Variation in Floral Induction Requirements of *Hibiscus* sp.

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ABSTRACT. Thirty-six *Hibiscus* L. species were grown for 20 weeks under three lighting treatments at 15, 20, or 25 ± 1.5 °C air temperature to identify flowering requirements for each species. In addition, species were subjectively evaluated to identify those species with potential ornamental significance based on flower characteristics and plant form. Lighting treatments were 9 hour ambient light (St. Paul, Minn., November to May, 45°N), ambient light plus a night interruption using incandescent lamps (2 μmol·m⁻²·s⁻¹; 2200 to 0200 HR), or ambient light plus 24-hour supplemental lighting from high-pressure sodium lamps (100 μmol·m⁻²·s⁻¹). Five day-neutral, six obligate short-day, six facultative short-day, three obligate long-day, and one facultative long-day species were identified. Fifteen species did not flower. Temperature and lighting treatments interacted to affect leaf number below the first flower and/or flower diameter on some species. *Hibiscus acetosella* Welw. ex Hiern, *H. cisplatinus* St.-Hil., *H. radiatus* Cav., and *H. trionum* L. were selected as potential new commercially significant ornamental species.

Hibiscus is the largest genus in the Malvaceae family (250 to 300 species; Bates, 1965). *Hibiscus* sp. are primarily tropical in origin, although several species are native to temperate and warm temperate regions (Table 1). Although the genus is quite large, only *H. rosa-sinensis* L. (Chinese hibiscus), *H. syriacus* L. (Rose-of-Sharon), *H. moscheutos* L., and hybrids developed by crossing *H. coccineus* (Medic.) Walt., *H. laevis* All., and *H. moscheutos* are grown commercially as ornamental plants.

Cultivated *Hibiscus* are known for their large flowers that range in color from yellow to white and shades of pink and red. Flower diameter of some herbaceous perennial cultivars can be up to 30 cm (R. Warner, personal observation).

Commercially grown *Hibiscus* are both day-neutral (*H. rosa-sinensis*) (Dole and Wilkins, 1999) and long-day plants [*H. syriacus* (Thomas and Vince-Prue, 1997), *H. moscheutos* (Runkle et al., 1996)]. *Hibiscus coccineus* flowers naturally in July (Bates, 1965), suggesting that it may also be a long-day plant. *Hibiscus hiernianus* Exell & Mend., *H. mastersianus* Hiern., and *H. mechowii* Garcke are short-day plants (Menzel et al., 1986). However, little information is available on the floral induction requirements of *Hibiscus* species not commercially cultivated.

The popularity of *Hibiscus* presently being cultivated suggests other *Hibiscus* sp. may have commercial potential as ornamental plants. Therefore, the objectives of this research were to 1) determine environmental requirements for flowering of *Hibiscus* sp. and 2) identify potentially significant new ornamental species. Environmental treatments were selected to cover a wide range of thermo- and photoperiodic possibilities to maximize the number of species that would be induced to flower.

Materials and Methods

Seeds of 36 *Hibiscus* sp. (Table 1) were soaked for 12 h in ≈75 °C water that was allowed to cool to room temperature (≈22 °C) (Nau, 1996) on 23 Nov. 1996. The experiment was repeated on 24

Oct. 1997. Seeds that did not imbibe after soaking were scarified manually. Seeds were then sown in 25-mL cells in a soilless media (Germination Mix, Strong-Lite Horticultural Products, Pine Bluff, Ark.) and covered with ≈2 to 4 mm of vermiculite (Premium Grade Medium Vermiculite, Strong-Lite Horticultural Products). Planting depth of each species varied and was ≈1.5 times the minimum diameter of a seed. Seeds were germinated under intermittent mist (6 s of mist every 10 min, from 0700 to 1800 HR daily) at 23 ± 1 °C air temperature. Seedlings were removed from the mist and transplanted into 450-mL pots in a soilless media (Universal Mix, Strong-Lite Horticultural Products) when cotyledons were parallel to the media surface (≈2 to 3 d after emergence from the media). Transplanted seedlings were then placed in a greenhouse maintained at 20 ± 1 °C air temperature under ambient daylight conditions (December 1996; November 1997; St. Paul, Minn.) for 7 d, after which seedlings were moved and environmental treatments were initiated.

