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Effects of LED Light on Seed Emergence and Seedling Quality of Four Bedding Flowers

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Abstract

Recently much attention has been paid by horticulturists to light-emitting diodes as a new source of economical and spectral-selective light. The reason is mainly coming from their versatility in handling and mounting, long working time, wattage use efficiency and lower heat production. In this study we examined their potential in promoting seed germination and producing quality flower seedlings for which we designed four growth chambers each equipped with a different light quality sources, namely red, blue, combination of 25% blue and 75% red and fluorescent lamps. Seeds of four annual bedding flowers including impatiens (*Impatiens balsamina*), zinnia (*Zinnia elegans*), petunia (*Petunia* × *hybrida*) and verbena (*Verbena aubletia*) were sown and grown to produce seedlings. Plants were illuminated 12 hours per day in the growth chambers. According to the results, seedlings under red light showed the highest emergence percentage, rate and value. Light quality variably affected growth characteristics among plant species. Impatiens and zinnia plants under blue light showed a significant increase in leaf number. The stem diameter of impatiens increased under red light. By contrast, in petunia stem diameter increased under blue light significantly. Inclusion of 25% blue light to red light reduced hypocotyl and shoot height and increased root fresh weight and root length of most plant types. Light quality did not affect the time of emergence (T_{50}), true leaf stage, four-leaf stage and shoot fresh weight. Our study demonstrated that light-emitting diodes could be an effective and reliable source of lighting under controlled environment for production of quality flower seedlings. Generally, the pure red light enhanced seedling emergence and during growth period, high quality seedlings could be produced when 25% blue light was added to red light.

Keywords: Bedding flowers, Light-emitting diode, Light quality, Seedling emergence, Seedling's quality.

INTRODUCTION

Introduction of light-emitting diode (LED) light to agricultural sector during the past decade is now going to create a new idea in artificial lighting especially in protected horticulture. This technology has been recently practiced by some growers for several purposes such as controlling flowering in photoperiodic plants, maximizing growth and yield by providing supplementary lighting and unifying light distribution within the heightened canopy of the greenhouse crops. Regarding the light role in germination potential of some flower seeds, LEDs could be chosen as a versatile and band width adjustable light source for controlling seedlings quality.

Borthwick *et al.* (1954) showed that red light may induce germination in a particular variety of lettuce seeds and far-red light could reverse this induction. Seedling quality can be affected by the factors prevailing in pre-emergence, emergence and post-emergence phases of seed germination. Some important morphological and physical attributes considered in evaluating annual flower seedling quality include; leaf area and node number, growth compactness, stem branching, stem diameter, root growth and branching level. Plant development and physiological behavior are strongly influenced by the light spectrum, which can modify the seedling morphological pattern as well (McNellis and Deng, 1995). Plants use predominantly the light in blue (400-500 nanometers) and red (600-700 nanometers) wavelengths of photosynthetically active radiation. Red light is considered the most efficient light for photosynthesis (Wollaeger and Runkle, 2014). Blue light has a variety of important photomorphogenic roles in plants, such as stomatal control (Schwartz and Zeiger, 1984), which affects water relations and CO_2 exchange; stem elongation (Cosgrove, 1981), and phototropism (Blaauw and Blaauw, 1970). However, the amount of blue light required for some growth traits such as stem elongation seems to be species-dependent. Combined blue-red lights were proven to be an effective lighting source for producing many plant species in controlled environments (Bula *et al*., 1991; Yanagi *et al.,* 1996 and Yorio *et al.*, 2001). Blue LEDs have a higher electrical conversion efficiency compared to red LEDs, B light is a higher-energy light, which can increase the energy consumption (Randall and Lopez, 2014). Therefore, to obtain positive plant responses, lower amounts of B light are preferred.

