Journal of Ornamental Plants
www.jornamental.iaurasht.ac.ir
ISSN (Print): 2821-0093 ISSN (Online): 2783-5219

Research Article
Volume 13, Number 2: 75-84, June, 2023
DOR: https://dorl.net/dor/20.1001.1.28210093.2023.13.2.1.4

The Role of UV Radiation Added to LED Lighting System in Growth Control of African Violet (*Saintpaulia ionantha* Wendl.)

Behnaz Akbarian[1], Mansour Matloobi[1*], Alireza Motallebi-Azar[1], Mohammadreza Dadpour[1]

[1]Department of Horticulture, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

Received: 07 December 2022 **Accepted:** 19 April 2023

***Corresponding author's email:** mmatloobi@gmail.com; matloobi@tabrizu.ac.ir

Abstract

Light Emitting Diodes (LEDs) can be used as a tool to control the quality of plants in order to meet the requirements of the market by accurately schedule uniform flowering based on a predetermined market date. The aim of this study was to investigate the effect of different light qualities of red (R), blue (B), and UV-A (UV) provided by LEDs, and white light produced by fluorescent lamps (FL) on growth, morphology and flowering characteristics of African violet (*Saintpaulia ionantha* Wendl.). An experiment was conducted in controlled environment growth chambers at 25 °C. Three ratios of R:B (1:0, 3:1, 0:1) and FL (14 h/d) were used as all-day treatments and UV LED (2 h/d) was supplemented for three ratios of R:B (1:0, 3:1, 0:1) and FL (14 h/d) as end of day (EOD) treatment. Statistical analysis showed addition of B to light spectrum inhibited abnormal leaf growth and promoted compactness. Flowering under FL treatment was distinctly inferior as measured by the number of floral buds, full blooms and inflorescences. However, addition of EOD UV plus R3B1 contributed to higher production of floral buds and full blooms in a short period of time. Supplementing UV light to LED treatments resulted in accelerated leaf expansion. Generally, supplemental UV plus R or B was an acceptable energy-efficient alternative for improving quality of African violet. Vegetative and reproductive phase of *Saintpaulia* were a function of light quality which could assist the predictability of flowering time in controlled environment systems.

Keywords: Flowering, Light quality, Ornamental plant, Photomorphogenesis, Ultra-violet Radiation.

INTRODUCTION

Light-emitting diode (LED) technology has been recently practiced by some growers for several purposes such as controlling flowering in photoperiodic plants, maximizing growth and changing shape of plants. LEDs could be chosen as a versatile and band width adjustable light source for manipulating vegetative growth, flowering and morphology of the plants or to plan production of potted plants in order to meet the demand of the market to deliver a uniform product with desired quality on a specific market date (Bourget, 2008). McCree (1972) reported that blue (400-500 nm) and red (600-700 nm) are considered primary wavelengths for leaf photosynthesis. Recent studies have found that the ultraviolet (280-400 nm) radiation also plays an important role in photosynthesis (Huché-Thélier *et al.,* 2016).

African violet (*Saintpaulia ionantha* Wendl.) in the Gesneriad family (Gesneriaceae) is the most popular of the *Saintpaulia* species, which is used as an ornamental potted houseplant. African violet is considered as a low-light day-neutral species. Faust and Heins (1993, 1994), noted that in *Saintpaulia*, inflorescence arises from the leaf axis when the leaf reaches to a certain size. They also determined that PPFD and average daily temperature are two primary factors which control leaf unfolding rate (LUR), leaf extension rate (LER) and flowering in this plant. Based on their model, decreasing PPFD from 10 to 1 mol m^{-2} day^{-1} in a shaded greenhouse, accordingly decreased optimal temperature from 25 °C to 23 °C, which resulted in a lower LUR. Also, they introduced an inflorescence development phasic scale as a function of temperature in order to help growers predict the right flowering time considering crop marketing date. Kwack and Kim (1969) noted that sunlight reduced by half in the greenhouse provides the best condition for encouraging optimal growth and ornamental quality of African violet plants. As light intensity was decreased from full sunlight to half and to shade condition, leaf area increased. Full sunlight induced solarization, chlorosis in leaves or backward leaf curling, even though it produced higher dry weight. Kim and Sang (1982) argued that light intensity was critical for four varieties ('Monique', 'Robert O', 'Julianne' and an undefined local variety) of *S. ionantha*, as it is considered a semi-shaded plant. They confirmed that a light intensity of 5,000-10,000 lux (6.25-12.50% of natural sunlight in a plastic house) was the best condition for optimal growth and higher ornamental value as a result of promotion in photosynthetic rate, flowering percentage, number of peduncles, number of florets/peduncles and leaf area.

