Interaction of Bulb Vernalization and Shoot Photoperiod on ‘Nellie White’ Easter Lily

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Abstract. Easter lily (*Lilium longiflorum* Thunb. ‘Nellie White’) bulbs were exposed to 1, 2, 3, 4, 5, or 6 weeks of cold before shoot emergence; 0, 1, 2, 3, 4, 5, or 6 weeks of long days (LD) upon shoot emergence; or a combination of cold followed by LD: 1/5 (weeks cold/weeks LD), 2/4, 3/3, 4/2, or 5/1. Experiments were repeated for three consecutive years. LD did not substitute equally for cold; at least 3 weeks of cold were required before LD treatments resulted in anthesis. Depending on the year, 100% of the plants flowered when treated with 3 to 6 weeks of cold alone or in combination with LD. Days to first flower anthesis from planting increased with decreasing weeks of cold in years 1 and 3, but was similar for all treatments in year 2. Decreasing weeks of cold in combination with LD, however, decreased days to anthesis in years 1 and 2, but had no effect in year 3. Regardless of LD, days from emergence to visible bud increased with decreasing weeks of cold in all years, and days to emergence from placement in the greenhouse increased with decreasing cold in years 1 and 3, but not in year 2. Increasing weeks of cold, regardless of LD, decreased leaf count, but had no effect on plant height. Flower count was unaffected by cold when combined with LD, but was significantly reduced by increasing weeks of cold.

Annually, Easter lily forcers face the difficulty of adjusting to variable Easter dates, variations in Easter lily bulb crops, and local weather conditions. Consequently, each year forcers must adapt to different unknown situations to produce a quality lily plant of proper height that flowers at the appropriate time. Long-standing recommendations suggest that Easter lily bulbs receive 1000 h (6 weeks) of cold treatment (vernalization), which results in rapid and uniform shoot emergence and flowering (De Hertogh and Wilkins, 1971a, 1971b). This vernalization reduces the number of flowers and leaves produced, the number of days from planting to flower, the length of lower leaves, and plant height. Fewer flowers and shorter lower leaves are acceptable because forcing time is reduced.

Numerous authors have reported that exposure of newly emerging shoots to long days (LD) has a similar effect as bulb vernalization, i.e., decreasing days to flower and flower and leaf counts (Lin and Wilkins, 1973; Weiler and Langhans, 1968; Wilkins et al., 1968a,

1968b). Most reports indicated that LD increase plant height (Kohl and Nelson, 1963; Smith and Langhans, 1962; Weiler and Langhans, 1968), but other reports noted that LD plants are shorter (Rob and Wilkins, 1977) or variable in height (Wilkins et al., 1968a, 1968b) compared with nonvernalized bulbs.

Roh and Wilkins (1973) suggested that LD could substitute equally for cold on a weekly basis. They theorized that flowering in Easter lily is controlled by two separate pathways. This information has been incorporated into Easter lily production through an “insurance policy,” which consists of 1 to 3 weeks of LD after 6 weeks of bulb vernalization to ensure flower induction (Wilkins et al., 1970). One week normally is used on early emerging plants and 2 or 3 weeks on late-emerging plants, especially if Easter is early. However, Weiler and Langhans (1968, 1972) found that LD do not substitute equally for cold. The objective of this study was to reconsider whether LD could substitute equally for cold in producing high-quality, rapid-forcing Easter lily plants.

Materials and Methods

Year 1—Minnesota. ‘Nellie White’ Easter lily bulbs (20–23 cm in circumference) were received in St. Paul, Minn., from a commercial supplier on 12 Oct. 1988 and held at 18 ± 1.0°C. On 13 Oct., bulbs were dipped in a solution containing a commercial miticide and fungicides (Wilkins, 1988) and planted, one per pot, in 15-cm-diameter (1720-ml) pots using an unamended 3 peat: 1 sand: 1 vermiculite (by volume) mixture. Planted bulbs were placed in a dark cooler at 18 ± 1.0°C for 26 days of additional root development.

