Pak. J. Bot., 45(3): 999-1004, 2013.

FLOWERING RESPONSE OF FACULTATIVE SHORT DAY ORNAMENTAL ANNUALS TO ARTIFICIAL LIGHT INTENSITIES

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Abstract

Seeds of 6 Facultative SDPs (Zinnia cv. Lilliput, Sunflower cv. Elf, French Marigold cv. Orange Gate, African Marigold cv. Crush, Cockscomb cv. Bombay and Cosmos cv. Sonata Pink) were sown into module trays containing homogeneous leaf mould compost. After germination, saplings of each cultivar were shifted into four light intensity chambers (42, 45, 92 and 119µmol.m^{-2}.s^{-1}) for a duration of 8h (from 08:00 to 16:00h) to observe their flowering response. The findings of this study showed that Facultative SDPs raised under low irradiance (42 and 45µmol.m^{-2}.s^{-1}) were more responsive to produce early flowers. However, there was a non-significant difference between 42 and 45µmol.m^{-2}.s^{-1} and 92 and 119µmol.m^{-2}.s^{-1} irradiance levels. Although Facultative SDPs under 42µmol.m^{-2}.s^{-1} flowered few days earlier than those received 45µmol.m^{-2}.s^{-1} irradiance but the quality of plants (plant height and leaf appearance) was inferior. It is therefore concluded that for better plant quality and early flowering Facultative SDPs should be grown under 45µmol.m^{-2}.s^{-1} irradiance. Moreover, these plants can be kept under high light intensity (92µmol.m^{-2}.s^{-1}) to prolong juvenile phase for continuous supply in the market.

Introduction

Light is one of the important factors maintaining growth and development of plants. The rate of growth and length of time a plant remains active are dependent on the amount of light it receives. Moreover, light energy is also used in photosynthesis, the plant's most basic metabolic process (Murchie *et al.,* 2002). However, the response of flowering of many plants depends on the duration, intensity and quality of light. On the basis of light duration (photoperiod) plants are categorised as: long day plants (LDPs), short day plants (SDPs) and day neutral plants (DNPs). The nomenclature of these categories reflects that long day plants require days to be longer than a critical length and short day plants require days to be shorter than a critical length in order to flower (Thomas & Vince-Prue, 1997; Thomas & Vince-Prue, 1984). However, plants do not detect light rather detect the lack of light (night length - the length of uninterrupted darkness) using phytochromes or blue light receptors (zeaxanthin, cryptochrome and phototropin). Many flowering plants use phytochromes to regulate the time of flowering based on the length of day and night and to set circadian rhythms (Taiz & Zeiger, 2010). Phytochromes are some proteins that can detect light and has two different isomers, phytochrome red (P_R) and phytochrome far-red (P_{FR}) which are sensitive to light in the red (620-750nm) and far-red (700-800nm) regions of the visible spectrum (390-750nm).

The intensity of light is an indication of the strength of a light source at a particular wavelength is also important in determining the flowering process in many plants. It has been reported that many long day ornamental plants responded better to more intense light sources (Baloch *et al.,* 2012). The intensity of irradiance vary from plant to plant such as flowering plants require 6,000-10,000 lux (74-124µmol.m^{-2}.s^{-1}), flowering bulbs need 500-1,000 lux (6-12µmol.m^{-2}.s^{-1}) and most foliage plants need 1,000-6,000 lux (12-74µmol.m^{-2}.s^{-1}) light irradiance (Thomas & Vince-Prue, 1997). Although, *Saintpaulia* flowered at 5,000-13,000 lux (62-161µmol.m^{-2}.s^{-1}) but the rate of flowering is higher at increased light intensity (Hildrum & Kristoffersen, 1969). For old plants, light intensity of 10,000-15,000 lux (124-186µmol.m^{-2}.s^{-1}) and 5,000-8,000 lux (62-99µmol.m^{-2}.s^{-1}) for young vegetative plants are recommended by Post (1942). Similarly, *Cicer arietinum* produced early and more flowers under high light intensity i.e. 28 kilolux (347µmol.m^{-2}.s^{-1}) than the lower (16 kilolux, 198µmol.m^{-2}.s^{-1}) one (Sandhu & Hodges, 1971). In other study, Karlsson (2001) reported that 12 mol·d^{-1}.m^{-2} (320µmol.m^{-2}.s^{-1}) light intensity is more important than the length of day (photoperiod) for cyclamen's growth, leaf development and rate of flowering.

