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EFFECTS OF SUPPLEMENTARY IRRADIANCE ON FLOWERING TIME OF OBLIGATE LONG DAY ORNAMENTAL ANNUALS UNDER NON-INDUCTIVE ENVIRONMENT

JALAL-UD-DIN BALOCH[1*], M. MUNIR[2] AND FARZANA BIBI[3]

[1]*Faculty of Agriculture, Gomal University, D.I.Khan, Pakistan.*
[2]*Frontier Agriculture, SOYL Precision Crop Production Division, Newbury, UK.*
[3]*Department of Horticulture, Agriculture University, Peshawar, Pakistan.*
[*]*Corresponding author's email: jalaluddinbaloch@yahoo.com*

Abstract

Seeds of five Obligate LDPs (Pot Marigold cv. Resina, Annual Phlox cv. Astoria Magenta, Cornflower cv. Florence Blue, Oriental Poppy cv. Burning Heart and Flax cv. Scarlet Flax) 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 Obligate LDPs grown under high irradiance (92 and 119µmol.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 Obligate LDPs 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 Obligate LDPs should be grown under 92µmol.m^{-2}.s^{-1} irradiance.

Introduction

Ornamental plants including annuals have a wide spectrum of uses in environmental management of which the most obvious is the direct effect on the ecological position of human being (Farooq *et al.,* 2011). The display of ornamentals is the functional and aesthetic integration of people and buildings using plant and space as main tool. The necessity of ornamentals in landscape architecture is for positive control of the fast changing landscape for the future (Simpson & Ogorzaly, 2001). Ornamental plants can also be used as cover mat on eroded areas (such as bedding plants), they help in eliminating dust, and they reduce glare, air and noise pollution and heat build-up (Hirschhorn & Oldenburg, 1991). They provide good location for adventure parks, children playing ground, rest area and other social events. Ornamental plants also serve as complementor, attractors, emphasizers, diverters, indicators, and provide aesthetic function by creating attractiveness for human activities. The habit of using ornamental plants functionally for environmental improvement is yet to be employed meaningfully in developing countries including Pakistan as most growers in these countries believe in cultivating the agronomic and vegetable crops rather than to cultivate ornamental plants on extensive basis (Shaheen *et al.,* 2011). It is well documented that the growers of ornamental plants in USA, UK, Holland, France and Germany are earning more than the agronomic crops which gives us a clear beneficial vision of this industry (Plasmeijer & Yanai, 2009).

Plants interact with their environment in numerous and diverse ways. Their growth is greatly affected by the environmental factors such as light, temperature, water and nutrition. If any environmental factor is less than ideal, it limits plant's growth (Erwin, 2006). Among these environmental factors light is very important for most ornamentals regarding their flower induction. Although it is the duration of the dark period in each diurnal cycle, which is of paramount importance, it is conventional to describe photoperiodic responses in terms of day length (photoperiod). Three main categories of photoperiodic response are recognised: photoperiod insensitive or day neutral plants (DNPs), and the two types of photoperiod sensitive plants, short day plants (SDPs) which require long nights and long day plants (LDPs) which require long days (short nights). In addition, within both SDPs and LDPs there are species with obligate or absolute or qualitative responses to photoperiod (flowering does not occur without the extension (in LDPs) or reduction (in SDPs) of the duration of photoperiod) and others with quantitative or facultative responses (flowering occurs without photoperiod but extension (in LDPs) or reduction (in SDPs) of the duration of photoperiod hasten flowering). Therefore, the ecological essence of photoperiodic response is in the timing of biological events i.e. circadian rhythm (Thomas & Vince-Prue, 1997; Taiz & Zeiger, 2010). Plants grown under inductive environment are more responsive as compared to those grown under non-inductive one such as long days of summer (inductive environment) have positive effects on growth and development of LDPs grown during this season and *vice versa* (Munir, 2003). However, the glut production of these plants during a specific growing season under inductive environment is mere wastage of resources. Therefore, a strategy is needed to expand the span of growing season for year-round production of these plants not only to enable growers to get maximum return of their produce but to maintain a steady supply of these plants in the market (Pearson *et al.,* 1994; Shinwari & Qaisar, 2011).

