gesting that there is an early critical period of nucleic acid synthesis, and that once this new RNA is formed, then the commencement of fruit growth may proceed.

Literature Cited

1. Cherry, J. H. 1973. Molecular biology of plants. Columbia Univ. Press, New York. p. 98-107.
2. Crane, J. C. 1969. The role of hormones in fruit-set and development. *HortScience* 4:108-111.
3. Elassar, G., J. Rudich, D. Palevitch, and N. Kedar. 1974. Induction of parthenocarpic fruit development in cucumber by growth regulators. *HortScience* 9:238-239.
4. Ford, R. H. and R. G. Stanley. 1968. Enzyme activity of pollen eluents. *Plant Physiol.* 43:Supp. p. 52.
5. Fuller, G. L. 1974. Regulatory mechanisms in cucumber fruit-set. PhD Thesis, Purdue Univ., Lafayette, Ind.
6. _____ and A. C. Leopold. 1975. Pollination and the timing of fruit-set in cucumbers. *HortScience* 10:617-619.
7. Gustafson, F. G. 1936. Inducement of fruit development by growth promoting chemicals. *Proc. Nat. Acad. Sci.* 22:628-636.
8. Harden, J. W., T. J. O'Brien, and J. H. Cherry. 1970. Stimulation of chromatin-bound RNA polymerase activity by a soluble factor. *Biochem. Biophys. Acta* 224:667-670.
9. Key, J. L. 1964. Ribonucleic acid and protein synthesis as essential processes for cell elongation. *Plant Physiol.* 39:365-370.
10. _____. 1966. Effect of purine and pyrimidine analogues on growth and RNA metabolism in the soybean hypocotyl. The selective action of 5-fluorouracil. *Plant Physiol.* 41:1257-1264.
11. _____. 1969. Hormones and nucleic acid metabolism. *Annu. Rev. Plant Physiol.* 20:449-474.
12. _____and J. Ingle. 1968. RNA metabolism in response to auxin, p. 711-722. *In* F. Wightman and G. Setterfield (eds.) Biochemistry and physiology of plant growth substances. Runge Press, Ltd., Ottawa.
13. Leopold, A. C. and F. I. Scott. 1952. Physiological factors in tomato fruit-set. *Amer. J. Bot.* 39:310-317.
14. Linskens, H. F. 1964. Biochemistry of incompatibility. p. 17. *In* Genetics today. Proc. XI Internat. Cong. Genetics Vol. 2, Pergamon Press. The Hague.
15. Luckwill, L. C. 1959. Fruit growth in relation to internal and external chemical stimuli. p. 223-251. *In* D. Rudnick (ed.) Cell, organism and milieu. Ronald Press, New York.
16. Makinen, Y. and J. L. Brewbaker. 1967. Diffusion of enzymes out of intact pollen grains. *Physiol. Plant.* 20:477-482.
17. Mascarenhas, J. P. and R. D. Goralnick. 1971. Synthesis of small molecular weight RNA in the pollen tube of *Tradescantia paludosa*. *Biochem. Biophys. Acta* 240:56-61.
18. Masuda, Y. and E. Tanimoto. 1967. Effect of auxin and antiauxin on the growth and RNA synthesis of etiolated pea internode. *Plant & Cell Physiol.* 8:459-465.
19. Nitsch, J. P. 1953. The physiology of fruit growth. *Annu. Rev. Plant Physiol.* 4:199-235.
20. Nooden, L. D. 1968. Studies on the role of RNA-synthesis in auxin induction of cell enlargement. *Plant Physiol.* 43:140-150.
21. Tupy, J. and N. S. Rangaswamy. 1973. The investigation of the effect of pollination on ribosomal RNA, transfer RNA and DNA contents in styles of *Nicotiana alata*. *Biol. Plant.* 15:95-101.

