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Effects of different photoperiods on flowering time of facultative short day ornamental annuals

Jalal-Ud-Din Baloch*, M. Qasim Khan, M. Munir[1] and M. Zubair[2]

Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan; [1]School of Plant Sciences, The University of Reading, Reading, UK; [2]University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan.
**E-mail: jalaluddinbaloch@live.com*

Abstract

An experiment was carried out to study flowering response of six facultative short day plants (zinnia cv. Lilliput, sunflower cv. Elf, French marigold cv. Orange Gate, African marigold cv. Crush, cockscomb cv. Bombay and cosmos cv. Sonata Pink) under four distinct controlled photoperiods (8, 11, 14 and 17 h d^{-1}). A curvilinear facultative response was observed in almost all cultivars studied. zinnia, sunflower, French marigold, African marigold, cockscomb and cosmos took minimum time to flower when grown under 8 h d^{-1} photoperiods however it was significantly ($P<0.05$) increased when photoperiod was increased to 17 h d^{-1}. These findings revealed plant scheduling prospect that is, the flowering time of facultative SDPs grown under long day photoperiod can be extended in order to continue supply of these plants in the market.

Key words: Ornamental annuals, short day plants, flowering, photoperiod, facultative short day plants

Introduction

Flowering is the end result of physiological processes, biochemical sequences, and gene action, with the whole system responding to the influence of environmental stimuli (photoperiod, temperature) and the passage of time (Zheng *et al.,* 2006). After attaining a certain size (completing the 'juvenile' phase), plants enter into the 'reproductive' phase (initiation and development of flowering). Evans (1969) referred to flowering as the inductive processes occurring in the leaf (O'Neil, 1992), mediated by the photoreceptor (phytochrome) that leads to the initiation of floral development (McDaniel *et al.,* 1992) at the meristem (evocation). It is also believed that flowering is induced by a stimulus (florigen), which is produced within the leaf (Chailakhyan, 1936) but this hormone has not yet been identified (Turck *et al.,* 2008). When the apical meristem of the plant is differentiated for flowering, its fate becomes irreversible (Bernier, 1988), although flower or inflorescence reversion to vegetative growth can also occur spontaneously in some species. This condition can be caused if plants are transferred to certain specific photoperiod or temperature regimes, which favour vegetative development (Battey and Lyndon, 1990).

Many flowering plants use a photoreceptor protein, such as phytochrome or cryptochrome, to sense seasonal changes in day length (photoperiod), which they take as signals to flower (Weller and Kendrick, 2008). The photoperiodic response of flowering is generally categorised into three main groups: short-day plants (SDPs) in which flowering is induced by longer nights; long-day plants (LDPs) where shorter nights promote flowering; and day-neutral plants (DNPs) in which flower are produced irrespective to day length. SDPs and LDPs can be further classified as qualitative or obligate (species that require a specific minimum or maximum photoperiod for flowering) and quantitative or facultative (flowering process is hastened by a specific minimum or maximum photoperiod). It is in fact, the night length rather than day length that controls flowering, so flowering in a long day (LD) plant is triggered by a short night (which, of course, also means a long day). Conversely, short day (SD) plants will flower when nights get longer than a critical length. This can be observed by using night breaks. For example, a short day plant (long night) will not flower if a pulse (5 minutes) of artificial light is shone on the plant during the middle of the night. This generally does not occur from natural light such as moonlight, lightning, fire flies, etc, since the light from these sources is not sufficiently strong to trigger the response (Thomas and Vince-Prue, 1997). Keeping in view the importance of photoperiod on flower induction an expeiment was desgined to determine the flowering response of six facultative SDPs to four photoperiods under the sub-tropical environmental conditions.

Materials and methods

The experiment was conducted in Agricultural Research Institute, Dera Ismail Khan, Pakistan, during the year 2005. Seeds of 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 March 2005 into module trays containing locally prepared 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 photoperiod chamber. Plants remained outside the photoperiod chambers for 8h (from 08:00 to 16:00h) where they were exposed to natural daylight and temperature (Table 1). At 16:00h each day, all plants were moved into the photoperiod chambers where they remained until 08:00h the following morning. Photoperiod within each of the chambers was extended