On 7 Nov., bulbs were randomly assigned to one of the following treatments: 1,2,3,4,5, or 6 weeks cold; 1, 2, 3, 4, 5, or 6 weeks LD upon shoot emergence; 1 week cold followed by 5 weeks LD (1/5), 214,313,412, or 5/1; or 0 weeks cold or LD (control). Cold-treated bulbs were placed in a dark cooler at 5.5 ± 1.0°C for the respective durations and then moved to a glasshouse under natural daylengths (45°N) [480 μmol·m⁻²·s⁻¹ photosynthetic active radiation (PAR)]. Plants were grown at 18 ± 2.0°C, and LD treatments began when the shoot emerged. LD were achieved by a 4-h night interruption (2200+200 HR) with incandescent light (minimum of 11 μmol·m⁻²·s⁻¹ PAR at shoot tip). After LD, plants were grown under natural daylength.

Plant height (measured from the medium surface to the top of the tallest pedicel), and leaf and flower counts were recorded when the tepals of the first flower opened (anthesis). Dates of shoot emergence and visible bud were also recorded during forcing. The study was terminated on 30 Apr. 1989. A completely randomized design with five to 10 plants as individual replicates was used. Data were tested using trend analysis within the cold, LD, or cold and LD combined treatments (SAS Institute, Cary, N.C.). Paired *t* tests were used to compare 6 weeks cold/0 weeks LD (6/0) with all other treatments.

Year 2—Oklahoma. ‘Nellie White’ Easter lily bulbs (20–23 cm in circumference) were received in Stillwater, Okla., from Oregon (Pacific Bulb Growers Research and Development Station) on 28 Oct. 1989 and held at 18 ± 0.5°C. On 30 Oct., bulbs were dipped in a solution containing a commercial miticide and fungicides (Wilkins, 1988) and planted, one per pot, in 15-cm-diameter (1720-ml) pots using a commercial peat: perlite: vermiculite medium (Fafard Growing Mix No. 2; Conrad Fafard, Springfield, Mass.). Planted bulbs were placed in a dark cooler at 18 ± 0.5°C for 16 days of additional root development.

On 16 Nov., bulbs were randomly assigned to the same treatments listed under year 1. Cold-treated bulbs were placed in a cooler at 5.5 ± 0.5°C for the respective durations and then moved to a fiberglass-reinforced, plastic-covered greenhouse under natural daylengths (36°N) (560 μmol·m⁻²·s⁻¹ PAR). Plants were grown at 23.0/18.0°C (day/night), and LD treatments began when the shoot emerged. Each treatment included eight to 12 bulbs and all other procedures were similar to year 1. The experiment was terminated on 30 Apr. 1990.

Year 3—Oklahoma. Easter lilies were handled in the same manner as in year 2, except bulbs were planted 18 Oct. 1990 and placed in a dark cooler at 18 ± 0.5°C for 15 days of additional root development. The experiment was terminated on 30 Apr. 1991.

Results

Results are based on data from plants that flowered by 30 Apr. of each year, except for days to emergence, which was based on data from all plants (Table 1). At least 3 weeks of cold combined with LD were needed to induce

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Table 1. Influence of cold treatment and long days (LD) on *Lilium longiflorum* 'Nellie White'. Means are an average of data from plants that flowered by 30 Apr., except for days from placement in the greenhouse to shoot emergence, which are from all five to 12 plants per treatment.