Light intensity is an indication of the strength of a light source. It influences the photosynthesis, stem length, leaf colour and flowering. Generally, plants grown in low light tend to be spindly with light green leaves whereas a similar plant grown in very bright light tends to be shorter, better branches, and have larger, dark green leaves. Thomas and Vince-Prue (1997) reported that the intensity of illumination vary from plant to plant such as flowering plants have high light requirements 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 and 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, Sandhu and Hodges (1971) reported that *Cicer arietinum* produced early and more flowers under high light intensity (28 kilolux or 347μmol.m^{-2}.s^{-1}) than the lower one (16 kilolux or 198μmol.m^{-2}.s^{-1}). 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.

The best quality light is natural daylight and wherever possible plants should be placed under natural source of light for healthy growth. However, to extend day length in winter artificial lighting can be beneficial when natural day length and light integral decrease. These supplementary lights trigger responses such as flowering. It is reported that LDPs grown as cut flower in winter (non-inductive environment) developed slowly due to low light levels (Flint, 1958). The slow growth and development process is also the main limiting factor in early production of these plants. Several approaches have been used to overcome this problem including the use of new cultivars, raising the glasshouse temperature and using artificial lighting. A wide range of lighting is available for this purpose including incandescent, mercury and fluorescent lamps and high-pressure sodium lamps. Among these, high-pressure sodium lamps are widely used in out-of-season greenhouse production systems (Post & Weddle, 1940). Harte (1974) suggested that with additional illumination (up to 16h) and a greenhouse temperature of 20-25°C during winter, two generations of snapdragon could be grown per year. Similarly, Whetman (1965) found that incandescent lamps hastened flowering by 3 weeks and high-pressure mercury vapour lamps by 4 weeks. The effects of these specific lamps may have been confounded by differences in light intensities as light intensity has been shown to have a strong effect on flowering time. This effect was so significant that in one study, snapdragon plants at the lowest light intensity (4000 lux) never flowered while at higher light intensity (30000 lux) plants of inbreds Sippe-50 and S-412 flowered after 110-120 days (Cremer *et al.,* 1998). Keeping in view the importance of supplementary lighting during winter for year-round production of LDPs an experiment was designed to observe the effects of different light intensities as 8 hour supplementary irradiance on flowering time of Obligate LDPs under climatic condition of Dera Ismail Khan.

Materials and Methods

Seeds of five Obligate LDPs such as Pot Marigold (*Calendula officinalis* L.) cv. Resina, Annual Phlox (*Phlox drummondii* L.) cv. Astoria Magenta, Cornflower (*Centaurea cyanus* L.) cv. Florence Blue, Oriental Poppy (*Papaver orientale* L.) cv. Burning Heart and Flax (*Linum usitatissimum* L.) cv. Scarlet Flax were sown on 1st of October 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, Obligate 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 a 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 0.2m.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 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 9cm 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 Obligate LDPs were analysed using the following linear model:

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

(where a and b are constants and I is irradiance)

Table 1. Environmental detail of experiment.

Growing season	Temperature (°C)			Daily light integral 08:00-16:00	Day length
	Max	Min	Avg		(hours)
October 2005	33.16	17.13	25.15	8.75 MJ.m^{-2}.d^{-1}	13.12
November 2005	26.87	9.53	18.20	7.53 MJ.m^{-2}.d^{-1}	12.39
December 2005	22.19	2.90	12.55	7.34 MJ.m^{-2}.d^{-1}	12.15
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

