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EFFECTS OF VARIED IRRADIANCE ON FLOWERING TIME OF FACULTATIVE LONG-DAY ORNAMENTAL ANNUALS

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Abstract

Seeds of five Facultative long day plants (FLDPs) i.e. Moss Rose cv. Sundance, Pansy cv. Baby Bingo, Snapdragon cv. Coronette, Petunia cv. Dreams and Annual Verbena cv. Obsession 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). The findings of this study showed that Facultative LDPs grown under high irradiance (92 and 119 µmol.m^{-2}.s^{-1}) flowered earlier. However, there was a non-significant difference between 42/45µmol.m^{-2}.s^{-1} and 92/119µmol.m^{-2}.s^{-1} irradiance levels. Although FLDPs under 119µmol.m^{-2}.s^{-1} flowered few days earlier than those received 92µmol.m^{-2}.s^{-1} irradiance but the quality of plants (plant height and leaf size/appearance) was inferior. It is therefore concluded that for better plant quality and early flowering FLDPs should be grown under 92µmol.m^{-2}.s^{-1} irradiance.

Introduction

Light is one of the essential factor in maintaining plants growth and development. The rate of growth and length of time a plant remains active is dependent on the amount of light it receives. Light energy is used in photosynthesis, the plant's most basic metabolic process (Murchie *et al.,* 2002). When determining the effect of light on plant growth there are three areas to consider: duration, intensity and quality. Effect of light duration (photoperiod) has been studied in the previous experiments (Baloch *et al.,* 2009b). In the present studies the response of Facultative long day plants (LDPs) to light intensities (irradiance) was investigated. Light intensity is an indication of the strength of a light source. It influences the photosynthesis, stem length, leaf colour and flowering. It significantly affects time to flowering in LDPs rather than the short day plants (SDPs) as LDPs are more responsive to light intensity whereas night break significantly affects the duration of flowering in SDPs (Thomas & Vince-Prue, 1997). They reported that the intensity of illumination vary from plant to plant such as flowering plants have high light requirement i.e., 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 from 1,000-6,000 lux (12-74µmol.m^{-2}.s^{-1}). Similarly, Hildrum & Kristoffersen (1969) found that the plants of *Saintpaulia* flowered with light intensities from 5,000 to 13,000 lux (62-161µmol.m^{-2}.s^{-1}). Post (1942) recommended a light intensity of 10,000 to 15,000 lux (124-186µmol.m^{-2}.s^{-1}) for old flowering plants and 5,000 to 8,000 lux (62-99µmol.m^{-2}.s^{-1}) for young vegetative plants. However, *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 one (198µmol.m^{-2}.s^{-1}) (Sandhu & Hodges, 1971).

In another study, Karlsson (2001) reported that light intensity 12 mol.d^{-1}.m^{-2} (320µmol.m^{-2}.s^{-1}) is more important than the length of day for cyclamen's growth, leaf development and rate of flowering. Working on inbreds of snapdragon (Sippe-50 and S-412) Cremer *et al.* (1998) observed that plants at the lowest light intensity (4000 lux) never flowered while at higher light intensity (30000 lux) flowered after 110-120 days. By comparing and contrasting the effects of light intensity and photoperiod on an early (Pink Ice) and a late (Orchid Rocket) flowering cultivar of snapdragon, Hedley (1974) observed that the increasing light intensity caused a dramatic reduction in leaf number at flowering in a late flowering cultivar but had no effect in an early flowering cultivar. Keeping in view an experiment was designed to study the response of some LDPs under four different light intensities during winter conditions.

