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RESEARCH ARTICLE

Photosynthetic and growth responses of green and purple basil plants under different spectral compositions

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Abstract Light spectrum of growing environment is a determinant factor for plant growth and photosynthesis. Plants under different light spectra exhibit different growth and photosynthetic behaviors. To unravel the effects of light spectra on plant growth, photosynthetic pigments and electron transport chain reactions, purple and green basil varieties were grown under five different light spectra including white (W: 400–730 nm), blue (B: 400–500 nm), red (R: 600–700 nm) and two combinations of R and B lights (R50B50 and R70B30), with same PPFD (photosynthetic photon flux density). Almost all values for shoot and root growth traits were higher in purple variety and were improved by combinational R and B lights (especially under R70B30), while they were negatively influenced by B monochromatic light when compared to growth traits of W-grown plants. Highest concentration of photosynthetic pigments was detected in R70B30. Biophysical properties of photosynthetic electron transport chain showed higher florescence intensity at all steps of OJIP kinetics in plants grown under R light in both varieties. Oxygen evolving complex activity (F_v/F_o) and PSII maximum quantum efficiency (F_v/F_m) in R-grown plants were lower than plants grown under other light spectra. Values for parameters related to specific energy fluxes per reaction center (ABS/RC, TR_o/RC, ET_o/RC and DI_o/RC) were increased under R light (especially for purple variety). Performance index was significantly decreased under R light in both varieties. In conclusion, light spectra other than RB combination, induced various limitations on pigmentations, efficiency of electron transport and growth of basil plants and the responses were cultivar specific.

Keywords Basil · Photosynthesis · OJIP · Growth traits · Light spectra

Introduction

Light is the main environmental cue that controls various aspects of plant growth and development ranging from seed germination to flowering (Carvalho et al. 2016). Different light attributes such as quality, quantity and duration affect plant growth and productivity (Colquhoun et al. 2013). Light sources such as metal-halide, fluorescent, high-pressure sodium, neon lamps and light-emiting diode (LED) can be used for production of plants in closed environments instead of sunlight (Lin et al. 2013). Most of these light sources contain wavelengths that are not important for plant growth or they are highly energy consumable. LEDs attracted lots of attentions due to their minimum heating, long lifetime, small mass and volume, solid state construction, and generation of specific wavelengths (Heo et al. 2002; Kim et al. 2004). With introduction of LEDs for plant production in closed environments, many studies have been conducted to find growth and physiological responses of plants under specific spectral compositions.

Plants dynamically respond to their surrounding light environments (Carvalho et al. 2016). Although the range of visible light (400–700 nm) is considered as the most important light spectrum for the photosynthesis, higher plants sense and respond to a range of light spectrum, from UV-C (260 nm) to the far red (720–780 nm) (Folta and Carvalho 2015). Exposure to each light spectrum triggers

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certain responses by plants. For instance, when plants are exposed to light environment with a low red/far red ratio or high in green light, they exhibit shade avoidance responses (Wang and Folta 2013; Carvalho et al. 2016). The exposure of plants to blue and UV wavelengths lead to carotenoids and anthocyanins accumulation in the leaves (Li and Kubota 2009; Carvalho et al. 2016). Blue light can limit stem elongation and induce leaf expansion (Neff and Chory 1998; Wang et al. 2015; Carvalho et al. 2016). Red and blue lights mainly contain range of wavelengths necessary for photosynthesis in plants (Cosgrove 1981; Kasajima et al. 2008). These studies highlight the importance of light spectra on regulation of different aspects of plant growth and physiology.

Excitation of electrons by intercepted light and transfer of electrons in the electron transport chain (ETC) of photosynthetic apparatus generate energy and reducing power for production of chemical compounds in plants (Jordan et al. 2001). Two photosystems (PSI and PSII) are involved in the ETC. It has been found that the PSII is sensitive to light spectra (Miao et al. 2016). Capturing light in the antenna complex of PSII by photosynthetic pigments (Chl a and b) triggers electron transport (Taiz and Zeiger 2002).

Patterns of electron transport under monochromatic and combinational light sources can facilitate understanding the physiological response of photosynthesis to light spectra. Fate of absorbed light energy and other information about structure and function of photosynthetic apparatus can be analyzed through Chl fluorescence signals by the so-called OJIP kinetics. This kinetics depends on energy flow in thylakoid membranes, which further gives insights into photosynthetic system by fluorescence signals measurement (Kalaji et al. 2017). Therefore, this test was mainly used in current study to investigate the effects of different light spectra on photosynthetic apparatus of basil plants. Pigments other than Chls such as carotenoids and anthocyanins are considered as accessory pigments involved mainly in photoprotection of plants under stressful conditions. However, little is known regarding the structure and function of photosynthetic apparatus under different light spectra in plants containing different leaf pigmentations. Therefore, in the current study, growth, development and photosynthetic performance of green and purple basil plants were investigated under different light spectra.

Sweet basil (*Ocimum basilicum* L.), a member of Labiatae family, is an annual and a tender summer herb, which grows in several regions around the world (Holm and Hiltunen 1999; Hussain et al. 2008; Chang et al. 2009). This plant was chosen for current experiment because it has cultivars with different pigmentations and there is a great interest to grow basil plants in closed environments under LEDs.

Materials and methods

Plant material and growth conditions

Seeds of two commercial basil plants (*O. basilicum*) with different leaf color [green (mobarake ecotype) and purple (ardestan ecotype)] were sown in cocopeat and perlite (1:1, V:V) in greenhouse. Following seven days (after germination) of plant growth in transplanting tray, the transplants were transferred to plastic pots (15 cm depth and 10 cm diameter) in the same culture medium. Plants were placed inside LED-illuminated chambers (l × w × h = 1 m × 0.7 m × 1 m) with exactly same environmental conditions (25/20 °C day/night temperature and 40% relative humidity) except their light regimes. Plants were subjected to five different light spectra including: white (W), blue (B), red (R), 70% red + 30% blue (R70B30) and 50% red + 50% blue (R50B50) provided by LED modules (24 W, Iran Grow Light Co, Iran). The light intensity in all growth chambers was adjusted to photosynthetic photon flux density (PPFD) of 250 ± 10 μmol m^{-2} s^{-1}. PPFD intensities and light spectra were monitored using a sekonic light meter (Sekonic C-7000, Japan). The relative spectra of the light treatments are shown in Fig. 1. The lighting cycles were 16/8 h day/night period. Seedlings were irrigated with half strength of Hoagland solution. One month following plant growth under different light spectra, the plants were evaluated for their photosynthetic pigments and biophysical parameters.