Days from								
Weeks of cold/LD	Plants flowering (%)	Placement in greenhouse to shoot emergence	Shoot emergence to visible bud	Placement in greenhouse to first flower anthesis	Planting to first flower anthesis ^z	No. leaves	No. flowers	Ht (cm)
Year 1—1988–89								
6/0	100	11	61	104	172	89.4	8.3	65.8
5/0	100	12 ^{NS}	68 ^{NS}	113 ^{NS}	174 ^{NS}	101.7 ^{NS}	9.3 ^{NS}	65.7 ^{NS}
4/0	100	11 ^{NS}	79 ^{**}	122 ^{**}	176 ^{NS}	121.0 ^{NS}	10.0 ^{NS}	73.6 ^{NS}
3/0	100	11 ^{NS}	90 ^{**}	135 ^{**}	182 [*]	141.0 ^{**}	11.6 ^{**}	69.0 ^{NS}
2/0	20	23 [*]	107 ^{**}	147 ^{**}	187 [*]	187.0 ^{**}	14.0 ^{**}	68.0 ^{NS}
1/0	0	18 ^{NS}	---	---	---	---	---	---
Significance		L [*]	L ^{**}	L [*]	L ^{**}	L ^{**} Q [*]	L ^{**}	NS
5/1	100	6 ^{NS}	70 ^{NS}	107 ^{NS}	168 ^{NS}	106.3 ^{NS}	8.6 ^{NS}	65.6 ^{NS}
4/2	100	22 [*]	57 ^{NS}	112 [*]	166 ^{NS}	107.4 ^{NS}	7.6 ^{NS}	69.8 ^{NS}
3/3	100	18 ^{NS}	66 ^{NS}	116 ^{**}	163 [*]	117.4 ^{NS}	8.4 ^{NS}	67.6 ^{NS}
2/4	100	15 ^{NS}	79 ^{**}	118 ^{**}	158 ^{**}	115.4 ^{NS}	6.8 ^{NS}	64.4 ^{NS}
1/5	100	24 [*]	67 ^{NS}	126 ^{**}	159 ^{**}	122.2 ^{NS}	8.8 ^{NS}	73.8 ^{NS}
Significance		L [*]	NS	L ^{**}	L [*]	L ^{**}	NS	NS
0/6	10	11 ^{**}	65	158	184	97.0	9.0	54.0
0/5	0	11 ^{NS}	---	---	---	---	---	---
0/4	0	10 ^{NS}	---	---	---	---	---	---
0/3	0	21 ^{NS}	---	---	---	---	---	---
0/2	0	19 [*]	---	---	---	---	---	---
0/1	0	14 ^{NS}	---	---	---	---	---	---
0/0	0	16 ^{NS}	---	---	---	---	---	---
Significance		NS	---	---	---	---	---	---
Year 2—1989–90								
6/0	100	5	62	101	159	71.2	5.0	38.9
5/0	100	4 ^{NS}	65 ^{NS}	105 ^{NS}	156 ^{NS}	77.0 ^{NS}	5.6 ^{NS}	40.2 ^{NS}
4/0	100	12 ^{NS}	75 [*]	121 ^{**}	165 ^{NS}	80.9 ^{NS}	5.3 ^{NS}	34.2 ^{NS}
3/0	100	8 ^{NS}	81 ^{**}	121 ^{**}	158 ^{NS}	86.5 [*]	6.1 ^{NS}	39.1 ^{NS}
2/0	100	5 ^{NS}	94 ^{**}	135 ^{**}	165 ^{NS}	104.5 ^{**}	7.5 ^{**}	41.3 ^{NS}
1/0	50	8 ^{NS}	103 ^{**}	139 ^{**}	162 ^{NS}	105.2 ^{**}	7.2 ^{**}	37.4 ^{NS}
Significance		NS	L ^{**}	L ^{**}	NS	L ^{**}	L ^{**}	NS
5/1	100	5 ^{NS}	62 ^{NS}	103 ^{NS}	154 ^{NS}	70.4 ^{NS}	5.2 ^{NS}	70.4 ^{NS}
4/2	100	12 ^{NS}	68 ^{NS}	113 [*]	157 ^{NS}	74.4 ^{NS}	5.6 ^{NS}	36.7 ^{NS}
3/3	100	9 ^{NS}	70 ^{NS}	114 ^{**}	151 ^{NS}	81.8 ^{NS}	5.3 ^{NS}	38.5 ^{NS}
2/4	100	6 ^{NS}	75 [*]	115 ^{**}	145 ^{**}	82.2 ^{NS}	5.1 ^{NS}	39.1 ^{NS}
1/5	70	7 ^{NS}	71 ^{NS}	113 [*]	136 ^{**}	76.5 ^{NS}	5.7 ^{NS}	36.6 ^{NS}
Significance		NS	L [*]	L [*]	L ^{**}	L ^{**}	NS	NS
0/6	67	6 ^{NS}	83 ^{**}	123 ^{**}	139 ^{**}	86.2 [*]	6.2 ^{NS}	36.7 ^{NS}
0/5	63	5 ^{NS}	91 ^{**}	134 ^{**}	150 ^{NS}	86.2 [*]	7.0 ^{**}	35.2 ^{NS}
0/4	18	6 ^{NS}	97 ^{**}	137 ^{**}	153 ^{NS}	98.5 [*]	8.5 ^{**}	28.0 ^{**}
0/3	0	3 ^{NS}	---	---	---	---	---	---
0/2	0	7 ^{NS}	---	---	---	---	---	---
0/1	0	5 ^{NS}	---	---	---	---	---	---
0/0	0	6 ^{NS}	---	---	---	---	---	---
Significance		NS	NS	NS	NS	NS	NS	L [*]
Year 3—1990–91								
6/0	100	20	49	102	159	76.8	5.3	30.9
5/0	100	19 ^{NS}	60 [*]	111 ^{**}	161 ^{NS}	84.0 ^{NS}	5.3 ^{NS}	33.4 ^{NS}
4/0	100	20 ^{NS}	64 ^{**}	119 ^{**}	162 ^{NS}	96.7 ^{**}	6.1 ^{**}	33.2 ^{NS}
3/0	83	20 ^{NS}	80 ^{**}	135 ^{**}	171 ^{**}	108.2 ^{**}	7.2 ^{**}	33.7 ^{NS}
2/0	0	26 ^{NS}	---	---	---	---	---	---
1/0	0	23 ^{NS}	---	---	---	---	---	---
Significance		L ^{**}	L ^{**}	L ^{**} Q ^{**}	L ^{**} Q ^{**}	L ^{**}	L ^{**}	NS
5/1	100	15 ^{NS}	58 [*]	107 [*]	157 ^{NS}	83.4 ^{NS}	5.5 ^{NS}	36.1 ^{NS}
4/2	100	21 ^{NS}	57 ^{NS}	117 ^{**}	160 ^{NS}	96.8 ^{**}	5.7 ^{NS}	36.5 [*]
3/3	100	20 ^{NS}	65 ^{**}	120 ^{**}	156 ^{NS}	95.8 ^{**}	5.4 ^{NS}	34.4 ^{NS}
2/4	78	28 ^{NS}	70 ^{**}	132 ^{**}	161 ^{NS}	104.4 ^{**}	7.0 [*]	38.7 [*]
1/5	0	27 ^{NS}	---	---	---	---	---	---
Significance		L ^{**}	L ^{**}	L ^{**}	NS	L ^{**}	NS	NS
0/6	0	55 ^{**}	---	---	---	---	---	---
0/5	0	45 ^{**}	---	---	---	---	---	---
0/4	0	65 ^{**}	---	---	---	---	---	---
0/3	0	58 ^{**}	---	---	---	---	---	---
0/2	0	55 ^{**}	---	---	---	---	---	---
0/1	0	54 ^{**}	---	---	---	---	---	---
0/0	0	56 ^{**}	---	---	---	---	---	---
Significance		NS	---	---	---	---	---	---

