	135	6.54
		16	81.6	8.5	142	6.20
	No	8	57.1	7.8	155	5.86
		12	73.4	7.8	156	5.80
		16	76.3	7.8	147	6.24
Transplant (T)						
Linear (L)			0.0260	NS	0.0197	0.0001
Quadratic (Q)			0.0158	NS	NS	0.0031
Light intensity (H)			0.0166	0.0006	0.0003	0.0090
Final photoperiod (F)						
L			0.0001	0.0003	0.0009	NS
Q			0.0001	NS	NS	NS
Significant interactions ($P < 0.05$)			TL*H	TL*FL	TQ*H TL*H*FL	TQ*H TQ*H*FL TL*H*FL

^zSeed were sown 14 Oct. 1998.

^yOne replication = one flat = 0.1561 m², sales B production cost = profit or loss.

^xPresence or absence of high intensity supplemental lighting.

^{ns}Nonsignificant.

8-9 true leaves had shorter and thinner stems but had higher profits due to increased production time in plug flats compared to transplants with 2-3 or 5-6 true leaves (Table 5). In year 2, transplant stage interacted with supplemental lighting and final photoperiod such that 2-3 true leafed transplants without HID supplemental lighting grown in the 16-h final photoperiod had longer stems than 5-6 or 8-9 true leafed transplants without HID supplemental lighting (Table 6). *Lupinus* cut stems were thicker when given HID supplemental lighting, especially when grown in the 8 or 12-h final photoperiod. However, little difference in stem length and diameter was noted among transplant stages for plants grown under HID supplemental lighting. Thus, HID supplemental lighting overcame the reduction in stem length and diameter from delayed transplanting. As in year 1, delayed transplanting also increased profits in year 2.

Supplemental lighting reduced days to anthesis, which is similar to results obtained with *Pelargonium* (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter and Rodriguez, 1971; Quatchak et al., 1986) and *Rosa* (Tsujita, 1987). *Lupinus* profits were highest when plants were grown with HID supplemental lighting and held in the plug flat until the 8-9 leaf transplant stage (Table 6).

In conclusion, *C. medium* 'Champion Blue' and 'Champion Pink' were long-day plants with the critical photoperiod between 8 and

12-h. All plants were capable of flowering at 8-9 true leaves (Tables 1 and 2).

Commercially, *Campanula* should be grown initially under the noninductive 8-h photoperiod to enhance vegetative growth. Plants should then be transferred at 5-6 true leaves into an inductive 16-h photoperiod for flowering. Commercial use of HID supplemental lighting would be recommended to decrease production time and increase profits when used in conjunction with the 16-h initial photoperiod. However, the 16-h initial photoperiod resulted in reduced stem length and diameter compared with the 8-h initial photoperiod. Therefore, if long, thick stems are desired more than short production time, the 8-h initial photoperiod should be used.

Lupinus was a facultative long-day plant as plants grown under the 16-h photoperiod flowered earlier than those grown under the 8- and 12-h photoperiods (Tables 5 and 6). Flowering percentage was 100% regardless of photoperiod and juvenility was not apparent in this study.

Commercially, *Lupinus* should be grown in a continuous 16-h photoperiod to minimize production time. Delayed transplanting increased profits due to decreased production area per plant. High intensity discharge supplemental lighting increased *Lupinus* stem length and diameter and decreased days to anthesis. While the benefits of increased light intensity may warrant the use of HID supplemental light-

ing to improve crop quality and profitability, the initial investment in the HID supplemental lighting system and the additional electricity expenses must be considered. However, supplemental lighting may not be beneficial if natural light levels exceed those in this study.

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