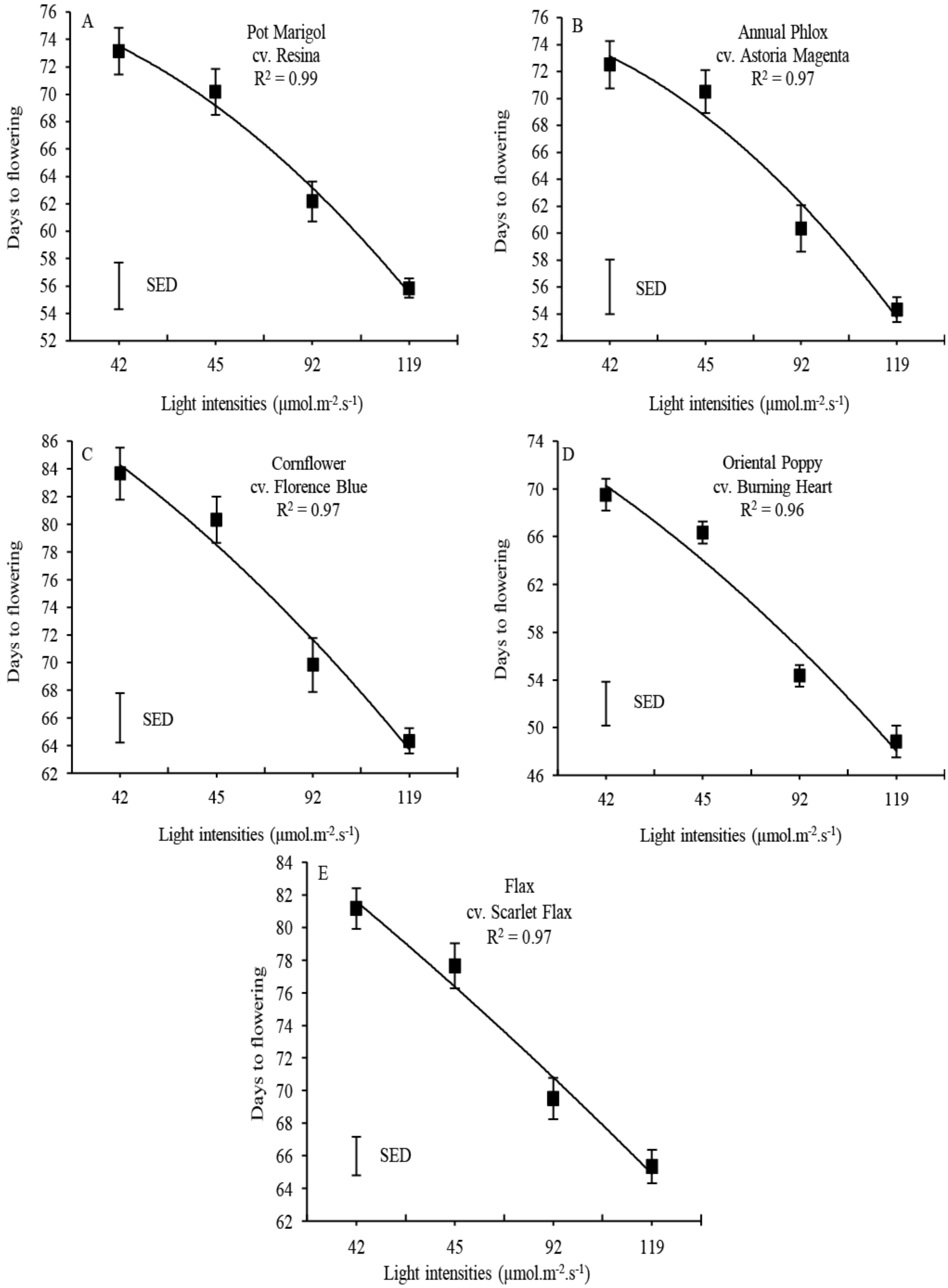

Fig. 1. Effect of varied light intensities on flowering time of (A) Pot Marigold cv. Resina, (B) Annual Phlox cv. Astoria Magenta, (C) Cornflower cv. Florence Blue, (D) Oriental Poppy cv. Burning Heart and (E) Flax cv. Scarlet Flax. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates whereas SED vertical bar showing standard error of difference among means.

