Full Length Article

Effects of Different Photoperiods on Flowering Time of Facultative Long Day Ornamental Annuals

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ABSTRACT

Experiments were carried out to study flowering response under four distinct controlled photoperiods (8, 11, 14 & 17 h d^{-1}). A curvilinear facultative response was observed in almost all cultivars studied. Moss Rose, Pansy, Snapdragon, Petunia and Annual Verbena took minimum time to flower, when grown under 17 h photoperiod however, it was significantly ($P<0.05$) increased, when photoperiod decreased to 8 h. These findings revealed a prospect of plant scheduling of the flowering time of facultative LDPs grown under short day photoperiod to extend their marketing period.

Key Words: Annuals; Facultative long day plants; Photoperiod; Flowering time

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 (Munir *et al.,* 2004; Zheng *et al.,* 2006). Generally, after attaining a certain size (completing the 'juvenile' phase) plants enter into the 'reproductive' phase (initiation & development of flowering). Inductive processes occur in the leaf (O'Neil, 1992) and result in floral initiation in which the apical meristem changes towards floral development (McDaniel *et al.,* 1992). It is also believed that flowering is induced by a stimulus (florigen), which is produced within the leaf (Turck *et al.,* 2008), but this hormone has not yet been identified. When the apical meristem of the plant is committed to 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 & 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 & Kendrick, 2008). Alteration in day-length or even in light integrals significantly affects flowering process (Baloch *et al.,* 2009). The photoperiodic response of flowering is generally categorised into three main groups: short-day plants (SDPs) in which flowering is hastened by longer nights; long-day plants (LDPs), where shorter nights promote flowering and day-neutral plants (DNPs), which flower irrespective to day-length. SDPs and LDPs can be further classified as obligate (species that require a specific minimum or maximum photoperiod for flowering) and facultative (flowering process is hastened by a specific minimum or maximum photoperiod). Keeping in view the importance of photoperiod on flower induction an expeiment was desgined to determine the flowering response of five facultative LDPs 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 LDPs such as Moss Rose (*Portulaca grandiflora* L.) cv. Sundance, Pansy (*Viola tricolour hortensis* L.) cv. Baby Bingo, Snapdragon (*Antirrhinum majus* L.) cv. Coronette, Petunia (*Petunia×hybrida* Juss.) cv. Dreams and Annual Verbena (*Verbena×hybrida* L.) cv. Obsession 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 (08:00-16:00 h) 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 8 h (from 08:00 to 16:00 h), where they were exposed to natural daylight and

temperature (Table I). At 16:00 h each day, all plants were moved into the photoperiod chambers, where they remained until 08:00 h the following morning. Photoperiod within each of the chambers was extended by two 60 Watt tungsten light bulbs and one 18 Watt warm white florescent long-life bulb (Philips, Holland) fixed above one meter high from the trolleys providing a light intensity (Photosynthetic Photon Flux Density, PPFD) of 7 μmol m^{-2} s^{-1}. In all photoperiod chambers, the lamps were switched on automatically at 1600 h 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 km away from the research site. Temperature was recorded with the help of Hygrothermograph (Nova Lynx Corporation, USA), while solar radiation was estimated using solarimeters (Casella Measurement, UK). Plants were shifted to 9 cm diameter pots containing leaf mould compost and river sand (3: 1 v/v) after 6 leaves emerged. Plants were irrigated normally and a nutrient solution [Premium Liquid Plant Food & 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 Gen Stat -8 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK & VSN International Ltd. UK).

RESULTS

Results showed a significant (P<0.05) difference among four photoperiods regarding flowering time parameter in facultative LDPs in this study (Fig. 1). Flowering time was prolonged, when these LDPs were grown in short days (SD, 8 h d^{-1}), while decreased under long day (LD) environment (17 h d^{-1}).