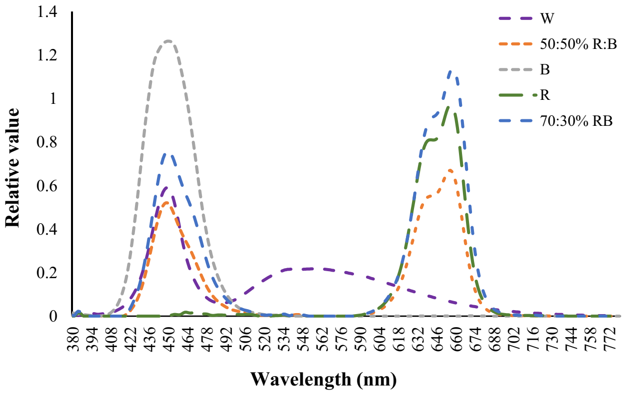


Fig. 1 Light spectra of blue (B), red (R), red 50 and blue50 (R50B50), red 70 and blue 30 (R70B30) and white (W) lighting environments measured at plant level in the growth chambers

Plant growth and morphology

One month following plant growth under different light spectra, growth and morphological characteristics such as height, leaf number, root volume, root fresh and dry weights, shoot fresh and dry weights, stem diameter and node number were measured. To measure dry weight, the samples were dried in a drying oven for 3 days at 80 °C. Root volume was measured based on the method described by Aliniaeifard et al. (2016).

Determination of chlorophyll contents

One month following plant growth under different light spectra, young fully developed leaves (3rd to 5th leaves in acropetal order) were used for determination of pigments. Chlorophyll (Chl) contents in basil plants were determined using the method of Lichtenthaler and Wellburn (1983). The samples (250 mg) were extracted in 5 ml acetone (80%) and the extract was separated by centrifugation (SIGMA-3K30) at 7000 g for 5 min. Then the absorbance of supernatant was spectrophotometrically (Lambda 25-UV/VIS spectrometer) measured at 645, 663 nm and the content of Chl a, b and total Chl were calculated based on the Lichtenthaler and Wellburn method (1983).

Total anthocyanins

The amount of anthocyanin was determined by using the method of Mita et al. (1997). Frozen samples (500 mg) were extracted in 10 ml of 1% HCL in methanol for 48 h. The liquid extract was separated by centrifugation at 7000×*g* for 5 min. Thereafter, the absorbance of the supernatant was measured at 515 nm.

Chl a fluorescence measurements

One month following plant growth under different light spectra, youngest fully developed leaves (3rd to 5th leaves in acropetal order) were used for measuring maximum quantum efficiency of photosystem II (F_v/F_m) with a Handy FlourCam FC 1000-H (Photon System Instruments, PSI, Czech Republic). Plants were dark-adapted for 20 min and attached leaves were immediately used to measure F_v/F_m. The FluorCam consisting of a CCD camera and four fixed LED panels, one pair supplying the measuring pulse and the second pair providing actinic illumination and saturating flash was used. F_v/F_m was calculated using a custom-made protocol (Genty et al. 1989; Aliniaeifard et al. 2014; Aliniaeifard and van Meeteren 2014). At the end of the short flashes, the samples were exposed to a saturating light pulse (3900 μmol m^{-2} s^{-1}) that resulted in a transitory saturation of photochemistry and reduction of primary quinone acceptor of photosystem II (Genty et al. 1989). After reaching steady state fluorescence, two successive series of fluorescence data were digitized and averaged, one during short measuring flashes in darkness (F_o), and the other during the saturating light flash (F_m). From this two parameters, F_v was calculated by the expression $F_v = F_m - F_o$. The F_v/F_m was calculated using the ratio $(F_m - F_o)/F_m$. The average values, and standard deviation of F_v/F_m were calculated by using version 7 FluorCam software.

The polyphasic Chl a fluorescence (OJIP) transients were measured by a FluorPen FP 100-MAX (photon system instruments, Drasov, Czech Republic) on young fully developed basil leaves following over-night dark adaptation. The fluorescence measurement was induced by a saturating light of approximately 3900 μmol m^{-2} s^{-1}. The OJIP transients were analyzed according to the JIP test (Strasser et al. 2000). The following data from the original measurement were used after extraction by FluorPen software: fluorescence intensities at 50 μs (F 50 μs, considered as the minimum fluorescence F_0), 2 ms (J-step, F_J), 60 ms (I-step, F_I), and maximum fluorescence (F_m). Performance index was calculated on the absorption basis (PI_{ABS}) and densities of QA^- reducing PSII reaction centers at time 0 and time to reach maximum fluorescence. The parameters related to the OJIP fluorescence transients including probability that a trapped exciton promote an electron in ETC beyond QA^- (Ψ_0), quantum yield of electron transport (φ_{E0}), quantum yield of energy dissipation (φ_{D0}), quantum yield for primary photochemistry (φ_{PAV}), maximum quantum yield of primary photochemistry (φ_{P0}), specific energy fluxes per reaction center (RC) for energy absorption (ABS/RC), trapped energy flux (TR_0/RC), electron transport flux (ET_0/RC) and dissipated energy flux (DI_0/RC) were calculated according to Kalhor et al. (2018).

Statistical analysis

Ten plants from green and purple leaf basils were grown under each light treatment. All data are presented as the mean ± standard deviation (SD). Mean separations were conducted using a Duncan test protected by ANOVA at $P \leq 0.05$.

Results

Light spectra induced changes in plant morphology

The morphology and growth of the two basil varieties were affected by the different light spectra. Tallest basil plants for the green variety were observed under R70B30 and for the purple variety, they were observed under R light. In both varieties, the shortest plants were detected under W light (Fig. 2a). In both varieties, the thickest stems were observed under R light and the thinnest stems were detected under B light (Fig. 2b). Highest shoot dry weight and root volume in both varieties were detected under R70B30 and lowest values of them were observed under B light (Fig. 2c). In both varieties, root dry weight was increased under R70B30 and decreased under B light when compared to root dry weight of plants grown under W light (Fig. 2d). In both varieties, highest and lowest numbers of leaves were observed under R50B50 and B lights, respectively (Fig. 2e). Number of nodes in purple variety was approximately two times higher than number of nodes in green variety. In purple variety, number of nodes was increased under R light and was decreased under B light, while in green variety, highest and lowest number of nodes were detected under R50B50 and W lights, respectively (Fig. 2F).