Slow growth and development process in winter is a limiting factor for early flower production in many long day annuals due to low light integrals. However, flowering process in short day plants accelerated under low ambient light (Baloch *et al.,* 2009a; Baloch *et al.,* 2009b). Similarly, artificial light intensity significantly affects time to flowering in long day plants rather than short day plants as long day plants are more responsive to light intensity whereas night break significantly affects the rate of flowering in short day plants (Thomas & Vince-Prue, 1997; Thomas & Vince-Prue, 1984). This assumption was tested in the present experiment wherein six short day ornamental annuals were selected to study their flowering response under four different light intensities during winter conditions.

Materials and Methods

Present research was carried out at Agricultural Research Institute, Dera Ismail Khan, Pakistan, during the year 2005-2006. Seeds of 6 Facultative SDPs such as Zinnia (*Zinnia elegans* L.) cv. Lilliput, Sunflower (*Helianthus annuus* L.) cv. Elf, French Marigold (*Tagetes Patula* L.) cv. Orange Gate, African Marigold (*Tagetes* *erecta* L.) cv. Crush, Cockscomb (*Celosia cristata* L.) cv. Bombay, Cosmos (*Cosmos bipinnatus* Cav.) cv. Sonata Pink were sown on 1st of October 2005 into module trays containing homogeneous leaf mould compost. Seed trays were kept at room temperature at night and they were moved out during the day (08:00-16:00h) under partially shaded area. After 70% seed germination, six replicates of each cultivar were shifted to the respective light intensity chamber i.e., 42µmol.m^{-2}.s^{-1}, 45µmol.m^{-2}.s^{-1}, 92µmol.m^{-2}.s^{-1} and 119µmol.m^{-2}.s^{-1}. Supplementary lights were provided by SON-E Eliptical sodium lamp (OSRAM, Germany) of 50 Watt (42µmol.m^{-2}.s^{-1}), 70 Watt (45µmol.m^{-2}.s^{-1}), 100 Watt (92µmol.m^{-2}.s^{-1}) and 150 Watt (119µmol.m^{-2}.s^{-1}) for a duration of eight hours (from 08:00 to 16:00h). At 16:00h each day, Facultative SDPs were moved into a blackout chamber where they remained until 08:00h the following morning. These chambers were continuously ventilated with the help of micro exhaust fan (Fan-0051, SUPERMICRO® USA) with an average air speed of 0.2m.s^{-1} over the plants when inside the chambers, to minimize any temperature increase due to heat from the lamps. Day length, solar radiation and temperature were measured in the weather station situated one kilometer away from the research site (Table 1). Temperature was recorded with the help of Hygrothermograph (NovaLynx Corporation, USA) while solar radiation was estimated using solarimeters (Casella Measurement, UK). Plants were potted into 9 cm pots containing leaf mould compost and river sand (3:1v/v) after 6 leaves emerged. Plants were irrigated by hand and a nutrient solution [(Premium Liquid Plant Food and Fertilizer (NPK: 8-8-8); Nelson Products Inc. USA)] was applied twice a week. Plants in each treatment were observed daily until flower opening (corolla fully opened). Numbers of days to flowering from emergence were recorded at harvest and the data were analysed using GenStat-8 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK and VSN International Ltd. UK). The rate of progress to flowering ($1/f$) is represented as the reciprocal of the time to flowering, therefore $1/f$ data of Facultative SDPs were analysed using the following linear model:

$$1/f = a + b\,I \quad \text{(where a and b are constants and } I \text{ is irradiance)}$$

Table 1. Environmental detail of experiment.