Moss Rose cv. Sundance (Fig. 1a) grown under 8 h photoperiod flowered 13 days later (74 days) as compared to 17 h photoperiod plants (61 days). Similarly, plants grown under 14 and 11 h photoperiod flowered after 63 and 67 days from emergence, respectively. Pansy cv. Baby Bingo (Fig. 1b) flowered 15 days earlier, when grown in 17 h photoperiod (55 days) than those, which were raised in short (8 h) photoperiod (70 days). These plants, when grown in 14 and 11 h photoperiod took 58 and 64 days to flower, respectively. A 29 days earlier flowering was observed, when plants of Snapdragon cv. Coronette (Fig. 1c) were grown under long (17 h) photoperiod (91 days) as compared to short (8 h) photoperiod (120 days). Plants of same cultivar took 95 and 110 days to flower, when grown under 14 and 11 h photoperiod, respectively. Petunia cv. Dreams (Fig. 1d), when grown under 8 h photoperiod flowered after

Table I. Environmental detail of 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

76 days from emergence, while plants receiving 17 h photoperiod flowered after 60 days (16 days later than long photoperiod). However, plants grown under 14 and 11 h photoperiod took 63 and 70 days to flower, respectively. Annual Verbena cv. Obsession (Fig. 1e) flowered 16 days late under SD (8 h) photoperiod (66 days) as compared to 17 h photoperiod (50 days). Similarly, plants receiving 14 and 11 h light period flowered after 53 and 58 days, respectively.

Data of facultative LDPs were analysed using the following 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:

Moss Rose cv. Sundance (Fig. 2a) and (Fig. 3a):

$1/f = 105.47\ (\pm1.97) + [-1.48\ (\pm0.15)]\ P$ (r^2 = 0.99, d.f. 23) **Eq. 1**

Pansy cv. Baby Bingo [Fig. 2(B) and Fig. 3(B)]:

$1/f = 104.14\ (\pm1.94) + [-1.71\ (\pm0.15)]\ P$ (r^2 = 0.99, d.f. 23) **Eq. 2**

Snapdragon cv. Coronette [Fig. 2(C) and Fig. 3(C)]:

$1/f = 146.50\ (\pm2.63) + [-3.42\ (\pm0.20)]\ P$ (r^2 = 0.99, d.f. 23) **Eq. 3**

Petunia cv. Dreams [Fig. 2(D) and Fig. 3(D)]:

$1/f = 111.64\ (\pm2.38) + [-1.86\ (\pm0.18)]\ P$ (r^2 = 0.99, d.f. 23) **Eq. 4**

Annual Verbena cv. Obsession [Fig. 2(E) and Fig. 3(E)]:

$1/f = 78.94\ (\pm2.00) + [-1.76\ (\pm0.16)]\ P$ (r^2 = 0.99, d.f. 23)   **Eq. 5**

Above equations are based on individual arithmetic means of respective factors, although all data was originally tested. Values in parenthesis show the standard errors of regression co-efficients. This model indicated that photoperiod had significant effects on the rate of progress to flowering in all facultative LDPs studied. For validation of the model, actual data of rate of progress to flowering were plotted against the predicted ones to develop a fitted relationship and almost all values were successfully plotted near the line of identity. This showed that the photoperiod had a significant effect on the rate of progress to flowering.

DISCUSSION

Results showed that cultivars of Moss Rose, Pansy, Snapdragon, Petunia and Annual Verbena had a facultative long day response i.e., long days enhanced flowering process. These results are in line with the findings of Erwin