Environmental treatments consisted of combinations of three air temperature treatments (15, 20, or 25 ± 1.5 °C), and three lighting treatments. Lighting treatments within each temperature were: short-day (SD; 9 h of ambient light, plants covered with opaque black cloth daily from 1700 to 0800 HR; temperature under the black cloth was not recorded), night-interruption [NI; ambient daylight plus 2 μmol·m⁻²·s⁻¹ irradiance from 2200 to 0200 HR, using incandescent lamps (Sylvania Directlite 100W, GTE Products Corp., Salem, Mass.)], or continuous lighting [CT; ambient daylight plus continuous 100 μmol·m⁻²·s⁻¹ supplemental lighting from high-pressure sodium lamps (Lucolux LU400, General Electric, Cleveland, Ohio)]. Plants were fertilized weekly with 14.3 mM N, 0 mM P, and 6.5 mM K, supplied by Ca(NO₃)₂ and KNO₃. Every fourth week, plants were fertilized with 14.3 mM N, 0.72 mM P, 6.5 mM K, 1.67 mM Ca, 1.1 mM Mg, plus trace amounts of micronutrients (Peter's Excel 15N–2.2P–12.5K Cal–Mg, The Scott's Co., Marysville, Ohio).

Data were collected at anthesis or after 20 weeks on leaf number below the first flower, plant height (from the media surface to the apical meristem), height to the first flowering node, first flower diameter, lateral shoot number (lateral shoots ≥2.5 cm), and visible flower bud number (≥1 cm in length). Plants with visible flower buds after 20 weeks remained in environmental treatments until anthesis. Potential commercial ornamental significance was evaluated subjectively based on floral characteristics, including flower size, flower color, flower number, whether plants flowered continuously, leaf and stem characteristics, and overall plant architecture.

The experiment was replicated twice over time, with each

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treatment consisting of four plants per replicate. Plants were completely randomized within each lighting/temperature treatment combination. Means were separated using Tukey's HSD test ($P < 0.05$) using the SPSS statistical analysis program (SPSS, Inc., 1997).

Results

FLOWER INDUCTION AND DEVELOPMENT. Lighting and temperature treatments interacted with species to affect leaf number below the first flower. For some species there were insufficient plants for all treatments, so plants were placed in the 20 and 25 °C temperature treatments, or under SD and NI in the 20 °C temperature treatment only (Tables 2 and 3). Fifteen species did not flower under any environmental treatment (Table 1). All species that flowered had a single flower in each leaf axil. Six species, *H. acetosella*, *H. cannabinus*, *H. engleri*, *H. mastersianus*, *H. nigricaulis*, and *H. schinzii* flowered with a lower leaf number

under the SD lighting treatment than under the NI lighting treatment (Table 2).

Hibiscus asper, *H. meeusei*, *H. physaloides*, *H. sabdariffa*, and *H. surattensis* flowered only under the SD lighting treatment (Tables 2 and 3). *Hibiscus radiatus* flowered under the SD lighting treatment at all three temperatures, but flowered under NI lighting only when grown at 15 °C (Tables 2 and 3). *Hibiscus surattensis* flowered with a similar leaf number below the first flower when grown under the SD or CT lighting treatments (Table 2), but did not flower when grown under the NI lighting treatment.

Species that flowered at 20 °C regardless of lighting treatment were *H. calyphyllus*, *H. cisplatinus*, *H. costatus*, *H. lunariifolius*, and *H. meraukensis* (Tables 2 and 3). These species flowered with a similar leaf number below the first flower under either the SD or NI lighting treatments.

Hibiscus aculeatus, *H. laevis*, and *H. moscheutos* required a photoperiod inductive for flowering to grow, i.e., for continued

Table 1. *Hibiscus* sp., source, native range, and native range latitude of species evaluated in this experiment.