Light spectra altered leaf pigment concentrations

Concentrations of all photosynthetic pigments in the basil leaves were significantly influenced by the light spectra. Chl a (Fig. 3a) and b (Fig. 3b) were dramatically decreased by growing green basil variety under B light spectrum. Highest amounts of Chl a and Chl b in the leaves of green variety basils were detected under R50B50 and R70B30, respectively. In the purple variety, the highest Chl a concentration was observed under B light and highest Chl b concentration was detected under R70B30. Highest total Chl content was detected under R70B30 in both varieties, while the lowest total Chl content was detected under R light for green variety and W light for purple variety. In both varieties, total Chl content was almost doubled under R70B30 when compared to total Chl content of W light (Fig. 3c).

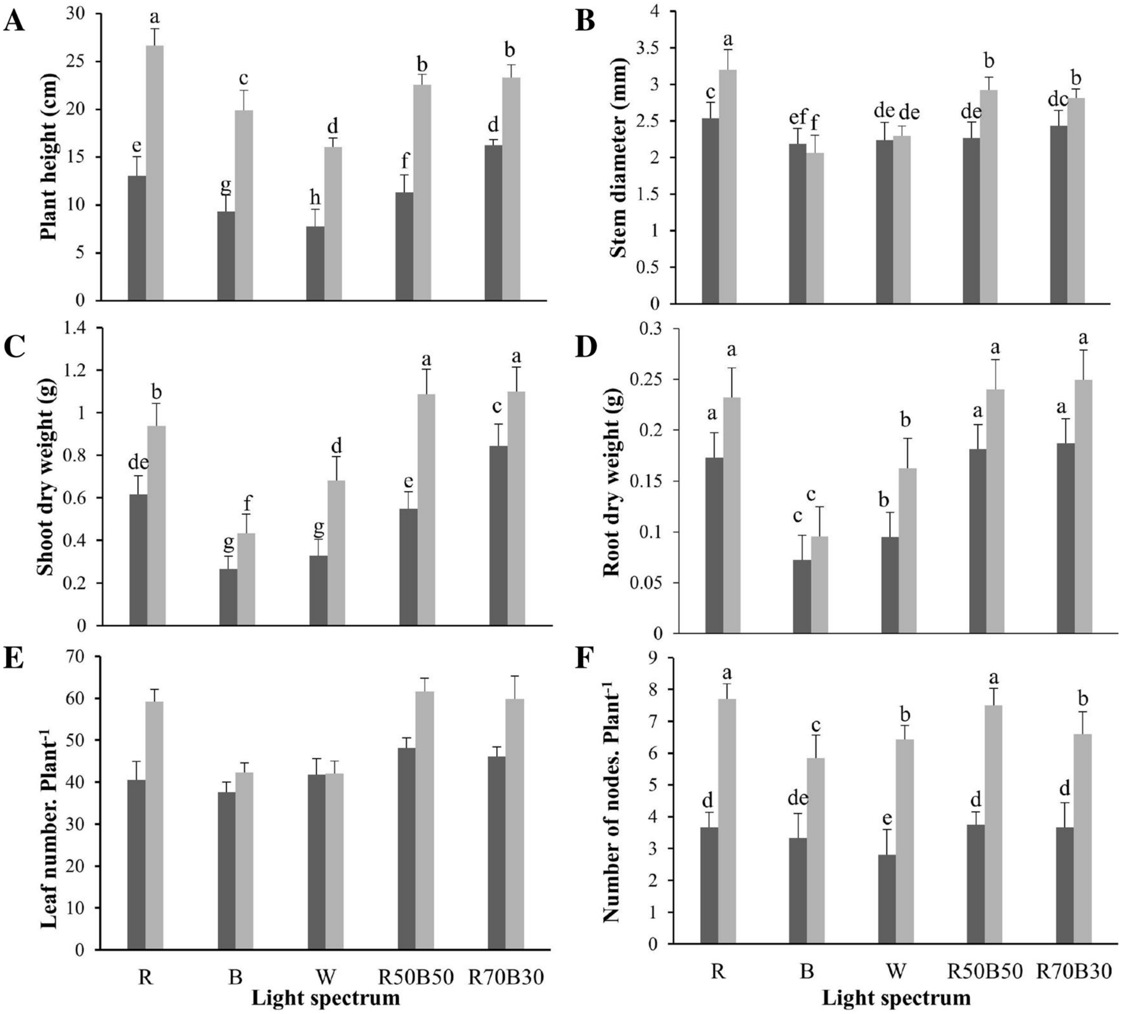


Fig. 2 Plant height (**a**), stem diameter (**b**), Shoot dry weight (**c**), root dry weight (**d**), Leaf number (**e**) and node number (**f**) in the green (black bars) and purple (grey bars) varieties of basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD. In E interactions between light spectrum and cultivar were not significant

