Screening Ornamental Sunflowers in the Seedling Stage for Flowering Reaction to Photoperiod

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SUMMARY. Ornamental sunflower (*Helianthus annuus*) cultivars grown as cut flowers range in sensitivity to photoperiod with regard to flowering from facultative short day (SD) to facultative long day (LD), with others insensitive to daylength. SD sensitivity is a problem for production in tropical areas, or in early spring sowings when the daylength triggers early flowering, and leads to small flowers and production of unsightly axillary buds. In the current work, 59 cultivars of sunflower were exposed to either 12- or 16-hour photoperiod in seedling trays in a greenhouse for 3 weeks, and transplanted outside. At flowering, plant height, leaf number, and flower diameter were measured. The studies were conducted in 2006, 2007, 2009, 2011, and 2012 with two cultivars (Procut Lemon and Sunrich Orange) serving as controls in each trial. Of the 59 cultivars screened, 52% were found to be day-neutral, 44% were SD, and two (3%) had a LD reaction. Two standard cultivars grown in each season showed consistent reactions to the photoperiod treatments in each year. The seedling screen is useful to identify cultivars suited for production in early spring in a temperate environment.

Sunflower has become a popular cut flower in North America, where it has been grown primarily in the field during the summer season (Armitage and Laushman, 2003). As demand has increased for sunflower at other times of the year, the daylength response for flowering of the cultivars has become important. Over the years, many sunflower cultivars have been classified as facultative SD plants (Dyer et al., 1959; Hayata and Imaizumi, 2000; Yanez et al., 2005), but daylength-neutral and even facultative LD cultivars have also been identified (Goyne and Schneiter, 1988; Mattson and Erwin, 2005; Schuster and Boyce, 1971). If SD cultivars are grown under SD conditions, they flower early, are small in stature, and have small flowers. These cultivars only develop their “normal” height and flower size characteristics in the longer days of summer that make them suitable for use as cut flowers at that time. As new cultivars are continually introduced by seed companies for the cut flower trade, it is important

to test the daylength reaction of these new lines, so that growers will be aware of the time of year to which production of these lines may be restricted.

Fortunately, the task of daylength screening of sunflower has been made easier by the finding that for many sunflower cultivars, flower primordia are formed within 3 weeks after emergence (Marc and Palmer, 1981; Yanez et al., 2012). If sunflower cultivars are sensitive to daylength before flower initiation, it allows a daylength screening process to be imposed during the seedling stage, and the resulting effects to be observed under field conditions thereafter, as was reported by Blacquire et al. (2002). We used this methodology to expose seedlings of 59 sunflower cultivars developed for use as cut flowers to long or short photoperiods in experiments over 5 years, and classified their responses. The objectives of the current work were to test cut-flower cultivars of sunflower for the effect of daylength

in the seedling stage on flowering date, number of leaves, plant height, and flower diameter.

Materials and methods

The findings of Blacquire et al. (2002) suggest that sunflower can be screened for flowering response to daylength by imposing photoperiod treatments in the seedling stage. Accordingly, seeds of sunflower cultivars were sown in 72-cell seedling trays having individual cell volumes of 56 mL and containing a peat-vermiculite artificial soil mix, and placed on greenhouse benches equipped with automatic blackout curtains that provided 12 h of photosynthetic light consisting of daylight supplemented by metal halide lamps supplied from 0700 to 1900 HR. Greenhouse temperatures were maintained at 24 ± 2 °C. Half of each bench was screened from the SD portion and received an additional 4 h of photoperiodic lighting supplied by screw-in fluorescent fixtures that provided 5 µmol·m⁻²·s⁻¹ photosynthetic photon flux at plant level supplied as a day extension from 1900 to 2300 HR. The seedlings thus received either a 12-h (SD) or a 16-h (LD) daylength treatment for the first 3 weeks after emergence. To prevent excessive elongation of the seedlings in the trays, they were brushed once daily by passing a wooden stick manually over the trays for about a minute duration, starting when the seedlings were about 1 week old. Space restrictions on the daylength greenhouse bench allowed only one replication on the bench at one time in the first 3 years, so replications in 1 year were sown consecutively at 3-week intervals. In 2011 and 2012, both replications were grown and screened at the same time. During the seedling growth period, the trays were fertilized with a 15N–2.2P–12.5K nutrient solution at the rate of 15 mg·L⁻¹ nitrogen during weekdays, and plain water on weekends.