Species	Source	Native range	Approximate latitude (°)
<i>H. acetosella</i> Welw. ex. Hiern	PI ² 260997	Angola	6–17 S
<i>H. aculeatus</i> Walt.	Commercial	Florida to Louisiana and North Carolina	30–35 N
<i>H. arnhemensis</i> F.D. Wilson ^y	PI 585151	N. Territory, Australia (Wilson, 1974)	12–25 S
<i>H. arnotianus</i> A. Gray ^y	Commercial	Hawaii, endemic to Oahu	23 N
<i>H. asper</i> Hook f.	PI 585165	Collected in Uganda	4 N–2 S
<i>H. biseptus</i> ^y	Commercial	S. Arizona and New Mexico (Rickett, 1970)	30–33 N
<i>H. calyphyllus</i> Cav.	PI 364895	Tropical and South Africa	0–30 S
<i>H. cannabinus</i> L.	Commercial	Probably Tropical Africa	23 N–23 S
<i>H. cisplatinus</i> St.-Hil. ^x	PI 372212	Argentina, Paraguay, Uruguay, and S. Brazil	23–33 S
<i>H. coccineus</i> Walt. ^y	Commercial	Georgia and S. Florida	28–33 N
<i>H. costatus</i> A. Rich ^x	PI 265239	Cuba, Mexico, C. America (Menzel et al., 1983)	12–23 N
<i>H. denudatus</i> Benth. ^y	Commercial	California to Texas and Northern Mexico	30–35 N
<i>H. diversifolius</i> Jacq. ^y	PI 263965	Africa and Asian Tropics	23 N–23 S
<i>H. dongolensis</i> Caill. ex Del. ^{xy}	PI 364899	Collected in South Africa	23–32 S
<i>H. engleri</i> Schumann ^x	PI 364901	Collected in South Africa	23–32 S
<i>H. fallax</i> Craven & F.D. Wilson ^y	PI 595768	Collected in N. Territory Australia	12–25 S
<i>H. furcellatus</i> Desr. ^y	PI 585122	West Indies, Central, and South America, Hawaii	0–25 N
<i>H. greenwayi</i> Baker f. ^y	PI 405056	Collected in Kenya	4 S–4 N
<i>H. laevis</i> All.	Commercial	Eastern United States	27–42 N
<i>H. lunariifolius</i> Willd. ^x	PI 369345	Collected in Uganda	2 S–4 N
<i>H. mastersianus</i> Hiern ^x	PI 585154	Collected in Zambia	8–18 S
<i>H. meeusei</i> Exell	PI 344232	Collected in Zambia	8–18 S
<i>H. meraukensis</i> Hocht.	PI 585121	Western Australia (Wilson, 1974)	15–35 S
<i>H. moscheutos</i> L.	Commercial	Eastern United States	27–42 N
<i>H. mutabilis</i> L. ^y	Commercial	Probably S. China and Taiwan	20–30 N
<i>H. nigricaulis</i> Baker f. ^x	PI 585155	Collected in Zambia	8–18 S
<i>H. physaloides</i> Guill.	PI 364904	Collected in South Africa	23–32 S
<i>H. radiatus</i> Cav.	PI 585159	Asian Tropics	0–23 N
<i>H. rostellatus</i> Guill. & Perr. ^y	PI 344219	Central Africa (Menzel and Wilson, 1963)	10 S–20 N
<i>H. sabdariffa</i> L.	PI 500741	Probably Tropical Africa	23 S–23 N
<i>H. schinzii</i> Gurke. ^x	PI 500714	Southern Africa	10–30 S
<i>H. surattensis</i> L.	PI 585138	Central Africa (Menzel and Wilson, 1963)	10 S–20 N
<i>H. taiwaniana</i> ^y	Commercial	China	20–40 N
<i>H. tiliaceus</i> L. ^y	Commercial	Old and New World Tropics	23 S–23 N
<i>H. trionum</i> L. Sunnyday	Commercial	Widespread in Europe, Africa, Asia, and Australia	
<i>H. zonatus</i> F. Muell. ^y	PI 585136	N. Territory, Australia (Wilson, 1974)	12–25 S

²USDA plant introduction (PI) number.

^ySpecies did not flower under any environmental treatment in this experiment.

^xSeeds were scarified manually.