Growing Season	Diurnal temperature (°C)			Daily light integral 08:00-16:00
	Maximum	Minimum	Average	
October 2005	33.16	17.13	25.15	8.75 MJ.m^{-2}.d^{-1}
November 2005	26.87	9.53	18.20	7.53 MJ.m^{-2}.d^{-1}
December 2005	22.19	2.90	12.55	7.34 MJ.m^{-2}.d^{-1}
January 2006	20.03	4.10	12.06	7.13 MJ.m^{-2}.d^{-1}
February 2006	26.64	9.00	17.82	7.03 MJ.m^{-2}.d^{-1}

Results

Time to flowering in SDPs such as Zinnia cv. Lilliput (Fig. 1A), Sunflower cv. Elf (Fig. 1B), French Marigold cv. Orange Gate (Fig. 1C), African Marigold cv. Crush (Fig. 1D), Cockscomb cv. Bombay (Fig. 1E) and Cosmos cv. Sonata Pink (Fig. 1F) was decreased significantly ($p<0.05$) with decrease in light intensity (42, 45, 92 and 119µmol.m^{-2}.s^{-1}). Plants under low irradiance (42 and 45µmol.m^{-2}.s^{-1}) took minimum time to flower whereas it increased significantly ($p<0.05$) under high irradiance levels (92 and 119µmol.m^{-2}.s^{-1}). However, there was non-significant difference between 42 and 45µmol.m^{-2}.s^{-1} and 92 and 119µmol.m^{-2}.s^{-1} irradiance levels regarding days to flowering.

It was observed that Zinnia cv. Lilliput (Fig. 1A) flowered 9 days earlier under low irradiance i.e. 42µmol.m^{-2}.s^{-1} (61 days) as compared to high irradiance i.e. 119µmol.m^{-2}.s^{-1} (70 days). Zinnia grown under 92µmol.m^{-2}.s^{-1} flowered after 67 days whereas it took 63 days under 45µmol.m^{-2}.s^{-1} irradiance. In Sunflower cv. Elf (Fig. 1B) a 9 days flowering time difference between 42µmol.m^{-2}.s^{-1} irradiance (62 days) and 119µmol.m^{-2}.s^{-1} irradiance (71 days) was observed. However, plants grown under 92µmol.m^{-2}.s^{-1} light intensity flowered after 69 days while 64 days to flower were counted in those plants which received 45µmol.m^{-2}.s^{-1} irradiance. French Marigold cv. Orange Gate (Fig. 1C) took 57 days to flower when grown under 42µmol.m^{-2}.s^{-1} irradiance followed by 59 days in 45µmol.m^{-2}.s^{-1} irradiance. Similarly, plants grown under high irradiance (119µmol.m^{-2}.s^{-1}) flowered after 66 days followed by 63 days in 92µmol.m^{-2}.s^{-1} irradiance. Plants of African Marigold cv. Crush (Fig. 1D) grown under 42, 45, 92 and 119µmol.m^{-2}.s^{-1} irradiance took 57, 59, 63 and 66 days to flower, respectively showing a 9 days difference between two extreme irradiance levels. Fig 1E depicted that Cockscomb cv. Bombay flowered 10 days earlier when grown under low (42µmol.m^{-2}.s^{-1}) irradiance (85 days) as compared to plants received high (119µmol.m^{-2}.s^{-1}) light intensity (94 days). Cockscomb grown under 92µmol.m^{-2}.s^{-1} irradiance took 91 days to flower whereas under 45µmol.m^{-2}.s^{-1} irradiance they took 87 days to bloom. Similarly, Cosmos cv. Sonata Pink (Fig. 1F) flowered 10 days earlier when grown under low (42µmol.m^{-2}.s^{-1}) irradiance (52 days) as compared to high (119µmol.m^{-2}.s^{-1}) irradiance (61 days). Cosmos plants grown under 92µmol.m^{-2}.s^{-1} chamber took 59 days to flower whereas under 45µmol.m^{-2}.s^{-1} irradiance they took 53 days to bloom.