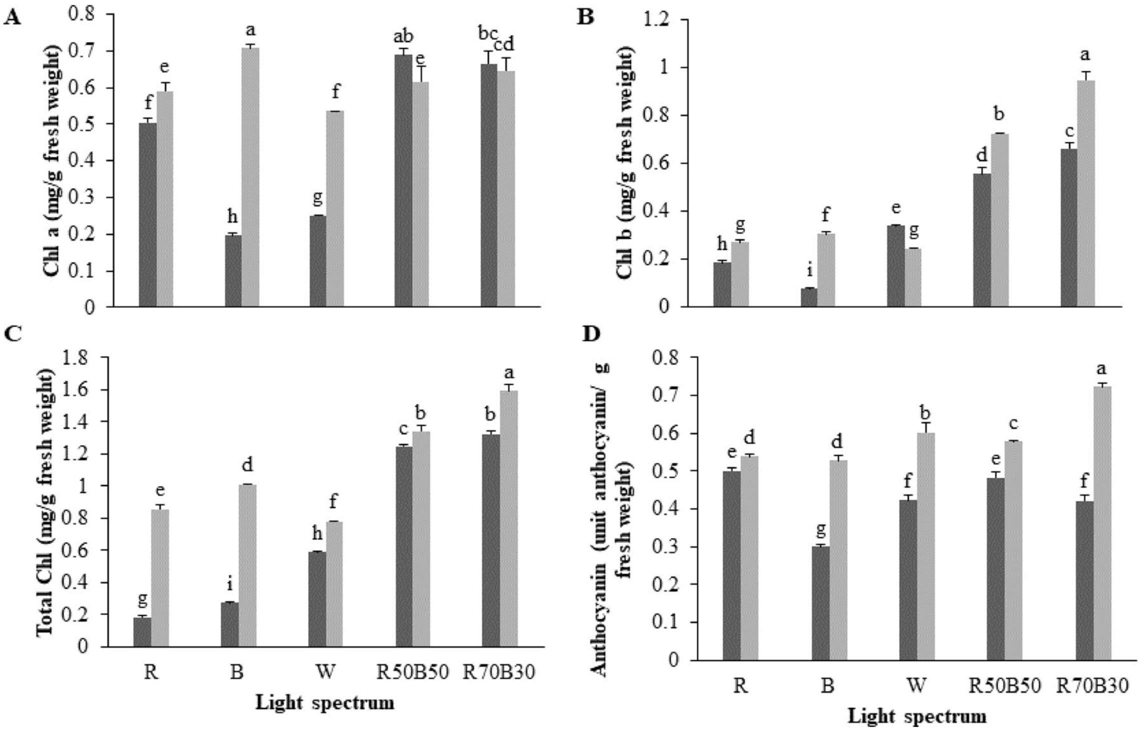


Fig. 3 Chl a (**a**), b (**b**), total Chl (**c**) and anthocyanin (**d**) of green (black bars) and purple (grey bars) varieties in the basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD

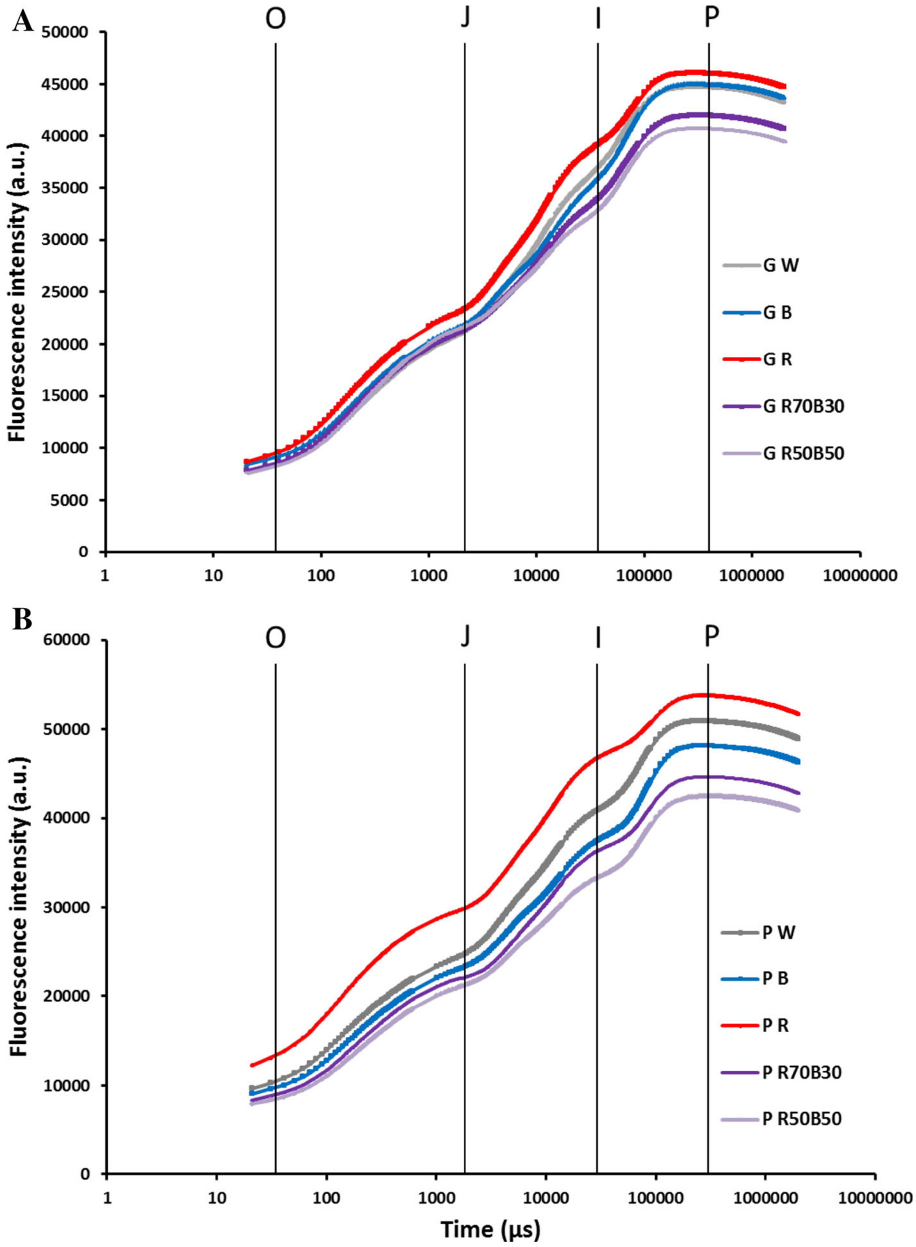
Under all light spectra, higher anthocyanin contents were detected in purple variety. Under R70B30 and B lights, anthocyanin content in purple variety was 30% higher than its content in green variety, while under R light there was only 3% difference between anthocyanin content of two varieties (Fig. 3d). The highest amount of anthocyanin (0.72 unit anthocyanin per g/fresh weight) was measured under R70B30 light in purple variety and the lowest anthocyanin content (0.29 unit anthocyanin per g/fresh weight) was detected under B light in green variety.