B light is important in chloroplast development, stomata number and length of palisade tissue cells (O'Carrigan *et al*., 2014). UVA is absorbed by B light photoreceptors (Casal, 2013). Kong *et al*. (2019) reported that B + UVA effects were similar to B, but different from R, on growth and morphology in four microgreen species which slightly varies with light intensity and plant species. UVA radiation increases stomatal conductance (g_s), and improves CO_2 utilization, consequently, enhances photosynthetic and transpiration rates (Kang *et al*., 2018). Verdaguer *et al*. (2017) stated that plant response to UVA (315–400 nm) still needs to be clarified. UVA exposure usually causes positive and negative physiological effects depending on the plant species and light conditions, while UVB (280–315 nm) effects appear to be primarily negative. EOD lighting using LEDs still needs further investigations, as they are cost-effective and require less energy when compared to conventional high-pressure luminaries. The objective of this study was to understand interactive effects of supplementary UV radiation added to B and R wavelengths in controlling vegetative and generative development of African violet and finding possible relationships between these two physiological characteristics with flowering time.

MATERIALS AND METHODS

Plant material

An experiment was conducted on African violet (*Saintpaulia ionantha* Wendl.) in controlled environment growth chambers, from July to September 2021. Prior to the start of the experiment, leaf cuttings of African violet were rooted. African violet plants were transplanted into 10-cm-diameter plastic pots containing a mixture of 50% perlite, 50% cocopeat (%v/v) and were placed inside growth chambers (24±2 °C, 60±10% RH). Plants were sub-irrigated with nutrient solution (EC ≈ 0.65 mS cm^{-1} and pH of 6.8) twice a week (when the soil was dry about half inch deep below the surface), consisting of 7.1 mM nitrate, 0.8 mM ammonium, 1 mM phosphate, 3.7 mM potassium, 2 mM calcium, 0.5 mM magnesium and 0.7 mM sulphate. Plants were relocated randomly inside the growth chamber once a week to minimize the position effect.

Growth conditions

Experiments were conducted in a custom-built illumination system. The light fixtures were placed horizontally 15–20 cm above the plant canopy. Each unit consisted of 20 pots. Growth chambers were illuminated with different light qualities. LED radiation systems consisted of blue (B; peak at 465 nm), red (R; peak at 650 nm), and ultraviolet (UV; peak at 390 nm). Treatments were provided by LED panels (Getian Opto-electronics, Inc., Shenzhen, China) and broad-band fluorescent lamps (FL; 4000K, Osram) (Fig. 1). Plants were illuminated with FL or monochromic R or B or mixed R3B1 (R:B=3:1) for 14 hours a day at a light intensity of approximately 118 µmol m-2 s-l as all-day treatments and FL or monochromic R or B or mixed R3B1 (R:B=3:1) (14 h/d) followed by 2-h of UVA radiation at about 10 µmol m^{-2} s^{-1} as end-of-day (EOD UV) treatment (Fig. 2). The experiment continued for 8 weeks.

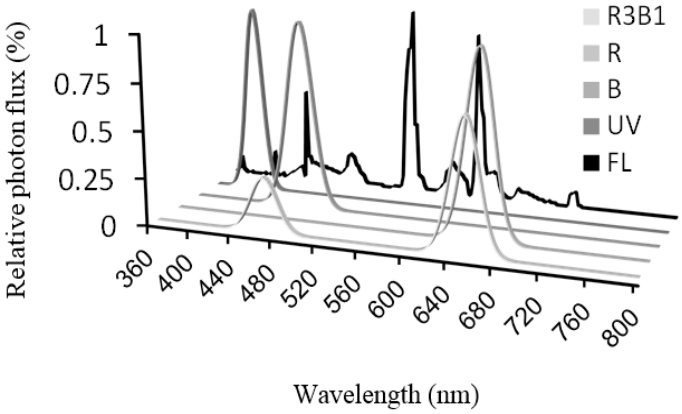

Fig. 1. Relative spectral photon flux distribution of different light sources provided by blue (B), red (R), UVA (UV) LEDs and fluorescent lamps (FL).