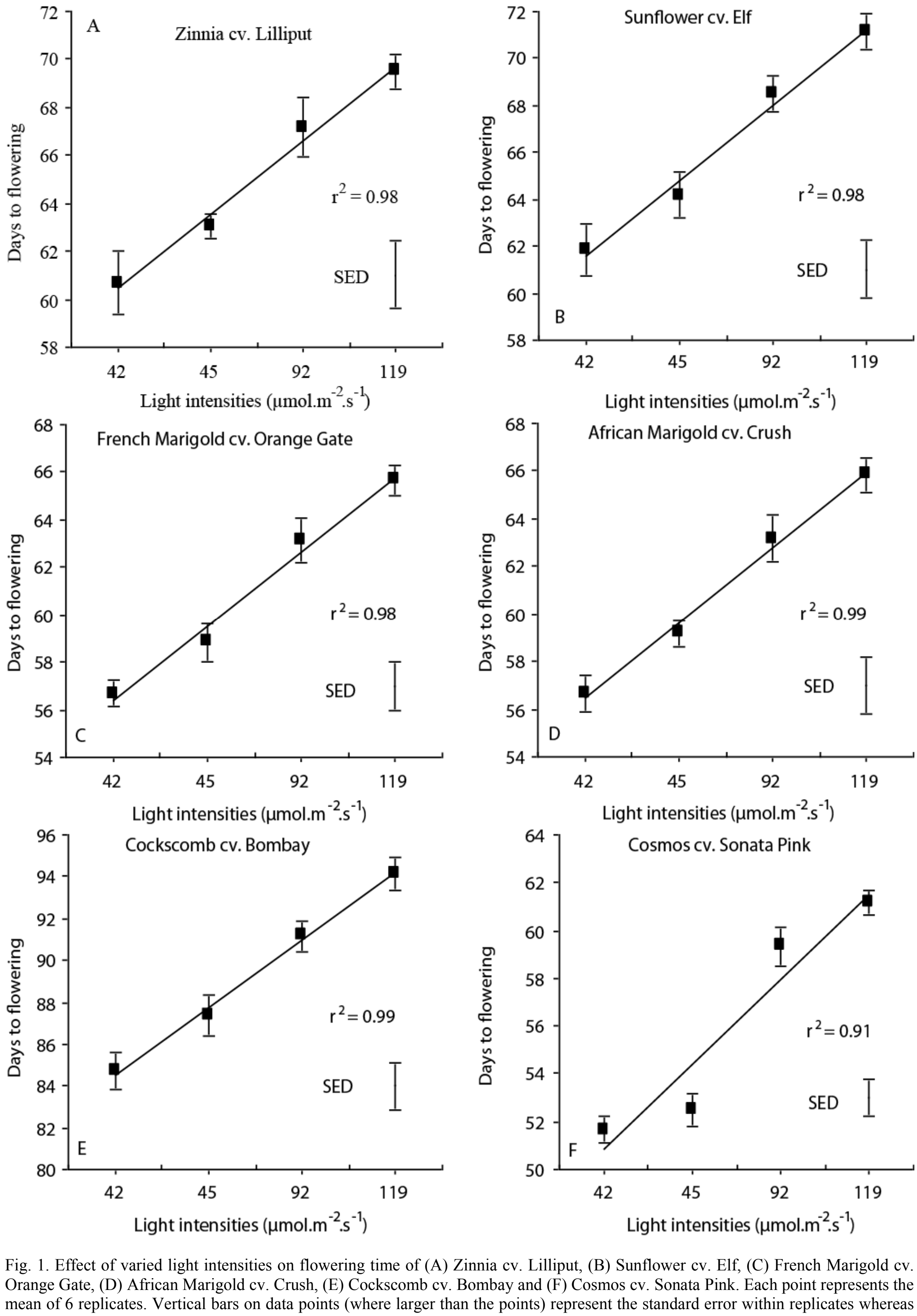

Fig. 1. Effect of varied light intensities on flowering time of (A) Zinnia cv. Lilliput, (B) Sunflower cv. Elf, (C) French Marigold cv. Orange Gate, (D) African Marigold cv. Crush, (E) Cockscomb cv. Bombay and (F) Cosmos cv. Sonata Pink. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates whereas SED vertical bar showing standard error of difference among means.