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Light and Temperature Effects on the Growth and Flowering of *Dicentra spectabilis* (L.) Lem[1]

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Additional index words. bleeding heart, photoperiod, cold requirement, light intensity, temperature

Abstract. **Growth and flowering of bleeding heart were promoted by 14 to 24 hour photoperiods or light interruptions in the middle of the night. Cold treatment of crowns promoted growth and flowering at short photoperiods. Light at 9 klx promoted growth and inflorescence formation, but greater intensities were required to achieve anthesis. Growing temperatures of 15-22.5°C were most desirable.**

Although Bailey (1) refers to *Dicentra spectabilis* (bleeding heart) as shade requiring, little information is available on the life cycle and growth requirements of the species. Environmental influences on growth and flowering were investigated in the present work to develop the species for a Valentine's Day flowering potted plant and to expand the line of flowering bedding plants sold in spring.

Materials and Methods

Plants for experimentation were produced by rooting terminal cuttings from stock plants grown in continuous light and maintained vegetative by pinching. Cuttings with 2 open leaves were treated at the basal end with a talc powder containing 2% indolebutyric acid. The cuttings were rooted under intermittent mist, planted into 10 cm clay pots, grown for about 1 month, and pinched. The experiments began on the date of pinch. As the pinched plants grew they were pruned to 1 shoot either from the uppermost axillary bud or from the node immediately below. There was little or no development of perennating crowns before the experiments began.

All plants except where noted were grown in a 20-22°C greenhouse, and during all phases of work the photoperiod was regulated by black cloth from 1600 until 800, and 75 lx incandescent lighting began at 1600 to achieve the specified photoperiod. The typical long photoperiod was 24 hr and the typical short photoperiod was 8 hr. Standard floricultural practices were employed (2).

The plants were harvested at anthesis. Leaves were weighted individually and area determined by cutting-out photocopied leaf imprints and relating the weight of the imprints to weight of the same paper of known area. Average leaf area was established by the formula:

$$\text{Avg leaf area per plant} = \frac{\text{total leaf fresh wt} \times \text{leaf area/g fresh wt}}{\text{total no. leaves}}$$

No. nodes and plant height were taken from the node of pinch. Flower size was estimated by multiplying flower diam by its length.

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Photoperiod. On April 27, 5 plants were placed on each of the 8, 10, 12, 14, 16, 18, and 24 hr photoperiod greenhouse benches and allowed to grow until flowering or stem death. In another experiment begun June 20, the effectiveness of night interruption was compared with continuous, 24 hr lighting. Night interruptions were 2 hr light (2300 to 100) or 4 hr (2200 to 200).

Light intensity. On June 1, 16 plants were placed into each of two 22.5°C, 16 hr photoperiod growth chambers at low (about 9 klx) and high (about 22 klx) light intensities.

Temperature. On June 1, 16 plants were placed into each of three 9 klx, 16 hr photoperiod growth chambers at continuous 15, 22.5, and 30°C.

Growth and flowering from cold-treated crowns. Two greenhouse experiments were conducted after stems of flowering plants senesced in 8 hr photoperiods. Experiment 1 began July 1, and crowns were stored in moist peatmoss at 5°C in darkness for 0, 4, 8, or 12 weeks and grown under 8 or 24 hr photoperiods. Experiment 2 began Nov. 6, and potted crowns were stored at 5° under 8 hr photoperiods, 750 lx cool white fluorescent light, for 0, 4, 8, 12, 16, or 20 weeks and grown under 8 or 24 hr photoperiods. Plant ht was measured from the soil line in this experiment.

Results

Photoperiod. At 8 and 12 hr photoperiods shoots were rosettes and remained vegetative while at 14, 16, 18, and 24 hr photoperiods the plants elongated and flowered (Table 1). At 24 hr photoperiods plant height was greatest while time required to flower, no. of nodes, and average leaf area were less than at 14 hr. At 24 hr photoperiods roots were abundant, long, and thin (fibrous) while at 8 hr the roots were sparse, thick, and short.

Stems of flowering and non-flowering plants senesced. Only stock plants kept vegetative by pinching grew continuously. Perennating crowns with several buds were well developed by the time of shoot senescence, and crown development, occurred more quickly at short photoperiods.

Light interruptions during the dark period (Table 2) increased plant fresh wt, no. of nodes, and average leaf area and reduced plant height compared to continuous lighting. Plants under night interruption appeared similar to those under 14-16 hr photoperiods, but the time from pinch to anthesis was not significantly greater than under continuous lighting. There was no difference between the 2 interruption treatments.