Advantages of LEDs over broad spectrum sources (e.g., fluorescent or HID lamps) include narrow-spectrum wavelengths, long functional life, low operating temperature and low energy consumption. With LEDs light quantity (Irradiance), quality (Spectrum) and photoperiod (Light Duration) can be controlled easily (Bourget, 2008; Morrow, 2008). Plug producers who use supplemental lighting from high intensity discharge (HID) lamps such as high-pressure sodium lamps (HPS) are able to reduce production time and produce more uniform and high-quality plugs that are compact, sturdy and fully rooted. Randall and Lopez (2014) grew seedlings of several annual bedding plants under solar light and supplemental light from either HPS lamps or LED varying proportions (%) of red:blue light (100:0, 85:15, or 70:30). For many seedlings grown under the 85:15 red:blue LEDs, height was shorter, also, stem diameter of some seedlings was larger compared with seedlings grown under HPS lamps. The results indicate that LEDs have the potential to be a suitable alternative supplemental light source during plug production and the seedling quality for the majority of the species tested under supplemental light from LEDs providing both red and blue light was similar or higher than those grown under HPS lamps.

The impact underlying the use of LEDs as a sole light source in ornamental plant propagation of seedlings (plugs) are not clear. In this study, we investigated the effects of light quality from different types of LEDs and fluorescent light, on seedling emergence and growth of petunia, zinnia, impatiens and verbena.

MATERIALS AND METHODS

Plant materials and growth conditions

The experiment was carried out in a growth chamber located in the Faculty of Agriculture, University of Tabriz, Tabriz, Iran. Seeds of four popular annual bedding plants including zinnia

(*Zinnia elegans* 'Art Deco'), petunia (*Petunia* × *hybrid* dwarf varieties mix), impatiens (I*mpatiens balsamina*) and verbena (*Verbena aubletia*) were bought and sown on December 24, 2014, in 4 x 9 cm plug trays containing a 1:1 mixture of perlite (an artificial substrate) and peat moss medium. Then, seeds were covered with a thin layer of vermiculite to maintain the moisture and were irrigated by spraying.

Four different light qualities were applied using 3 LED lights and one fluorescent light. The LED lights were custom-designed and constructed in a way that the four chambers were individually illuminated by red (R), blue (B), combination of red (75%) and blue (25%) or BR LED lights and the last one with warm fluorescent lamps (Fl). The growth chambers were set to have 25 °C temperature during the day and slightly cooler during the night having relative humidity ranged from 60% to 70%. The chambers received a cycle of 12 hours lighting and 12 hours darkness. The experiment was carried out in 2014, from December 24 till February 14 (79 days). During the germination and growth period, trays were irrigated using surface water spraying. Two weeks after sowing, the young seedlings were thinned out so that only one seedling were allowed to grow in each cell.

Seedling emergence and growth

Seedling emergence was recorded when the epicotyl was visible above the medium. To evaluate the seedling emergence potential, the following criteria were measured and calculated: emergence percentage (Camberato and Mccarty, 1999), emergence value (Czabator, 1962), emergence speed (Maguire, 1962) and the time to 50 percent emerge or T_{50} (Ching, 1959).

The number of days from planting to the observation of the first and second set of true leaves was recorded. During growth period, continuous measuring of morphological features for each plant was done. Stem length (from the stem base to the apex) and hypocotyl length (from the root base to the cotyledon leaves) were measured every 7 days. At the four-leaf stage (when four true leaves were fully expanded), plants were harvested. The total number of leaves was counted, stem diameter (at the middle of stem) and root length (from the root base to the root tip) were measured and recorded. Fresh weight of shoot and root was individually measured and recorded.

Statistical analysis

Data were analyzed base on split-plot design, with the light quality as main plot and the plant type as subplot. Analysis of variance were performed using the SAS general mixed models PROC MIXED procedure (SAS Institute., Cary, NC). Prior to statistical data analysis, necessary data transformations were carried out in order to ensure the homogeneity of variance (Badger and Ungar, 1989). Groups were compared by using Tukey's multiple range test at $P < 0.05$.