Table 2. Effect of temperature and lighting treatment on leaf number below the first flower of *Hibiscus* sp. Species are grouped into the appropriate photoperiodic response group. Numerals in parentheses represent leaf number at the end of the experiment on plants that did not flower. Plants were grown under 9 h ambient light (St. Paul, Minn., from November to May) (SD), ambient light plus a 2 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ night interruption using incandescent lamps from 2200 to 0200 HR (NI), or ambient light plus 100 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ continual supplemental lighting from high pressure sodium lamps (CT).

Species	Air	Leaf no.		
	temp (°C)	SD	NI	CT
			Facultative short-day	
<i>H. acetosella</i>	20	17 ² a ^y A ^x	38 bA	37 b
	25	15 aA	47 bB	na ^w
<i>H. cannabinus</i> ^v	15	17 aA	26 bA	27 bA
	20	25 aB	34 bB	38 bB
<i>H. engleri</i>	20	10 a	19 b	na
<i>H. mastersianus</i>	20	7 aA	10 bA	14 c
	25	12 aB	23 bB	(38)
<i>H. nigricaulis</i>	20	6 aA	12 bA	17 cA
	25	10 aB	22 bB	24 bB
<i>H. schinzii</i>	20	8 a	13 b	na
			Obligate short-day	
<i>H. asper</i>	15	7 A	(18)	(21)
	20	7 A	(20)	(20)
	25	23 B	(25)	(26)
<i>H. meeusei</i>	20	6 A	(17)	na
	25	7 A	(21)	na
<i>H. physaloides</i>	20	15 A	(22)	(24)
	25	24 aB	(27)	(29)
<i>H. radiatus</i> ^u	15	11 aA	21 b	24 bA
	20	16 aA	(31)	32 bB
	25	11 aA	(41)	(45)
<i>H. sabdariffa</i>	15	Dead	Dead	Dead
	20	8 A	(16)	(16)
	25	7 A	(21)	(19)
<i>H. surattensis</i>	15	Dead	Dead	(9)
	20	10 aA	(20)	10 aA
	25	13 aB	(31)	13 aB
			Day neutral	
<i>H. calyphyllus</i>	20	15 a	13 a	15 a
<i>H. cisplatinus</i>	20	21 a	21 a	21 a
<i>H. costatus</i>	20	9 a	9 a	na
<i>H. lunariifolius</i>	20	13 a	13 a	na
<i>H. meraukensis</i>	20	9 a	9 a	8 a
			Facultative long-day	
<i>H. trionum</i>	15	7 aA	8 aA	7 aA
	20	16 cB	10 bB	6 aA
	25	22 cC	11 bB	6 aA
			Obligate long-day	
<i>H. aculeatus</i>	20	Dead	28 aB	33 aB
	25	Dead	22 aA	25 aA
<i>H. laevis</i>	20	gc ^t	24 aA	24 aA
	25	gc	25 aA	24 aA
<i>H. moscheutos</i>	15	gc	23 A	na
	20	gc	24 aA	25 aA
	25	gc	23 aA	24 aA

²Numerals represent treatment means.

^yLower case letters indicate mean separation within a species and temperature, across lighting treatment, by Tukey's studentized range test, $P < 0.05$.

^xUpper case letters indicate mean separation within a species and lighting treatment, across temperature, by Tukey's studentized range test, $P < 0.05$.

^wPlants were not grown in this treatment.

^vPlants became too tall to maintain in 25 °C treatments.

^uFacultative short-day plants at 15 °C.

^tGrowth ceased after plants unfolded ≈ 10 leaves.

Table 3. Effect of temperature and lighting treatment on days to first open flower of *Hibiscus* sp. Species are grouped into the appropriate photoperiodic response group. Plants were grown under 9 h ambient light (St. Paul, Minn., from November to May) (SD), ambient light plus a 2 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ night interruption using incandescent lamps from 2200 to 0200 HR (NI), or ambient light plus 100 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ continual supplemental lighting from high pressure sodium lamps (CT).