Light intensity. Plant height was greater at 22 klx than at 9 klx (Table 3). Flowering at the higher intensity occurred within 40 days and the flowers were normal in color, size, and shape, while all inflorescences at 9 klx aborted. Plants at 22 klx had lighter colored leaves with a more concave upper surface than plants at 9 klx. Senescence occurred sooner under 22 klx than 9 klx. Root fresh wt was greater in high light.

Temperature. Growing at the highest temp, 30°C, considerably reduced fresh wt and area/leaf (Table 4). Plants at 15° were darker green with better expanded leaves, thicker stems, and redder stems and petioles compared to plants at 22.5°.

Differentiation of inflorescences occurred during week 3 of growth after pinch at 15°C and during week 5 at 22.5°. Plants at 30° died without a progressive yellowing from the oldest to the newest leaf. Root wt was greater at 15° than 30°.

Growth and flowering from cold-treated crowns. Cold treatment of crowns in darkness caused sprouting. Twelve weeks of cold was essential for growth of all plants. Cold promoted inflorescence formation only when the plants were subsequently grown at 24 hr photoperiods, and the long photoperiods were essential for flowering to proceed to anthesis. (Table 5).

Using light during cold storage in a later experiment resulted in little qualitative requirement for cold to promote sprouting. There was only a single instance in which cold increased %

Table 1. Effect of various photoperiods on growth and flowering of bleeding heart.[z]

Photoperiod (hr)	Plant ht (cm)	Avg leaf area (cm^2)	No. nodes	Days pinch to anthesis
8	–	–	–	–
10	–	–	–	–
12	–	–	–	–
14	22a	53a	15.4a	59a
16	32b	44b	13.6b	47b
18	38c	43b	12.bc	38b
24	46d	38b	11.2c	33bc

[z]Mean separation in columns followed by Tukey's test, 5% level.

Table 2. Effect of night light interruption on growth and flowering of bleeding heart.[z]

Variable	Continuous light	Night interruption 4 hr	Night interruption 2 hr
Shoot fresh wt (g)	21b	32a	41a
Plant ht (cm)	75b	49a	38a
Avg leaf area (cm^2)	39b	53a	58a
No. nodes	14b	18a	20a
Days pinch to anthesis	56a	60a	66a

[z]Mean separation in rows by Tukey's test, 5% level.

Table 3. Influence of light intensity on bleeding heart in 16 hr photoperiod, 22.5°C growth chambers.[z]

Variable	Light intensity 9,000 lx	Light intensity 22,000 lx
Shoots		
Fresh wt (g)	15 a	15 a
Dry wt (%)	13 a	16 a
Plant ht (cm)	16 a	20 b
Avg leaf area (cm^2)	45 a	40 a
No. nodes	12 a	12 a
% inflorescence differentiation	100	100
% inflorescence abortion	100	0
Days pinch to anthesis	—	40
Roots		
Fresh wt (g)	10 a	20 b
Dry wt (%)	15 a	18 a

[z]Means separation in rows by Tukey's test, 5% level.

Table 4. Influence of temp on bleeding heart in 16 hr photoperiod, 9 klx growth chambers.[z]

Variable	15°C	22.5°	30°
Shoots			
Fresh wt (g)	11a	15a	1b
Dry wt (%)	14a	13a	12a
Plant ht (cm)	9a	16a	3b
Avg leaf area (cm^2)	39a	45a	3b
No. nodes	11a	13b	13b
% inflorescence differentiation	100	100	0
% inflorescence abortion	100	100	—
Days pinch to visible inflorescence	18a	30b	—
Roots			
Fresh wt (g)	15a	10ab	8b
Dry wt (%)	16ab	14a	19b

[z]Mean separation in rows by Tukey's test, 5% level.

Table 5. Effect of cold treatment of crowns of bleeding heart in darkness or in 8 hr light/day on regrowth and flowering in 8 and 24 hr photoperiods.