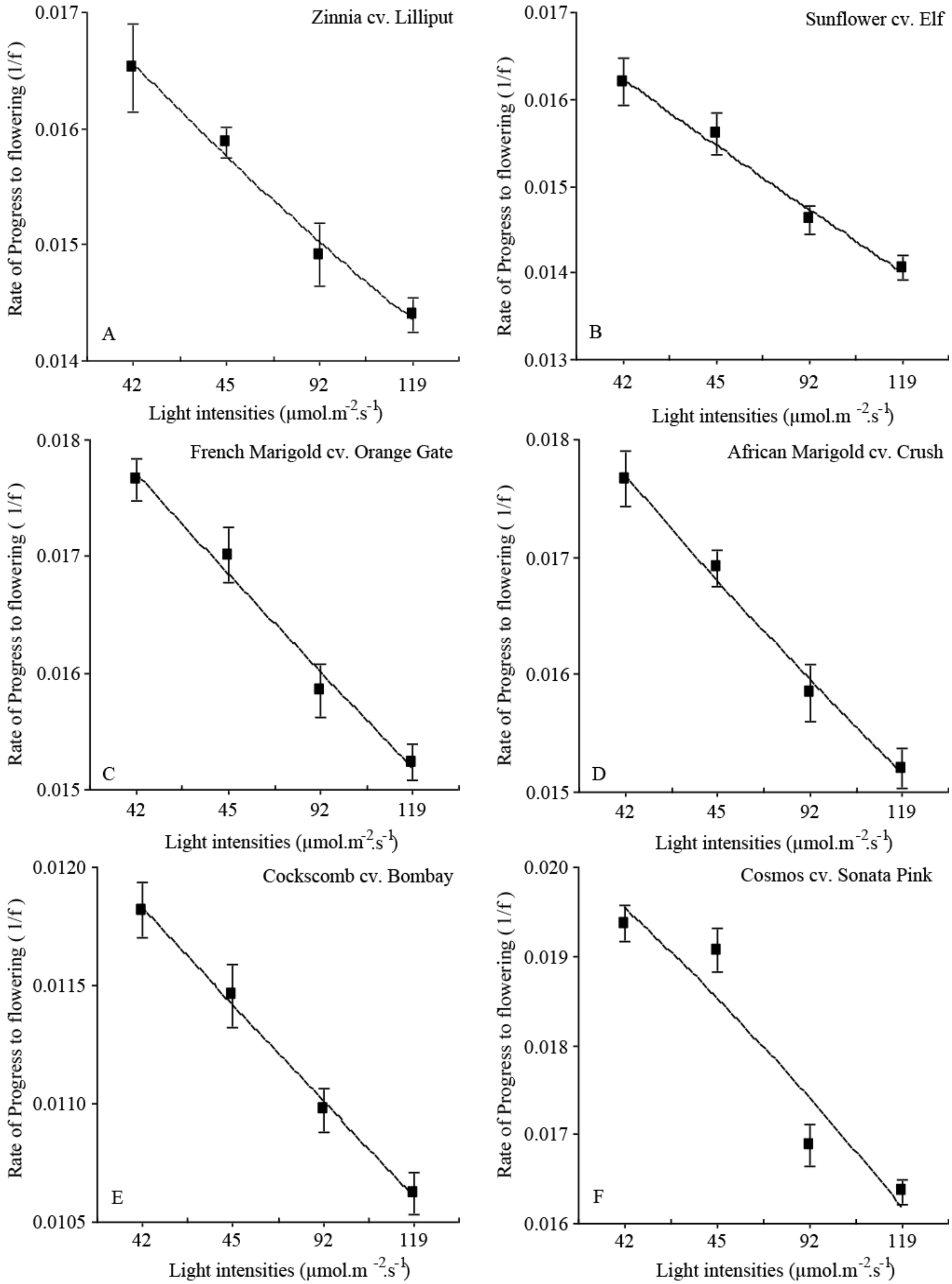

Fig. 2. Effect of varied light intensities on the rate of progress to flowering (1/*f*) of (A) Zinnia cv. Lilliput, (B) Sunflower cv. Elf, (C) French Marigold cv. Orange Gate, (D) African Marigold cv. Crush, (E) Cockscomb cv. Bombay and (F) Cosmos cv. Sonata Pink. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates.