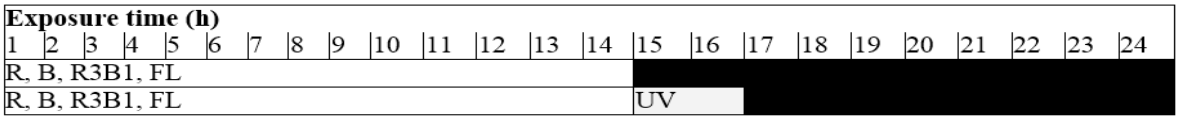

Fig. 2. Light treatments duration design for *Saintpaulia*. Treatments comprised of blue (B), red (R), ultraviolet (UV) LEDs and fluorescent lamps (FL).

Measurements

Growth parameters were measured after the onset of light treatments. The number of unfolded leaves greater than 7 mm in length were counted and recorded per plant at 2-week intervals. Leaf unfolding rate (LUR) was determined by the slope of the number of leaves regressed over time. On every plant, each leaf's axil was examined two times a week for the presence of a visible bud (VB) greater than 1 mm. At VB stage the length of subtending leaf of flower bud was measured and recorded. At least four unfolded leaves were randomly selected from each light treatment to measure leaf length and width, leaf thickness and petiole length during the period of lighting treatment, at 2-week intervals. The leaf shape index was calculated as the ratio of leaf length to the corresponding leaf width (Takenaka, 1994). A digital vernier caliper was used to measure leaf thickness. At least four plants per light treatment were used to record the flowering stage, based on a phasic-development inflorescence scale introduced by Faust and Heins (1994). Stage nine was added as the wilting stage described by the time when at least 50% of petals started to shrivel. Total inflorescence development was calculated from the first stage to the full bloom stage. Ornamental flower life time was registered from the full bloom till the time when more than 50% of petals wilted. At the end of the experiment, plant height was determined by measuring the distance from the base of the plant to the highest point of the rosette leaf arrangement. Specific leaf area (SLA) was calculated as unit leaf area per leaf dry weight from four leaves per light treatment. Leaf SPAD index (an indicator of chlorophyll concentration per unit leaf area) was determined for each plant, using a portable chlorophyll meter (CL-01, Hansatech Instruments Ltd, Kings Lynn, UK). Digital images were acquired from front-view and top-view per plant, using a Canon IXUS 155 digital camera and a fixed-lighting stand. Last measurements of the experiment were carried out when at least 50% of pots reached their peak of blooming. In this stage, number of floral buds (>3mm), number of fully open flowers, number of inflorescences and diameter of fully open flowers were recorded for each plant. Inflorescence length was measured from the leaf's axil up to the fully open apical flower.

Statistical analysis

A completely randomized design (CRD) was employed. Analysis of variance was performed using SPSS 26.0 software (IBM, Inc., Chicago, IL, USA). Statistical significance was tested by one-way ANOVA and separated with Duncan test at $P<0.05$. Correlations were tested using Pearson's correlation coefficient.

RESULTS

Light quality significantly influenced the number of leaves (Table 1). The maximum leaf formation occurred under R3B1 by 0.42 leaves/day, while the minimum occurred under B light by 0.32 leaves/day. EOD UVA radiation resulted in highest LUR rate (0.2 leaves/day) when it was added to R daily light, however this parameter averaged to as low as 0.17 leaves/day in other treatments (Fig. 4). R increased leaf length, petiole length and canopy height significantly. Addition of 25% of B in the light spectrum reduced these parameters. The plants under B had the minimum leaf shape index. Supplemental UVA significantly enhanced leaf length and reduced petiole length under LEDs compared to FL. R3B1+ EOD UV reduced petiole length by 76.8% compared to the FL+ EOD UV. Monochromic B and monochromic R increased leaf thickness significantly. Canopy height of the plants grown under R and FL, with or without

UVA, was significantly higher than RB and B, with or without UVA. With UV, the plants grown under R3B1 had the highest chlorophyll index and SLA significantly reduced under FL compared to other treatments (Fig. 5).

Flowering parameters were affected by light quality (Table 1). Leaf blade length at VB ranged from 32.9 mm in B to 46.5 mm in R and 30.6 mm in R3B1+EOD UV to 34.2 mm in FL+ EOD UV (Fig. 4). The number of inflorescences was the lowest under B+ EOD UV and FL, with or without UVA. The number of floral buds was maximum under R3B1 and B with or without UV and R without UV. B and R3B1+ EOD UV produced maximum number of full blooms. The largest flowers occurred in FL without UV and the longest inflorescences were generated under FL with or without UV. Flower development was advanced under B (Fig. 3). Although, not significant, B plus UV delayed petal senescence by 6 days compared to the FL plus UV.

Table 1. Summary of one-way ANOVA for vegetative and flowering characteristics of African violet affected by light treatments.