Table 1. Environmental details of the experiment

Growth Period	Diurnal temperature (°C)			Daily light integral 08:00-16:00 MJ m^{-2} d^{-1}
	Maximum	Minimum	Average	
March 2005	26.19	13.29	19.74	8.43
April 2005	32.87	15.73	24.30	9.45
May 2005	36.39	20.35	28.37	9.40
June 2005	42.27	30.70	36.48	9.99
July 2005	36.77	25.68	31.23	9.42

by two 60Watt tungsten light bulbs and one 18Watt warm white florescent long-life bulb (Philips, Holland) fixed above one metre height from the trolleys providing a light intensity (Photosynthetic Photon Flux Density, PPFD) of 7mmol m^{-2} s^{-1}. In all photoperiod chambers, the lamps were switched on automatically at 16:00h for a duration dependents on the day length required (8, 11, 14, 17 h d^{-1}). These chambers were continuously ventilated with the help of micro exhaust fan (Fan-0051, SUPERMICRO® USA) with an average air speed of 0.2 m s^{-1} over the plants when inside the chambers, to minimize any temperature increase due to heat from the lamps.

Temperature and solar radiation were measured in the weather station situated one kilometer away from the research venue. 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 (3:1 v/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). Number of days to flowering from emergence were recorded at harvest and the data were analysed using GenStat-8 (Lawes Agricultural Trust, Rothamsted Experimental Station, U.K. and VSN International Ltd. U.K.).