Fig. 1. Effect of different photoperiods on flowering time of (a) Moss Rose cv. Sundance, (b) Pansy cv. Baby Bingo, (c) Snapdragon cv. Coronette, (d) Petunia cv. Dreams and (e) Annual Verbena cv. Obsession. 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
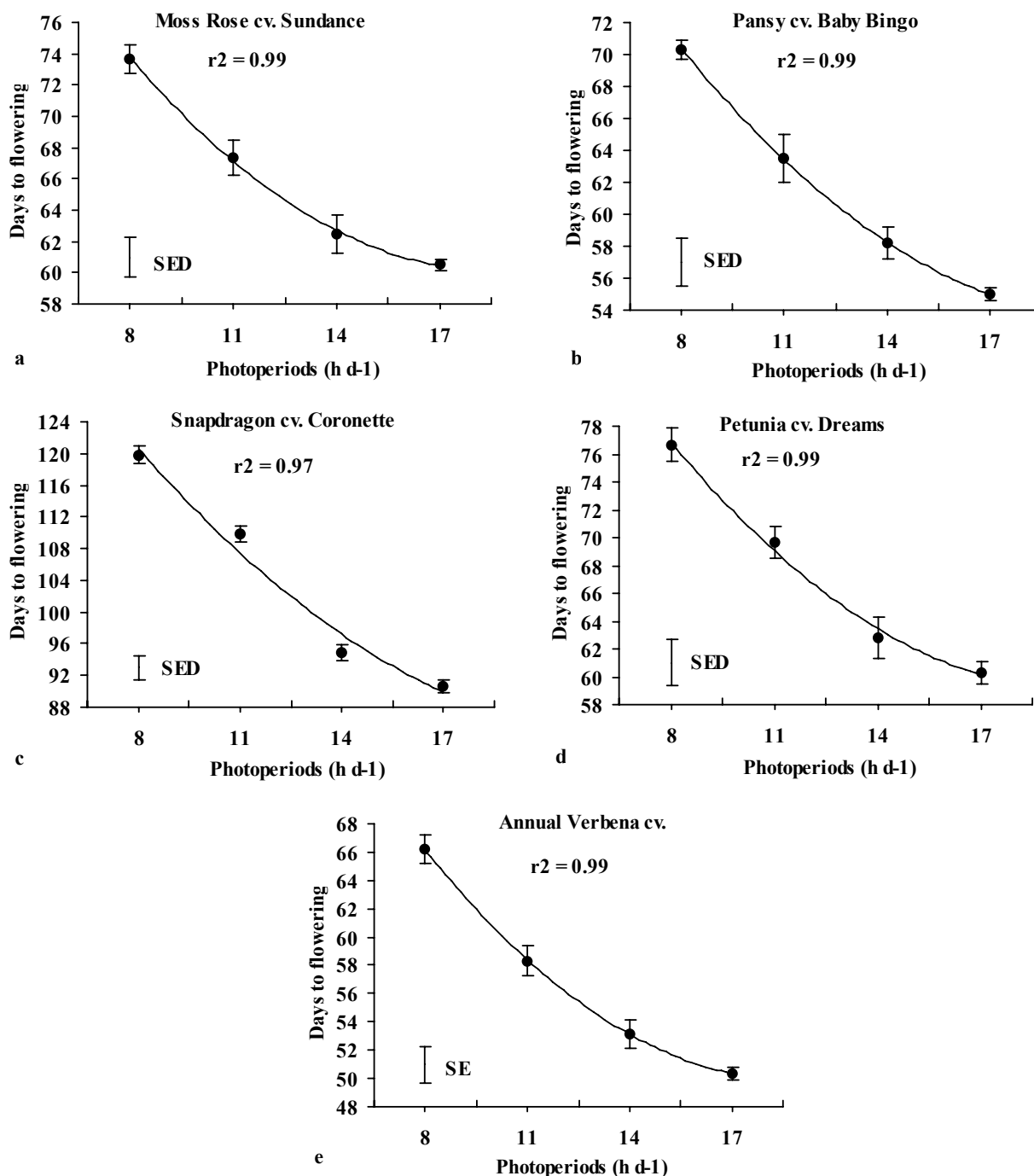

and Warner (2002), who reported that plants LD photoperiod hastened flowering in many LDPs studied. Flowering time of the cultivars was hastened up to 13 (Moss Rose), 15 (Pansy), 29 (Snapdragon) and 16 days (Petunia & Annual Verbena) earlier in long days (17 h). The response of LDPs observed in present study supported the fact that

these plants were from Mediterranean or temperate climate, where the day-length (photoperiod) is much longer than in the tropics and plants originating from this region prefer an open environment with ample sunshine (Summerfield *et al.,* 1997).