Traits	MS (Treatment)	MS (Error)	F-test
Leaf number	19.8	1.9	10.4**
Leaf length	1945.1	76.9	25.3**
Leaf thickness	0.5	0.04	11.9**
Petiole length	2430.8	46.5	52.3**
Leaf shape index	0.05	0.01	4.02**
Specific leaf area	33793.9	4325.9	7.8**
Canopy height	20.7	1.1	18.5**
SPAD index	192.2	7.7	24.9**
Leaf length at visible bud	100.67	3.76	26.8**
Number of full blooms	435.6	45.1	9.6**
Number of floral buds	2194.4	207.4	10.6**
Inflorescence number	22.7	6.2	3.6**
Inflorescence length	551.2	27.02	20.4**
Flower diameter	46.6	4.1	11.2**

**: Significant at $P < 0.01$ based on the LSD test.

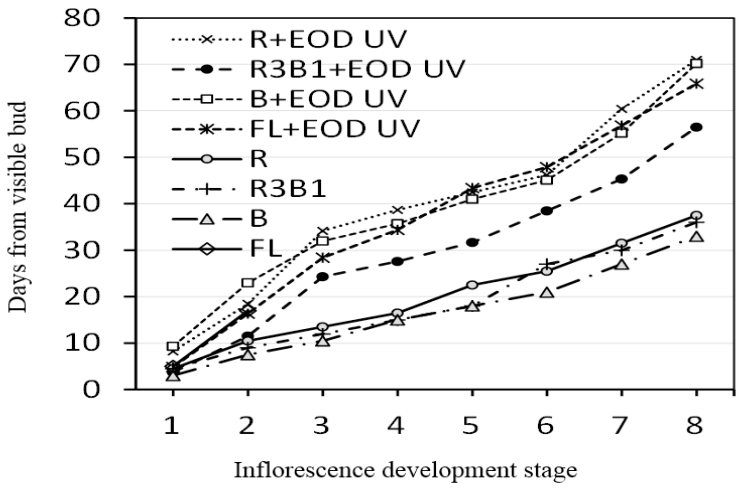

Fig. 3. Inflorescence development rate of *Saintpaulia* under R:B=1:0 (R), 0:1 (B), 3:1 (R3B1) LEDs or FL with or without EOD UV.