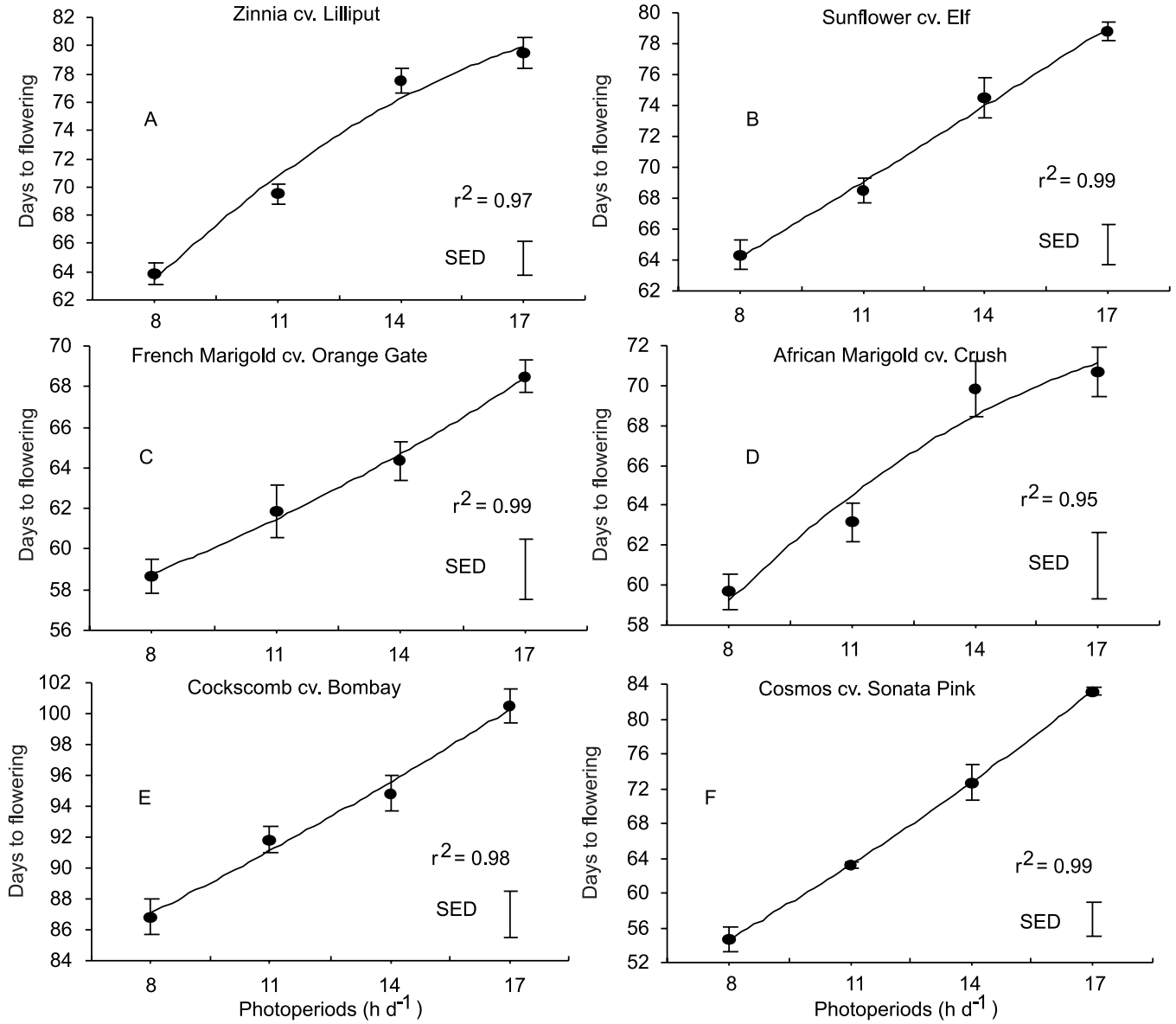

Fig. 1. Effect of different photoperiods on flowering time of (A) Zinnia cv. Lilliput, (B) Sunflower cv. Elf, (C) French marigold cv. Orange Gate, (D) African marigold cv. Crush, (E) Cockscomb cv. Bombay and (F) Cosmos cv. Sonata Pink. Each point represents the mean of 6 replicates. Vertical bars on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