Materials and Methods

Present research study was carried out at Agricultural Research Institute, Dera Ismail Khan, Pakistan, during the year 2005-2006. Seeds of five 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 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 LDPs were moved into a 17h photoperiod chamber where they remained until 08:00h the following morning. Photoperiod (17h) within chamber was extended by two 60Watt tungsten light bulbs and one 18Watt warm white florescent long-life bulb (Philips, Holland) fixed above 1m high from the trolleys providing a light intensity (PPFD) of 7µmol m^{-2} s^{-1}. In this photoperiod chamber, the lamps were switched on automatically at 1600h for further nine hours duration. 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 and 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 site (Fig 1-4). Temperature was recorded with the help of Hygrothermograph (NovaLynx Corporation, USA) while solar radiation was estimated using solarimeters (Casella Measurement, UK). After the emergence of six leaves, plants were potted into 9cm pots containing leaf mould compost and river sand (3:1v/v). 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 LDPs were analysed using the following linear model (Adams *et al.,* 1998; Munir, 2003):

$$1/f = a + b\,I$$

where a and b are constants and I is irradiance

Results

Day length, average photosynthetic active radiation, monthly (maximum, minimum and average) temperature recorded during the year 2005/2006 are shown in Fig. 1 to 4 respectively. However, the precise environmental detail during the experiment is given in Table 1. Results obtained from present experiment indicated that different light intensities (42, 45, 92 and $119 \mu mol.m^{-2}.s^{-1}$) significantly ($P<0.05$) affect flowering time of Facultative LDPs (Moss Rose cv. Sundance (Fig 5A), Pansy cv. Baby Bingo (Fig 5B), Snapdragon cv. Coronette (Fig 5C), Petunia cv. Dreams (Fig 5D) and Annual Verbena cv. Obsession (Fig 5E). Plants under low irradiance (42 and 45 $\mu mol.m^{-2}.s^{-1}$) took more time to flower whereas it decreased significantly ($P<0.05$) when these plants were grown under high irradiance ($119 \mu mol.m^{-2}.s^{-1}$). However, there was non-significant difference between $42/45 \mu mol.m^{-2}.s^{-1}$ and $92/119 \mu mol.m^{-2}.s^{-1}$ irradiance regarding days to flowering.

Table 1. Environmental detail of the experiment.

Growing Season	Diurnal temperature (°C)			Daily light integral 08:00-16:00	Day length ($h.d^{-1}$)
	Maximum	Minimum	Average		
October 2005	33.16	17.13	25.15	$8.75 MJ.m^{-2}.d^{-1}$	12.72
November 2005	26.87	9.53	18.20	$7.53 MJ.m^{-2}.d^{-1}$	11.99
December 2005	22.19	2.90	12.55	$7.34 MJ.m^{-2}.d^{-1}$	11.75
January 2006	20.03	4.10	12.06	$7.13 MJ.m^{-2}.d^{-1}$	12.12
February 2006	26.64	9.00	17.82	$7.03 MJ.m^{-2}.d^{-1}$	12.52