Seedlings were transplanted to an outdoor experimental area near

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Ithaca, NY (lat. 42.42°N, long. 76.50°W) having sandy loam soil (coarse-loamy, mixed, active, mesic Lamellic Hapludalf), on beds 4 inches high and 40 inches wide, watered by two trickle irrigation lines, and covered with black polyethylene mulch. Seedlings were spaced 9 × 9 inches apart in four rows on each bed. There were 24 seedlings per daylength treatment for each cultivar. Experimental design in the field was a split plot, with daylength treatment as main plot, and cultivars as subplots. This arrangement minimized shading by adjacent plots, as nearly half the cultivars had reduced height after SD treatment. The number of cultivars screened, the number of replications, and their dates of planting in each year are shown in Table 1. To quantify the variation in the screening conditions over the 5 years, the two cultivars, Procut Lemon and Sunrich Orange, were included in each planting. ‘Procut Lemon’ has consistently produced no reaction to the treatments imposed, whereas ‘Sunrich Orange’ flowered nearly 3 weeks earlier after SD treatment.

Plants were harvested at anthesis, defined as the time when the majority of petals (ray flowers) had unfolded to an angle of 90° or more to the disk. At harvest, plant height was measured from the soil surface to the top of the flower head and flower disk diameter was taken as the distance across the disk ignoring petals. Leaf number included those on the main stem, leaf scars at the stem base, and leaves near the head that had visible petioles.

The effect of the seedling daylength treatments on the two standard cultivars was analyzed statistically via JMP software (version 11; SAS Institute, Cary, NC) using a mixed model, with year, cultivar, treatment, and cultivar × treatment as fixed effects. Statistical analysis of the daylength reaction of the 59 cultivars screened was done using a mixed model, with replications random, and fixed effects for cultivars, treatments, and their interactions. Each year was analyzed separately.

Results

Daylength treatments applied to sunflower seedlings for the first 3 weeks after emergence had profound effects on some cultivars (Table 2). The two cultivars that were included in each planting of the cultivar screen

trials showed two such extremes. ‘Sunrich Orange’ flowered 18 d earlier when given 12-h daylength compared with 16-h daylength, whereas ‘Procut Lemon’ showed no difference in time to flowering after the two treatments. The differences in time to flowering with daylength treatment for ‘Sunrich Orange’ were also

daylength response of cultivars without confounding treatment effects with season of growth.

The detailed analysis for the 59 cultivars screened indicate that the reaction to the daylength treatments imposed ranged from a facultative SD response to a facultative LD response (Table 3), with 31 cultivars (52%)

Table 1. Timetable and number of sunflower cultivars screened for daylength sensitivity, and number of replications planted in specific years. Cultivars total more than those listed in Table 3 because ‘Procut Lemon’ and ‘Sunrich Orange’ and a few others were grown in more than 1 year.

Yr	Cultivars (no.)	Replications (no.)	Dates of sowing
2006	22	3	11 May, 5 June, 6 July
2007	16	3	15 May, 5 June, 29 June
2009	11	2	14 May, 5 June
2011	13	2	24 June
2012	12	2	16 May

Table 2. The influence of a 3-week daylength treatment begun at emergence on daylength-controlled greenhouse benches on flowering date and plant characteristics at flowering of ‘Procut Lemon’ and ‘Sunrich Orange’ sunflower, grown over 5 years. Plants were transplanted to the field after daylength treatment.

Cultivar	Daylength (h)	Time to flowering (d) ^z	Ht (cm) ^y	Flower diam (cm)	Main stem leaves (no.)
Procut Lemon	12	65	108	6.1	17
Procut Lemon	16	65	106	6.5	18
Sunrich Orange	12	56	78	4.2	16
Sunrich Orange	16	74	133	8.0	24
Year		NS ^x	NS	**	NS
Cultivar		NS	NS	NS	***
Treatment		***	***	***	***
Cultivar × treatment		***	***	***	***

^zDays after sowing.

^y1 cm = 0.3937 inch.

^xAnalysis via JMP software (version 11; SAS Institute, Cary, NC) using a mixed model, with year, cultivar, treatment and cultivar × treatment as fixed effects; NS, **,***Nonsignificant or significant at the $P \leq 0.01$ or 0.001, respectively.

reflected in other plant characteristics. The plants that flowered early were only 59% as tall, had significantly smaller flowers, and had 16 instead of 24 leaves (Table 2). In addition, the early flowering plants of ‘Sunrich Orange’ produced flower buds in the axils of nearly every leaf (Fig. 1), a disfiguring feature as these late buds did not reach anthesis until the main flower had senesced.

The statistical analysis of the two standard cultivars indicated that the effect of years was not significant for most variables measured (Table 2). This provided confidence that the daylength treatments were identifying the

Fig. 1. ‘Sunrich Orange’ sunflower at anthesis, after being grown from emergence for 3 weeks under 16- (left) or 12-h daylength in a daylength-controlled greenhouse facility, before being planted to the field.