Species	Air	Days to first open flower		
	temp (°C)	SD	NI	CT
			Facultative short-day	
<i>H. acetosella</i>	20	103 ² a ³ B ^x	159 bA	155 b
	25	69 aA	152 bA	na ^w
<i>H. cannabinus</i> ^v	15	166 aB	195 bB	192 bB
	20	145 aA	177 bA	169 bA
<i>H. engleri</i>	20	57 a	85 b	na
<i>H. mastersianus</i>	20	40 aA	49 bA	52 b
	25	41 aA	63 bB	na
<i>H. nigricaulis</i>	20	46 aA	67 bA	75 bA
	25	45 aA	92 bB	94 bB
<i>H. schinzii</i>	20	60 a	89 b	na
			Obligate short-day	
<i>H. asper</i>	15	66 B	dnf ^u	dnf
	20	52 A	dnf	dnf
	25	109 C	dnf	dnf
<i>H. meeusei</i>	20	54 B	dnf	na
	25	43 A	dnf	na
<i>H. physaloides</i>	20	59 A	dnf	dnf
	25	70 B	dnf	dnf
<i>H. radiatus</i> ^t	15	119 aC	175 b	177 bB
	20	88 aA	dnf	122 aA
	25	60 A	dnf	dnf
<i>H. sabdariffa</i>	20	74 B	dnf	dnf
	25	56 A	dnf	dnf
<i>H. surattensis</i>	20	71 aB	dnf	68 aA
	25	53 aA	dnf	47 aA
			Day neutral	
<i>H. calyphyllus</i>	20	155 a	167 a	160 a
<i>H. cisplatinus</i>	20	144 a	147 a	141 a
<i>H. costatus</i>	20	82 a	86 a	na
<i>H. lunariifolius</i>	20	61 a	66 a	na
<i>H. meraukensis</i>	20	97 a	101 a	98 a
			Facultative long-day	
<i>H. trionum</i>	15	110 cA	92 bC	61 aC
	20	109 cA	79 bB	43 aB
	25	107 cA	68 bA	36 aA
			Obligate long-day	
<i>H. aculeatus</i>	20	Dead	160 aB	151 aB
	25	Dead	131 bA	99 aA
<i>H. laevis</i>	20	gc ^s	135 aB	131 aB
	25	gc	119 aA	115 aA
<i>H. moscheutos</i>	15	gc	133 C	na
	20	gc	112 aB	105 aB
	25	gc	99 aA	90 aA

²Numerals represent treatment means.

³Lower case letters indicate mean separation within a species and temperature, across lighting treatment, by Tukey's studentized range test, $P < 0.05$.

^xUpper case letters indicate mean separation within a species and lighting treatment, across temperature, by Tukey's studentized range test, $P < 0.05$.

^yPlants were not grown in this treatment.

^tPlants became too tall to maintain in 25 °C treatments.

^wPlants did not flower in this treatment.

^lFacultative short-day plants at 15 °C.

^sGrowth ceased after plants unfolded ≈ 10 leaves.

Table 4. Comparison of flower color and diameter of 21 *Hibiscus* sp. grown under the lighting treatment that resulted in earliest flowering at 20 °C.

Species	Flower color (center color)	Flower diam (mm)
<i>H. acetosella</i>	Yellow (maroon)	83 ^z h ^y
<i>H. aculeatus</i>	Yellow (maroon)	75 g
<i>H. asper</i>	Yellow (maroon)	52 e
<i>H. calyphyllus</i>	Yellow (red-brown)	47 d
<i>H. cannabinus</i>	Cream (maroon)	101 i
<i>H. cisplatinus</i>	Pink	107 j
<i>H. costatus</i>	Pink	51 e
<i>H. engleri</i>	Yellow (brown)	33 bc
<i>H. laevis</i>	Pink (maroon)	82 h
<i>H. lunariifolius</i>	Yellow (maroon)	64 f
<i>H. mastersianus</i>	Yellow (maroon)	55 e
<i>H. meeusei</i>	Yellow (maroon)	24 a
<i>H. meraukensis</i>	Light pink	30 b
<i>H. moscheutos</i>	White (maroon)	124 k
<i>H. nigricaulis</i>	Yellow (maroon)	24 a
<i>H. physaloides</i>	Yellow (maroon)	68 f
<i>H. radiatus</i>	Maroon	74 g
<i>H. sabdariffa</i>	Cream (maroon)	47 d
<i>H. schinzii</i>	Yellow (red-brown)	35 c
<i>H. surattensis</i>	Yellow (maroon)	37 c
<i>H. trionum</i> ‘Sunnyday’	Cream (maroon)	43 d

^zNumerals represent species mean.