Polyphasic Chl a fluorescence (OJIP) kinetics

In our study, to assess the photosynthetic function under different light spectra, the nondestructive analysis of polyphasic fast Chl transient measurement was used in the leaves under dark-adapted state. In both varieties, growing plants under R light led to an induction in Chl fluorescence intensity during all steps of the OJIP graph (F_0, F_J, F_I and F_m), while lowest Chl fluorescence intensity during OJIP steps was detected under R50B50 (Fig. 4). In both varieties, highest differences between two steps (F_V, V_I and V_J) were observed under R light and the lowest F_V (Fig. 5a), V_I and V_J (data not shown) were detected under R50B50. In both varieties, F_v/F_m under R light was considerably decreased in comparison with F_v/F_m of plants grown under other light spectra. This decrease in F_v/F_m in the leaves of purple plants was considerably lower than its value in green variety (Fig. 5b). In both varieties, lowest F_v/F_0 (Fig. 5c) and F_m/F_o (Fig. 5d) were detected under R light and their highest values were detected under W and R70B30 lights in green and purple varieties, respectively.

In purple variety, under all light spectra, values for parameters related to specific energy fluxes per reaction (ABS/RC, TR_o/RC, ET_o/RC and DI_o/RC) were higher than their values in green variety (Fig. 6a–d). In both varieties, ABS/RC, TR_o/RC, ET_o/RC and DI_o/RC had highest values under R light and lowest values under R50B50. In purple varieties, all parameters related to specific energy fluxes per reaction center were higher in comparisons with their values in green variety. Plants grown under R light (especially purple variety) showed the highest φ_{Do} (Fig. 7a). In green variety, φ_{PAV} was highest under R70B30 and was lowest under B light. In purple variety, the highest and lowest φ_{PAV} values were detected under R and B lights, respectively (Fig. 7b). The highest φ_{Eo} was detected under RB combinational lights in both varieties (Fig. 7c). Φ_{Do} was dramatically increased in plants grown under R light (especially purple variety) and decreased in W light in both varieties (Fig. 7d). Among all light spectra, lowest Ψ_o value was detected under R light in both varieties; however, Ψ_o values in green variety were higher than their values in purple variety. This difference was more highlighted in plants grown under R and R70B30 lights

Fig. 4 Intensity of chlorophyll a fluorescence during different steps of OJIP curve (vertical lines) exhibited by leaves of green (**a**) and purple (**b**) varieties of basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD



(Fig. 7d). Under all light spectra, PI_{ABS} of green variety was higher than PI_{ABS} of purple variety (Fig. 8). In both varieties, PI_{ABS} was increased by growing plants under combinational lights, while its value was decreased in plants grown under R light.

Analyzing of OJIP data in both varieties using spider plot diagram showed more variation in purple variety in comparison with green variety (Fig. 9a, b). In both varieties, growing plants under R light caused substantial changes in the fate of the absorbed light by PSII. In purple variety, involvement of R spectrum in the incident light (R and R70B30) resulted in substantial change in plant responses to the light, while in the green variety spectral range in only R region of visible light induced different responses of PSII biophysical parameters. PI_{ABS} in both varieties represent the most sensitive parameter for detection of photosynthetic performance under different light spectra.

Discussion

Growth and morphology of plants were considerably influenced by light spectra and variety in this study. Purple variety of basil plants had more vegetative growth in comparison with the growth parameters of green variety. Furthermore, RB combinational lights caused a better growth in comparison with monochromatic R and B lights.

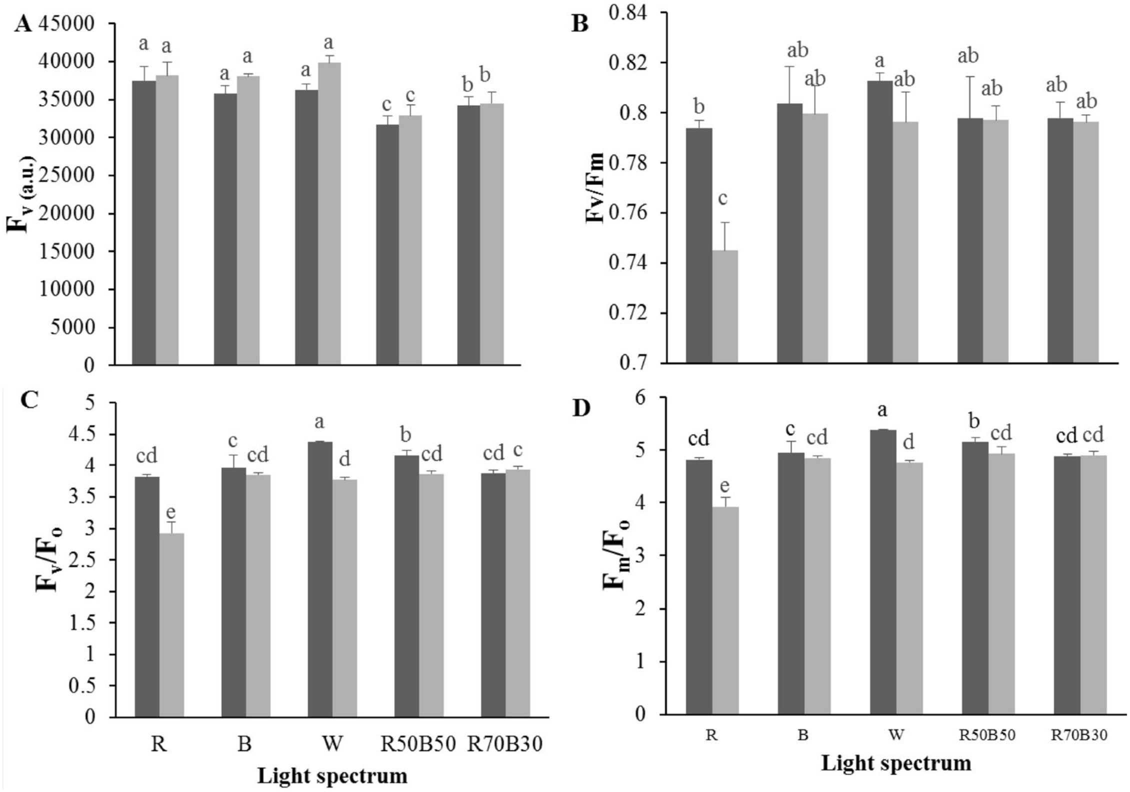


Fig. 5 Chlorophyll a fluorescence of the OJIP-test including F_v (**a**), F_v/F_m (**b**), F_v/F_o (**c**) and F_m/F_o(D) from leaves of green (black bars) and purple (grey bars) varieties of basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD

It has been frequently reported that R and B light spectra are the main light wavelengths for plant growth and development (Kozai 2016). The effects of R and B lights are mainly related to the absorption spectra of Chl a and b, which is in the range of wavelengths for R and B lights (Hopkins 1999; Son and Oh 2013). The use of both lights (R and B) together increases the Chl content of the plant (Wu et al. 2007). In accordance, in this study the highest concentrations for Chl pigments were detected in R and B combinational lights (Fig. 3).