Table 3. The reaction of 59 sunflower cultivars arranged in alphabetical order to exposure to either 12- or 16-h daylength in the first 3 weeks after emergence with regard to plant height at flowering and time to flowering after subsequent transplanting to the field. Data are means of two or three replicated split plots each containing about 24 plants. Statistical analysis was conducted separately for each year, comparing cultivar by treatment slices.

Cultivar	Time of screen (yr)	Plant ht (cm) ^z			Time to flowering (d)			Sensitivity rating ^x
		Short day	Long day	Signifi- cance ^y	Short day	Long day	Signifi- cance	
Big Smile	2009	23	44	*	54	63	**	FSD
Buttercream	2009	143	133	NS	66	63	NS	DN
Chianti	2006	117	128	NS	62	68	NS	DN
Coconut Ice	2012	114	107	NS	64	58	NS	DN
Dafne	2012	70	128	***	53	73	***	FSD
Double Quick Orange	2012	153	111	***	84	73	**	FLD
Florenza	2006	114	112	NS	64	65	NS	DN
Frilly	2012	168	116	***	78	67	**	FLD
Full Sun Improved	2006	157	183	NS	69	72	NS	DN
Giant Sungold	2012	170	169	NS	99	97	NS	DN
Gold Rush	2011	100	130	*	58	66	**	FSD
Goldy Double	2012	163	146	NS	89	89	NS	DN
Moonbright	2006	112	167	***	60	75	***	FSD
Music Box	2011	52	65	NS	58	59	NS	DN
Orange Glory	2007	70	117	***	53	73	***	FSD
Orange King	2007	107	145	***	57	71	***	FSD
Peach Passion	2009	68	65	NS	63	62	NS	DN
Premier Lemon	2007	35	80	***	44	62	***	FSD
Premier Light Yellow	2006	39	95	***	45	63	***	FSD
Procut Amber Glow	2011	116	123	NS	58	58	NS	DN
Procut Apricot Lite	2007	106	113	NS	62	64	NS	DN
Procut Bicolor	2006	150	123	NS	68	62	NS	DN
Procut Bicolor Plus	2011	122	118	NS	68	64		DN
Procut Brilliance	2009	122	118	NS	68	64	NS	DN
Procut Early Orange	2007	84	105	NS	52	61	***	FSD
Procut Gold	2011	127	118	NS	60	59	NS	DN
Procut Lemon ^w	all	109	112	NS	62	63	NS	DN
Procut Orange	2007	90	105	NS	55	62	*	FSD
Procut Peach	2006	132	129	NS	62	62	NS	DN
Procut Peach Blush	2007	121	121	NS	62	61	NS	DN
Procut Red	2011	158	148	NS	72	72	NS	DN
Procut Red Lemon Bicolor	2007	94	98	NS	62	62	NS	DN
Procut White Lite	2007	82	112	***	58	69	***	FSD
Procut Yellow	2007	99	119	NS	58	65	*	FSD
Procut Yellow Lite	2006	123	126	NS	62	62	NS	DN
Ring of Fire	2006	112	109	NS	66	69	NS	DN
Solara	2006	82	136	***	53	71	***	FSD
Sonya	2006	86	90	NS	65	68	NS	DN
Soraya	2006	139	136	NS	79	80	NS	DN
Starburst Gold	2011	142	147	NS	64	64	NS	DN
Starburst Panache	2011	135	143	NS	61	63	NS	DN
Strawberry Blonde	2006	161	145	NS	65	63	NS	DN
Sunbright	2006	105	163	***	57	78	***	FSD
Sunbright Supreme	2006	83	156	***	52	75	***	FSD
Sunny	2006	101	160	***	56	79	***	FSD
Sunrich Gold	2006	80	143	***	52	67	***	FSD
Sunrich Lemon Summer	2009	68	121	***	51	72	***	FSD
Sunrich Orange ^w	all	79	137	***	53	71	***	FSD
Sunrich Orange Summer	2006	63	123	***	49	69	***	FSD
Tapuz	2009	85	151	***	54	77	***	FSD
Terra Cotta	2009	160	147	NS	83	80	NS	DN
TH 472	2006	60	111	***	48	68	***	FSD
The Joker	2006	163	145	NS	63	61	NS	DN
Tosca	2007	70	111	***	51	68	***	FSD

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Table 3. (Continued) The reaction of 59 sunflower cultivars arranged in alphabetical order to exposure to either 12- or 16-h daylength in the first 3 weeks after emergence with regard to plant height at flowering and time to flowering after subsequent transplanting to the field. Data are means of two or three replicated split plots each containing about 24 plants. Statistical analysis was conducted separately for each year, comparing cultivar by treatment slices.