Rate of progress to flowering increased linearly with decrease in irradiance in all Facultative SDPs. Zinnia cv. Lilliput (Fig. 2A), Sunflower cv. Elf (Fig. 2B), French Marigold cv. Orange Gate (Fig. 2C), African Marigold cv. Crush (Fig. 2D), Cockscomb cv. Bombay (Fig. 2E) and Cosmos cv. Sonata Pink (Fig. 2F) grown under high irradiance (119µmol.m^{-2}.s^{-1}) slowly progressed to produce flower as compared to same cultivars grown under 42µmol.m^{-2}.s^{-1}. Multiple linear regression showed that irradiance affected the rate of progress to flowering in all Facultative SDPs independently, indicating that the general model ($1/f$ = a + b I) was appropriate in describing the flowering response of these plants to irradiance. The best fitted model describing the effects of mean Irradiance (I) on the rate of progress to flowering ($1/f$) can be written as:

Eq. 1. Zinnia cv. Lilliput (Fig. 2A):
$1/f = -0.0173\ (\pm 0.000338) + 0.0000251\ (\pm 0.00000409)\ I$
(r^2 = 0.82, d.f. 22)

Eq. 2. Sunflower cv. Elf (Fig. 2B):
$1/f = -0.0169\ (\pm 0.000278) + 0.0000239\ (\pm 0.00000336)\ I$
(r^2 = 0.84, d.f. 22)

Eq. 3. French Marigold cv. Orange Gate (Fig. 2C):
$1/f = -0.0186\ (\pm 0.000285) + 0.0000287\ (\pm 0.00000345)\ I$
(r^2 = 0.88, d.f. 22)

Eq. 4. African Marigold cv. Crush (Fig. 2D):
$1/f = -0.0185\ (\pm 0.000294) + 0.0000284\ (\pm 0.00000356)\ I$
(r^2 = 0.87, d.f. 22)

Eq. 5. Cockscomb cv. Bombay (Fig. 2E):
$1/f = -0.0122\ (\pm 0.000498) + 0.0000133\ (\pm 0.00000181)\ I$
(r^2 = 0.85, d.f. 22)

Eq. 6. Cosmos cv. Sonata Pink (Fig. 2F):
$1/f = -0.0209\ (\pm 0.000293) + 0.0000405\ (\pm 0.00000355)\ I$
(r^2 = 0.93, d.f. 22)

Above 1-6 equations are based on individual arithmetic means of respective factors, although all data were originally tested. The values in parenthesis show the standard errors of the regression coefficients. The outcome of this model indicated that irradiance had significant effects on the rate of progress to flowering in all Facultative SDPs studied.