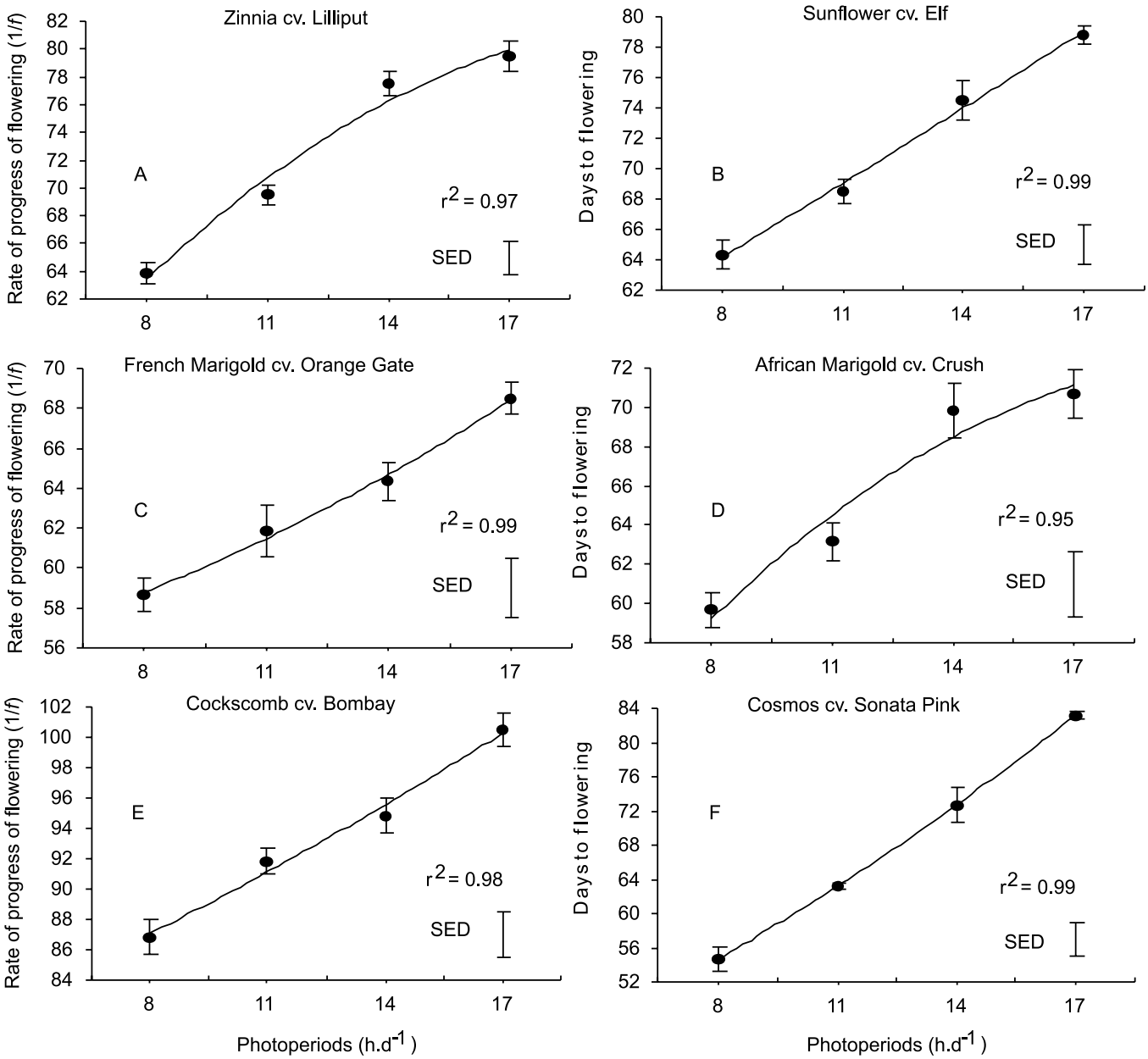

Fig. 2. Effect of different photoperiods on rate of progress to flowering (*1/f*) of (A) Zinnia cv. Lilliput, (B) Sunflower cv. Elf, (C) French marigold cv. Orange Gate, (D) African marigold cv. Crush, (E) Cockscomb cv. Bombay and (F) Cosmos cv. Sonata Pink. Each point represents the mean of 6 replicates.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

Results

Time to flowering in SDPs such as zinnia cv. Lilliput, sunflower cv. Elf, French marigold cv. Orange Gate, African marigold cv. Crush, cockscomb cv. Bombay and cosmos cv. Sonata Pink increased significantly ($P<0.05$) with increase in photoperiod. Plants received maximum duration of light took maximum time to flower whereas it was decreased significantly under minimum photoperiod treatments.

It was observed that zinnia cv. Lilliput (Fig. 1A) flowered 16 days earlier under SD *i.e.* 8 h d^{-1} photoperiod (64 days) as compared to LD *i.e.* 17 h d^{-1} photoperiod (80 days) followed by 14 h d^{-1} photoperiod (78 days) and 11 h d^{-1} photoperiod (70 days). Similarly, sunflower cv. Elf (Fig. 1B) bloomed 15 days earlier under 8 h d^{-1} photoperiod (64 days) compared to 17 h d^{-1} photoperiod (79 days) while plants grown in 14 and 11 h d^{-1} photoperiod flowered after 69 and 75 days, respectively. French marigold cv. Orange Gate (Fig. 1C) flowered 10 days early under 8 h d^{-1} photoperiod (59 days) as compared to 17 h d^{-1} photoperiod (69 days) followed by 14 and 11 h d^{-1} photoperiod *i.e.* 64 and 62 days, respectively. Similarly, African marigold cv. Crush (Fig. 1D) grown under 8 h d^{-1} photoperiod (60 days) flowered 11 days earlier than the 17 h d^{-1} photoperiod (71 days). Plants of same cultivar took 70 and 63 days to flower when grown under 14 and 11 h d^{-1} photoperiod. Cockscomb cv. Bombay (Fig. 1E) flowered 14 days earlier when grown under 8 h d^{-1} photoperiod (87 days) as compared to 17 h d^{-1} photoperiod (101 days) followed by 95 days in 14 h d^{-1} photoperiod and 92 days in 11 h d^{-1} photoperiod. Similarly, cosmos cv. Sonata Pink (Fig. 1F) when grown under 8 h d^{-1} photoperiod flowered 29 days earlier (55 day) as compared to 17 h d^{-1} photoperiod (83 days) whereas plants grown under 14 and 11 h d^{-1} photoperiod bloomed after 73 and 63 days from emergence, respectively.