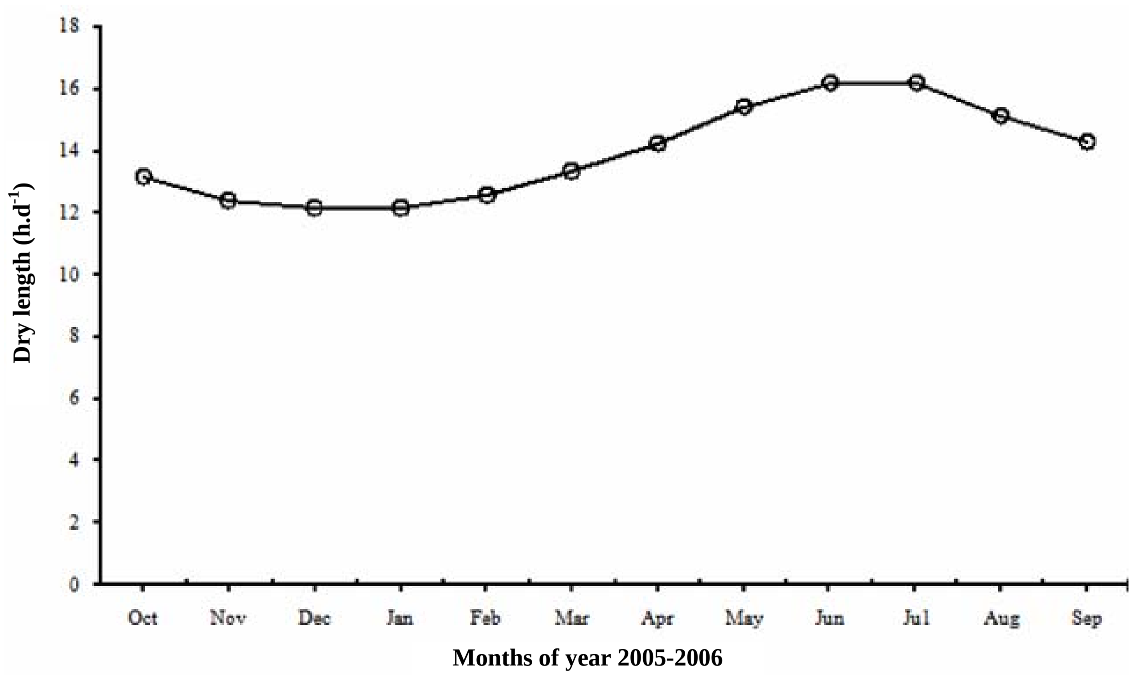

Fig. 1. Day length ($h.d^{-1}$) recorded from dawn to sunset at weather station.

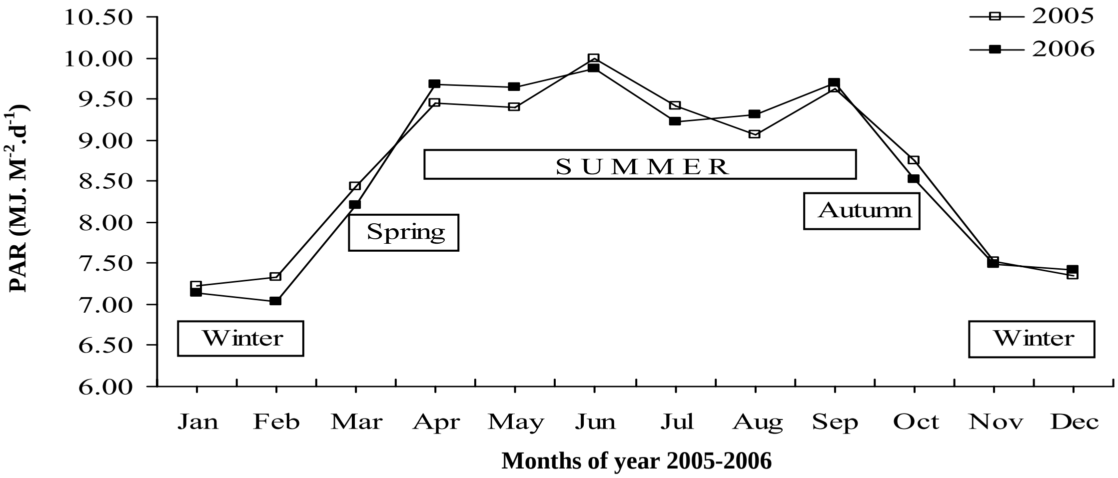

Fig. 2. Average photosynthetic active radiation (PAR, MJ.m^{-2}.d^{-1}) recorded using solarimeters at weather station during the experimental year 2005-2006.