LDPs grown under inductive environment (17 h

Fig. 2. Effect of different photoperiods on rate of progress to flowering (1/*f*) of (a) Moss Rose cv. Sundance, (b) Pansy cv. Baby Bingo, (c) Snapdragon cv. Coronette, (d) Petunia cv. Dreams and (e) Annual Verbena cv. Obsession. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates
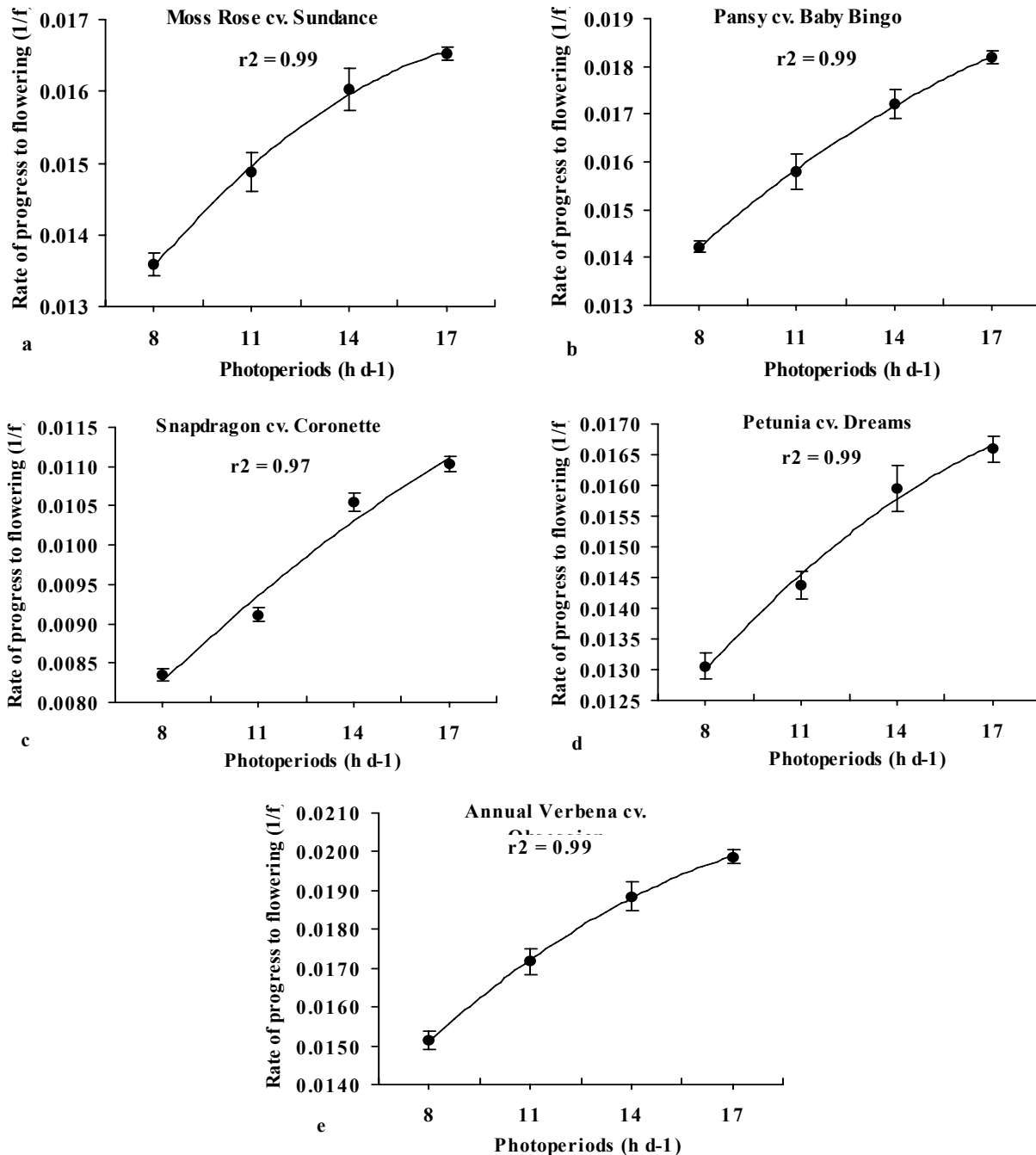

photoperiod) induced flowering earlier than those grown shorter than this. The reason of early flowering under inductive environment is due to the stimulation of floral genes, which are implicated in the transition of flowering (phase change) are those that encode photoreceptors such as phytochromes and cryptochromes, which are involved in the photoperiodic response (Mouradov *et al.,* 2002). Therefore,

any descending (in LDPs) alteration in photoperiod from the optimum affects plant's perception of light and can delay phase change from juvenile to flowering. In general, far-red and blue light promote flowering in *Arabidopsis,* whereas red light inhibits flowering (Lin, 2000).

Flower development at the shoot apex is initiated in response to environmental cues. A systemic signal, called