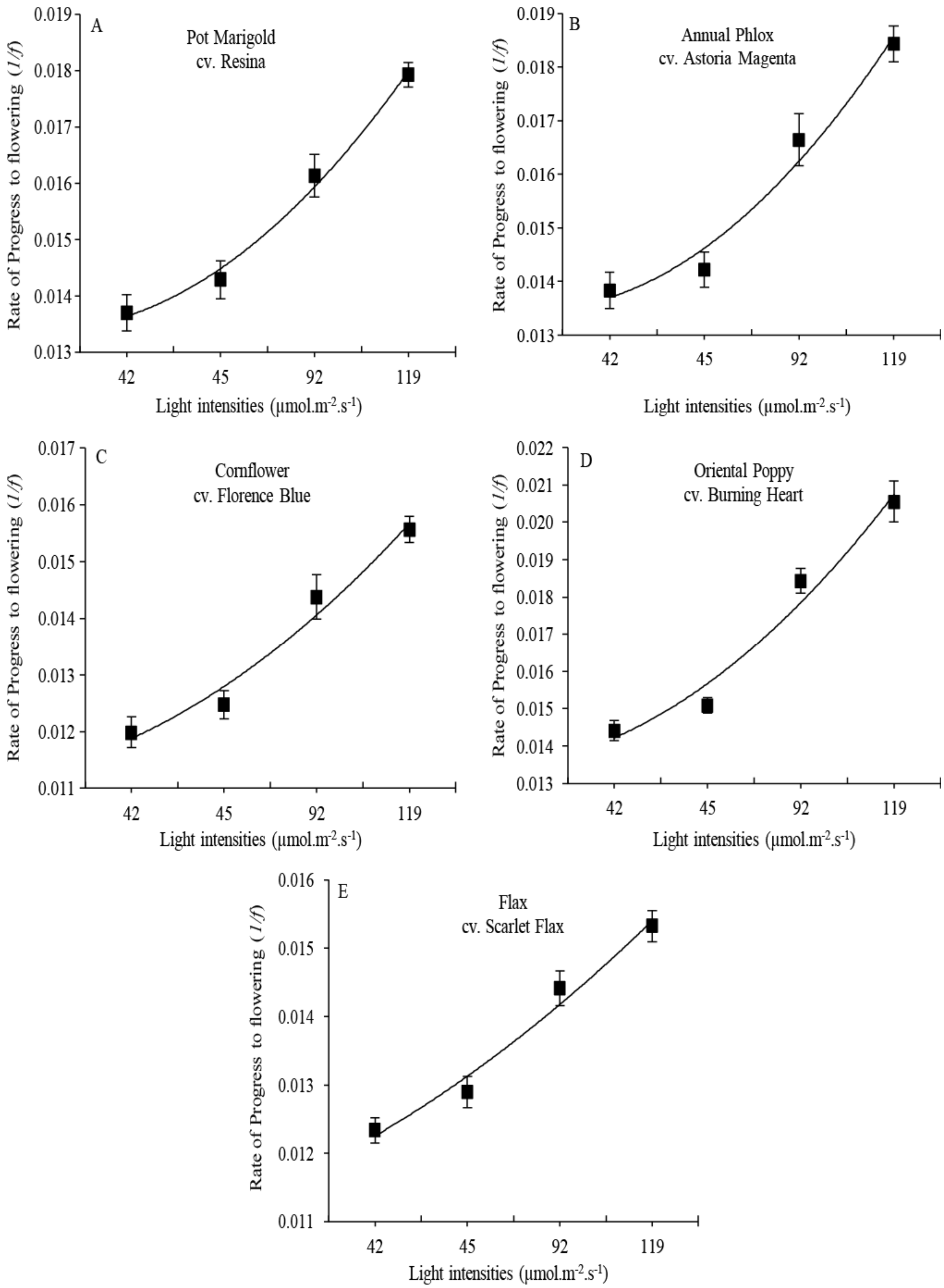

Fig. 2. Effect of varied light intensities on rate of progress to flowering (1/*f*) of (A) Pot Marigold cv. Resina, (B) Annual Phlox cv. Astoria Magenta, (C) Cornflower cv. Florence Blue, (D) Oriental Poppy cv. Burning Heart and (E) Flax cv. Scarlet Flax. Each point represents the mean of 6 replicates. Vertical bars on data points (where larger than the points) represent the standard error within replicates.