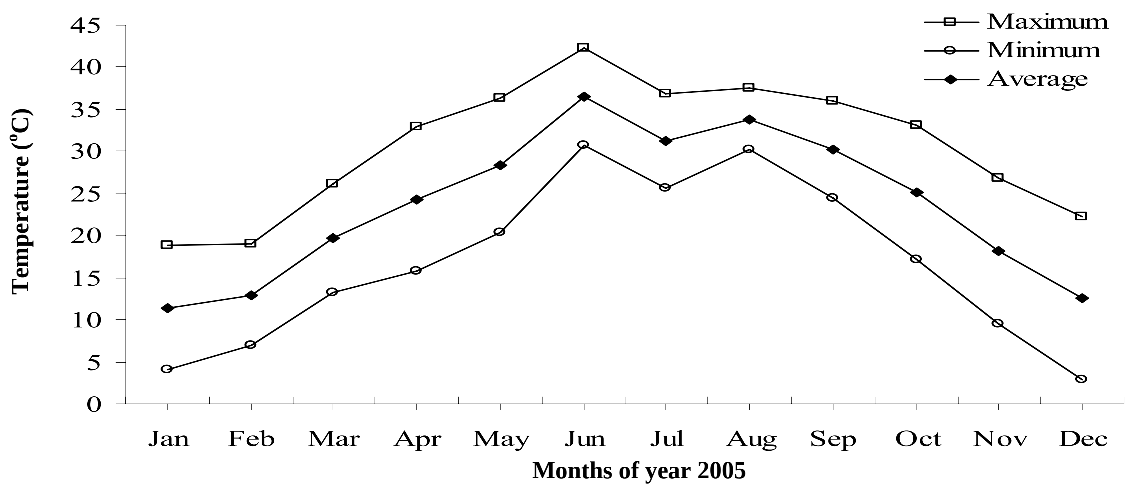

Fig. 3. Monthly maximum, minimum and average temperature (°C) recorded using a hygrothermograph at weather station during the experimental year 2005.

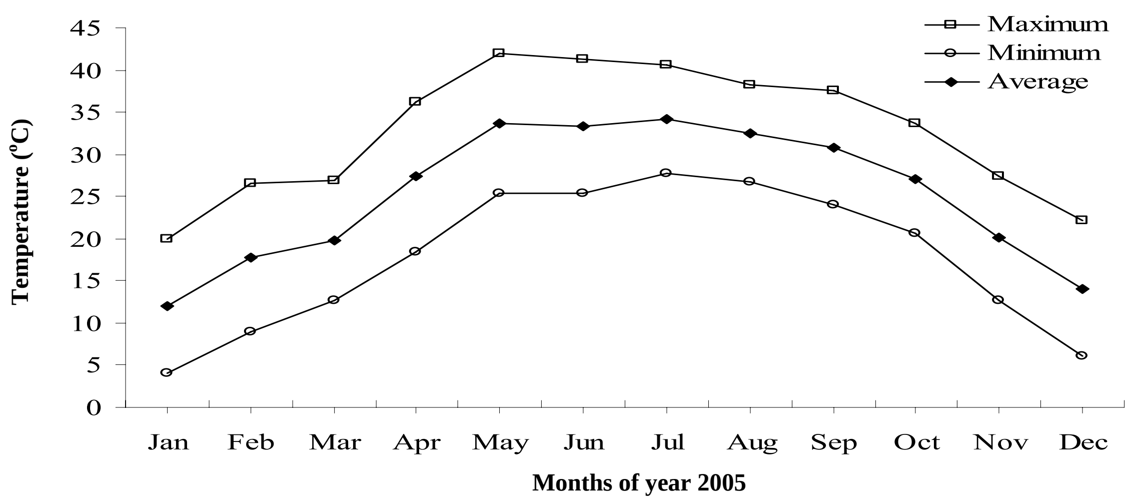

Fig. 4. Monthly maximum, minimum and average temperature (°C) recorded using a hygrothermograph at weather station during the experimental year 2006.