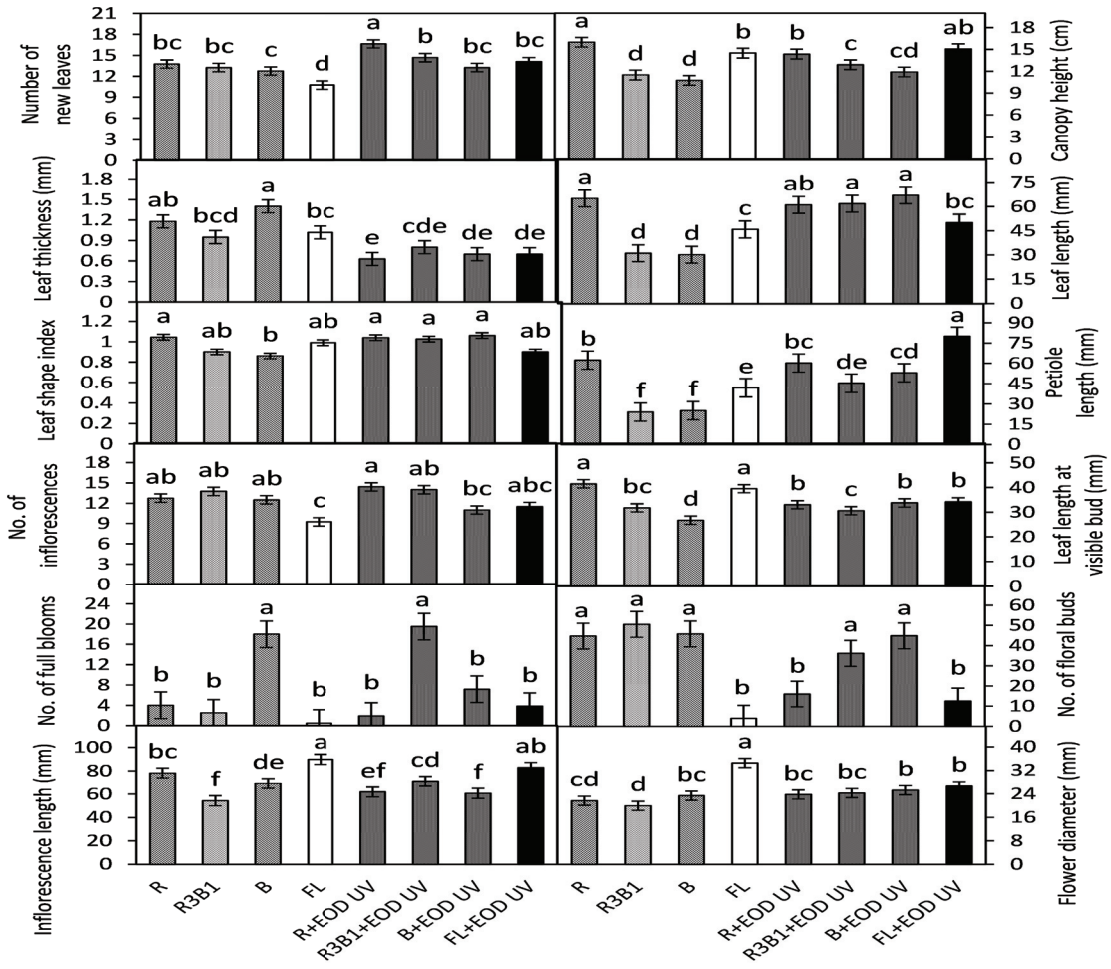

Fig. 4. Effects of light quality on growth and flowering traits of *Saintpaulia*. Treatments comprised of blue (B), red (R), ultraviolet (UV) LEDs and fluorescent lamps (FL). Data are means ± SD. Data bearing the same letter are not significantly different at P< 0.05, according to Duncan test.

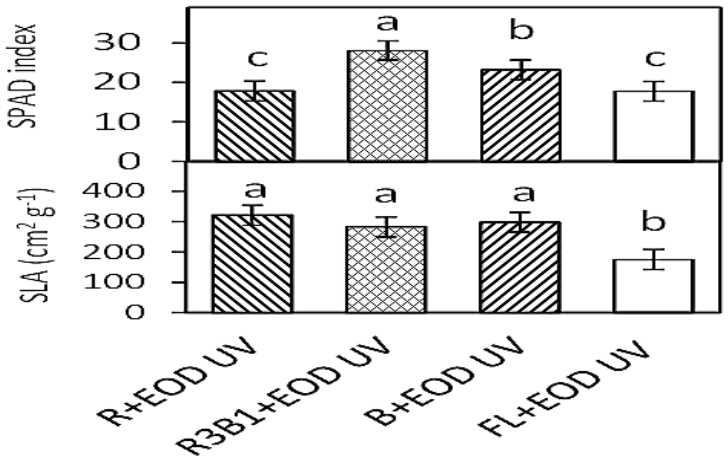

Fig. 5. Effects of light quality on growth traits of *Saintpaulia*. Treatments comprised of blue (B), red (R), ultraviolet (UV) LEDs and fluorescent lamps (FL). Data are means ± SD. Data bearing the same letter are not significantly different at P < 0.05, according to Duncan test.

DISCUSSION

Growth responses

UVA significantly stimulated leaf production in monochromic R. It appears that, supplemental UVA to B added light treatments resulted in accelerated leaf area expansion, increased leaf shape index and petiole length, indicating that UVA in combination with R and B LEDs extremely affects leaf morphology and causes rapid growth of African violet. There is a possible explanation for increased leaf length under R or LED treatments with UVA vs. FL, it might be that leaf blades of the plants under these treatments expanded in response to shade avoidance phenomenon. UVA radiation, similar to B, activates phototropins and cryptochromes which can promote shade avoidance response (Keller *et al*., 2011). In consistent with our results, Chen *et al*. (2019) reported that supplementing UVA radiation to mixed B, R, and Fr LED increased leaf area and leaf number in lettuce (*Lactuca sativa*), which facilitated light interception and increased biomass production. However, several studies reported that UVA increased leaf thickness and reduced leaf area in lettuce (He *et al*., 2021; Hooks *et al*., 2021). In tomato plants (*Solanum lycopersicum*), R light with added UVA increased leaf size (Khoshimkhujaev *et al*., 2014; Zhang *et al*., 2020). However, different intensities of UV-A added to 3:7 R:B did not change the leaf area but significantly increased leaf number in tomato plants (Kim and Hwang, 2019). Hence, leaf area response to light quality depends greatly on plant species, PPFD or spectra combinations. It seems that SLA under FL reduced because leaves expanded slowly, rather than dry matter accumulation. This was further supported by individual leaf area and SPAD data which was the least under FL.