^zPlanting dates: year 1, 13 Oct. 1988; year 2, 30 Oct. 1989; year 3, 18 Oct. 1990.

^{*}Plants did not reach anthesis by 30 Apr.

*, **, NS Significant at $P \leq 0.05$ or 0.01 or nonsignificant, respectively, as compared to treatment 6/0 or from linear (L) or quadratic (Q) response.

flowering in all years (Table 1). Only one plant flowered in year 1, 67% in year 2, and no LD-only plants flowered in year 3. The plants that flowered under 6 weeks of LD in year 2 had more leaves and required more days from emergence to visible bud, from placement in greenhouse to anthesis, and from visible bud to anthesis (data not presented) than plants grown with 6 weeks of cold.

Weiler and Langhans (1968, 1972) also noted that LD-only plants did not flower and that 3 to 4 weeks of cold combined with LD applied until anthesis were required to induce 100% flowering. They grew the plants at a 21C minimum. In contrast, Roh and Wilkins (1973) conducted studies at a 15.6C night minimum and found that LD could substitute equally for cold on a weekly basis. In our studies, the night minimum temperatures were regularly > 18C. In year 2, the night temperature during one 4-day period (22–25 Dec. 1989) ranged from 10 to 16C, which may have vernalized the plants enough to allow 18%, 63%, and 67% of plants receiving 4, 5, or 6 weeks of LD, respectively, to flower (Table 1). Roh and Wilkins (1973) used night forcing at 15.6C, which provided an unplanned cold treatment (Hill and Durkin, 1968; Roberts and Moeller, 1971). Night forcing was at 15.6C in other studies, which also found that LD could induce flowering (Rob and Wilkins, 1977; Wilkins et al., 1968a, 1968b). Lin and Wilkins (1973) also noted that LD alone were not effective when forcing temperatures were 21C. Differences in bulb maturity, bulb weight, and temperature in the production fields also may have caused the variation between years in Easter lily response to LD and cold (Roberts et al., 1978, 1985).

