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GROWTH, FLOWERING AND DRY MATTER PARTITIONING RESPONSE OF MID-FLOWERING SNAPDRAGON CULTIVAR LIBERTY WHITE GROWN UNDER DIFFERENT LIGHT GRADIENTS

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Abstract

The rationale of the present study was to quantify the effects of different shade levels (30%, 40%, 50% and 60%) and a control (no shade) on growth, flowering and dry matter partitioning traits of Snapdragon cultivar Liberty Wight. A linear relationship was observed between different shade levels and flowering time, rate of progress to flowering, leaf numbers, leaf area, plant height, plant spread, plant fresh weight, plant dry weight, leaf fresh weight and lead dry weight. These growth and development traits increased linearly from 30% to 60% shade levels, however, the rate of progress to flowering was inverse to flowering time when plants were kept under shades. A polynomial hyperbolic relationship was observed in specific leaf area, specific leaf weight, leaf weight ratio, leaf area ratio, relative growth rate and net assimilation rate. It is concluded that different shade levels significantly ($P\leq0.05$) prolonged various growth and development phases of Snapdragon cultivar Liberty White. These finding can be applied to enhance crop quality and to delay growth and flowering time for steadily supply of plants to the market.

Key words: Snapdragon, *Antirrhinum majus* L., Liberty white, Shade levels, Light gradients, Growth, Flowering, Dry matter partitioning.

Introduction

Sunlight, an electromagnetic radiation is crucial for the growth and development of plants. It has dual nature, both a particle (photon) and a wave (the flow of photon). Photon is what the plants sense, contained an amount of energy called as quanta whereas the movement of light conceptualized as a wave depends on its wavelength. The energy of photon is inversely proportional to the wavelength, therefore, shorter the wavelength, higher the energy (Iqbal, 1983; Taiz & Zeige, 2002; Ross, 2012). Plants use the energy from sunlight to produce glucose and release oxygen from carbon dioxide and water (photosynthesis), whereas by cellular respiration, the glucose is converted into pyruvate, which releases adenosine triphosphate (ATP) and carbon dioxide. Both processes are vital for the growth and development of plants (Jurić *et al*., 2013). Therefore, insufficient supply of sunlight, because of shade of surrounding buildings in an urban area, indoor beautification of sun loving plants, growing plants under woods significantly affect the metabolic processes of plants (Baloch *et al*., 2009; Zhao *et al*., 2012). Plants take on various adaptation strategies to survive under adverse environment conditions like varied light gradients, drought, high or low temperatures, and nutrient restrictions. The knowledge about these adaptations helps to manage the growth and care issues of plants (Middleton, 2001). Different types of shade are commonly used in horticultural industry across the globe, which have an effect on plant morphology. Plant growth and development under low intensities negatively affected due to decreased light, however, shade-plants follow different approaches of optimal use of available energy (Wu & Tan, 2002).

The majority of Mediterranean region garden plants including snapdragon (*Antirrhinum majus* L.) require full daylight all day long for the utmost success (Munir *et al*., 2004). A number of early, mid and late flowering snapdragon cultivars are preferred by the consumers across the world and the major economic importance of this plant is to be grown as boarder, bedding and cut-flowers production for the beautification of home and public buildings, or may be used in handheld bouquets (Shafique *et al*., 2011). The main factors that affect the production and quality of plants are climate, plant nutrition and water. The latter two are managed through fertilization and irrigation practices, however, light, that is one of the most imperative factors in a climate, is difficult to control (Dai *et al.,* 2009). Any variation in light duration, quality or quantity affects plant physiology, morphology and production (Cavagnaro & Trione, 2007; Cai, 2011). Plant growth needs an uninterrupted and appropriate supply of light intensity for photosynthesis (Dai *et al.,* 2009). Shade, not only influences the quantity of light captured by the plants but also affects micro climate of plants such as temperature, humidity, carbon dioxide concentrations, evapotranspiration, etc., which are also essential environmental factors for plant growth (Song *et al.,* 2012). Plant growth and development response varies to different shade intensities and can be positive or negative. Positive effects of shade on plant growth and flowering were observed in short day plants (Baloch *et al.,* 2009), *Trichloris crinita* (Cavagnaro & Trione, 2007), and *Capsicum chinense* (Jaimez & Rada, 2006). However, negative effects of shade on flowering were reported in long day plants (Baloch *et al.,* 2009), and on growth in *Paeonia lactiflora*, (Zhao *et al.,* 2012), *Bromus tectorum* (Pierson *et al.,* 1990), *Eustoma grandiflorum* (Lugassi-Ben-Hamo *et al.,* 2010) and *Liatris spicata* (Flavia *et al.,* 2007).