It has been shown that R light generally increase plant growth by increasing fresh and dry weights, height and leaf area of the plants (Wang et al. 2009; Johkan et al. 2010; Heo et al. 2012; Son and Oh 2013), while, B light instead of directly affecting the biomass has an effect on photosynthetic functionality, formation of Chl and development of chloroplasts (Wang et al. 2009; Johkan et al. 2010; Savvides et al. 2011; Son and Oh 2013; He et al. 2017). However, in current study, B light resulted in declined growth in both basil varieties. In accordance, it has been shown that B light prevents cell growth, and can regulate expression of the genes that inhibit shoot elongation (Banerjee and Batschauer 2005; Shimazaki et al. 2007; Sabzalian et al. 2014). Furthermore, it has been reported that B light induces changes in development, density, opening and closure of stomata and reduce the synthesis of Chl (Kinoshita et al. 2001), while R light induce Chl synthesis and promote transcription of mRNAs to produce a set of light harvesting complexes in the PSII (Stutte 2009). Combination of R and B lights resulted in accumulation of anthocyanins in different plant species such as tomato (Giliberto et al. 2005) and lettuce plants (Samuolienė et al. 2012) which is in line with the result of current study. However, B light has been also reported as the most effective light spectrum for production of anthocyanin in plants (Crawford 1995). It seems the B light intensity varied among different species to trigger a specific response (Ouzounis et al. 2014).

Environmental conditions have a very important impact on the reactions involved in photosynthetic process of the plants. The photosynthetic reactions are directly effected by various light parameters including its spectrum and intensity (Chen et al. 2004; Zivcak et al. 2014). In our study, Chl fluorescence data were analyzed by the OJIP test. The OJIP test works based on the energy flow across the thylakoid membranes. Using this kinetics, we can investigate the efficiency of various biological phases of the electron transport system (Strasser et al. 2000; Rapacz

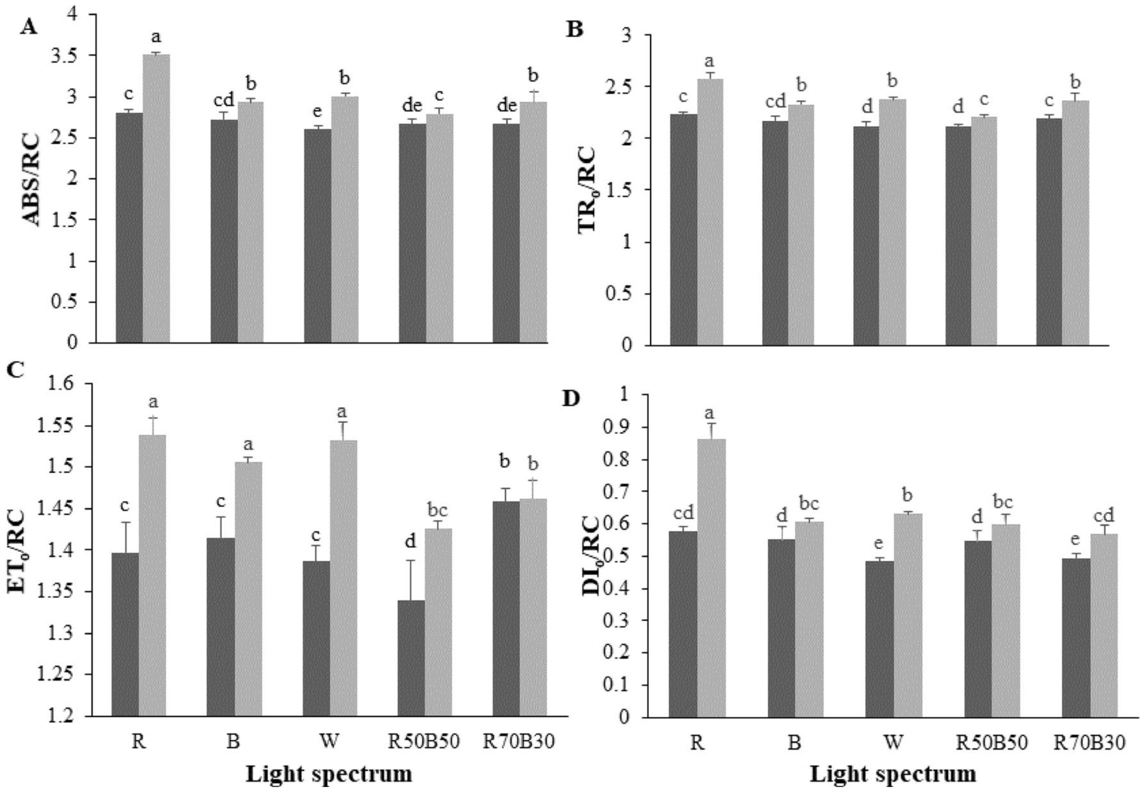


Fig. 6 Specific energy fluxes per reaction center (RC) for energy absorption (ABS/RC; **a**), trapped energy flux (TR_0/RC; **b**), electron transport flux (ET_0/RC; **c**) and dissipated energy flux (DI_o/RC; **d**) from the fluorescence transient exhibited by leaves of green (black bars) and purple (grey bars) varieties of basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD

et al. 2015; Kalaji et al. 2016). Through OJIP test, we can recognize the performance of PSII operating system. In the current study, the OJIP-derived biophysical characteristics confirmed the down-regulation of PSII operating system in green variety especially under R light. This result revealed that growing plants under combinational light spectra can help plant to develop a better photosynthetic apparatus. The high fluorescence intensity in F_o step is indicative of closure of reaction centers in the PSII. According to Zlatev and Yordanov (2004), the increase in F_o is related to damage to the protein D1 of the PSII structure. F_v/F_m decreased under R light and increased in white and blue light. F_v/F_m is related to photochemical quenching and the efficiency of the energy taken by PSII reaction centers. Decrease in F_v/F_m by R light can be related to the reduction of photochemical activity due to the inactivation of the PSII reaction centers and the damage to the D1 protein (Wu 2016). Parameters related to the energy dissipation in PSII such as φ_{Do} and DI_o/RC were increased by growth of plants under R light (Figs. 7a, 6d). This parameter represents the rate of energy conversion to heat (Falqueto et al. 2017). Conversion of energy into heat is a response from the plant to protect cells against light-induced damage. In contrast to our result, Yang et al. (2018) reported that B light down-regulate the photosynthesis efficiency and increase non-photochemical quenching in tomato plants. However, in agreements with our finding, it has been reported that R light reduces F_v/F_m and increases energy dissipation from the plant (Aliniaeifard et al. 2018). Therefore, a certain unspecified intensities of B light is vital to keep proper functionality of photosynthetic system (Hogewoning et al. 2010). Otherwise occurrence of different abnormalities in photosynthesis and morphology (such as extreme leaf epinasty) would not be surprising (Aliniaeifard et al. 2018). ABS/RC increased under R light but photochemical quenching decreased. Increasing the rate of light absorption in R light may be as a result of inactivation of PSII response centers or an increase in the size of the receptors (Lu and Vonshak 1999; Parvanova et al. 2004). Although the maximum TR_o/RC in basil plants was detected under R light, electron transfer beyond QA (ψ_0) was restricted in plants exposed to R light, as a consequence down-regulation of efficiency of quantum yield occurred (Aliniaeifard et al. 2018). The ET_o/RC is related to TR_o/RC and active reaction centers. Increased TR_o/RC when ET_o/RC is low, indicate inactivity of PSII reaction centers (Ramalho et al. 2002).

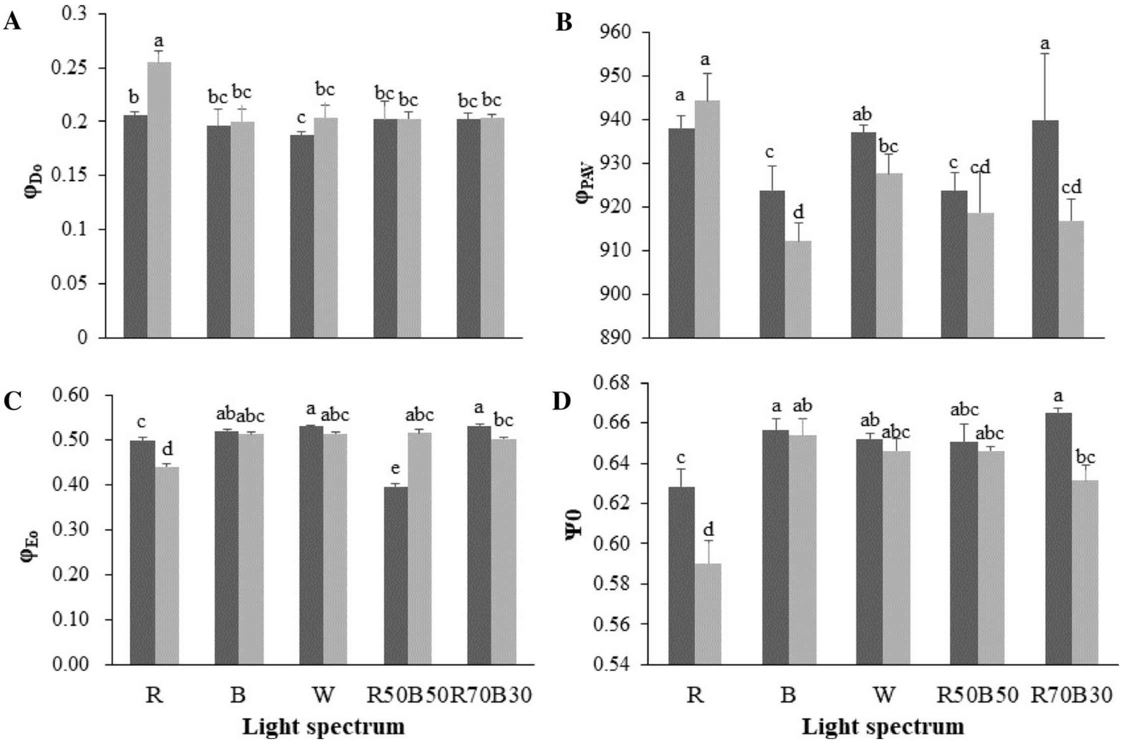


Fig. 7 Quantum yield of energy dissipation (φ_{D0}; **a**), quantum yield for primary photochemistry (φ_{PAV}; **b**), quantum yield of electron transport (φ_{E0}; **c**) and probability that a trapped exciton promote an electron in ETC beyond QA^- (Ψ_0; **d**), from the fluorescence transient exhibited by leaves of green (black bars) and purple (grey bars) basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD

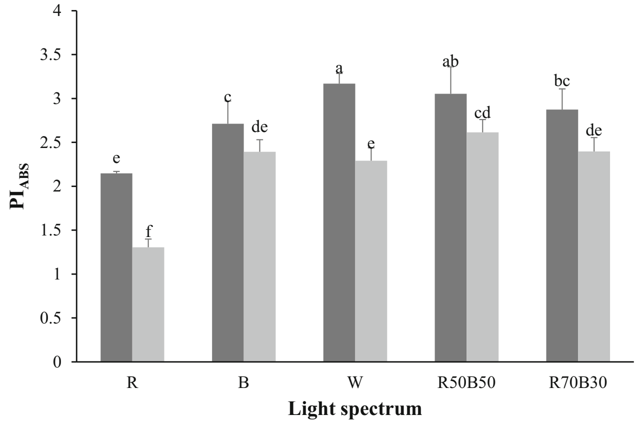


Fig. 8 PI_{ABS} from the fluorescence transient exhibited by leaves of green (black bars) and purple (grey bars) basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. Bars represent mean ± SD