In all years, 5/1 plants reached anthesis from planting in a similar number of days as 6/0 plants (Table 1). In year 3, however, the 5/1 plants took significantly more days from emergence to visible bud and from placement in greenhouse to anthesis than the 6/0 plants. In years 1 and 2, 6/0 plants placed in the greenhouse reached anthesis before the 5/1 plants, but the differences were not significant ($P \leq 0.05$). Variations in average daily temperature probably account for the different responses between years. Plants in 4/2 and 3/3 reached anthesis from planting at the same time or sooner and had similar heights and flower counts as 6/0 plants in all years. However, the 4/2 and 3/3 plants required a similar number of days, or more, from placement in the greenhouse to shoot emergence and anthesis and from shoot emergence to visible buds than 6/0 plants. The 4/2 and 3/3 plants also had the same number, or more, leaves than the 6/0 plants. Roh and Wilkins (1973) found that decreasing cold exposure combined with an increasing number of LD increased leaf count, decreased days from planting to anthesis, and had no effect on height and flower count. Although Weiler and Langhans (1968, 1972) applied LD from the end of the cold treatment until flowering, they also found that decreasing cold increased leaf count and the percentage of flowering plants, and decreased days from planting to anthesis.

While plant height was not influenced by combinations of cold and LD in our studies, Weiler and Langhans (1968) noted that height increased with decreasing cold, which was due to the continual application of LD during forcing (Smith and Langhans, 1962; Weiler and Langhans, 1968).

Easter lily response to cold alone was similar to that from earlier work (De Hertogh and Wilkins, 1971a, 1971b; Miller and Kiplinger, 1966; Roh and Wilkins, 1973): increasing cold exposure decreased leaf and flower counts and number of days from emergence to visible bud and from planting or placement in the greenhouse to anthesis (Table 1). In years 1 and 3, as with previous work, days to emergence decreased linearly with increasing weeks of cold (Rob and Wilkins, 1973), but was not influenced by cold in year 2. The difference between years may have been due to rapid shoot emergence in year 2; the majority of shoots emerged in fewer than 10 days, resulting in no differences between treatments. In the other two years, however, most shoots emerged after ≥ 10 days. Year 2 bulbs may have been more mature than those in years 1 and 3. Roberts et al. (1978) noted that shoots from heavier (more mature) bulbs emerged quicker than those from lighter (more immature) bulbs. Plant height was not influenced by weeks of cold exposure, which corresponds to results obtained by Merritt (1963).

As with previous reports (Rob and Wilkins, 1977; Weiler and Langhans, 1968; Wilkins et al., 1968a, 1968b), increasing weeks of LD decreased days to anthesis, days from emergence to visible bud, and leaf and flower counts, although the trends were not significant ($P \leq 0.05$), probably because of the low percentage of flowering plants (Table 1). Plant height increased significantly with increasing weeks of LD, which is similar to Smith and Langhans' (1962) and Weiler and Langhans' (1968) results.

In summary, LD did not substitute equally for cold in Easter lily flowering; at least 3 weeks of cold combined with LD were required for 100% flowering (Table 1). Plants receiving 3, 4, or 5 weeks of cold in combination with 3, 2, or 1 week of LD, respectively, flowered at the same time or slightly earlier than plants receiving 6 weeks of cold. By using LD in combination with cold, growers could free up cooler space, but more time in the greenhouse would be required because of increasing days from emergence to visible bud with decreasing weeks of cold. Days from placement in the greenhouse to emergence and from visible bud to anthesis (data not presented) were not influenced by cold.

Also important to consider is that greenhouse temperatures <18C might inadvertently provide temperatures low enough for flower induction. This information may be of negligible importance to growers, because anthesis would be delayed even though the low temperatures might enhance flower induction relative to plants grown with higher temperatures. However, researchers should be aware of the effects of night forcing temperatures on experiments.

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