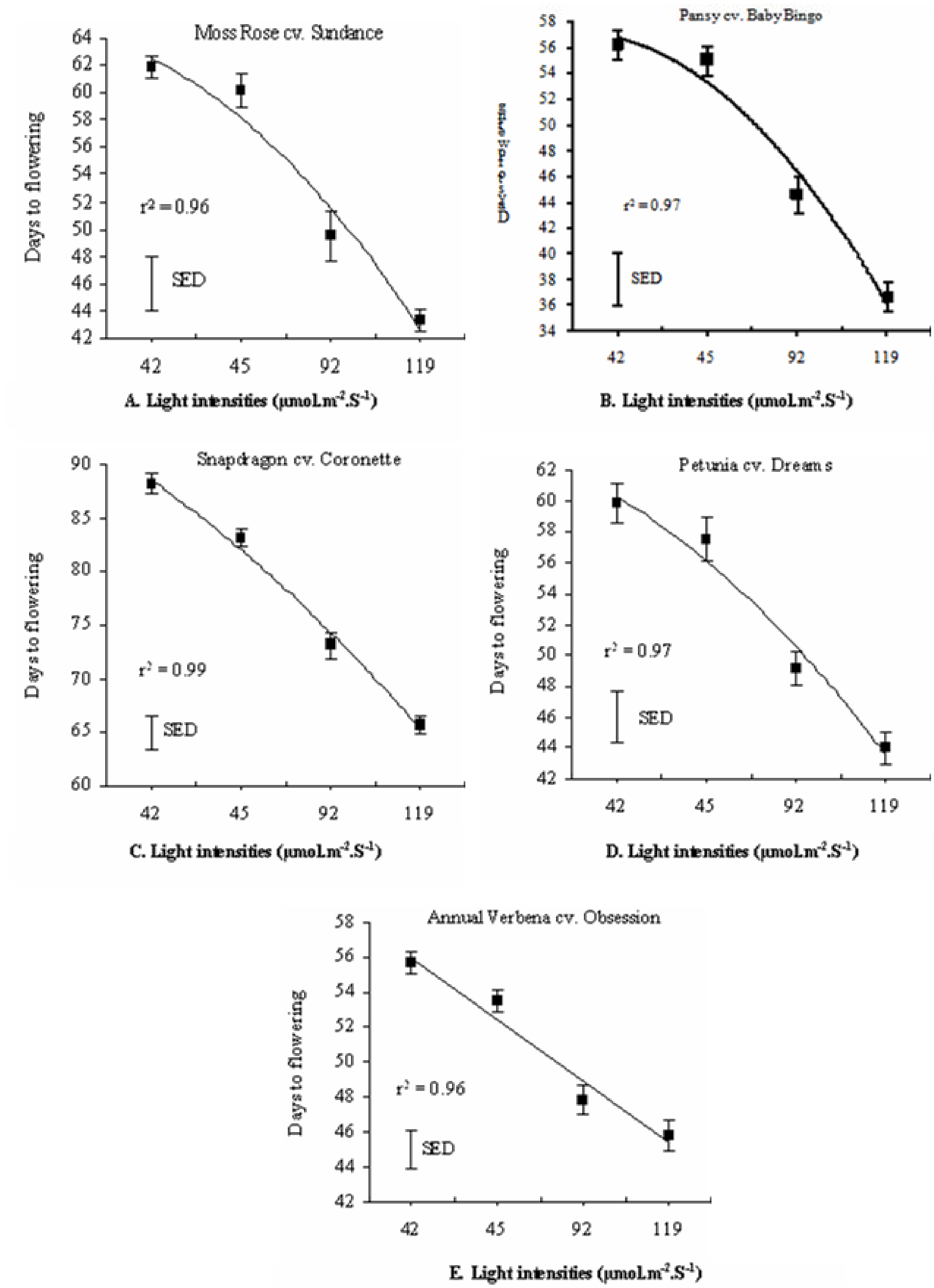

Fig. 5. Effect of different light intensities on flowering time of (A) Moss Rose cv. Sundance, (B) Pansy cv. Baby Bingo, (C) Snapdragon cv. Coronette, (D) Petunia cv. Dreams and (E) Annual Verbena cv. Obsession. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates whereas SED vertical bar showing standard error of difference among means.