Expt.	No. weeks at 5°C	% emergence		Days from end of cold to emerg.		% emerged plants which differentiated inflor.		Days emerg. to anthesis		Plant ht (cm)	
		Photoperiod		Photoperiod		Photoperiod		Photoperiod		Photoperiod	
		8	24	8	24	8	24	8	24	8	24
1 *(Stored in darkness)*											
	0	0	0	–	–	–	–	–	–	–	–
	4	0	0	–	–	–	–	–	–	–	–
	8	75	75	27±2	24±14	25	25	A	A	–	–
	12	100	100	24±12	5±1	25	100	41±0	47±0	–	–
2 *(Stored in light)*											
	0	60	100	41±3	40±2	0	60	–	80±20	–	56±7
	4	100	100	8±5	11±2	0	60	–	67±5	–	66±11
	8	100	100	1±0	1±0	40	80	A	53±20	18±4	56±15
	12	100	100	2±1	S	40	60	33±7	38±8	23±0	63±12
	16	100	100	S	S	100	100	48±6	23±5	31±8	54±18
	20	100	100	S	S	100	100	15±5	14±2	39±8	44±7

A = Aborted inflorescences.
S = Sprouted when brought from cold storage.

sprouting (between 0 and 24 weeks of cold at 8 hr photoperiods). However, increasing the cold storage period from 0 to 8 weeks reduced greenhouse time required for sprouting, and by 20 weeks the shoots in storage were 2 - 4 cm tall. The cold required for flowering, was achieved after 16 weeks storage. Long photoperiods after 0 to 12 weeks cold caused more plants to flower, and after 16 weeks storage (when all plants in both photoperiods had been induced to flower) hastened anthesis. However, after 20 weeks storage there were few remaining differences attributable to photoperiod. Anthesis was achieved in short photoperiods after 16 to 20 weeks cold treatment.

At short photoperiods plants were marketable while at long photoperiods plants were too tall.

Discussion

The developmental cycle of *D. spectabilies* probably involves: (a) shoot and root development favored by optimal soil moisture, soil fertility, temp, and light flux, (b) retention of foliage after flowering favored by long photoperiods and permitting continued day matter accumulation and crown development, (c) stem senescence promoted by high summer temp and shorter, late summer, photoperiods, and (d) breaking of dormancy and induction of flowering by cold overwintering.

Flowering under short photoperiods after cold treatment may be useful for the spring market, and chemical growth retardation may be unnecessary because the plants will be short. For growth and flowering from crowns, 16 - 20 week 5°C will be required. Different time-temp combinations should be investigated, but temp <5° may prevent sprouting before storage is complete.

The promotion of growth and flowering by long photoperiods and maintenance of vegetative growth by pinching is clearly unlike normal outdoor developmental regulation but of special interest for year-around commercial production of flowering plants when combined with daminozide treatment for growth retardation (3).

The optimum long photoperiod for cutting and plant production is probably less than the 24 hr used in these studies. Higher quality growth and reasonably rapid flowering occurred with interruptive night lighting or at 14-16 hr photoperiods.

Unexpectedly, inflorescences aborted in light conditions approximatley equivalent to 7% the flux of a bright summer day even at the coolest temp which may suggest energy is stored in the plant's crown during the summer which contributes to flowering the next spring. This is likely since vegetative growth was satisfactory in either growth chamber light flux, while anthesis at the higher flux was associated with greater root growth. Another possible mechanism for successful spring flowering in shaded garden areas may be great assimilation rates before the leaves of nearby deciduous trees expand. The data suggest high light flux in cool temp may produce most rapid growth but further work is needed to define this precise relationship.

The 20-22°C temp used in many of these experiments seems to be above the optimum for the species since the extent and quality of above-ground growth and root growth was high and inflorescence differentiation was most rapid at 15°. Presumably anthesis also would occur rapidly at 15° if light flux was high. The cool optimum correlates well with the high quality growth of the species observed in early spring and cool climates but 15° probably is a too cold temp for quantitative studies of the species' cold requirement.

Literature Cited

1. Bailey, L. H. 1914. Dicentra. p 1001-1002 *In* L. H. Bailey (ed.) The standard cyclopedia of horticulture. Macmillan, New York.
2. Laurie, A., D. C. Kiplinger, and K. S. Nelson. 1968. Commercial flower forcing. Macmillan, New York.
3. Lopes, L. C. and T. C. Weiler. 1977. Chemical growth retardation of *Dicentra spectabilis* (L.) Lem. *HortScience* (in press).