Fig. 3. The relationship between the actual rate of progress to flowering against those fitted by the flowering model (1/*f* = a+b*P*) for (a) Moss Rose cv. Sundance, (b) Pansy cv. Baby Bingo, (c) Snapdragon cv. Coronette, (d) Petunia cv. Dreams and (e) Annual Verbena cv. Obsession grown under 8 (□), 11 (◊), 14 (○) and 17 h d⁻¹ (Δ) photoperiod. The sold line is the line of identity
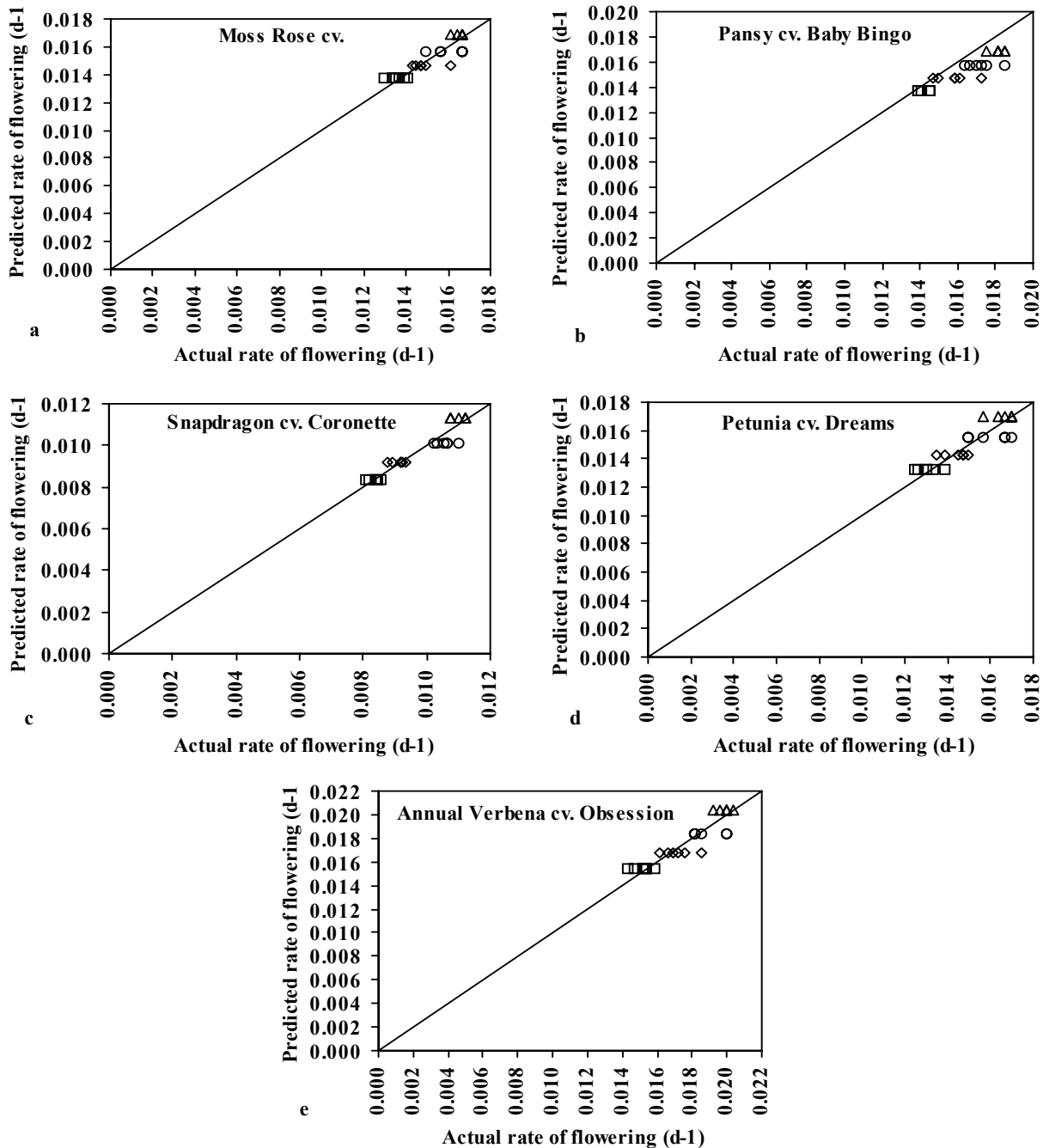
the floral stimulus is transmitted from the leaves through the phloem and induces floral development at the shoot apex. An *et al.* (2004) identified pathway of genes required for the initiation of flowering in response to photoperiod in *Arabidopsis*. The nuclear zinc-finger protein Constans (CO) plays a central role in this pathway and in response to LD activates the transcription of FT (Flowering Locus T) gene, which encodes a RAF-kinase-inhibitor-like protein. After the activation of FT, CO regulates the synthesis or transport of a systemic flowering signal, thereby positioning this signal within the established hierarchy of regulatory proteins that controls flowering. This assertion can be related to present study in a way that facultative LDPs committed to flower earlier, when they received sufficient duration of LD.