Results

Results obtained from present experiment indicated that different light intensities (42, 45, 92 and 119µmol.m^{-2}.s^{-1}) significantly ($p<0.05$) affect flowering time of Obligate LDPs (Pot Marigold cv. Resina (Fig. 1A), Annual Phlox cv. Astoria Magenta (Fig. 1B), Cornflower cv. Florence Blue (Fig. 1C), Oriental Poppy cv. Burning Heart (Fig. 1D) and Flax cv. Scarlet Flax (Fig. 1E). Plants under low irradiance (42 and 45 µmol.m^{-2}.s^{-1}) took more time to flower whereas it decreased significantly ($p<0.05$) when these plants were grown under high irradiance (119µmol.m^{-2}.s^{-1}). However, there was non-significant difference between 42/45µmol.m^{-2}.s^{-1} and 92/119µmol.m^{-2}.s^{-1} irradiance regarding days to flowering.

Pot Marigold cv. Resina (Fig. 1A) took 73, 70, 62 and 56 days to flower when grown under 42, 45, 92 and 119µmol.m^{-2}.s^{-1} light intensities, respectively. A 17 days difference was observed between the two extreme light intensities. Similarly, low irradiance (42µmol.m^{-2}.s^{-1}) delayed flowering time in Annual Phlox cv. Astoria Magenta (Fig. 1B) by 18 days (took 73 days to flower) as compared to high (119µmol.m^{-2}.s^{-1}) irradiance (54 days) followed by 12 days under 92µmol.m^{-2}.s^{-1} irradiance (60 days). However, plants took 71 days to flower when received 45µmol.m^{-2}.s^{-1} light intensity. Similarly, time to flowering was increased up to 19 days when Cornflower cv. Florence Blue (Fig. 1C) was grown under 42µmol.m^{-2}.s^{-1} light intensity (84 days) as compared to 119µmol.m^{-2}.s^{-1} irradiance (64 days). However, Cornflower plants took 70 days to flower when grown under 92µmol.m^{-2}.s^{-1} light intensity and 80 days when grown under 45µmol.m^{-2}.s^{-1} irradiance. Oriental Poppy cv. Burning Heart (Fig. 1D) flowered 21 days later under low (42µmol.m^{-2}.s^{-1}) irradiance (70 days) as compared to high (119µmol.m^{-2}.s^{-1}) irradiance (49 days). Plants grown under 92µmol.m^{-2}.s^{-1} light intensity took 54 days to bloom whereas it was 66 days in 45µmol.m^{-2}.s^{-1} light intensity. Similarly, 42µmol.m^{-2}.s^{-1} irradiance (81 days) delayed flowering time up to 16 days in Flax cv. Scarlet Flax (Fig. 1E) as compared to 119µmol.m^{-2}.s^{-1} irradiance (65 days). Flax plants received 92µmol.m^{-2}.s^{-1} irradiance flowered after 70 days of emergence whereas in 45µmol.m^{-2}.s^{-1} light intensity chamber they took 78 days to flower.