The supply of snapdragon to the market as potted bedding plants or for cut-flowers depends on the growing conditions. If snapdragon crop matures too early or late, it would have a negative effect on growers' income. Therefore, there is a need to understand how plant environment affects growth, flowering and quality of snapdragon and how this can be manipulated to regulate the supply of this flowering crop to the market (Pearson *et al.,* 1994). In this study, a mid-flowering cultivar of Snapdragon was selected, which is commonly used for bedding plant and cut-flower production in the world. The objective of the study was to determine the effect of different light gradients (shades) on plant morphological and dry matter parameters, which can be manipulated by the floriculture industry for steady supply of this crop to the market.

Materials and Methods

The present study was carried out at the Agricultural Research and Veterinary Experimental Station, King Faisal University, Al-Ahsa during 2013. The aim of the study was to reveal the growth, flowering and dry matter partitioning response of Snapdragon (*Antirrhinum majus* L.) cultivar Liberty White grown under different shade regimes. Seeds were obtained from Colegrave Seeds Ltd., Banbury, U.K., and were sown on 1st March 2013 into module trays (Thermo, PS45JP, 42 mm each cell diameter, Plantpak Ltd., U.K.) containing a peat-based compost (Proper Substratum, Planta Guard, KSA). Seed trays were watered and held for germination at room temperature (16-18°C). After 70% seed germination, plants were transplanted into 9 cm pots (volume 370 ml) containing a mixture of peat-based compost and perlite (3:1 v/v) at pH 5.9. Plants were transferred to four shade (30, 40, 50 and 60% shade) and a control compartments (0% shade). Light inside the shading and non-shading chambers was measured with the help of T-10A illuminance meter (Konica Minolta, Japan) and then the shade percentage of each shading net was calculated. The experiment was laid out on randomized complete design with ten replications in each treatment (shade regimes). Plants were irrigated by hand to avoid root-borne diseases and NPK nutrient solution of 13:13:13 (Hyponex, Japan) was applied twice a week along with the water application. Plants were observed daily until the opening of first flower and plant growth, flowering and dry matter partitioning parameters were logged at harvest. Environmental variables were recorded at the local weather station situated half a kilometer away from the research site (Table 1). Data were analysed by using the analysis of variance and regression statistical techniques of GenStat-17 (VSN International Ltd., Hemel Hempstead, U.K.). Mean separation test was also applied to assess least significant difference (LSD) among treatment means using the same statistical program.

Results

A significant ($p \leq 0.05$) linear increase in days taken to flowering (Fig. 1A), leaf number (Fig. 1C), leaf area (Fig. 1D), plant height (Fig. 1E) and plant spread (Fig. 1F) was observed when plants were grown under varied shade regime. Plants under 30, 40, 50 and 60% shades took 7, 18, 32 and 39 more days to flower compared to control (100 days). However, an opposite trend was observed in rate of progress to flowering, as flower induction rate per day was higher in control plants and linearly decreased when plants were placed in 30 to 60% shades chambers (Fig. 1B). Leaf number significantly increased when plants was grown under shades. Plants in control chamber produced 15 leaves, which were linearly increased to 19 (30%), 25 (40%), 32 (50%) and 38 (60%). Similar trend was observed in leaf area parameter, which was increased 19%, 39%, 48% and 60% compared to control when plants were placed in 30, 40, 50 and 60% shades, respectively. Plant height and spread were linearly increased when plants were grown under shades. Taller plants were recorded in 60% shade chamber (50 cm) followed by 50% (45 cm), 40% (41 cm) and 30% (36 cm) chambers. Similarly, maximum plant spread (20 cm) was observed in plants grown under 60% followed by 50% (18 cm), 40% (16 cm) and 30% (12 cm) shades.