The transduction of the light signals involves a complex web of interactions between photoreceptors and

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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 to communicate photoperiod activity involves the entrainment of the circadian rhythms, a self-reinforcing endogenous clock that allows light/dark co-ordinated 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 m RNA abundance.

These studies established 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 (SD, 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). From the present study, it is revealed that after completing the juvenile phase (attaining a specific leaf numbers), the competent leaf (newly developed one) respond to the inductive photoperiod and induced floral signal toward apex to produce flower that is why an early flowering response was observed under inductive photoperiod environment in LDPs.

CONCLUSION

Flowering time in Moss Rose, Pansy, Snapdragon, Petunia and Annual Verbena can be prolonged under SD non-inductive environment in order to continue supply of these plants in the market and to enhance their flower display period. However, these LDPs can be subjected to LD inductive environment if an early flowering is required. These plants can be grown under non-inductive SD environment during juvenile phase to improve their quality for marketing view point. Results further show the possibility of year round production of these plants, which will eventually increase the income of ornamental growers.

REFERENCES

An, H., C. Roussot, P. Suárez-López, L. Corbesier, C. Vincent, M. Piñeiro, S. Hepworth, A. Mouradov, S. Justin, C. Turnbull and G. Coupland, 2004. Constans acts in the phloem to regulate a systemic signal that induces photoperiodic flowering of *Arabidopsis*. *Develop.,* 131: 3615–3626

Baloch, J.U.D., M.Q. Khan, M. Zubair and M. Munir, 2009. Effects of different shade levels (light integrals) on time to flowering of important ornamental annuals. *Int. J. Agric. Biol.,* 11: 138–144

Battey, N.H. and R.F. Lyndon, 1990. Reversion of flowering. *Bot. Rev.,* 56: 162–189

Bernier, G., 1988. The control of floral evocation and morphogenesis. *Annl. Rev. Plant Physiol. Plant Mol. Biol.,* 39: 175–219

Erwin, J.E. and R.M. Warner, 2002. Determination of photoperiodic response group and effect of supplemental irradiance on flowering of several bedding plant species. *Acta Hort.,* 580: 95–99

Lin, C., 2000. Photoreceptors and regulation of flowering time. *Plant Physiol.,* 123: 39–50

McDaniel, C.N., 1996. Developmental physiology of floral initiation in *Nicotiana tabacum* L. *J. Exp. Bot.,* 47: 465–475

McDaniel, C.N., S.R. Singer and S.M.E. Smith, 1992. Developmental states associated with the floral transition. *Develop. Biol.,* 153: 59–69

Mizoguchi, T., L. Wright, S. Fujiwara, F. Cremer, K. Lee, H. Onouchi, A. Mouradov, S. Fowler, H. Kamada, J. Putterill and G. Coupland, 2005. Distinct roles of Gigantea in promoting flowering and regulating circadian rhythms in *Arabidopsis*. *Plant Cell,* 17: 2255–2270

Mouradov, A., F. Cremer and G. Coupland, 2002. Control of flowering time interacting pathways as a basis for diversity. *Plant Cell,* 14: 111–130

Munir, M., M. Jamil, J. Baloch and K.R. Khattak, 2004. Growth and flowering of *Antirrhinum majus* L. under varying temperatures. *Int. J. Agric. Biol.,* 6: 173–178

O'Neil, 1992. The photoperiodic control of flowering: Progress toward the understanding of the mechanism of induction. *Photochem. Photobiol.,* 56: 789–801

Summerfield, R.J., R.H. Ellis, P.Q. Craufurd, Q. Aiming, E.H. Roberts and T.R. Wheeler, 1997. Environmental and genetic regulation of flowering of tropical annual crops. *Euphytica,* 96: 83–91

Turck, F., F. Fornara and G. Coupland, 2008. Regulation and Identity of Florigen: Flowering Locus T Moves Center Stage. *Annu. Rev. Plant Biol.,* 59: 573–594

Weller, J.L. and R.E. Kendrick, 2008. Photomorphogenesis and photoperiodism in plants. *In*: Björn, L.O. (ed.), *Photobiology, the Science Life and Light,* 2nd edition, pp: 417–463. Springer, New York, U.S.A

Zheng, Z.L., Z. Yang, J.C. Jang and J.D. Metzger, 2006. Phytochromes A_1 and B_1 have distinct functions in the photoperiodic control of flowering in the obligate long-day plant *Nicotiana sylvestris*. *Plant Cell Environ.,* 29: 1673–1685