It appears that UVA could not suppress elongation growth induced by R light. In contrast, Khoshimkhujaev *et al*. (2014), reported that addition of high intensity UVA to R reduced the height of tomato seedlings. Addition of UVA to FL resulted in maximum petiole elongation which was related to the higher biomass partitioning toward petiole elongation rather than leaf expansion. Chlorophyll did not form substantially or developed fully under monochromic R or B with additional UVA. It is reported that in several plant species, addition of B to R light increased PSII photochemical efficiency (F_v/F_m), quantum yield (Φ_{PSII}), electron transfer rate (ETR), chlorophyll a/b ratio and development of photosynthetic apparatus (Heo *et al*., 2002; Tesema *et al*., 2013; Zheng and van Labeke, 2017; Izzo *et al*., 2021).

Monochromic R resulted in leaf hyponasty in *Saintpaulia*. However, the plants grown under B+EOD UV treatment showed epinasty response (Fig. 6). Similarly, Kwack and Kim (1969) reported that in full sun conditions of greenhouse, African violet leaves curled backward. UVA plus B might result in a high energy radiation that led to excessive light stress which induced photoinhibition responses by activating photoprotective mechanisms in form of leaf area reduction and irregular leaf shape (Loconsole and Santamaria, 2021). Also, in cabbage, adding low or high level of UVA to B contributed to some damages in terms of reduced cotyledon size and irregular cotyledon shape (e.g., broken margins) (Kong *et al*. 2019). The leaves of UVA supplemented plants under R3B1 were fully expanded, whereas the margin of leaves that received R light were curled upward. Kreslavski *et al*. (2018) suggested that high R/Fr ratio increased resistance of plant to UV radiation and high-intensity light, due to the increase of active form of phytochrome (P_{Fr}) or phytochrome B (phyB) content. In African violet plants grown under FL with or without UV, no leaf blade curling was observed.

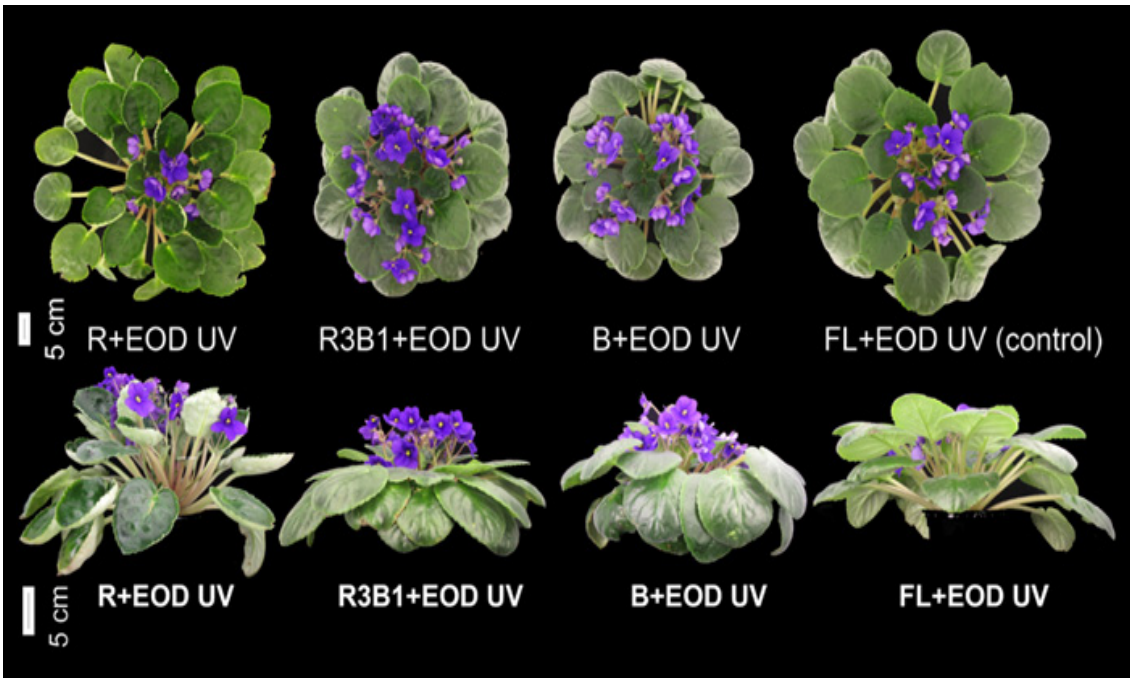

Fig. 6. Top view and side view of representative Saintpaulia plants under light treatments at the end of the experiment. Treatments comprised of blue (B), red (R), ultraviolet (UV) LEDs and fluorescent lamps (FL). The values after each light-emitting diode type indicate their ratios. The scale bar indicates 5 cm.

