African Journal of Biotechnology Vol. 11(22), pp. 6169-6177, 15 March, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1191
ISSN 1684–5315 © 2012 Academic Journals

Full Length Research Paper

Regulation of the growth and photosynthesis of cherry tomato seedlings by different light irradiations of light emitting diodes (LED)

Liu Xiaoying[1], Guo Shirong[1], Chang Taotao[1], Xu Zhigang[1]* and Takafumi Tezuka[2]

[1]Nanjing Agricultural University, Nanjing, Jiangsu 210095, China.
[2]Institute of Biological Science, Nagoya University, Nagoya 464-8601, Japan.

Accepted 23 February, 2012

The growth and photosynthetic characteristics of cherry tomato seedlings were investigated under seven light irradiations such as dysprosium lamps (white light; control, C), red light emitting diodes (LEDs) (R), blue LEDs (B), orange LEDs (O), green LEDs (G), red and blue LEDs (RB) and red, blue and green LEDs (RBG) with the same photosynthetic photon flux density (about 320 µmol m^{-2} s^{-1}) for 30 days. Morphological appearances of seedlings were significantly different between light treatments, that is, the plants under RB and RBG were shorter and stronger than those under C, while those under O, G and R were higher and weaker. The higher carbohydrate contents were in plants containing blue treatment, B, RB and RBG. Photosynthetic pigments were shown to have significant difference under respective light irradiations of LEDs. The higher photosynthetic pigments were in leaves of seedlings containing blue light treatment, RBG, RB, B, C and G treatments, the lower the pigments were in those with R and O treatments. Net photosynthesis (Pn) was the highest in leaves of seedlings with RB and RBG and the lowest in those with G. Compared with C treatment, light compensation point and light saturation point of seedlings with R, RB and RBG increased, but those with O and G decreased. Electron transport rate (ETR), quantum efficiency of photosystem II photochemistry (ΦPSII), photochemical quenching (qP) and efficiency of excitation energy capture by open PSII reaction centres (Fv′/Fm′) in seedlings with B, RB and RBG treatments were significantly greater than those of the other treatments. Taken together, RB and RBG of LEDs were shown to be beneficial factors for the growth and photosynthesis in cherry tomato seedlings.

Key words: Light-emitting diode (LED), light quality, cherry tomato, growth, photosynthetic characteristics.

INTRODUCTION

Plant development and physiology are strongly influenced by the light spectrum of the growth environment. Light quality regulates a variety of plant development pathways from germination to flower induction and fruit development (Smith, 1994; Jiao et al., 2007). The plant translates the complex set of light quality signals into biochemical signals, by means of a discrete number of photoreceptors, such as the ultraviolet (UV)-A/blue light receptors, the cryptochrome and phototropin families, and the red/far red light receptors, the phytochrome family (Banerjee and Batschauer, 2005). In addition, phytochrome has also been found to mediate various blue light responses (Lin, 2000). Although, the involvement of photoreceptors has been demonstrated for a wide range of spectrum-dependent plant responses, the underlying mechanisms of the effect of different growth spectra on plant development are not known in detail (Hogewening et al., 2010).

It is often cloudy and/or rainy for a long time in winter

*Corresponding author. E-mail: xuzhigang@njau.edu.cn.

Abbreviations: LED s, Light emitting diodes; **R,** redLEDs; **B,** blue LEDs; **O,** orange LEDs; **G,** green LEDs; **RB,** red and blue LEDs; **RBG,** red, blue and green LEDs; **Pn,** net photosynthesis; **ETR,** electron transport rate; **ΦPSII,** quantum efficiency of photosystem II photochemistry; **Qp,** photochemical quenching.