It was observed that plant fresh (Fig. 2A) and dry weight (Fig. 2B) and leaf fresh (Fig. 2C) and dry weight (Fig. 2D) were linearly and significantly ($p \leq 0.05$) increased with increased in shade levels. Plants placed in 60% shade chamber produced maximum plant fresh weight (24.67 g), plant dry weight (3.56 g), leaf fresh weight (9.42 g) and leaf dry weight (1.70 g) compared to other shade levels. However, plants kept under control chamber (without shade) produced minimum plant fresh weight (11.33 g), plant dry weight (1.53 g), leaf fresh weight (3.11 g) and leaf dry weight (0.44 g). A curvilinear response of Snapdragon cv. Liberty White was observed regarding plant derived parameters such as specific leaf area (Fig. 3A), specific leaf weight (Fig. 3B), leaf weight ratio (Fig. 3C), leaf area ratio (Fig. 3D), relative growth rate (Fig. 3E) and net assimilation rate (Fig. 3F). All derived parameters, except leaf area ratio were significantly influenced when grown under different shade levels. Plants in control have had maximum specific leaf area (246.40 cm^2 g^{-1}), which was significantly decreased in shades and minimum (146.89 cm^2 g^{-1}) was recorded in 50% shade chamber. However, a contrary response of specific leaf weight observed when plants were grown under control chamber, as minimum was in control (0.00406 g cm^{-2}) and maximum (0.00681 g cm^{-2}) was in 50% shade chamber. More or less similar trend was noted regarding leaf weight ratio i.e. minimum (29 g g^{-1}) in control and maximum (48 g g^{-1}) in 60% shade treatments. Although leaf area ratio parameter was non-significantly influenced by any shade treatment, however, maximum (75.68 cm^2 g^{-1}) was recorded in 60% shade and minimum (69.09 cm^2 g^{-1}) was in 50% shade levels. Relative growth rate decreased significantly from control to 60% shade treatments i.e. highest (0.66 g g^{-1} d^{-1}) relative growth rate was observe in control, which gradually decreased to 0.28 g g^{-1} d^{-1} under 60% shade level. Similar trend observed in net assimilation rate, which was higher (0.00935 g cm^{-2} d^{-1}) in control treatment and lower (0.00372 g cm^{-2} d^{-1}) in 60% shade.

Table 1. Meteorological data of experiment.

Growing season	Temperature (°C)				Day length (HH:MM)	Solar radiation MJ m^{-2} day^{-1}	Relative humidity (%)	Rain days	Rainfall mm	Wind speed (km h^{-1})
	Average		Absolute							
	Min	Max	Min	Max						
March	14	29	5	41	12:01	19.6	41	4	1	14
April	19	35	7	45	12:48	22.8	35	3	3	13
May	23	42	17	49	13:27	25.5	25	1	0	13
June	28	45	18	49	13:47	25.6	21	-	-	15
July	29	46	22	51	13:37	25.3	22	-	-	15