Moss Rose cv. Sundance (Fig 5A) when grown under low irradiance (42 and 45 $\mu mol.m^{-2}.s^{-1}$) flowered after 62 and 60 days from emergence, respectively however plants of same cultivar under high irradiance (92 and 119 $\mu mol.m^{-2}.s^{-1}$) flowered after 50 and 43 days, respectively. High irradiance reduced flowering time by 19 days. Similarly, Pansy cv. Baby Bingo (Fig 5B) took 56 ($42\mu mol.m^{-2}.s^{-1}$) and 55 ($45\mu mol.m^{-2}.s^{-1}$) days to flower under low light intensity followed by 45 ($92\mu mol.m^{-2}.s^{-1}$) and 37 days under high light intensity ($119\mu mol.m^{-2}.s^{-1}$). Plants under low light intensity took 20 days more to flower (late flowering) as compared to plants received high light intensity. Flowering was observed twenty-one days earlier when plants of Snapdragon cv. Coronette (Fig 5C) were grown under high ($119\mu mol.m^{-2}.s^{-1}$) irradiance (took 66 days to flower) as compared to plants of cv. Coronette were raised under low ($42\mu mol.m^{-2}.s^{-1}$) irradiance (took 88 days to flower). On the other hand, plants received $45\mu mol.m^{-2}.s^{-1}$ light intensity produce flowers after 83 days whereas those plants grown under $92\mu mol.m^{-2}.s^{-1}$ light level flowered after 73 days. A 16 days late flowering was observed in Petunia cv. Dreams (Fig 5D) when they were grown under low ($42\mu mol.m^{-2}.s^{-1}$) irradiance (60 days) as compared to high ($119\mu mol.m^{-2}.s^{-1}$) irradiance (44 days). Similarly, plants grown under second low irradiance ($45\mu mol.m^{-2}.s^{-1}$) took 58 days to flower whereas plants received $92\mu mol.m^{-2}.s^{-1}$ irradiance took 49 days to flower. Fig 5E depicted that Annual Verbena cv. Obsession flowered 10 days late under $42\mu mol.m^{-2}.s^{-1}$ (56 days) while plants took 46 days to flower when received $119\mu mol.m^{-2}.s^{-1}$ irradiance. However, time to flowering was 54 days under $45\mu mol.m^{-2}.s^{-1}$ and 48 days under $92\mu mol.m^{-2}.s^{-1}$ irradiance.

Rate of progress to flowering increased linearly with irradiance up to $119\mu mol.m^{-2}.s^{-1}$. For example, Facultative LDPs (Moss Rose cv. Sundance (Fig 6A), Pansy cv. Baby Bingo (Fig 6B), Snapdragon cv. Coronette (Fig 6C), Petunia cv. Dreams (Fig 6D) and Annual Verbena cv. Obsession (Fig 6E) grown at $119\mu mol.m^{-2}.s^{-1}$ irradiance progressed slowly to produce flower as compared to same cultivars grown under 92 and $119\mu mol.m^{-2}.s^{-1}$. Multiple linear regression showed that irradiance affected the rate of progress to flowering in all FLDPs independently, indicating that the general model ($1/f = a + b\ I$) was appropriate in describing the flowering response of Moss Rose, Pansy, Snapdragon, Petunia and Annual Verbena 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. Moss Rose cv. Sundance (Fig 6A):
$1/f = 0.0125\ (\pm 0.000596) + 0.0000877\ (\pm 0.00000721)\ I$
($r^2 = 0.94$, d.f. 22)

Eq. 2. Pansy cv. Baby Bingo (Fig 6B):
$1/f = 0.0129\ (\pm 0.000838) + 0.000116\ (\pm 0.0000102)\ I$
($r^2 = 0.93$, d.f. 22)

Eq. 3. Snapdragon cv. Coronette (Fig 6C):
$1/f = 0.00968\ (\pm 0.000249) + 0.0000457\ (\pm 0.00000301)\ I$
($r^2 = 0.96$, d.f. 22)

Eq. 4. Petunia cv. Dreams (Fig 6D):
$1/f = 0.0138\ (\pm 0.000605) + 0.0000746\ (\pm 0.00000733)\ I$
($r^2 = 0.91$, d.f. 22)

Eq. 5. Annual Verbena cv. Obsession (Fig 6E):
$1/f = 0.0163\ (\pm 0.000417) + 0.0000481\ (\pm 0.00000506)\ I$
($r^2 = 0.90$, d.f. 22)

Above equations 1-5 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 LDPs studied.