RESULTS

Emergence parameters

Light quality affected the seedling emergence parameters except T50. However, the interaction (Plant type x Light) for these parameters appeared to be non-significant (Table 1). T_{50} for zinnia, petunia, and impatiens was 5, 7, and 7 days, respectively. Less than 50% of verbena seedlings emerged during the experiment. According to Table 1 the emergence parameters were highest under R light. The second highest ones were observed under B light. The emergence percentage and value were minimum under BR and Fl light. The emergence speed was minimum under Fl light.

Growth parameters

Light quality did not affect the true leaf and four leaf stages of seedlings. Light quality significantly influenced all growth parameters except shoot fresh weight (FW) and a significant in-

Table 1. The emergence and growth parameters of seedlings cultivated under different light environments and summary of the effects of plant type (P), light quality (L) and their interactions plant type/light quality (PxL) on emergence and growth traits. Each value represents the least mean squares ± se of four plant types per light treatment

Light treatment	Blue	Red	Blue+Red	Fluorescent	F tests		
					P	L	PxL
Emergence percentage (%)	65.22 ab	68.97 a	56.44 b	55.45 b	*	*	ns
Emergence speed (seedling/day)	0.49 ab	0.51 a	0.46a b	0.43 b	*	*	ns
Emergence value	14.14 ab	15.52 a	12.67 b	11.42 b	*	*	ns
Leaf number	17.71±0.9 a	12.45±0.8 bc	10.91±1.2 c	14.91±0.9 ab	*	*	*
Hypocotyl length (cm)	1.36±1.0 c	3.51±0.9 a	1.66±1.4 c	2.91±1.1 b	*	*	*
Stem length (cm)	4.14±3.3 b	6.88±3.1 a	3.19±4.7 b	6.65±3.5 a	*	*	*
Root length (cm)	17.29±12.0 a	15.29±11.0 a	19.07±16.5 a	9.115±12.4 b	*	*	ns
Stem diameter (mm)	2.97±0.11 a	2.77±0.11a b	2.69±0.12a b	2.43±0.12 b	*	*	*
Root FW (g)	0.710±0.08 a	0.544±0.07 a	0.723±0.11 a	0.222±0.08 b	*	*	*
Shoot FW (g)	1.402±0.14 a	1.586±0.13 a	1.128±0.20 a	1.526±0.15 a	*	ns	*

*Within line, means followed by the same letter are not significantly different according to Tukey's honestly (0.05). ns, * and ** denote, respectively not significant, significant on the $P < 0.05$ and $P < 0.01$

teraction between light quality and plant type was observed for all the characteristics except root length (Table 1). Impatiens and verbena showed the maximum leaf number under B light, while the R and BR light produced the minimum leaf number (Fig. 1a). In zinnia and impatiens, both the B and BR lights resulted in the shortest hypocotyl significantly. The highest hypocotyl length was observed under R and Fl light for zinnia and under R light for impatiens (Fig. 1c). The behavior of the stem length was different when comparing petunia with zinnia and impatiens. The B and BR light reduced stem length of zinnia and impatiens. Whereas, in petunia the R and BR light reduced the stem length significantly. Stem elongation showed a significant increase in R light for zinnia, in R and Fl light for impatiens and in B and Fl light for petunia (Fig. 1e). A variable response to light quality in stem diameter of different plant types was observed. The diameter of stem significantly increased by B light for petunia and R light for impatiens, compared to Fl light. A constant stem diameter was observed for zinnia under light treatments. For verbena data was not recorded (Fig. 1b). The shoot FW in zinnia, petunia and verbena was not affected by light quality. Although, in impatiens the greatest shoot FW was seen under R light and significantly decreased under BR light treatment (Fig. 1f). The light quality affected root length similarly among the plant types. According to Table 1, the root length showed a significant reduction under Fl light compared to LED treatments and the BR light treatment resulted in the maximum root length (Fig. 1g). According to Table 1, the plants grown under the Fl light had the minimum root FW. There was a significant increase at the root FW with the BR light in zinnia, also with the B and R light in impatiens, compared to the Fl light (Fig. 1d).