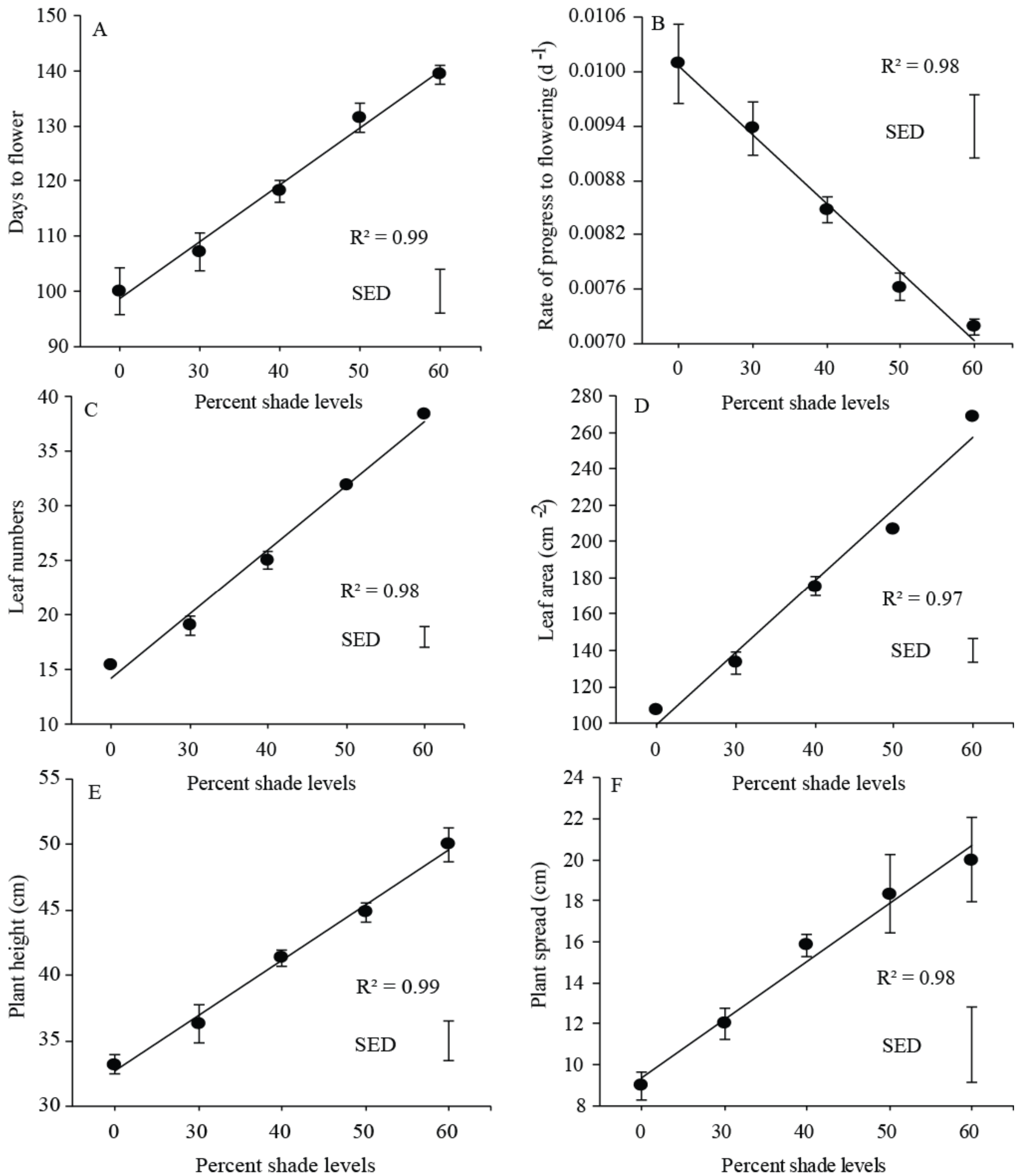

Fig. 1. Effect of different shade regimes on (A) days to flowering, (B) rate of progress to flowering, (C) leaf number, (D) leaf area, (E) plant height, and (F) plant spread of Snapdragon. Vertical bars on data points represent the standard error within replicates. SED bar showed the standard error of difference among means.