^yMean separation by Tukey’s Studentized range test, $P < 0.05$.

leaf unfolding (Tables 2 and 3). For instance, growth of *H. laevis* and *H. moscheutos* ceased under the SD lighting treatment after plants unfolded about 10 leaves. *Hibiscus aculeatus* plants (roots and shoots) died when grown under the SD lighting treatment, regardless of temperature. Plants of all three species flowered only under the NI or CT lighting treatments. Leaf number below the first flower was similar under NI or CT for all three species.

Hibiscus trionum ‘Sunnyday’ had six leaves below the first flower bud, regardless of the light/temperature treatment. However, the first flower buds aborted under SD and NI treatments at 20 and 25 °C, resulting in variation in leaf number below the first flower to develop completely to anthesis and days to anthesis

(Tables 2 and 3). For instance, plants grown under the CT lighting treatment had about six leaves below the first flower to open regardless of temperature. Similarly, plants grown at 15 °C had about seven leaves below the first flower to open regardless of the lighting treatment. However, plants grown at 20 or 25 °C had a lower leaf number below the first flower to open when grown under the CT lighting treatment than when grown under the NI or SD lighting treatments. Similarly, plants grown at 20 or 25 °C had a lower leaf number below first flower to open when grown under the NI than the SD lighting treatment.

Temperature interacted with lighting treatment to affect leaf number below the first flower and days to anthesis on *H. cannabinus*, *H. mastersianus*, *H. nigricaulis*, and *H. physaloides* (Tables 2 and 3). For instance, leaf number of *H. mastersianus* below the first flower when grown under the SD lighting treatment was 7 and 12 leaves on plants grown at 20 and 25 °C, respectively. Similarly, *H. mastersianus* plants grown under the NI lighting treatment unfolded 10 and 23 leaves before forming a flower at 20 and 25 °C, respectively.

FLOWER COLOR AND DIAMETER. Flowers of 12 of the 21 species that flowered were yellow with maroon, or sometimes brown, centers (Table 4). Other flower colors observed were pink, white, and maroon. Flower diameter at 20 °C under the lighting treatment that resulted in earliest flowering for each species ranged from 24 mm for *H. meeusei* and *H. nigricaulis*, to 124 mm for *H. moscheutos* (Table 4).

Temperature interacted with lighting treatment to affect flower diameter of two species, *H. radiatus* and *H. nigricaulis*. *H. radiatus* flower diameter under the SD lighting treatment at 15, 20, and 25 °C was 31, 72, and 100 mm, respectively. Increasing temperature from 20 to 25 °C increased *H. nigricaulis* flower diameter from 24 to 54 mm under SD.

LATERAL SHOOT NUMBER AND PLANT HEIGHT. *Hibiscus sabdariffa*, *H. surattensis*, and *H. trionum* were the only species with lateral shoots. Increasing temperature increased the number of lateral shoots for all three species when grown under the CT lighting treatment (Table 5). For example, *H. surattensis* had 0, 4, and 7 lateral shoots under CT at 15, 20, and 25 °C, respectively. In contrast, *H. surattensis* plants had a similar number of lateral shoots under all three lighting treatments at 20 °C. However, plants grown at 25 °C had 2, 6, and 7 lateral shoots when grown under the SD, NI, and CT lighting treatments, respectively.

Species, lighting treatment, and temperature interacted to affect

Table 5. Effect of lighting and temperature treatment on lateral shoot number of three *Hibiscus* sp. Lighting treatments: 9 h ambient light (St. Paul, Minn., from November to April) (SD); ambient light plus 2 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from 2200 to 0200 HR (NI), or ambient light plus 100 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ continuous light (CT).

Species	Temp (°C)	Lateral shoot no.		
		SD	NI	CT
<i>H. sabdariffa</i>	15	Dead	Dead	Dead
	20	1 ^z a ^y A ^x	5 bA	4 bA
	25	0 aA	7 bB	8 bB
<i>H. surattensis</i>	15	Dead	Dead	0 A
	20	4 aB	4 aA	4 aB
	25	2 aA	6.0 bB	7 bC
<i>H. trionum</i> ‘Sunnyday’	15	5 bA	3 bA	2 aA
	20	5 bA	2 aA	3 aB
	25	7 bA	4 aA	5 aB

^zNumerals represent treatment mean.