Cultivar	Time of screen (yr)	Plant ht (cm) ^z			Time to flowering (d)			Sensitivity rating ^x
		Short day	Long day	Significance ^y	Short day	Long day	Significance	
Valentine	2006	104	113	NS	58	65	NS	DN
Vincent Choice	2012	77	81	NS	47	56	*	FSD
Vincent Fresh	2012	73	87	NS	47	54	NS	DN
Zahav	2009	91	157	***	55	77	***	FSD
Zohar	2009	59	121	***	51	72	***	FSD

^z1 cm = 0.3937 inch.

^yAnalysis via JMP software (version 11; SAS Institute, Cary, NC) using a mixed model, with replications random, and fixed effects for cultivars, treatments and their interactions; NS, *, ***, ****Nonsignificant or significant at the $P \leq 0.05$, 0.01, or 0.001, respectively.

^xClassification of sunflower cultivars according to their reaction to photoperiod: day-neutral (DN); facultative short day (FSD), flowering significantly earlier after short-day than long-day treatment; facultative long day (FLD), flowering significantly earlier after long-day treatment.

^zStandard cultivars grown each year. See Table 2 for detailed analysis.

showing no statistically significant difference between LD and SD treatments, and thus were considered daylength-neutral. Twenty-six cultivars (44%) had a significantly longer delay (more than 7 d) in flowering after LD vs. SD length treatments. Only 'Frilly' and 'Double Quick Orange' flowered 11 d earlier after LD treatment than SD treatment, and were considered to show a facultative LD response. This classification of sensitivity is rather arbitrary, as the difference between LD and SD treatments in flowering dates among cultivars ranged continuously from minus 11 to 23 d (Table 3, Fig. 2).

Earliness in flowering was accompanied by reduced plant stature (Table 3), smaller number of leaves, and other associated characteristics (not shown), such as increased axillary bud number and smaller flowers, as shown for 'Sunrich Orange' in Fig. 1 and Table 2.

Discussion

Our research confirms the findings of other investigators that sunflower cultivars exhibit a range of responses to daylength with regard to time to flowering, from facultative SD to facultative LD and daylength-neutral (Mattson and Erwin, 2005; Schuster and Boyce, 1971; Yanez et al., 2005).

By subjecting cultivars in the first 3 weeks after emergence to SDs or LDs, followed by growth to anthesis in LD conditions, the screening technique selected primarily for daylength effect on flower initiation, which can occur in the first 3 weeks from

Fig. 2. The correlation between the difference in node number on the main stem and the flowering date difference for 51 sunflower cultivars when screened by exposing them in the seedling stage to either 12- or 16-h daylength. Leaf numbers were not determined for cultivars screened in 2011, and are not included in the correlation. Line equation is $y = 2.01x + 2.42$, $r = 0.94$.

germination (Marc and Palmer, 1981; Yanez et al., 2012). Thus, exposure to an unfavorable photoperiod for flower initiation resulted in an increase in leaf number, as flower initiation was delayed (Table 2, Fig. 2). For the cultivars in this study, increasing the leaf number by one corresponded to a delay in flowering of about 2 d (Fig. 2).

For the extremely sensitive SD cultivars, the flowering delay was in some cases as long as the 21-d LD treatment imposed, suggesting that

flower initiation was prevented by LDs. But since in our trials, the seedlings were transplanted into the LD conditions of early to midsummer, we can conclude that flower initiation was only delayed, not prevented by the unfavorable photoperiod. Yanez et al. (2012) have shown similar results with 'Sunrich Orange' in greenhouse studies.

When the period from germination to anthesis is divided into time to flower initiation and the preanthesis flower development period, previous

research has pointed out that response to daylength may differ in these two stages. Marc and Palmer (1981) found that two cultivars that showed little reaction to short daylength before flower initiation became SD sensitive between flower initiation and anthesis. Rawson and Hindmarsh (1982), on the other hand, found that five cultivars were hastened to initiate flowers by LDs, but the period to anthesis was shortened by SDs in three of these cultivars, making them appear day-neutral. Perhaps, more common was the response of 24 ornamental sunflower cultivars studied by Yanez et al. (2005), for which a SD response in time to visible flower buds was followed by additional SD reaction in the preanthesis period.

From a practical standpoint, the early screening test used here identifies cultivars that are accelerated to flower when exposed to SDs in the early seedling stage. These conditions occur if seedlings are produced under natural daylengths in March for transplanting to high tunnels. Although the early flowering noted for such plants is not in itself objectionable, the small flowers, short stem length, and profusion of axillary flower buds limit the commercial appeal of such

plants (Fig. 1). An early LD treatment can eliminate these symptoms by keeping the plant in a vegetative stage during early development. Another solution is to choose daylength neutral cultivars for early production. As the technique used here only subjects the seedlings to the first 3 weeks of SDs, it may not be appropriate for cultivars that are to be grown under conditions of constant SDs.

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