DISCUSSION

Seedling emergence

Phytochromes are involved in the sensing of the environmental light condition by seeds, and the control of germination by R and far-R light was one of the earliest phytochrome-mediated responses described (Casal and Sánchez, 1998). Phytochromes, also absorb and respond to the blue light (Banerjee and Batschauer, 2005). According to Table 1, the significant increase in seedling emergence percentage, speed and value under R light was not depended to the plant type. Impatiens showed a significant increase in emergence speed under R light compared to Fl light. Emergence percentage for zinnia and impatiens was recorded maximum 88.89% and 72.22% in R light, for petunia 85.19% in B light and for verbena 22.22% in both R and B light.

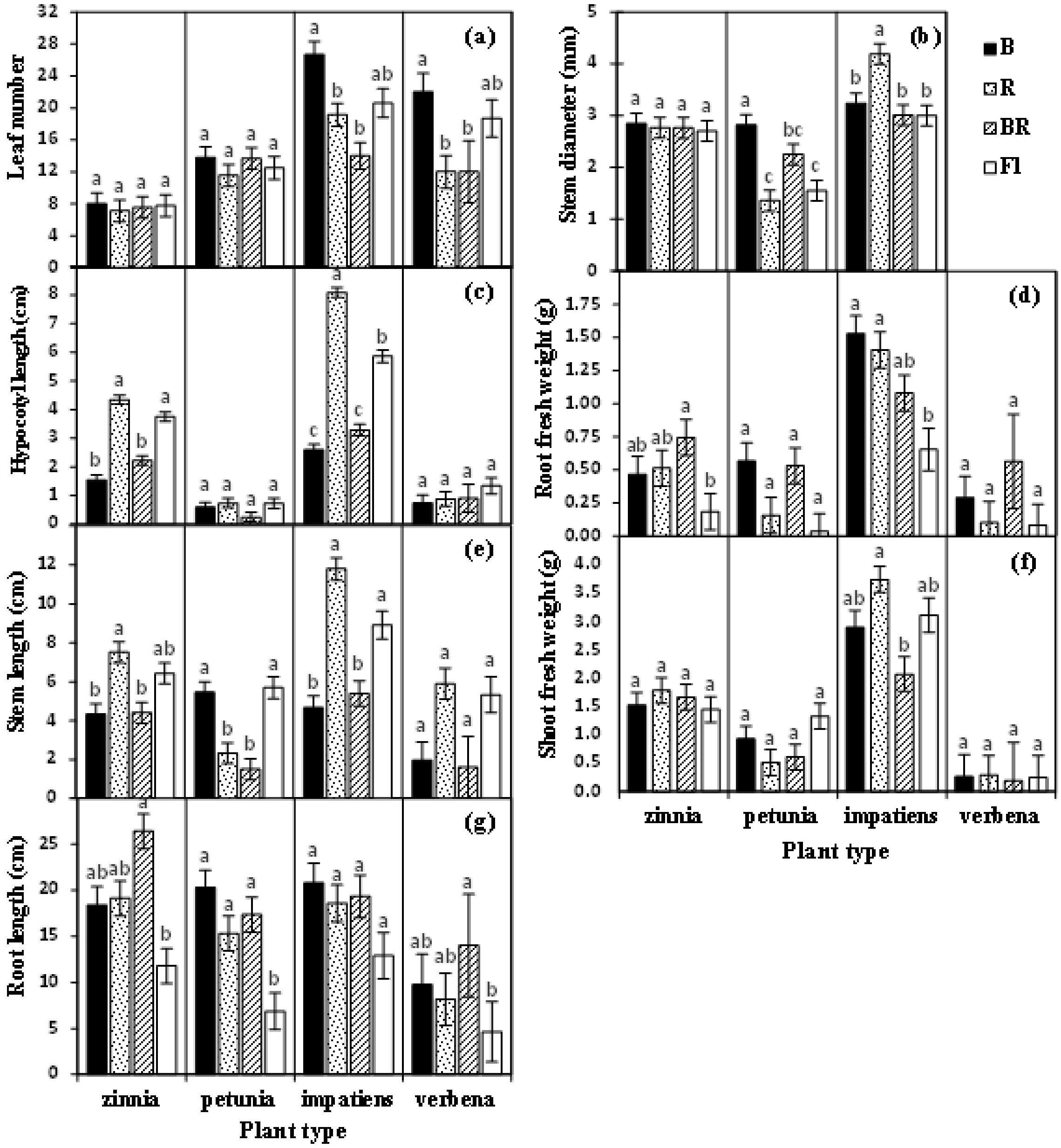

Fig. 1. The effect of light quality from LEDs including blue (B), red (R), combined 25% blue and 75% red (BR) with white fluorescent (Fl), on the growth differences of four seedling crops observed in: (a) Leaf number (b) Stem diameter (c) Hypocotyl length (d) Root FW (e) Shoot length (f) Shoot FW (g) Root length. Means sharing a letter are not statistically different by Tukey's test at $P < 0.05$

According to reduced seedling emergence of verbena, light quality had less effect on the seedling emergence. Suggesting that seeds of verbena may not require light for germination and may be affected by or responsive to other treatments. According to Neff *et al*. (2009), verbena requires darkness to germinate. In addition, that might have been due in part to hard seed coat. The light requirement for germination depends on the seed coat (Nyman, 1961).

Leaf number and morphology

The pure B light increased the leaf number in impatiens and verbena significantly. Also, in zinnia and petunia the leaf number was the highest under B light but rather conservative among treatments (Fig. 1a). In contrast, studies by Yanagi *et al.* (1996) showed that lettuce plants grown under R LEDs had more leaves. Also, Wollaeger and Runkle (2014), found that B light did not affect the number of leaves in petunia and impatiens. However, our findings showed similar results for petunia and opposed the results for impatiens, which may be due to the different cultivars used. This may suggest that the effect of the light quality on leaf number depends on the species and cultivars.