Flowering responses

Flowering under FL with or without UVA was distinctly inferior compared to other treatments. B and R3B1+EOD UV were superior in production of more full blooms. This can be explained by high photosynthesis and production of carbohydrates which resulted in flowering promotion. Suppressed flowering in monochromic R and B under UVA conditions might be related to the low photosynthetic activity, chlorophyll content and/or involvement of phytochromes and cryptochrome in flower development (Reed *et al*., 1993; Mockler *et al*., 1999; Heo *et al*., 2002) . It is possible that in African violet multiple photoreceptors were involved in flower initiation and development. UVA decreased floral bud production under R. Higher inflorescence production was almost synchronized with higher LUR as there was an acceptable positive correlation between leaf number and inflorescence number (R^2=0.71). Under UV conditions, the number of inflorescences was more a function of LUR rather than LER, since leaf expansion rate did not differ among LED treatments. Exposure to UVA reduced flower diameter under FL and peduncle length under R, probably due to the antagonistic effect of UVA with R or FL radiations. There was a strong positive correlation between both traits (R^2=0.88). Addition of UVA delayed flower development (Fig. 3). By adding a low level of B to R light with supplemental UVA, flowering was advanced.

CONCLUSION

In African violet, growth, flower initiation and development vary with minimal variation in light quality. A small amount of B light was necessary to inhibit abnormal leaf morphology and excessive elongation. Based on the results, it is possible to regulate vegetative and reproductive phase of plants by manipulating light quality in accordance with the plant developmental stage

and predetermined market criteria. Application of EOD UV LEDs were shown to be efficient for improving quality of African violet. However, the mechanisms of spectral interactions from B, R and UV on plant physiology and their relations with concomitant light mixes still need to be further investigated.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Department of Horticulture, Faculty of Agriculture, University of Tabriz, for their support and contribution to this study. Authors are grateful to Dr. Nosratollah Najafi (Department of Soil Science, Tabriz University, Tabriz, Iran) for providing technical support and Mohammad Adlipour for providing laboratory assistance.

Literature Cited

Bourget, C.M. 2008. An introduction to light-emitting diodes. HortScience, 43:1944-1946.

Casal, J. J. 2013. Photoreceptor signaling networks in plant responses to shade. Annual Review of Plant Biology, 64(1): 403–427.

Chen, Y., Li, T., Yang, Q., Zhang, Y., Zou, J., Bian, Z. and Wen, X. 2019. UVA radiation is beneficial for yield and quality of indoor cultivated lettuce. Frontiers in Plant Science, 10(December): 1–10.

Faust, J.E. and Heins, R.D. 1993. Modeling leaf development of the African violet (*Saintpaulia ionantha* Wendl.). Journal of the American Society for Horticultural Science, 118(6): 747–751.

Faust, J.E. and Heins, R.D. 1994. Modeling inflorescence development of the African violet (*Saintpaulia ionantha* Wendl.). Journal of the American Society for Horticultural Science, 119(4): 727–734.

He, R., Zhang, Y., Song, S., Su, W., Hao, Y. and Liu, H. 2021. UV-A and FR irradiation improves growth and nutritional properties of lettuce grown in an artificial light plant factory. Food Chemistry, 345:128727.

Heo, J., Lee, C., Chakrabarty, D. and Paek, K. 2002. Growth responses of marigold and salvia bedding plants as affected by monochromic or mixture radiation provided by a Light-Emitting Diode (LED). Plant Growth Regulation, 38(3): 225–230.

Hooks, T., Masabni, J., Sun, L. and Niu, G. 2021. Effect of pre-harvest supplemental uv-a/blue and red/blue led lighting on lettuce growth and nutritional quality. Horticulturae, 7(4): 1–14.

Huché-Thélier, L., Crespel, L., Gourrierec, J. Le., Morel, P., Sakr, S. and Leduc, N. 2016. Light signaling and plant responses to blue and UV radiations-perspectives for applications in horticulture. Environmental and Experimental Botany, 121: 22–38.

Izzo, L.G., Mickens, M.A., Aronne, G. and Gómez, C. 2021. Spectral effects of blue and red light on growth, anatomy, and physiology of lettuce. Physiologia Plantarum, 172(4): 2191–2202.

Kang, S., Zhang, Y., Zhang, Y., Zou, J., Yang, Q. and Li, T. 2018. Ultraviolet-a radiation stimulates growth of indoor cultivated tomato (*Solanum lycopersicum*) seedlings. HortScience, 53(10): 1429–1433.