Data from facultative SDPs were analysed using the following

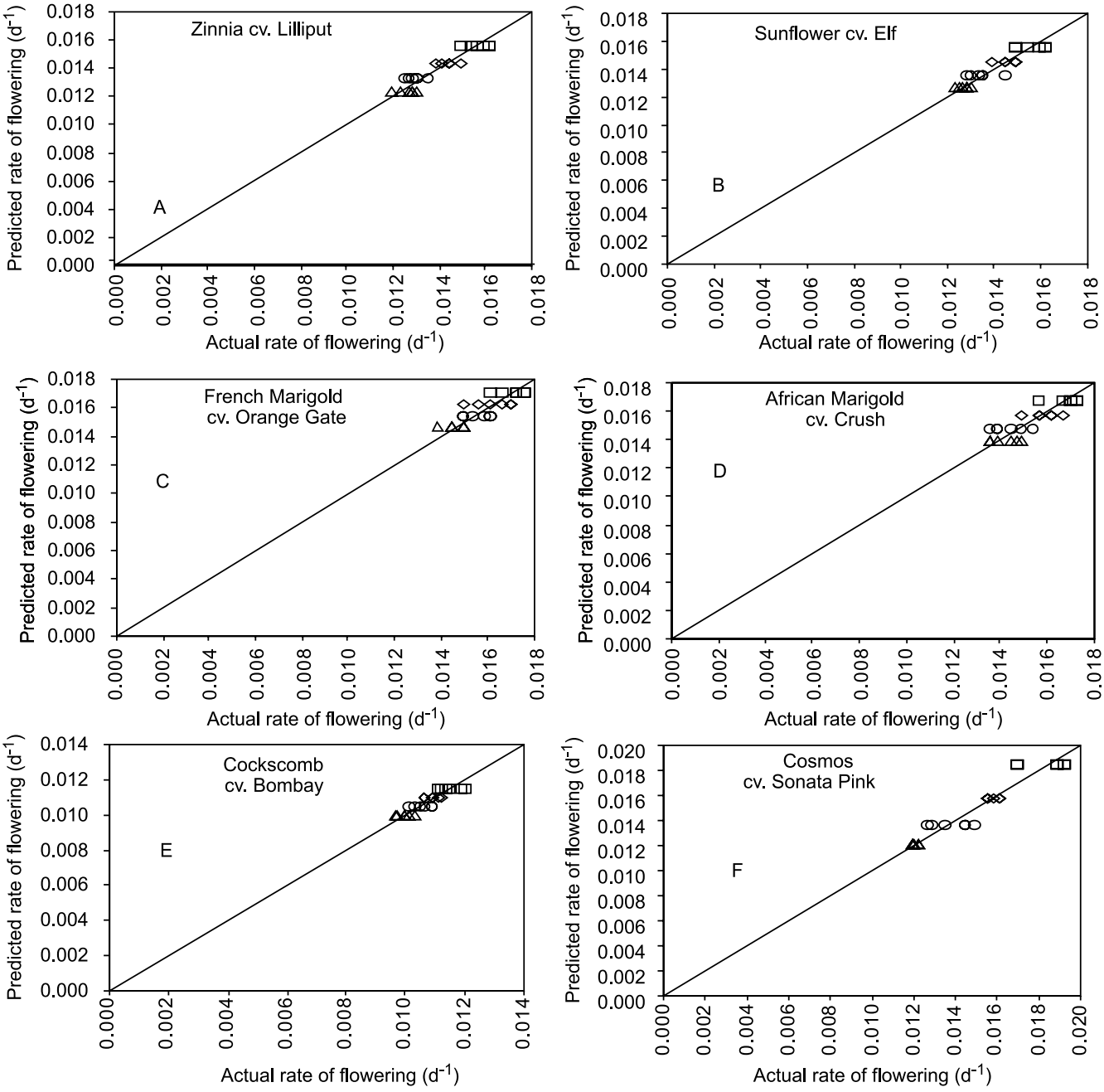

Fig. 3. The relationship between the actual rate of progress to flowering against those fitted by the flowering model ($1/f = a + bP$) for (A) Zinnia cv. Lilliput, (B) Sunflower cv. Elf, (C) French marigold cv. Orange Gate, (D) African marigold cv. Crush, (E) Cockscomb cv. Bombay and (F) Cosmos cv. Sonata Pink grown under 8 (□), 11 (◊), 14 (○) and 17 (Δ) h d^{-1} photoperiod. The sold line is the line of identity.

model:

$1/f = a + bP$

The best fitted model describing the effects of mean photoperiod (P) on the rate of progress to flowering ($1/f$) can be written as:

Zinnia cv. Lilliput (Fig. 2A) and (Fig. 3A):

$1/f = 70.67\ (\pm 1.92) + 1.88\ (\pm 0.15)\ P \quad (r^2 = 0.97, \text{d.f. } 23)$ Eq. 1

Sunflower cv. Elf (Fig. 2B) and (Fig. 3B):

$1/f = 71.92\ (\pm 1.77) + 1.65\ (\pm 0.14)\ P \quad (r^2 = 0.99, \text{d.f. } 23)$ Eq. 2

French marigold cv. Orange Gate (Fig. 2C) and (Fig. 3C):

$1/f = 50.00\ (\pm 1.84) + 1.07\ (\pm 0.14)\ P \quad (r^2 = 0.99, \text{d.f. } 23)$ Eq. 3

African marigold cv. Crush (Fig. 2D) and (Fig. 3D):

$1/f = 70.31\ (\pm 2.35) + 1.32\ (\pm 0.18)\ P \quad (r^2 = 0.95, \text{d.f. } 23)$ Eq. 4

Cockscomb cv. Bombay (Fig. 2E) and (Fig. 3E):

$1/f = 96.17\ (\pm 1.98) + 1.47\ (\pm 0.15)\ P \quad (r^2 = 0.98, \text{d.f. } 23)$ Eq. 5

Cosmos cv. Sonata Pink (Fig. 2F) and (Fig. 3F):

$1/f = 28.83\ (\pm 2.39) + 3.17\ (\pm 0.19)\ P \quad (r^2 = 0.99, \text{d.f. } 23)$ Eq. 6

Above 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 photoperiod had significant effects on the rate of progress to flowering in all facultative SDPs studied. To validate the model, actual data of rate of progress to flowering were plotted against the predicted

ones in order to develop a fitted relationship. Almost all values were successfully plotted near the line of identity which also showed that the photoperiod had a significant effect on the rate of progress to flowering.