Discussion

Results of previous studies showed 11 (French Marigold), 13 (African Marigold), 15 (Cosmos), 16 (Cockscomb) and 19 days (Zinnia and Sunflower) earlier flowering when Facultative SDPs were raised in short ambient day length i.e., September to end of November (Baloch *et al.,* 2009a). In another study, the same Facultative SDPs produced 10 (French Marigold), 11 (African Marigold), 14 (Cockscomb), 15 (Sunflower), 16 (Zinnia) and 29 days (Cosmos) earlier flowers when grown under SD (8h.d^{-1}) environment (Baloch *et al.,* 2010). The difference in days taken to flowering between the 2 studies was assumed to be the difference in light integrals. Therefore, another experiment was designed to test flowering behaviour of these Facultative SDPs under ambient light integrals using shades. The findings of that study showed 8 (African Marigold), 9 (Cosmos), 10 (Zinnia and Sunflower) and 11 days (French Marigold and Cockscomb) earlier flowering when these plants were grown under 40% shade i.e. received 4.52 MJ m^{-2} d^{-1} light integrals (Baloch *et al.,* 2009c). Keeping in view the outcome of these studies, present experiment was designed to grow same Facultative SDPs under artificial light integrals (irradiance) to observe their flowering response. It is therefore appeared from present study that Zinnia, Sunflower, French Marigold, African Marigold, Cockscomb and Cosmos flowered 9-10 days late when received 8 hour 119µmol.m^{-2}.s^{-1} supplementary light. It is indicated that the use of artificial lights for the early or late production of Facultative SDPs is not as much beneficial as in LDPs (Baloch *et al.,* 2011). However, this technique could be followed for higher marketable return to prolong floral display or for special occasions such as Christmas time or even for export purpose. The possible assumption for late bloom in these SDPs could be that carbohydrate assimilates progression become slow under high light intensity, an opposite response as in LDPs (Wiśniewska & Treder, 2003) therefore plants could not attain reasonable plant height and apex size in a minimum time to evoke floral stimulus (Hackett & Srinivasani, 1985).

These Facultative SDPs can be grown under ambient conditions in summer (March to September) however they took long time to flower (Baloch *et al.,* 2009a). The duration of juvenile phase of these plants grown during summer is extended due to long day length i.e., 13-16 h.d^{-1} (Baloch *et al.,* 2010) and ample light integrals i.e. 8.60-10 MJ.m^{-2}.d^{-1} (Baloch *et al.,* 2009c). Present findings showed that flowering time could be extended up to 9-10 days if these plants are grown in winter (their responsive season) under high irradiance (119µmol.m^{-2}.s^{-1}). The reason why SDPs were less responsive to supplementary lights than the LDPs could be that the flower initiation in SDPs is usually inhibited by night break lighting treatments of short duration and low irradiance (flash of red light-660nm) given near the middle of the night period (Aung, 1976). However, interruption of night by far-red light (730nm) enhanced flowering in SDPs. For example, Hamner & Bonner (1938) observed that flowering in *Xanthium* (SDP) could be induced by a short light interruption in the middle of the night. Similar results were obtained in other SDPs such as *Chenopodium rubrum*, *Glycine max* and *Xanthium strumarium* (Thomas & Vince-Prue, 1997). Similarly, Schwabe (1959) observed in *Kalanchoe blossfeldiana*, Biloxi soybean, *Perilla ocymoides,* and *Chenopodium amaranticolor* (SDPs) that long days interspersed in a period of short day induction exert an active inhibition on flowering. He also confirmed that as little as one second of light per day is sufficient for flowering in *Kalanchoe*, however, no flowering occurred in complete darkness. In tomato (SDP) it was observed that by extending day length or irradiance plants produced more leaves, increased leaf area and plant dry weight, more branches therefore increased flowering time (Hurd, 1973). However, Adams *et al*., (2008) reported that *Impatiens* and tomato (SDPs) showed less dramatic increases in dry weight as a result of long day lighting than Petunia (LDP), but no consistent effects on leaf area or growth habit were observed. In tomato, increased growth was accompanied by increased chlorophyll content, but this had no significant effect on photosynthesis. In both species, increased growth may have been due to a direct effect of long day lighting on photosynthesis.

Conclusion

It can be concluded from present research findings that flowering time of Zinnia, Sunflower, French Marigold, African Marigold, Cockscomb and Cosmos can be delayed under high irradiance (92/119µmol.m^{-2}.s^{-1}) in order to continuous supply of these plants in the market and to enhance their flower display period. However, these facultative SDPs can be subjected to low irradiance (42/45µmol.m^{-2}.s^{-1}) if an early flowering is required. Moreover, these plants can be grown under high irradiance (92/119µmol.m^{-2}.s^{-1}) during juvenile phase to improve plant quality for marketing/consumers' viewpoint. The outcome of present study also indicated a possibility of year-round production of these plants, which will subsequently increase the income of growers related to ornamental industry.

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(Received for publication 20 January 2012)