^yLower case letters indicate mean separation across lighting treatment, within a species and temperature, by Tukey’s studentized range test, $P < 0.05$.

^xUpper case letters indicate mean separation across temperature, within a species and lighting treatment, by Tukey’s studentized range test, $P < 0.05$.

plant height at anthesis (Table 6). For instance, *H. asper* height at anthesis was 247, 332, and 789 mm under SD when grown at 15, 20, and 25 °C, respectively. Height of *H. radiatus* at anthesis at 15 °C was 217, 342, and 506 mm under SD, NI, and CT, respectively. Plant height at anthesis across all treatments ranged from 150 mm for *H. costatus* to 1500 mm for *H. acetosella* (Table 6).

Discussion

Fifteen species did not flower in any treatment after 20 weeks (Table 1). This is not surprising considering many of these species are shrubs or trees in their indigenous habitats and may have a juvenile period longer than the length of the experiment (Salisbury and Ross, 1992).

Variation in the photoperiodic requirement for flower induc-

tion among *Hibiscus* sp. studied herein is consistent with results reported for other *Hibiscus* sp. (Menzel et al., 1986; Thomas and Vince-Prue, 1997; Wilkins and Kotecki, 1982) and other genera, including *Allium* L. and *Coleus* Lour. (Thomas and Vince-Prue, 1997). For instance, interrupting a 15 h night ≥ 1 h with a low irradiance (1 to $3 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from incandescent lamps) induced 90% of a *H. moscheutos* 'Disco Belle Mixed' population to flower (Runkle et al., 1998). Results herein support the classification of *H. moscheutos* as a long-day plant. However, subsequent work we conducted indicated *H. moscheutos* 'Disco Belle Pink' is an obligate long-day plant only when daily light integral is $\leq 13 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ (Warner, 1999). *Hibiscus moscheutos* 'Disco Belle Pink' is a facultative long-day plant when daily light integral is $\geq 13 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ under a 9 h photoperiod.

Our classification of *H. cannabinus*, *H. mastersianus*, *H.*

Table 6. Effect of temperature and lighting treatment on plant height (mm) at anthesis of 17 *Hibiscus* sp. Plants were grown under 9 h ambient light (St. Paul, Minn., from November to May) (SD), ambient light plus $2 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ from 2200 to 0200 HR (NI), or ambient light plus $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ continuous light (CT).

Species	Air temp (°C)	Plant ht (mm)		
		SD	NI	CT
<i>H. acetosella</i>	20	488 ^a A ^x	946 bA	568 a
	25	494 aA	1500 bB	dnf ^w
<i>H. aculeatus</i>	20	dnf	578 aA	668 aA
	25	dnf	895 aB	790 aB
<i>H. asper</i>	15	247 A	dnf	dnf
	20	332 A	dnf	dnf
	25	789 B	dnf	dnf
<i>H. calyphyllus</i>	20	256 a	256 a	244 a
<i>H. cisplatinus</i>	20	485 a	507 a	477 a
<i>H. costatus</i>	20	150 a	273 b	--- ^v
<i>H. engleri</i>	20	289 a	278 a	---
<i>H. laevis</i>	20	dnf	527 aA	551 aA
	25	dnf	672 bB	611 aB
<i>H. lunariifolius</i>	20	263 a	310 a	---
<i>H. mastersianus</i>	20	909 aA	972 bA	915 a
	25	1079 aB	1338 bB	dnf
<i>H. meeusei</i>	20	172 A	dnf	---
	25	230 A	dnf	---
<i>H. meraukensis</i>	20	162 a	272 b	285 b
<i>H. moscheutos</i>	15	dnf	522 A	---
	20	dnf	611 bB	545 aA
	25	dnf	637 bB	563 aA
<i>H. nigricaulis</i>	20	222 aA	409 cA	348 bA
	25	523 aB	633 aB	1072 bB
<i>H. physaloides</i>	20	729 A	dnf	dnf
	25	814 B	dnf	dnf
<i>H. radiatus</i>	15	217 aA	342 b	506 c
	20	528 C	dnf	dnf
	25	369 B	dnf	dnf
<i>H. sabdariffa</i>	20	176 A	dnf	dnf
	25	198 A	dnf	dnf
<i>H. schinzii</i>	20	181 a	183 a	---
<i>H. surattensis</i>	20	307 aA	dnf	280 aA
	25	570 bB	dnf	479 bB

^aNumerals represent treatment mean.