Discussion

A facultative SD photoperiodic response of zinnia cv. Lilliput, sunflower cv. Elf, French marigold cv. Orange Gate, African marigold cv. Crush, cockscomb cv. Bombay and cosmos cv. Sonata Pink was observed during present investigation. These results are in line with the findings of Erwin and Warner (2002) who reported that flowering was hastened by SD photoperiod in SDPs. Present study indicated that flowering was hastened up to 16 (zinnia), 15 (sunflower), 10 days (French marigold), 11 (African marigold), 14 (cockscomb) and 29 days (cosmos) under SD environment (8 h d^{-1}). The response of SDPs observed in present study is supporting the fact that most SDPs are of tropical or sub-tropical origin (Summerfield *et al.*, 1997). Studies have been carried out previously to support this evidence in zinnia (Young *et al.*, 2003), sunflower (Young *et al.*, 2003; Yañez *et al.*, 2004), French and African marigold (Tsukamoto *et al.*, 1968, 1971), cockscomb (Kanellos and Pearson, 2000; Young *et al.*, 2003; Goto and Muraoka, 2008) and cosmos (Warner, 2006).

SDPs grown under inductive environment (8 h d^{-1} photoperiod) induced flowering earlier than those grown above this. The reason of early flowering under inductive environment is due to the stimulation of floral genes which are involved in the transition of flowering (phase change) that encode photoreceptors such as phytochrome (perceives red (660nm) and far-red (730nm) light) and the cryptochromes (perceives UV-A and blue light). It is reported in *Arabidopsis* that the phytochromes A and B in conjunction with the cryptochromes 1 and 2 are involved in the photoperiodic response (Mouradov *et al.,* 2002). Therefore, any ascending alteration in photoperiod (in SDPs) from the optimum one affects plants' perception of light and can delay phase change from juvenile to flowering. However, in general, far-red and blue light promote flowering in *Arabidopsis* whereas red light inhibits flowering (Lin, 2000).

The transduction of the light signals involves a complex web of interactions between photoreceptors and their corresponding interacting proteins. In term of floral induction, perception of photoperiod appears to be one of the most important transducers of the plant's environment. An important mechanism used by the plants phytochromes and cryptochromes is to communicate photoperiod activity which involves the entrainment of the circadian rhythms, a self-reinforcing endogenous clock that allows light/dark coordinated gene expression. Mizoguchi *et al.* (2005) reported that GIGANTEA (GI) gene regulates circadian rhythms and acts earlier in the hierarchy than CO and FT and suggested that GI acts between the circadian oscillator and CO to promote flowering by increasing CO and FT mRNA abundance.

These studies established an understanding that different genes control flowering process and these genes are evoked when a leaf is fated to respond to the inductive photoperiod, the leaf exports floral stimulus towards apex. In most cases, when the photoperiod becomes non-inductive (17 h d^{-1}, in present study), the leaf stops exporting signal. The important developmental event in leaf formation, as far as photoperiodic induction is concerned, appears to be the commitment of a leaf to develop the capacity to respond to the inductive photoperiod (McDaniel, 1996). In present study, it is revealed that after completing the juvenile phase (attaining a specific leaf numbers), the competent leaf (newly developed one) responded to the inductive photoperiod (short day-length) and induced floral signal toward apex to produce flower that is why an early flowering response was observed under inductive photoperiod environment in SDPs.

It can be concluded from the findings of present research that flowering time in zinnia, sunflower, French marigold, African marigold, cockscomb and cosmos can be prolonged under 17 h d^{-1} non-inductive environment to facilitate continuous supply of these plants in the market and to enhance their flower display period. However, these SDPs can be subjected to SD inductive environment (8 h d^{-1}) if an early flowering is required. These floweres can also be grown under non-inductive environment during juvenile phase to improve their quality for marketing viewpoint. The outcome of present study indicated a possibility of year-round production of these flowers, which will eventually increase the income of ornamental growers.

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