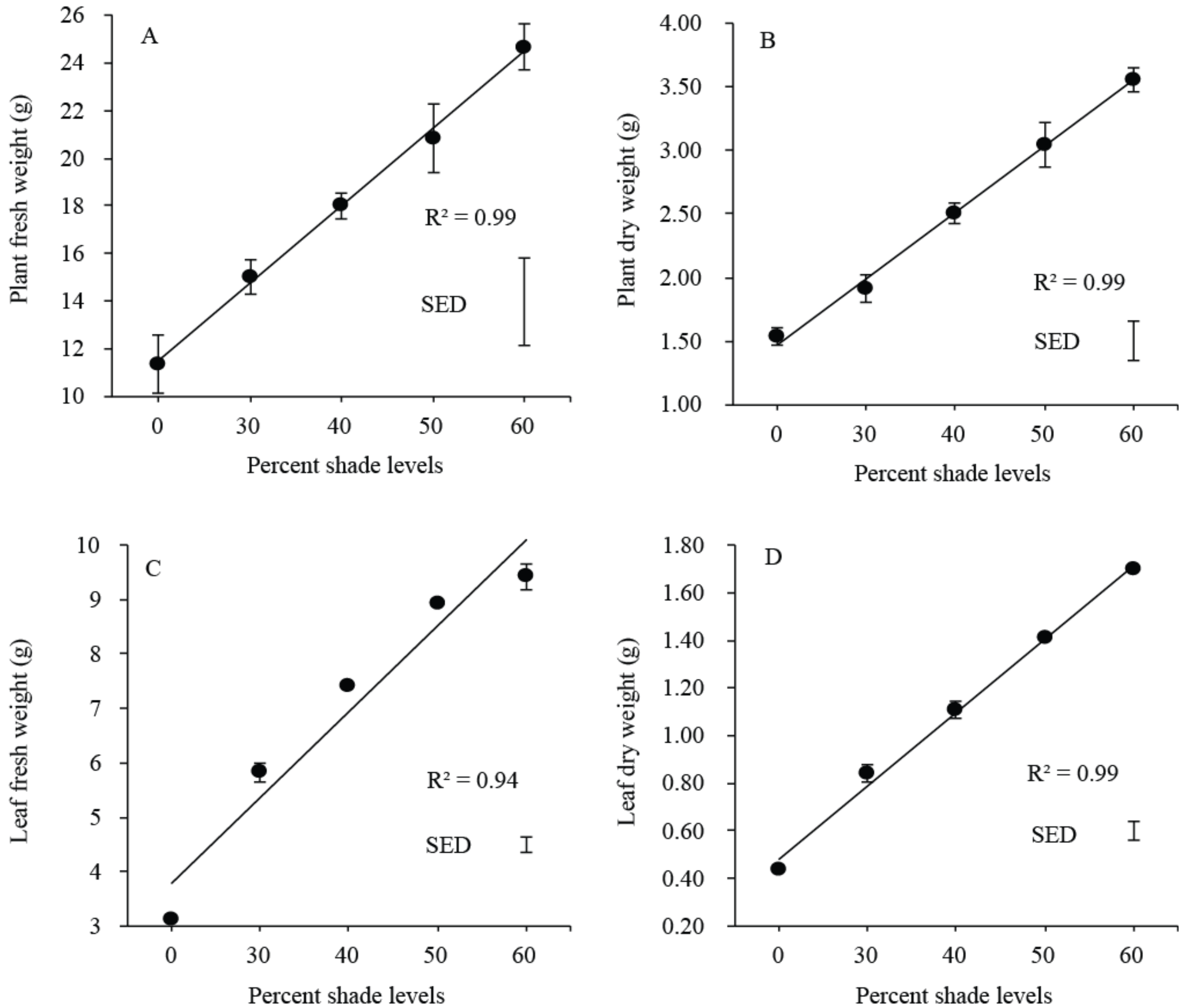

Fig. 2. Effect of different shade regimes on (A) plant fresh weight, (B) plant dry weight, (C) leaf fresh weight, and (D) leaf dry weight of Snapdragon. Vertical bars on data points represent the standard error within replicates. SED showed the standard error of difference among means.

Discussion

Shade is commonly used during summer for growing of ornamental plants, which influence plant growth and development by changing the morphology of plants (Wu & Tan, 2002). The results of present study clearly indicated that the growth and development of snapdragon, a facultative long day plant adversely affected under different shades. This could be because of the Mediterranean origin of the snapdragons wherein they have lot of sunshine and long days for their best growth (Summerfield *et al*., 1997).

In present study, different shade levels delayed flowering time of cultivar Liberty White due to decreased rate of progress to flowering per day. Similar results were reported in a dwarf (Munir *et al.,* 2004) and mid-flowering (Baloch *et al.,* 2009) cultivars of snapdragon where flowering initiation and time delayed under high low respectively. In peony, shade decreased photosynthetic capacity, light saturation point and light compensation point and increased the apparent quantum yield, mainly due to stomatal conduction declined. These decreases caused the soluble sugar, soluble protein and malondialdehyde contents to decline, which led to delayed initial flowering date and prolonged flowering time (Zhao *et al*., 2012). Lugassi-Ben-Hamo *et al*. (2010) observed a delaying effect of shade on floral transition in lisianthus, however, time to flowered was temperature dependent. It is also reported that in some plants, the reduction in red to far-red light ratio under shade triggers shade avoidance responses such as stem elongation and the hastening of flowering due to Phytochrome B photoreceptor (Endoa *et al*., 2005). However, in present study the flowering time and the pace of flower development did not coincide with the shade avoidance phenomenon, as both traits were maximum under low light gradient. The gibberellins (GA) biosynthesis is regulated by light in pea, a long day plant (Weller *et al*., 2010), which is also one of the floral induction pathways and impairing of GA signaling in the vascular tissues of Arabidopsis delayed flowering (Porri *et al*., 2012). In present study, delay in floral time under shade of snapdragon being a long day plant, might be because of the impeded GA synthesis or declined photosynthetic activity that down-regulated the photochemical capacity associated with photoprotective mechanisms or chronic photodamage caused by partial destruction of the photosynthetic apparatus under low light intensities.