Rate of progress to flowering increased linearly with increase in irradiance in all Obligate LDPs. Pot Marigold cv. Resina (Fig. 2A), Annual Phlox cv. Astoria Magenta (Fig. 2B), Cornflower cv. Florence Blue (Fig. 2C), Oriental Poppy cv. Burning Heart (Fig. 2D) and Flax cv. Scarlet Flax (Fig. 2E) grown under 42µmol.m^{-2}.s^{-1} irradiance progressed slowly to produce flower as compared to same cultivars grown under 92 and 119µmol.m^{-2}.s^{-1}. Multiple linear regression showed that irradiance affected the rate of progress to flowering in all Obligate LDPs 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. Pot Marigold cv. Resina (Fig. 2A):

$1/f = 0.0116\ (\pm 0.000411) + 0.0000517\ (\pm 0.00000498)\ I$
($r^2 = 0.99$, d.f. 22)

Eq. 2. Annual Phlox cv. Astoria Magenta (Fig. 2B):
$1/f = 0.0117\ (\pm 0.000463) + 0.0000559\ (\pm 0.00000561)\ I$
($r^2 = 0.97$, d.f. 22)

Eq. 3. Cornflower cv. Florence Blue (Fig. 2C):
$1/f = 0.0102\ (\pm 0.000372) + 0.0000452\ (\pm 0.00000451)\ I$
($r^2 = 0.97$, d.f. 22)

Eq. 4. Oriental Poppy cv. Burning Heart (Fig. 2D):
$1/f = 0.0115\ (\pm 0.000467) + 0.0000763\ (\pm 0.00000566)\ I$
($r^2 = 0.96$, d.f. 22)

Eq. 5. Flax cv. Scarlet Flax (Fig. 2E):
$1/f = 0.0111\ (\pm 0.000301) + 0.0000362\ (\pm 0.00000365)\ I$
($r^2 = 0.97$, 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 Obligate LDPs studied.

Discussion

Irradiance, either independently or in combination have a critical role in the development of many plant species (Baloch *et al.,* 2012; Baloch *et al.,* 2013). Our previous findings showed 12 (Flax), 11 (Annual Phlox and Oriental Poppy), 10 (Pot Marigold) and 9 days (Cornflower) of earlier flowering when these Obligate LDPs were raised under long ambient day length i.e., April to mid of June (Baloch *et al.,* 2009a). In another study, the same Obligate LDPs flowered 25 (Pot Marigold and Oriental Poppy), 24 (Annual Phlox and Flax) and 22 days (Cornflower) earlier when grown under LD (17h.d^{-1}) environment (Baloch *et al.,* 2011). The difference in days taken to flowering between the two studies was assumed to be the difference in light integrals. Therefore, another experiment was designed to test flowering induction of these Obligate LDPs under ambient light integrals using shades. Plants grown under 40% shade (received 4.52 MJ m^{-2} d^{-1} light integrals) delayed flowering up to 31 (Oriental Poppy), 24 (Annual Phlox), 23 (Pot Marigold), 22 (Cornflower) and 20 (Flax) days (Baloch *et al.,* 2009b). Keeping in view the outcome of these studies, present experiment was designed to grow these Obligate LDPs under artificial light integrals to observe their flowering time during winter condition providing 8 hour supplementary irradiance. This study revealed that Oriental Poppy (21 days), Cornflower (19 days), Annual Phlox (18 days), Pot Marigold (17 days) and Flax (16 days) flowered earlier when received 8 hour 119µmol.m^{-2}.s^{-1} supplementary irradiance during non-inductive winter conditions. It is hence anticipated that the use of artificial lights during non-inductive conditions could enhance the rate of progress to flowering which significantly reduces flowering time. It is possibly assumed that when there is high irradiance available to the Obligate LDPs, the carbohydrate assimilates progression may become rapid (Wiśniewska & Treder, 2003) hence plants attained reasonable plant height and apex size in a minimum time to evoke floral stimulus from leaves (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 numbers 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). Adams *et al*., (1998) reported that Petunia (LDP) 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, Obligate 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). 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 Obligate LDPs during winter season in Pakistan for their year-round production and to supply these plants to 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).

Conclusion

From present research findings it can be concluded that flowering time of Pot Marigold, Annual Phlox, Cornflower, Oriental Poppy and Flax 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. However, these Obligate LDPs can 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. 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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