Flowering of Cold-treated Field-grown *Astilbe*

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Summary. In 1996 and 1997, eight cultivars of cold-treated field-grown *Astilbe* were grown in a 20 °C greenhouse with short days (SDs = 9-h natural days) or long days (LDs = 9-h natural days with night interruption with incandescent lamps from 2200 to 0200 hr) to determine how photoperiod influences flowering. Cultivars studied were *Astilbe* ×*arendsii* Arends 'Bridal Veil', 'Cattleya', 'Fanal', and 'Spinell'; *A. chinensis* Franch. 'Superba'; *A. japonica* A. Gray 'Deutschland' and 'Peach Blossom'; and *A. thunbergii* Miq. 'Ostrich Plume'. Flowering percentage was highest (≥90%) for 'Cattleya', 'Deutschland', 'Fanal', 'Ostrich Plume', and 'Peach Blossom', regardless of photoperiod. Photoperiod did not affect the time to visible inflorescence or flower number for any cultivar studied. The time from visible inflorescence to first flower took 27 to 36 days, irrespective of photoperiod. Time to flower varied by cultivar; 'Deutschland' was the earliest to flower (31 to 41 days) and 'Superba' was the last to flower (51 to 70 days). 'Fanal' and 'Ostrich Plume' flowered slightly but significantly faster (by 1 to 6 days) under LDs than SDs. For five cultivars, the inflorescence was taller under LDs than SDs. All cultivars reached visible inflorescence and flower significantly faster (by 1 to 15 days) in 1997 than in 1996.

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Astilbe are hardy herbaceous perennials characterized by compound leaves and colorful, plume-like inflorescences. They make attractive potted plants and cut flowers, and there are many species and cultivars from which to choose (De Hertogh, 1996). In 1994, *Astilbe* were the fifth-best-selling herbaceous perennials in the United States and Canada (Rhodus and Hoskins, 1995).

Pemberton and De Hertogh (1992) reported that crowns of some *Astilbe* cultivars harvested in the fall could be forced to flower if planted immediately and provided warm temperatures. However, once cold temperatures and dormancy had been imposed, an extended duration of cold was required for flowering (Beattie and Holcomb, 1983; Pemberton and De Hertogh, 1992). For four cultivars of *Astilbe* ×*arendsii*, maximum flower fresh weight and number occurred when plants were chilled at 5 °C for 12 weeks compared to shorter cold treatment durations (Beattie and Holcomb, 1983). Pemberton and De Hertogh (1992) also reported that *A.* ×*arendsii* cold requirements varied by cultivar, but highest flowering percentage occurred following ≥12 weeks of 2 °C. De Hertogh (1996) recommended at least 8 weeks of cold treatment before forcing dormant crowns.

The effect of photoperiod on flowering of *Astilbe* has not been established clearly. Pemberton and De Hertogh (1992) reported that plants grown with a 3-h night interruption (NI) showed visible bud and flowered slightly earlier than those grown without, although data were not treated statistically. Beattie and Holcomb (1983) described a slight hastening of flowering when plants were grown under 14-h long days (LDs) compared to those grown under 9-h short days (SDs), but no data were presented. Small temperature differences between photoperiods could have accounted for the slight hastening of flowering. LDs increased plant height and inflorescence number on some cultivars studied (Beattie and Holcomb, 1983). De Hertogh (1996) recommends an LD photoperiod for early forcing, otherwise natural increasing photoperiods; Iversen (1994) recommends 16-h daylengths.

There is little and variable information on time to flower for *Astilbe* in the greenhouse. At 18 to 20 °C (day) and 16 to 18 °C (night), time to flower for nine cultivars ranged from 60 to 70 d (De Hertogh, 1996). Three *Astilbe* cultivars grown at the same temperature regimen took 70 to 119 d to flower, depending on cultivar and duration of cold treatment (Pemberton and De Hertogh, 1992).

We conducted this study to quantify time to flower and the effect of photoperiod on flowering of eight cold-treated field-grown *Astilbe* cultivars representing four species.

Materials and methods

Plant material. Eight *Astilbe* cultivars were studied: *A.* ×*arendsii* 'Bridal Veil', 'Cattleya', 'Fanal', and 'Spinell'; *A. chinensis* 'Superba'; *A. japonica* 'Deutschland' and 'Peach Blossom'; and *A. thunbergii* 'Ostrich Plume'. The experiment was replicated in time (1996 and 1997) and only the cold treatments varied.