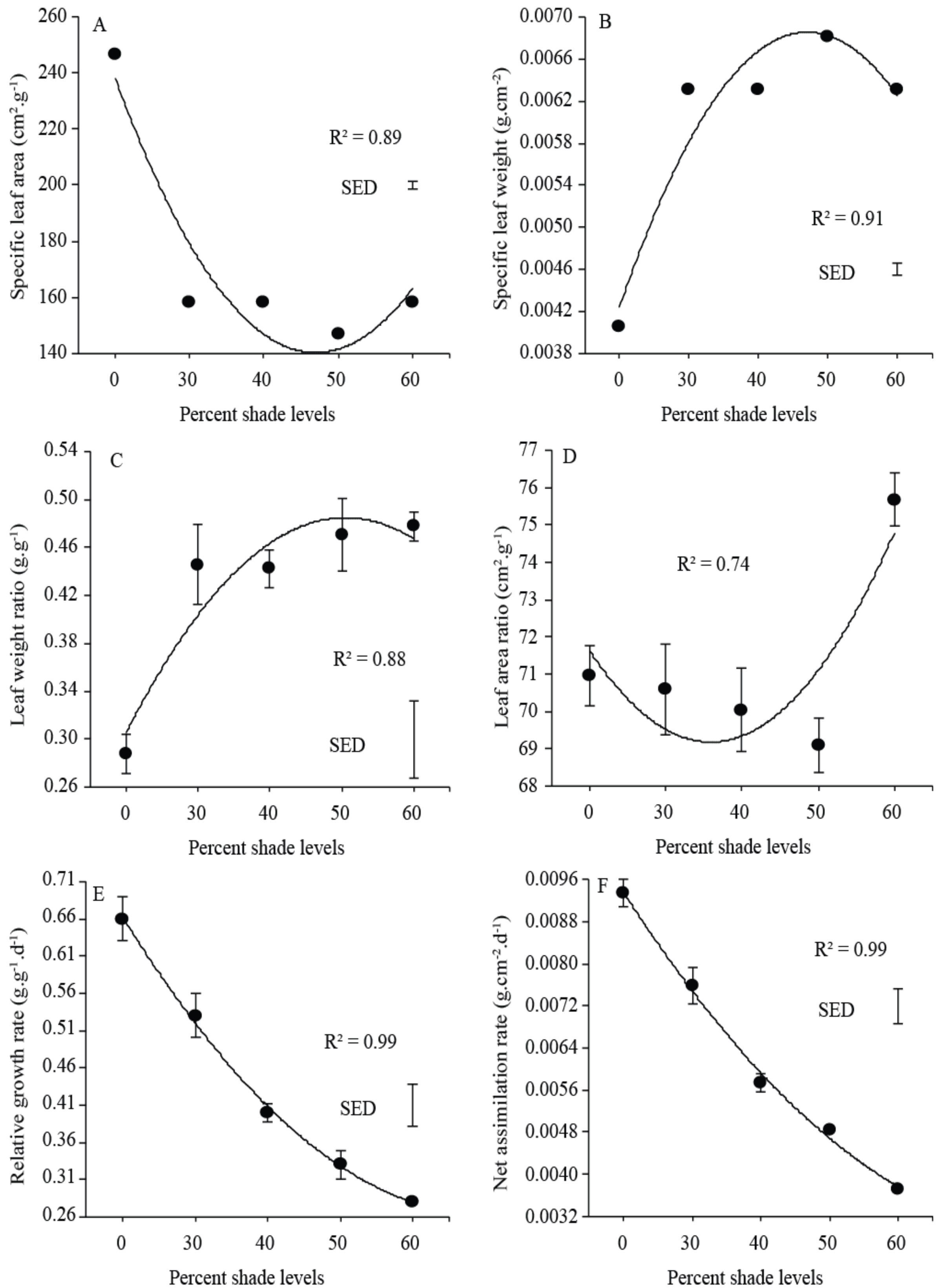

Fig. 3. Effect of different shasde regimes on (A) specific leaf area, (B) specific leaf weight, (C) leaf weight ratio, (D) leaf area ratio, (E) relative growth rate, and (F) net assimilation rate of Snapdragon. Vertical bars on data points represent the standard error within replicates. SED showed the standard error of difference among means.

Present study showed a linear increase in leaf number, leaf area, plant height and spread when snapdragons were grown in shade, which could be due to the decrease in red to far-red light ratio (Endoa *et al*., 2005). Similar results were reported regarding leaf numbers, leaf area and plant height of snapdragon cultivar Chimes White (Munir *et al*., 2004), height of sage plants (Zervoudakis *et al*., 2012) and canopy spread in *Spiraea* spp., (Stanton *et al*., 2010), which were enhanced by the low light regimes. Plant dry matter partitioning is the result of the flow of assimilates from source organs via a transport path to the sink organs. The sink strength, the competitive ability of an organ to attract assimilates plays an important role during the movement of assimilates from one organ to another (Marcelis, 1996). However, plant dry matter allocation in leaf and stem was increased linearly with increased in shade levels, which indicated that plant grown under low light levels (30, 40, 50, and 60% shades) received 70, 60, 50 and 40% photosynthetically active radiation (PAR), respectively. The decreased PAR negatively affected the regularity of photosynthesis, which consequently prolonged the vegetative growth of cultivar Liberty White. Findings of present study also showed that sink strength of stem cells was higher than the leaf cells that is why maximum assimilates were stored in stem than leaves. The other possible explanation could be that the floral induction of snapdragon is photoperiod dependent (Munir *et al*., 2010; Baloch *et al*., 2013), therefore, due to decreased light integrals under shade restricted the apical meristem to perceive the floral signaling (Munir *et al*., 2015), which extended plant juvenile phase. Similar results were reported in Garden Pea where cultivar IPSA3 was found sensitive to low light levels (Akhter *et al*., 2009).