Keller, M.M., Jaillais, Y., Pedmale, U.V., Moreno, J.E., Chory, J. and Ballaré, C.L. 2011. Cryptochrome 1 and phytochrome B control shade-avoidance responses in *Arabidopsis* via partially independent hormonal cascades. Plant Journal, 67(2): 195–207.

Khoshimkhujaev, B., Kwon, J.K., Park, K.S., Choi, H.G. and Lee, S.Y. 2014. Effect of monochromatic UV-A LED irradiation on the growth of tomato seedlings. Horticulture Environment and Biotechnology, 55(4): 287–292.

Kim, H.M. and Hwang, S.J. 2019. The growth and development of 'Mini Chal' tomato plug

seedlings grown under various wavelengths using light emitting diodes. Agronomy, 9(3): 1-19. doi:10.3390/agronomy9030157

Kim, J.K. and Sang, C.G. 1982. A study on the growth and flowering of *Saintpaulia ionantha* under controlled light intensities. Journal of Korean Society for Horticultural Science, 23: 323-331.

Kong, Y., Schiestel, K. and Zheng, Y. 2019. Pure blue light effects on growth and morphology are slightly changed by adding low-level UVA or far-red light: A comparison with red light in four microgreen species. Environmental and Experimental Botany, 157: 58–68.

Kreslavski, V.D., Los, D.A., Schmitt, F.J., Zharmukhamedov, S.K., Kuznetsov, V.V. and Allakhverdiev, S.I. 2018. The impact of the phytochromes on photosynthetic processes. Biochimica et Biophysica Acta - Bioenergetics, 1859(5): 400–408.

Kwack, B. and Kim, I. 1969. Growth and ornamental value of *Saintpaulia* and *Hypoestes* under the different light conditions. Journal of Korean Society for Horticultural Science, 6: 75-79.

Loconsole, D. and Santamaria, P. 2021. UV lighting in horticulture: A sustainable tool for improving production quality and food safety. Horticulturae, 7(1): 1–13.

McCree, K.J. 1971. The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural Meteorology, 9(C): 191–216.

Mockler, T.C., Guo, H., Yang, H., Duong, H. and Lin, C. 1999. Antagonistic actions of Arabidopsis cryptochromes and phytochrome B in the regulation of floral induction. Development, 126(10): 2073–2082.

O'Carrigan, A., Babla, M., Wang, F., Liu, X., Mak, M., Thomas, R., Bellotti, B. and Chen, Z.H. 2014. Analysis of gas exchange, stomatal behaviour and micronutrients uncovers dynamic response and adaptation of tomato plants to monochromatic light treatments. Plant Physiology and Biochemistry, 82: 105–115.

Reed, J.W., Nagpal, P., Poole, D.S., Furuya, M. and Chory, J. 1993. Mutations in the gene for the red/far-red light receptor phytochrome B alter cell elongation and physiological responses throughout *Arabidopsis* development. Plant Cell, 5(2): 147–157.

Takenaka, A. 1994. Effects of leaf blade narrowness and petiole length on the light capture efficiency of a shoot. Ecological Research, 9(2): 109–114.

Tesema, M., Asbjorn, K., Ragnar, H. and Elisabeth, J. 2013. A high proportion of blue light increases the photosynthesis capacity and leaf formation rate of *Rosa* × *hybrida* but does not affect time to flower opening. Physiologia Plantarum, 148 (1):146–159.

Verdaguer, D., Jansen, M.A.K., Llorens, L., Morales, L.O. and Neugart, S. 2017. UV-A radiation effects on higher plants: Exploring the known unknown. Plant Science, 255: 72–81.

Zhang, Y., Kaiser, E., Zhang, Y., Zou, J., Bian, Z., Yang, Q. and Li, T. 2020. UVA radiation promotes tomato growth through morphological adaptation leading to increased light interception. Environmental and Experimental Botany, 176: p.104073.

Zheng, L. and van Labeke, M.C. 2017. Long-term effects of red- and blue-light emitting diodes on leaf anatomy and photosynthetic efficiency of three ornamental pot plants. Frontiers in Plant Science, 8(May): 1–12.

How to cite this article:

Akbarian, B., Matloobi, M., Motallebi-Azar, A., & Dadpour, M. R. (2023). The Role of UV Radiation Added to LED Lighting System in Growth Control of African Violet (*Saintpaulia ionantha* Wendl.). Journal of Ornamental Plants, 13(2), 75-84.

https://jornamental.rasht.iau.ir/article_702433.html