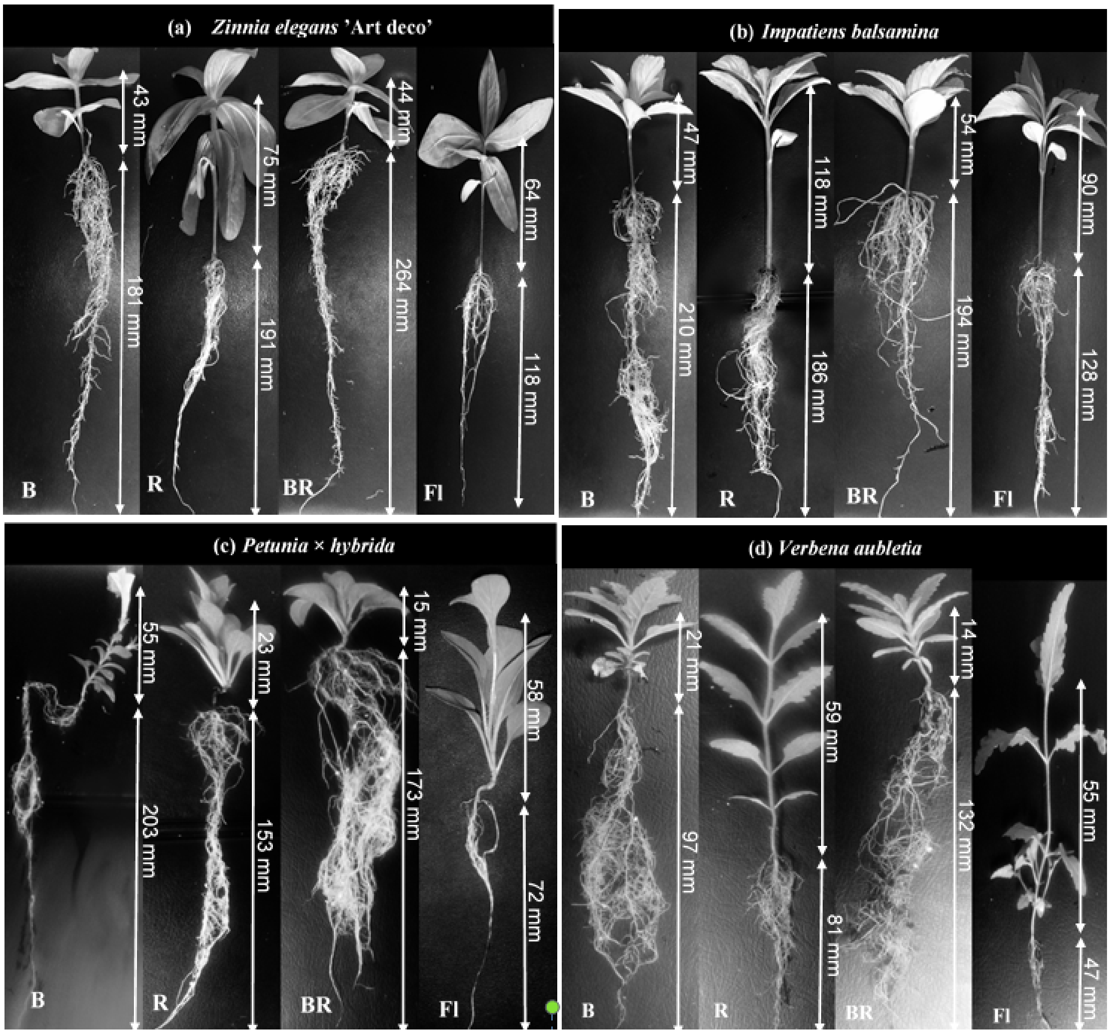

Fig. 2. Seedlings of (a) *Zinnia elegans* (b) *Impatiens balsamina* (c) *Petunia × hybrida* (d) *Verbena aubletia* propagated under blue (B), red (R), combined 25% blue and 75% red (BR) LED and white fluorescent (Fl) lights. Values represents the least mean squares of the stem and root length (mm) for each plant type per light treatment

Furthermore, zinnia plants under only R light showed leaf epinasty compared to the other light treatments, visually (Fig. 2). Fukuda *et al.* (2008), reported that in geranium (*Pelargonium zonale*), the decreased epinasty was depend on the B light intensity. Leaf epinasty is controlled by cell elongation in the abaxial epidermis triggered by B light irradiation of the adaxial side of the leaf.

Hypocotyl height

B light has great effects on photomorphogenesis of plants. The hypocotyl of impatiens and zinnia seedlings under R light became elongated, but that effect could be substantially prevented by adding at least 25% of B light. These plants had the least hypocotyl length under the B and BR light. Plants grown under Fl light often had hypocotyl height similar to that of the plants grown under only R light (Fig. 1c). Hoenecke *et al.* (1992) also reported that adding at least 15 µmol m^{-2} s^{-1} of B light to R light inhibits hypocotyl elongation in lettuce seedlings. By contrast, Hernández and Kubota (2015) found that cucumber seedlings under B light treatment had 46% greater hypocotyl length than those under R light. All these suggest that the hypocotyl elongation response to blue light seems to be species-dependent.

Stem height

Shoot height is a good predictor of growth following transplanting. Light quality promotes stem elongation. Inhibition of stem elongation is mediated by multiple photoreceptors concurrently, including mainly phytochrome and cryptochrome (Lin, 2000). Stem elongation had a remarkable increase with the R light in zinnia, the R and Fl light in impatiens and the B and Fl light in petunia compared to the BR light (Fig. 1e).