The results of present research indicated that the specific leaf area was higher in control chamber where resource-rich ambient environment tends to exist. Hence, a leaf with high specific leaf area captured more PAR per unit mass than a leaf with low specific leaf area (Evans & Poorter, 2001). However, specific leaf weight, leaf weight ratio and leaf area ratio were higher in plants grown under shade, which might be due to the decrease in temperature and PAR (Evans & Poorter, 2001). Under such shade conditions, plants of cultivar Liberty White had low specific leaf area because of slow growth hence produced higher leaf dry matter and leaf thickness. Plant relative growth rate is influenced by leaf net carbon assimilation rate, specific leaf area and leaf weight ratio (Shipley, 2006). Our finding showed that higher relative growth rate in control chamber was because plants were received ample PAR gained more carbon per unit leaf area (net assimilation rate), produced maximum specific leaf area and reduced leaf thickness (leaf weight ratio). Patterson *et al.* (1978) observed reduced relative growth rate, net assimilation rate and relative leaf area expansion rate when plants were grown under low light intensities. However, Medek *et al.* (2007) reported that leaf area ratio and specific leaf area had a greater effect on relative growth rate at >20°C while high net assimilation rate best correlate with relative growth rate at low temperature. In another study, higher relative growth rate achieved due to a greater specific leaf area and leaf area ratio (James & Drenovsky, 2007).

Conclusion

These results concluded that Snapdragon cultivar Liberty White grown in high irradiance exhibited better growth and development compared with plants grown in the shade, which generally attributed to its superior physiological performance. However, plants experienced to long-term exposure to shade delayed flowering and enhanced plant biomass and dry matter. Present findings also revealed a positive relationship of relative growth rate with specific leaf area and net assimilation rate. However, the outcomes can also be applied to the floriculture industry to delay flowering of cultivar Liberty White in order to maintain its steady supply in the market.

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References

Akhter, N., M.M. Rahman, M. Hasanuzzaman and K. Nahar. 2009. Dry matter partitioning in Garden Pea (*Pisum sativum* L.) as influenced by different light levels. *Acad. J. Plant Sci*., 2: 233-236.

Baloch, J.U.D., M. Munir and M. Abid. 2013. An appraisal of the use of reciprocal transfer experiments: assessing the stages of photoperiod sensitivity in pansy, snapdragon, petunia and cosmos. *Pak. J. Bot*., 45: 421-426.

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. Agri. Biol*., 11: 138-144.

Cai, Z.Q. 2011. Shade delayed flowering and decreased photosynthesis, growth and yield of Sacha Inchi (*Plukenetia volubilis*) plants. *Ind. Crop Prod*., 34: 1235-1237.

Cavagnaro, J.B. and S.O. Trione. 2007. Physiological, morphological and biochemical responses to shade of *Trichloris crinita*, a forage grass from the arid zone of Argentina. *J. Arid Environ*., 68: 337-347.

Dai, Y.J., Z.G. Shen, Y. Liu, L.L. Wang, D. Hannaway and H.F. Lu. 2009. Effects of shade treatments on the photosynthetic capacity, chlorophyll fluorescence, and chlorophyll content of *Tetrastigma hemsleyanum* Diels et Gilg. *Environ. Exp. Bot*., 65: 177-182.

Endoa, M., S. Nakamuraa, T. Arakib, N. Mochizukia and A. Nagatania. 2005. Phytochrome B in the mesophyll delays flowering by suppressing *Flowering Locus T* expression in Arabidopsis vascular bundles. *Plant Cell*, 17: 1941-1952.

Evans, J.R. and H. Poorter. 2001. Photosynthetic acclimation of plants to growth irradiance: the relative importance of specific leaf area and nitrogen partitioning in maximizing carbon gain. *Plant Cell Environ*., 24: 755-767.

Flavia, S.C., C.S. Gilda and C.C. Fabiola. 2007. Effect of four shading levels on flower stem and corm quality of liatris (*Liatris spicata*). *Agri. Téc*., 67: 100-104.

Iqbal, M. 1983. *An Introduction to Solar Radiation*. Academic Press, USA. Pp. 29-42.

Jaimez, R.E. and F. Rada. 2006. Flowering and fruit production dynamics of sweet pepper (*Capsicum chinense* Jacq) under different shade conditions in a humid tropical region. *J. Sustain. Agri*., 27: 97-108.

James, J.J. and R.E. Drenovsky. 2007. A basis for relative growth rate differences between native and invasive forb seedlings. *Rangeland Ecol. Manage*., 60: 395-400.

Jurić, S., L. Vojta and H. Fulgosi. 2013. Electron transfer routes in oxygenic photosynthesis: Regulatory mechanisms and new perspectives. In: *Photosynthesis*. (Ed.): Z. Dubinsky, InTech, Croatia. pp. 23-46.

Lugassi-Ben-Hamo, M., M. Kitron, A. Bustan and M. Zaccai. 2010. Effect of shade regime on flower development, yield and quality in Lisianthus. *Sci. Hortic-Amsterdam*, 124: 248-253.