^wLower case letters indicate mean separation within a species and temperature, across lighting treatment, by Tukey's studentized range test, $P < 0.05$.

^xUpper case letters indicate mean separation, within a species and lighting treatment, across temperature, by Tukey's studentized range test, $P < 0.05$.

^vPlants did not flower in this treatment.

^vPlants were not grown in this treatment.

sabdariffa, and *H. surattensis* as short-day plants is consistent with previous results (Crane, 1949; Crane and Acuna, 1945; Menzel et al., 1986). *Hibiscus surattensis* flowered under both SD and CT, but flowering was completely inhibited by NI. Inhibition of flowering by NI, but not SD or CT, has been reported for other short-day plants, including *H. sabdariffa* (El-Afry et al., 1980; Mansour, 1975). However, for results presented herein, *H. sabdariffa* did not flower when grown under CT. Similarly, Cockshull (1979) reported that three cultivars of the short-day plant, *Dendranthema ×grandiflorum* Kitam. (syn. *Chrysanthemum ×morifolium* Ramat.) (chrysanthemum), initiated flower buds when grown under continuous light. However, flower buds of only one of the three cultivars, 'Golden Stardust', developed to anthesis, and only when the temperature was 10 or 16 °C.

The photoperiodic response for flowering of a given species is closely linked to the indigenous habitat of that species. Plants from latitudes 30 to 55 °N are often long-day plants that may or may not require vernalization (Roberts and Summerfield, 1987). This ensures that plants will flower and produce seed during the warm summer months before going dormant for the winter. In contrast, plants from latitudes of 0 to 30 °N are often short-day plants or day-neutral (Roberts and Summerfield, 1987). Our results are consistent with observations of Roberts and Summerfield (1987) where *Hibiscus* sp. native to the United States (i.e., *H. militaris* and *H. moscheutos*) were obligate long-day plants. In contrast, species native closer to the equator (i.e., *H. calyphyllus*, *H. cannabinus*, and *H. radiatus*) were day-neutral and short-day plants (Tables 1 and 2).

High temperature treatment (25 °C) delayed flowering of some *Hibiscus* sp. under inductive lighting treatments (Tables 2 and 3). For example, increasing temperature from 20 to 25 °C increased leaf number below the first flower on *H. mastersianus* and *H. nigricaulis*, i.e., developmental delay. In contrast, increasing temperature from 20 to 25 °C increased leaf number below the first flower and days to anthesis on *H. asper* and *H. physaloides*, i.e., developmental delay and delay in time. In all cases, *Hibiscus* sp. that exhibited high temperature delay in flowering eventually flowered. Interestingly, species that exhibited high temperature delay were among facultative or obligate short-day plant groups only.

High temperature inhibition or delay of flowering has been observed in other species. Short-day induced flower initiation in *Euphorbia pulcherrima* Willd. ex Klotzsch. (poinsettia) is delayed when night temperature exceeds 22 °C (Dole and Wilkins, 1999). Similarly, short-day induced flowering in *Dendranthema ×grandiflorum* and *Schlumbergera truncata* (Haw.) Moran. (Thanksgiving cactus) is delayed when day or night temperature exceeds 22 °C (Karlsson et al., 1989; Erwin et al., 1990). *Pharbitis nil* Choisy. flowering is delayed (Reese and Erwin, 1997) and *Pelargonium ×hortorum* L.H. Bail. (geranium) flower number per inflorescence decreases as average daily temperature increases (Erwin and Heins, 1993).

Based on subjective characteristics mentioned previously, we determined that *H. cisplatinus* and *H. radiatus* have potential as new commercial ornamental crops. *Hibiscus acetosella* and *H. trionum* are currently commercially available, but are not widely grown.

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