In our study, PI_{ABS} represented the most sensitive parameters to light spectra (Fig. 8). More sensitivity of PI_{ABS} than F_v/F_m is because of this fact that PI_{ABS} responds to fluorescence changes between F_o and F_m, while F_v/F_m examines changes in F_o and F_m values (Van Heerden et al. 2007). PI_{ABS} is related to the energy fluxes from the early step of absorption process until reduction of plastoquinone (Strasser et al. 2000). It has been also reported that PI_{ABS} is a sensitive parameter to different environmental stresses and it has been used to measure photosynthetic and plant performance under abiotic stresses including high temperature (Martinazzo et al. 2012), salinity (Mathur et al. 2013), nutrient deficiency (Kalaji et al. 2014) and submergence (Sarkar and Ray 2016). This parameter represents the function of PSII, a decrease in PI_{ABS} rates could be due to suppression of electron transfer as a result of decrease in PSII functionality (Bukhov et al. 1992). In the current study, quantum yield of ETC system was decreased in purple variety. Decreased quantum yield in purple variety can be related to the limitation on electron transfer beyond QA. Presence of high concentration of anthocyanins in the purple variety caused a decline in the efficiency of biophysical parameters while resulted in more light energy dissipations as can be seen in higher φ_{Do} and DI_o/RC in the leaves of purple varieties. In agreement with these findings, red leaf *Coleus* varieties which contained high concentrations of anthocyanins have lower quantum yield for the intercepted light, while their carbon fixation process is not different compared to green varieties (Burger and Edwards 1996). Therefore it seems in the current study, although anthocyanins resulted in decrease in quantum yield, but it does not necessarily mean negative impact on gas

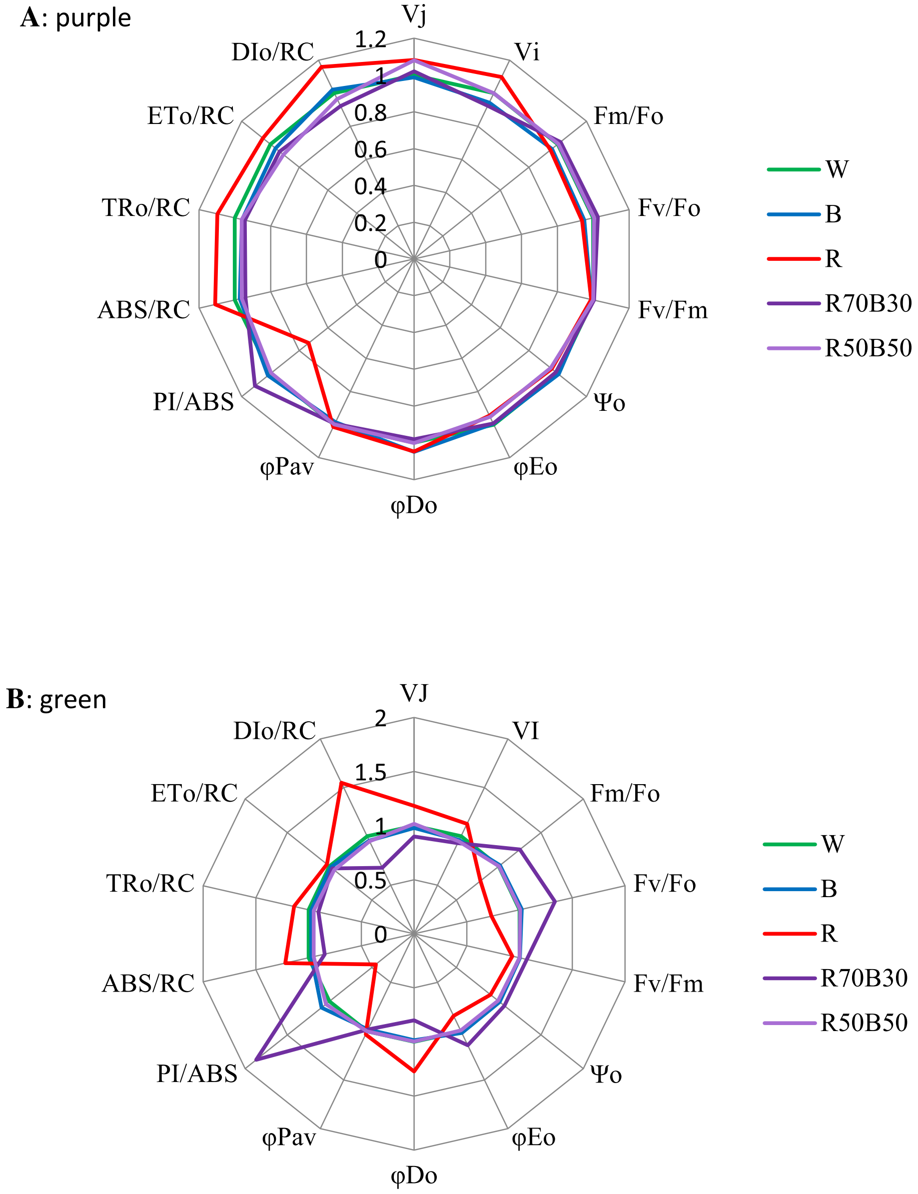


Fig. 9 Spider plot of the OJIP-test parameters from the fluorescence transient exhibited by leaves of purple (**a**) and green (**b**) basil plants grown under different light spectra [blue (B), red (R), white (W) and red and blue (RB)] with same intensity. The values of the calculated parameters were shown as relative to those of the control plants (W treatment)

exchange responses and therefore negative impact on growth parameters.

Conclusion

Management of desirable light environment for basil plants can help to increase yield and quality of this herb. Currently, many research teams all over the world have targeted the issues related to the best light intensity and spectra for plants. In current study, we showed that monochromatic R and B lights are not suitable for growth, pigmentation and biophysical properties of electron transport chain of basil plants. In both purple and green basil varieties, combination of R and B lights (especially 70R30B) caused favorable growth, pigmentation and Chl fluorescence parameters of basil plants. Therefore, new approaches for cultivation of vegetables, medicinal plants and flowers under artificial light systems should consider combination of R and B lights to prevent problems for growth, morphology and photosynthesis during commercial production of plants.

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