Marcelis, L.F.M. 1996. Sink strength as a determinant of dry matter partitioning in the whole plant. *J. Exp. Bot*., 47: 1281-1291.

Medek, D.E., M.C. Ball1 and M. Schortemeyer. 2007. Relative contributions of leaf area ratio and net assimilation rate to change in growth rate depend on growth temperature: comparative analysis of subantarctic and alpine grasses. *New Phytol*., 175: 290-300.

Middleton, L. 2001. Shade-tolerant flowering plants: adaptations and horticultural implications. *Acta Hort*., 552: 95-102.

Munir, M., M. Jamil, J.U.D. Baloch and K.R. Khattak. 2004. Impact of light intensity on flowering time and plant quality of *Antirrhinum majus* L. cultivar Chimes White. *J. Zhejiang Univ. Sci*., 5: 400-405.

Munir, M., P. Hadley, J. Carew, M. Zubair, S. Adams, S.B. Hussain, J.U.D. Baloch, N. Hussain and M. Amanullah. 2010. An appraisal of the use of reciprocal transfer experiments: assessing the stages of photoperiod sensitivity in *Antirrhinum majus* L. *Pak. J. Bot*., 42: 1931-1940.

Munir, M., P. Hadley, J. Carew, S. Adams, S. Pearson and B. Sudhakar. 2015. Effect of constant temperatures and natural daylength on flowering time and leaf number of *Antirrhinum* using the photo-thermal model. *Pak. J. Bot*., 47: 1717-1720.

Patterson, D.T., C.R. Meyer and P.C. Quimby. 1978. Effects of irradiance on relative growth rates, net assimilation rates, and leaf area partitioning in cotton and three associated weeds. *Plant Physiol*., 62: 14-17.

Pearson, S., P. Hadley, D.R. May, A. Parker and S.R. Adams. 1994. The effect of temperature on bedding plants. Report to the Horticultural Development Council: PC74.

Pierson, E.A., R.N. Mack and R.A. Black. 1990. The effect of shading on photosynthesis, growth, and regrowth following defoliation for *Bromus tectorum*. *Oecologia*, 84: 534-543.

Porri, A., S. Torti, M. Romera-Branchat and G. Coupland. 2012. Spatially distinct regulatory roles for gibberellins in the promotion of flowering of Arabidopsis under long photoperiods. *Development*, 139: 2198-2209.

Ross, J. 2012. *The Radiation Regime and Architecture of Plant Stands*. Dr. W. Junk Publishers, The Netherlands. Pp. 9-35.

Shafique, A., M. Maqbool, M.A. Nawaz and W. Ahmed. 2011. Performance of various snapdragon (*Antirrhinum majus* L.) cultivars as cut flower in Punjab, Pakistan. *Pak. J. Bot*., 43: 1003-1010.

Shipley, B. 2006. Net assimilation rate, specific leaf area and leaf mass ratio: which is most closely correlated with relative growth rate? A meta-analysis. *Funct. Ecol*., 20: 565-574.

Song, R., D. Kelman, K.L. Johns and A.D. Wright. 2012. Correlation between leaf age, shade levels, and characteristic beneficial natural constituents of tea (*Camellia sinensis*) grown in Hawaii. *Food Chem*., 133: 707-714.

Stanton, K.M., S.S. Weeks, M.N. Dana and M.V. Mickelbart. 2010. Light exposure and shade effects on growth, flowering, and leaf morphology of *Spiraea alba* Du Roi and *Spiraea tomentosa* L. *HortSci*., 45: 1912-1916.

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.

Taiz, L. and E. Zeige. 2002. *Plant Physiology*. 3rd edition. Sinauer Associates Inc., USA. Pp. 171-192.

Weller, J.L., V. Hecht, J.K.V. Schoor, S.E. Davidson and J.J. Ross. 2009. Light Regulation of gibberellin biosynthesis in pea is mediated through the COP1/HY5 pathway. *The Plant Cell*, 21: 800-813.

Wu, N.B. and F. Tan. 2002. Studies of water regimes of *Cinnamomum pauciflorum* seedlings grown under different light intensity conditions. *J. Southwest Agri. Univ*., 27: 755-758.

Zervoudakis, G., G. Salahas, G. Kaspiris and E. Konstantopoulou. 2012. Influence of light intensity on growth and physiological characteristics of common sage (*Salvia officinalis* L.). *Braz. Arch. Biol. Technol*., 55: 89-95.

Zhao, D., Z. Hao and J. Tao. 2012. Effects of shade on plant growth and flower quality in the herbaceous peony (*Paeonia lactiflora* Pall.). *Plant Physiol. Biochem*., 61: 187-196.

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