Many studies have reported the inhibitory effect of B light on stem elongation. Responses to the B light have varied among species studied (Johkan *et al.,* 2010; Schuerger *et al*., 1997). Randall and Lopez (2014) reported that for seedlings grown under the 85:15 R:B supplemental LEDs, height of *Catharanthus, Celosia, Impatiens, Petunia, Tagetes, Salvia,* and *Viola* was shorter compared to HPS or R:B LEDs (100:0 or 70:30). However, the experiment of Randall and Lopez was carried out in the greenhouse with natural light. The B light inhibits stem elongation, which subsequently limits photon capture and constrains biomass accumulation, and increases leaf thickness and chlorophyll concentration (Wollaeger and Runkle, 2015). Petunia plants under the R light looked very small. Haliapas *et al*. (2008) also reported the R light inhibits increase in height of petunia.

Furthermore, petunia plants grown under B LED exhibited flower induction. However, under other treatments floral bud formation and flowering were not observed. Fukuda *et al*. (2008) also reported that B light induces floral induction in petunia and B light of lower irradiance appears to be insufficient to induce flowering in petunia or alternatively, R light is an inhibitory signal. The number of days to flowering of petunia was around 65 days under the B light.

Stem diameter

Diameter is a predictor of survival and seedling performance after transplanting. The B light increased stem diameter in petunia significantly, in contrast, decreased stem diameter in impatiens compared to the R light and had no effect on zinnia. Fl light resulted in a significant diameter reduction in petunia and impatiens (Fig. 1b). According to the results, depending on the genotype, stem diameter may increase or remain unaffected in response to light quality.

Shoot fresh weight

Impatiens plants grown under BR light had significantly less shoot FW than those grown under only R light. Although, shoot FW of the rest of plant types was constant under light treatments, the R light in zinnia and verbena and B and Fl light in petunia resulted in a slightly greater shoot FW (Fig. 1f). This is consistent with the experiment of Wollaeger and Runkle (2014) where plants under the R light had 48% to 112% greater shoot FW than plants grown under treatments with 25% or greater B light. The relatively high fresh shoot weight of plants under R treatment can be attributed to plant adaptations such as accumulating greater amount of chlorophylls in leaves and increased stem length of plants grown under R light, which eventually resulted in plants that had the greatest biomass.

Root length

Root length is an important indicator for a potential uptake of water and nutrients. In zinnia and verbena the BR light produced longer roots than Fl light. In petunia the B, R and BR light remarkably increased the root length compared to Fl light (Fig. 1g).

Root fresh weight

Successful transplantation and promoted early growth after transplant require vigorous roots. In all of the plant types except impatiens, by adding 25% B light to R light, root FW increased. In zinnia, the BR light and in impatiens both the B light and R light showed significantly higher root FW than Fl light. In petunia and verbena, root FW under B or BR light was not different from that under R light. All plant types had the least root FW under Fl light (Fig. 1d). Previous study by Johkan *et al.* (2010) reported that root dry weight of lettuce under irradiation with BR LED was higher than that in the other plant treatments (B or R LED).

CONCLUSION

This study indicates that light quality might have contrasting effects on the morphological characteristics of different ornamental crops. Seedlings grown under the 75R: 25B LED treatment were generally of higher quality (compact, larger stem caliper, higher root fresh weight and less morphological disorders). However, petunia seedlings showed the highest quality under B light. This result is in agreement with previous reports on the determinant role of B light. The pure R light enhanced the emergence of seedlings. LED lighting systems with effective spectra can be developed to produce high quality seedlings and reduce the need for plant growth inhibitors or other height-suppressing strategies. Also, seedling morphology does not always predict transplanting success. Combining morphological measurements with an appropriate measure of physiological quality may result in improved features of transplanting performance.

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