Discussion

Light duration and irradiance, either independently or in combination have a critical role in the development of many plant species (Khawar *et al*., 2010). The results of previous studies showed 10 (Moss Rose, Pansy and Annual Verbena), 13 (Petunia) and 14 days (Snapdragon) earlier flowering when Facultative LDPs were raised in long ambient day length i.e., April to mid of June (Baloch *et al.,* 2009a). In another study, it was shown that same FLDPs produced 13 (Moss Rose), 15 (Pansy), 16 (Petunia and Annual Verbena) and 26 days (Snapdragon) earlier flowers when grown under LD ($17h.d^{-1}$) environment (Baloch *et al.,* 2009b). The difference in days for flowering between the two studies was assumed to be the difference in light integrals. Therefore, another experiment was designed to test flowering behaviour of these Facultative LDPs under ambient light integrals (using shades). The findings of that study showed 17 (Annual Verbena), 21 (Moss Rose), 23 (Petunia), 24 (Pansy) and 31 days (Snapdragon) late flowering when these plants were grown under 40% shade (Baloch *et al.,* 2009c). On the basis of these studies, present experiment was conducted growing same FLDPs under artificial light integrals (irradiance) to observe the flowering time. It is observed during the present study that Annual Verbena, Petunia, Moss Rose, Pansy and Snapdragon flowered 10, 16, 19, 20 and 23 days earlier when received 8 hour $119\mu mol.m^{-2}.s^{-1}$ supplementary light. It is anticipated that the use of artificial lights could enhance the rate of progress to flowering, which reduces blossom time. It is possibly assumed that when there is high irradiance available to the FLDPs, the carbohydrate assimilates progression may become rapid (Wiśniewska & Treder, 2003) therefore plants attain reasonable plant height and apex size in a minimum time to evoke floral stimulus (Hackett & Srinivasani, 1985). Similarly, some previous investigations have shown that increased irradiance promotes flower initiation in the *Sinapis alba* (LDP) and some changes occurred that are normally observed during the transition to flowering (full evocation), e.g., elevated soluble sugar and starch levels, increased number of mitochondria and changed nucleolus structure. These changes are of similar magnitude and follow the same sequence as the corresponding changes during full evocation (Havelange & Bernier, 1983).