Cold treatments, 1996. Field-grown no. 1 bare-root crowns were harvested in Michigan by a wholesale grower on 12 Oct. 1995 and then were stored in a –2.5 °C freezer until shipping on 6 Nov. Twenty-five crowns of each cultivar were received at Michigan State Univ. on 8 Nov. and were placed at 5 °C for 5 d. Twenty of the most uniform crowns of each cultivar then were planted and randomly placed on a greenhouse bench in a constant 20 °C greenhouse with natural (≈10.5-h) photoperiods for 2 weeks to establish plants before transferring them to cold storage. About 5% of plants developed a few leaves; most remained leafless.

On 27 Nov., plants were placed in a controlled-environment chamber for 12 weeks at 5 °C; the chamber was illuminated from 0800 to 1700 hr at ≈25 $\mu mol \cdot m^{-2} \cdot s^{-1}$ from cool-white fluorescent lamps (VHOF96T12; Philips, Bloomfield, N.J.), as measured by a LI-COR quantum sensor (model LI-189; LI-COR, Lincoln, Nebr.).

Cold treatments, 1997. Bare-root crowns were harvested in The Netherlands on various dates in December 1996 and January 1997 and received by a Michigan wholesale grower who stored them in a –2.5 °C freezer until shipping to Michigan State Univ. on 31 Jan. Twenty-five crowns of each cultivar were received on 3 Feb. 1997 and were placed in a 5 °C controlled environment chamber until planting. Twenty of the most uniform crowns were planted on 27 Feb.; thus, crowns were exposed to ≤5 °C for 7 to 13 weeks, depending on cultivar.

Plant culture. Crowns were planted into 5-inch (12.7-cm) square containers (1.1-L volume) with a commercial soilless medium composed of composted pine bark, horticultural vermiculite, Canadian sphagnum peat, processed bark ash, and washed sand (MetroMix 510; Scotts-

Table 1. The effects of photoperiod on flowering of cold-treated field-grown *Astilbe*.

Cultivar	Photoperiod	Year	Flowering (%)	Days to visible inflorescence	Days from visible inflorescence to flower	Days to flower	Flower no.	Final plant ht (cm)
Bridal Veil	SD[z]	1996	75	24	33	56	1.7	37
		1997	81	15	32	46	1.9	45
	LD[y]	1996	70	24	29	53	1.9	40
		1997	70	11	32	43	2.7	42
	Significance							
	Photoperiod (P)			NS	*	NS	NS	NS
	Year (Y)			**	NS	**	NS	*
	P × Y			NS	*	NS	NS	NS
Cattleya	SD	1996	90	21	31	52	2.1	53
		1997	100	14	34	48	3.0	54
	LD	1996	100	23	30	52	1.9	58
		1997	100	16	32	48	3.0	57
	Significance							
	P			NS	*	NS	NS	NS
	Y			**	**	**	**	NS
	P × Y			NS	NS	NS	NS	NS
Deutschland	SD	1996	90	11	29	41	3.6	28
		1997	100	8	23	31	4.9	26
	LD	1996	100	10	27	37	5.1	28
		1997	90	8	23	32	3.9	32
	Significance							
	P			NS	NS	NS	NS	*
	Y			*	**	**	NS	NS
	P × Y			NS	NS	NS	NS	*
Fanal	SD	1996	100	17	32	49	3.6	32
		1997	90	10	30	41	2.1	47
	LD	1996	100	15	28	43	4.3	34
		1997	100	10	30	40	2.2	46
	Significance							
	P			NS	*	*	NS	NS
	Y			**	NS	**	**	**
	P × Y			NS	*	*	NS	NS
Ostrich Plume	SD	1996	90	23	34	57	2.3	44
		1997	100	10	36	48	1.8	52
	LD	1996	100	21	32	53	3.1	55
		1997	90	10	36	46	2.2	60
	Significance							
	P			NS	*	*	NS	**
	Y			**	**	**	NS	*
	P × Y			NS	NS	*	NS	NS
Peach Blossom	SD	1996	100	12	32	44	4.1	40
		1997	90	8	31	43	3.7	36
	LD	1996	100	12	31	39	3.9	42
		1997	100	9	29	37	4.2	41
	Significance							
	P			NS	*	NS	NS	*
	Y			**	*	**	NS	NS
	P × Y			NS	NS	NS	NS	NS
Spinell	SD	1996	67	27	34	60	1.7	41
		1997	90	11	34	45	1.8	46
	LD	1996	70	24	32	56	2.1	52
		1997	100	11	32	43	1.8	51
	Significance							
	P			NS	NS	NS	NS	*
	Y			**	NS	**	NS	NS
	P × Y			NS	NS	NS	NS	NS
Superba	SD	1996	80	37	33	70	2.1	44
		1997	70	20	32	51	1.7	54
	LD	1996	100	26	34	60	2.4	67
		1997	100	23	32	55	1.5	55
	Significance							
	P			NS	NS	NS	NS	**
	Y			**	*	**	*	NS
	P × Y			*	NS	*	NS	**

[z]SD = short day: 9-h photoperiod.
[y]LD = long day: 9-h photoperiod plus 4-h night interruption.
[NS],*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Sierra Horticultural Products Co., Marysville, Ohio).

LIGHT TREATMENTS. Ten plants of each cultivar were apportioned randomly to one of two greenhouse benches with different photoperiods—SDs or LDs. Opaque black cloth was pulled at 1700 HR and opened at 0800 HR every day on both benches so plants received similar daily light integrals. From 0800 to 1700 HR, high-pressure sodium lamps provided a supplemental photosynthetic photon flux (PPF) of ≈50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at plant level when the ambient greenhouse PPF was <400 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In 1997, the average daily light integral during the experiment was ≈13 $mol \cdot m^{-2} \cdot d^{-1}$. LDs were created with incandescent lamps that were lit from 2200 to 0200 HR and delivered 1 to 3 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at plant height.

GREENHOUSE TEMPERATURE CONTROL. All plants were grown in a glass greenhouse at 20 °C. Actual average daily air temperatures from the beginning of forcing to the average date of flowering on the SD and LD benches were 19.7 and 20.6 °C in 1996 and 20.8 and 20.8 °C in 1997, respectively.

DATA COLLECTION AND ANALYSIS. The date the first inflorescence was visible (without dissection) and the date the first flower opened were recorded for each plant. When the first flower opened, visible inflorescences were counted, and total plant height from the top of the container was measured. Plants that did not have visible inflorescences after 12 weeks of forcing were considered nonflowering and discarded. Days to visible bud, days from visible bud to flower, and days to flower from the start of forcing were calculated. The few plants that died during the experiment were discarded and not included in the results.

Results and discussion

Flowering percentage was at least 90% for 'Cattleya', 'Deutschland', 'Fanal', 'Ostrich Plume', and 'Peach Blossom' for both years under SDs or LDs (Table 1). Flowering of 'Spinell' was relatively poor (≈70%) in 1996 but improved (≥90%) in 1997. All 'Superba' flowered under LDs but only 70% or 80% flowered under SDs. In both years, 70% to 81% of 'Bridal Veil' flowered. Pemberton and De Hertogh (1992) found that two-thirds of 'Peach Blossom' cold-treated for 9 or 15 weeks and all plants cold-treated for 12 weeks flowered; only one-third of 'Deutschland' cold-treated for 12 or 15 weeks flowered.

Time to flower varied by cultivar; 'Deutschland' was the earliest to flower (31 to 41 d) and 'Superba' was the latest (51 to 70 d). Little data have been published on time to flower of *Astilbe*, and comparing our data to studies with different or undefined temperature regimens is difficult. For example, 'Deutschland' was reported by De Hertogh (1989) to take 47 d to flower at an unspecified temperature, whereas at an 18 to 20 °C day and 16 to 18 °C night regimen, flowering took at least 88 d (Pemberton and De Hertogh, 1992).

Photoperiod did not significantly affect time to first visible inflorescence for any cultivar studied (Table 1). For five cultivars, LDs hastened (by 1 to 4 d) the time from visible inflorescence to first flower. Except for 'Deutschland' in 1997, the time from visible inflorescence to first flower took 27 to 36 d, regardless of year or photoperiod. De Hertogh (1989) reported the time from visible bud to flower was 9 to 15 d, which suggests that he may have used a different definition for visible bud. 'Fanal' and 'Ostrich Plume' flowered slightly but significantly faster (by 1 to 6 d) under LDs than SDs. In 1996, the LD bench was nearly 1 °C warmer than the SD bench, which contributed to some or all of the hastening of flowering under LDs. Time to flower for the other six cultivars was unaffected by photoperiod.

In our study, photoperiod did not affect the number of inflorescences for any cultivar, although 'Deutschland', 'Ostrich Plume', 'Peach Blossom', 'Spinell', and 'Superba' were taller under LDs than SDs. Light from incandescent lamps, which we used for NI, is known to promote stem elongation, and use of other light sources (e.g., cool-white fluorescent or high-pressure sodium lamps) may have less effect on stem and inflorescence elongation. In the study by Beattie and Holcomb (1983), who also used incandescent lamps, two of the four cultivars studied, including 'Fanal', produced more and taller inflorescences under a 14-h photoperiod than a 9-h one.

All *Astilbe* cultivars reached visible inflorescence and flowered significantly earlier in 1997 than in 1996. The acceleration of flowering in 1997 was as little as 1 or 2 d for 'Peach Blossom' and as much as 13 to 15 d for 'Spinell'. Time from visible inflorescence to first flower was significantly different in 1997 for five cultivars, and flower number was different for three cultivars, but there were no consistent trends. 'Bridal Veil', 'Fanal', and 'Ostrich Plume' were significantly taller in 1997 than in 1996.