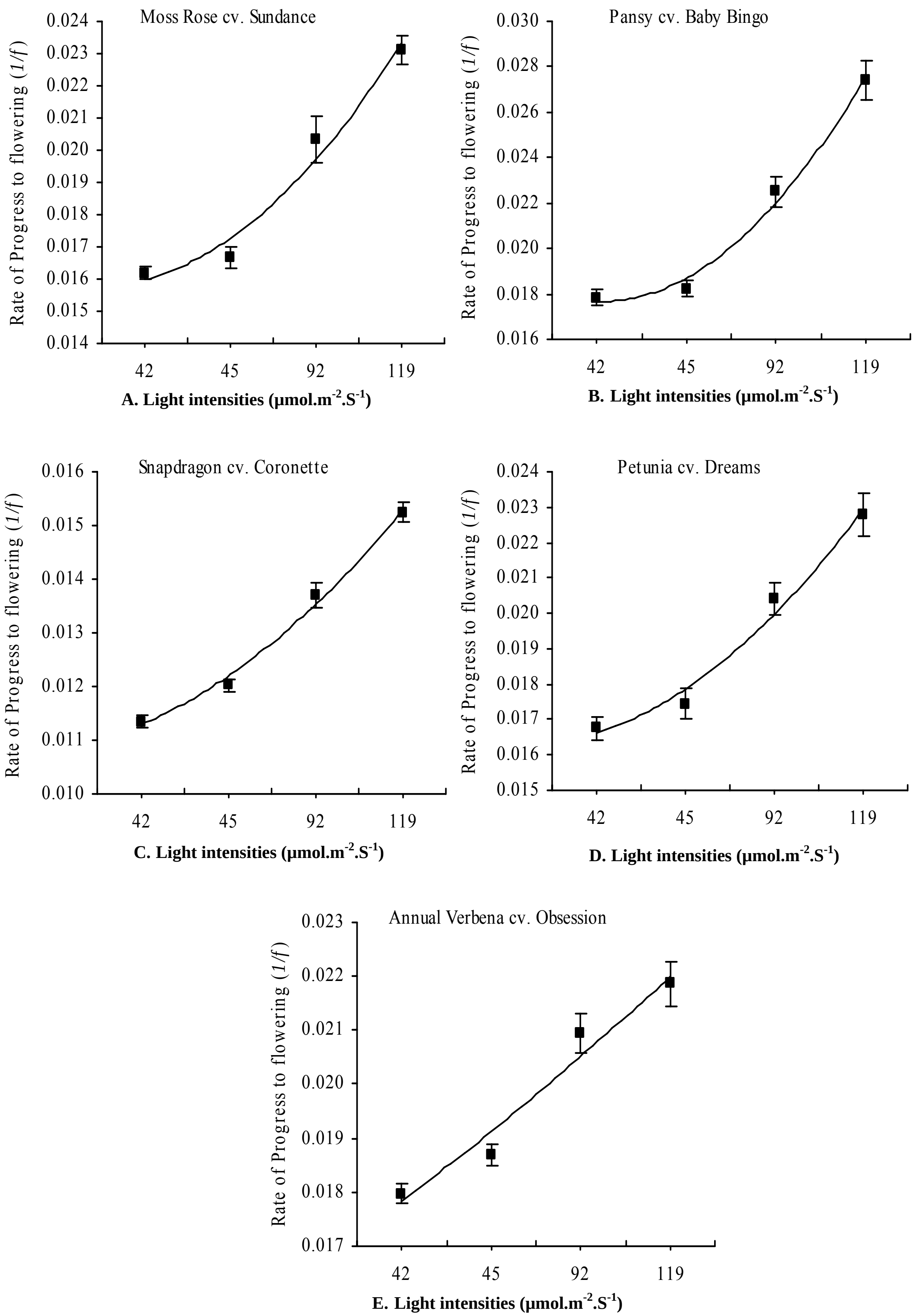

Fig. 6. Effect of different light intensities on rate of progress to flowering (*1/f*) of (A) Moss Rose cv. Sundance, (B) Pansy cv. Baby Bingo, (C) Snapdragon cv. Coronette, (D) Petunia cv. Dreams and (E) Annual Verbena cv. Obsession. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates.

Adams *et al.*, (1998) reported that Petunia showed the most dramatic response to irradiance as dry weight and specific leaf area significantly increased by low irradiance. At low PPFD, the increased leaf area more than compensated for any loss in photosynthetic capacity per unit leaf area. In present study, Facultative LDPs took maximum time to flower when grown under low irradiance (42/45µmol.m^{-2}.s^{-1}) because of the prolonged vegetative growth (increase in leaf area and plant height). Similarly, Shimai (2001) observed that flowering time was significantly hastened under high irradiance in Petunia. Jadwiga (2003) obtained similar results and reported that supplementary lighting accelerated flowering time by 3 weeks in lily cv. Laura Lee during winter which opens an avenue for LDPs to be grown in winter as well. The findings of present research can be applied to grow Facultative LDPs during winter season in temperate regions of Pakistan for their year-round production and to supply these plants in the market at the time of demand. Therefore, by expanding growing time of these plants nurserymen or ornamental industry can reasonably increase their income (Erwin & Warner, 2002). However, optimum temperature should be maintained for a successful crop production in temperate climate otherwise slow plant growth and leaf development could affect the supply and demand chain (Pramuk & Runkle, 2003; Munir *et al.,* 2004; Ushio *et al.,* 2007).

Conclusion

On the basis of above studies it may be concluded that flowering time of Moss Rose, Pansy, Snapdragon, Petunia and Annual Verbena can be delayed under low irradiance (42/45µmol.m^{-2}.s^{-1}) in order to continuous supply of these plants in the market and to enhance their flower display period. These FLDPs may be subjected to high irradiance (92/119µmol.m^{-2}.s^{-1}) if an early flowering is required. These plants can be grown under low irradiance (42/45µmol.m^{-2}.s^{-1}) during juvenile phase to improve plant quality for marketing/consumers' viewpoint. In addition, the 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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