The differences in time to visible inflorescence and flower between years may be at least partially attributed to the different cold treatments and slightly warmer temperatures in 1997. For example, in 1997, crowns were stored for 24 d in a 5 °C cooler. The crowns may have developed during storage, which could account for some of the hastening of flowering. The crowns also originated from different countries with different climates, harvest dates, and postharvest treatments. Finally, plants shipped from The Netherlands are given a hot-water treatment for 2.5 h at 43 °C for nematode control before shipment. How or whether these factors influenced flowering is unknown.

Flowering *Astilbe* make attractive potted plants, and many of the pink- and red-flowering cultivars have a long postharvest life (2 or 3 weeks). Inflorescences of white-flowering cultivars generally are shorter lived and are perhaps best sold just before first flowering. Cultivars whose entire population did not flower (e.g., 'Bridal Veil') may not be economically suitable for production as flowering potted plants. As De Hertogh (1996) points out, *Astilbe* are extremely sensitive to drought stress either in greenhouse production or in the landscape and readily develop necrotic leaf margins that make plants unattractive.

In conclusion, our study on cold-treated field-grown *Astilbe* crowns indicates that photoperiod has no horticulturally significant effect on time to flower or the number of inflorescences produced. A high percentage of plants flowered under either cold treatment regimen. LDs may increase the inflorescence height, which may be desirable for production of cut flowers but perhaps undesirable for potted plant production. Differences in time to flower from start of forcing is of commercial significance, and additional research on the effects of cold temperatures and durations are warranted.

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Extension Education Methods

Producing Print-on-demand Publications for Instructional and Extension Materials

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ADDITIONAL INDEX WORDS. color printing, electronic publishing, digital images, video capture

SUMMARY. Print-on-demand (POD) publications are being produced from computer to printer to increase the diversity of printed extension and educational materials. The layouts are stored in libraries on the computer and text files and digital images are added to the layouts. Images can be edited before insertion into the layouts to enhance the image. The completed materials are stored in portable document format (PDF) on disk and are printed as needed or distributed over computer networks. Printing materials as needed greatly increases the diversity of materials and gives greater flexibility in revising publications than bulk printing.

The basic system for producing print-on-demand (POD) publications consists of a computer, a mass storage device, and a printer (Table 1). Depending on the source of images, other equipment may be needed. There are a variety of computer programs for editing digital images and for developing layouts. Different ways of producing these publications have been explored at the Univ. of Guam. Digital images from different sources were compared for ease of use and resolution. This paper describes our experiences and the basics of producing POD publications.

Several methods are used to acquire images. Photo CDs are a source of high-resolution images scanned from film, but more time is needed to obtain the images because of commercial processing. With live video capture, a video camera is connected directly to a computer, and images are digitized in real time. Tape-recorded images also can be used, but the image quality is poorer than that of live video. Digital cameras are very useful sources of digital images.

High-resolution digital images in formats usable on computers are now commonly available (Pihlak et al., 1993). These images are incorporated easily into publications on the computer, resulting in the production of printed materials with color and monochrome pictures. Potentially, there is a large volume of printed material that is of value to smaller audiences, e.g., workshops, classes, and individual clientele, but it is not practical or economical to produce and store bulk printings. Electronically stored publications can be printed as needed to satisfy the above-mentioned audiences. These POD publications make it feasible to produce and maintain the lower-demand printed materials. POD publications are being produced at the Univ. of Guam for use as extension fact sheets, classroom materials, and posters (McConnell et al., 1993; McConnell and Marutani, 1994). Figures 1 and 2 are examples of recent POD publications.

POD materials can be produced in a relatively short time. For example, a handout for an orchid workshop was produced between sessions during a 1-day workshop. During a break after the first session, images that showed how to repot orchids were digitized from a video recording. The pictures were incorporated into a layout of a handout, with text describing the photos. The completed layout was

Table 1. Equipment needed for a print-on-demand (POD) system.

Components	Notes
Minimal basic equipment	
• Computer	Should have sufficient memory (RAM) for working with digital graphics (24 MB minimum, ≥50 MB recommended).
• Mass storage device	Large capacity is recommended (2 GB minimum).
• Printer	Can use any printer. Color is a useful feature (minimum of 300 dpi resolution). Optional equipment depending on method of image acquisition
• CD drive	Used with photo CDs.
• Video capture board	Used to connect video camera to computer. Generally used to digitize three-dimensional objects, but can also digitize two-dimensional images.
• Scanners	Available as film and flat bed. Used to digitize media.
• Digital camera	Produce instant digital images

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