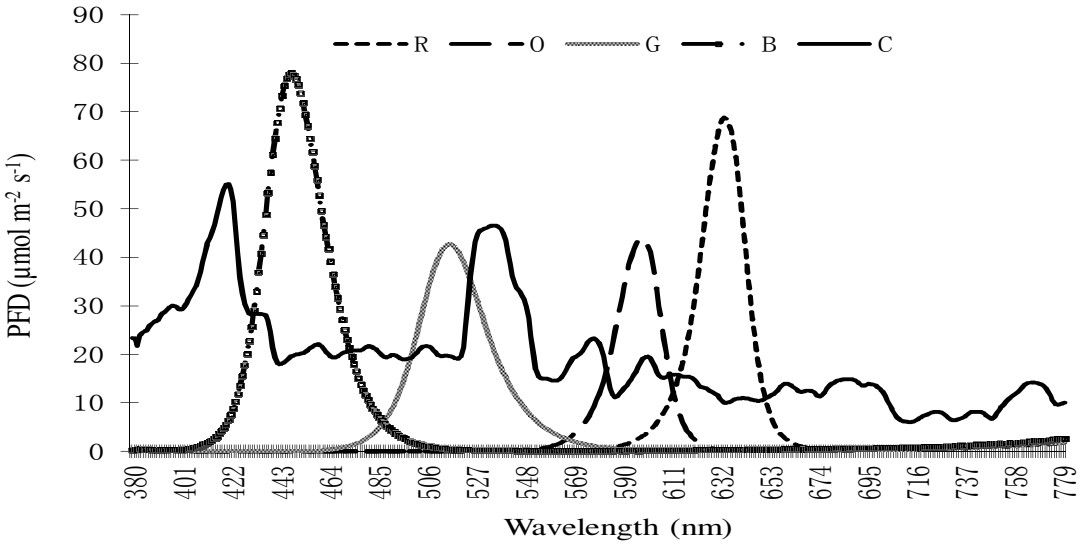

Figure 1. Spectral distribution of respective light treatments (C, dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs). Spectral distribution of RB (red and blue LEDs) is a combination of R and B, and spectral distribution of RBG (red, blue and green LEDs) is a combination of R, B and G.

and early spring in southern provinces of China. These climates have a serious influence on the growth of plants, especially the production of crops in greenhouses. Therefore, plants in such greenhouses need to be irradiated using fluorescent lamps, high pressure sodium lamps, metal halide lamps and dysprosium lamps as a source of supplemental light. However, these lamps have shortcomings such as emitting a lot of heat and causing low efficiency of photosynthesis.

Light-emitting diode (LED) is the new fourth-generation light source with good spectral characteristics and spectral width (wavelength) of emission peak ± 15 nm, and can be assembled as light quality which plants need (Goins et al., 1997). Moreover, LED has the advantages such as low energy consumption and a light source with the radiation of less heat. Therefore, LED will be widely used as a new type of good light source to be effective for the propagation and growth of plants. Numerous studies have shown the effects of LEDs on plants such as elongation, axillary shoot formation, leaf anatomy, and rhizogenesis (Tennessen et al., 1994; Tanaka et al., 1998; Wu et al., 2008; Miyamoto et al., 2006; Kim et al., 2004a). Although many researches suggested that light quality regulated growth, photosynthesis, metabolism and gene expression (Neff et al., 2000; Yu and Ong, 2003; Wang et al., 2009), many researches about light quality were carried out with irradiation of red and blue light (Goins et al., 1997; Hogewoning et al., 2010) and few studies were carried out about effects of orange, green and other light. Many questions about the effects of light quality on high plants were still not understood (Wang et al., 2009). Moreover, spectral light changes evoke different morphogenetic and photosynthetic responses that can vary among different plant species (Wang et al., 2009).

Cherry tomato (*Solanum esculentum* var. *cerasiforme*) plants are one of the cultivars of tomato species and annual plants which prefer high light. The fruits of cherry tomato plants have pleasing appearances and a delicious taste, and are well accepted by consumers. The photosynthesis and growth of the tomato plants are greatly influenced by the quality and intensity of light (Kinet, 1977; Hiroshi et al., 2000). Few studies about effects of different LED light on cherry tomato have been carried out.

The objective of this study was to examine how LED light quality affects plant photosynthesis and growth, and to find a suitable light source for culturing cherry tomatoes. Morphological characters, photosynthesis parameters, chlorophyll fluorescence and carbohydrate metabolites have been determined on cherry tomato plants after exposure to different LED light.

MATERIALS AND METHODS

Plant materials and culture condition

Seedlings of cherry tomato (*S. esculentum* var. cerasiforme) (provided by Taiwan farmers Co.), which developed two leaves after germination were transplanted and grown in plastic pots containing a mixture of peat and vermiculite (3:1, v/v) under light treatments. Each treatment contained 20 seedlings. The treatments were provided by a dysprosium lamp (white light, control; C) (LZ400D/H, 400W, YaHuaNing Co., Nanjing, China) and LEDs designated as red (R), blue (B), orange (O), green (G), red and blue (RB) and red, blue and green (RBG). The RB combination of spectral energy distribution was shown to be R:B = 1:1. The RBG combination of spectral energy distribution were shown to be R:B:G = 3:3:1. Spectral distribution of light treatments is shown in Figure 1. Except for the power of green lamp in RBG treatment, which was 3 W, the

Table 1. Effects of LED light irradiation on the growth and morphological appearances of cherry tomato plants.

Light treatment	Plant height (cm)	Stem diameter (cm)	Leaves area (cm^2)	Fresh weight (g)	Dry weight (g)	Content of water (%)	SLA (cm^2/g)	Healthy index
C	12.5^{c}	3.1^{a}	9.83^{a}	3.34^{ab}	0.31^{ab}	91^{a}	62.53^{c}	0.075^{b}
R	19.2^{a}	2.9^{a}	5.26^{b}	2.14^{bc}	0.20^{bc}	91^{a}	72.75^{b}	0.030^{c}
B	12.8^{c}	3.2^{a}	7.26^{b}	4.32^{a}	0.45^{a}	90^{a}	55.47^{cd}	0.113^{a}
O	17.2^{ab}	2.9^{a}	4.87^{b}	1.82^{c}	0.14^{c}	92^{a}	87.34^{a}	0.022^{c}
G	16.1^{b}	2.9^{a}	5.13^{b}	2.42^{bc}	0.20^{bc}	92^{a}	81.09^{ab}	0.035^{c}
RB	9.8^{d}	3.0^{a}	5.62^{b}	2.92^{ab}	0.31^{ab}	89^{a}	45.15^{e}	0.094^{ab}
RBG	8.5^{d}	3.2^{a}	5.92^{b}	2.46^{bc}	0.25^{bc}	90^{a}	52.39^{de}	0.093^{ab}

C, Dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs; RB, red blue LEDs; RBG, red, blue and green LEDs; SLA, specific leaf area. Different letters indicate significant differences at $P<0.05$ (n=3).

power of every LED lamp treatment was 9 W. The number of lamp in treatments of R, B and RB was 9 each, while the number of lamp used in treatments O, G and RBG was 12. Respective LEDs were operated with the same photosynthetic photon flux density (PPFD) (about 320 µmol m^{-2} s^{-1}) for 30 days. Spectral distribution and total power for each treatment are as shown in Figure 1. Seedlings were incubated at 28°C during daytime and 18°C at night, relative humidity (RH) was 60 ~ 80%, and a day length of 12 h was used. The light system was designed and made by Nanjing Agricultural University.

Morphological and physiological analyses

Morphological and physiological analyses were carried out using seedlings after light irradiation for 30 days. Response curves of photosynthetic photon flux density (PPFD) were made out using a photosynthesis instrument (LI-6400, LI-COR, USA). PPFD was set so as to measure within a range from 0 to 1400 µmol m^{-2} s^{-1} for the purpose of the measurement of net photosynthesis (Pn), stomatal conductance (Gs) and intercellular CO_2 concentration (Ci) (which were measured up to 1400 µmol m^{-2} s^{-1}). Photosynthesis parameters of each sample were measured every 3 min. Photosynthetic pigments was extracted by 80% cold acetone (v/v) and determined as described (Arnon, 1949). Chlorophyll (Chl) fluorescence was measured with a fluorometer (PAM2100, WALZ, Germany). Leaves were dark-adapted for approximately 20 min prior to measurements of the effective quantum yield of photochemical energy conversion (ΦPSII), electron transport rate (ETR), photochemical (qP), non-photochemical (qN) quenching, maximal photochemical efficiency of PSII (Fv/Fm) and the efficiency of excitation energy capture by open PSII reaction centres (Fv′/Fm′) of Chl fluorescence. Measurements were obtained over a range of photosynthetically active radiation (PAR) values between 0 and 1455 µmol m^{-2} s^{-1} and calculated according to the method described previously (Van and Snel, 1990). Chlorophyll florescence parameters of each sample were measured every 6 min. Healthy index of seedlings were calculated according to the following formula:

Index = stem diameter / height × whole-plant dry weight (Liu et al., 2010).

Measurements of carbohydrate content

Freeze-dried leaves, stems, and roots were used for the determination of carbohydrate content. It was extracted in 25 ml 80% ethanol (v/v) for overnight, and the supernatants were analyzed for the sucrose contents and total soluble sugars. The pellets were boiled for 3 h in 10 ml 2% HCl (v/v) and then the supernatants were collected for the assay of starch content. The contents of total soluble sugar, sucrose, and starch, were determined with the method of Buysse and Merckx (1993).

Statistical analysis

Data were analyzed using a multifactor analysis of variance. Differences among means were calculated using the LSD (least significant difference) range test with a family wise error rate of 0.05 by using the statistical analysis software SAS8.0. The variables were measured after 30 days under the mentioned treatments.

RESULTS

Morphological analyses

Light irradiations with LEDs had significant effects on morphological appearances of cherry tomato seedlings (Table 1 and Figure 2). Compared with C treatment, the plants of R, O and G treatment were significantly weaker and higher, while the plants of B, RB and RBG treatments were stronger and lower. Stem diameter did not show significant differences among all light treatments. Leaf area of plants irradiated with C was significantly larger than those under the other LEDs and there was shown to be no significant difference among those under the irradiations of the other LEDs. Dry weight and fresh weight of the plants with B were significantly higher than that with respective irradiations of the R, O, G LED and that with RB, and RBG followed. The content of water in plants had no significant difference among all light treatments. Specific leaf area (SLA) under O and G treatments was greater than that under the other respective irradiations of LEDs, while that of RB treatment showed the lowest SLA. Root numbers of B, RB and RBG treatments were significantly higher as compared to the root numbers of R, O and G treatments, and root growth under R and O was especially inferior to that under the other irradiations of LEDs (Figure 2). Taken together, the appearances of tomato seedlings grown under respective seven light treatments are as shown in Figure 2.

Figure 2. Effects of LED light irradiation on the growth of cherry tomato plants (C, dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs).

Functional factors of photosynthesis

Contents of photosynthetic pigments

The contents of Chl and carotenoid in leaves of plants under different irradiations of LEDs were shown to have no significant differences (Table 2). Compared with C treatment, the contents of Chla, Chlb, Chl(a+b) and carotenoids in leaves of plants with RBG showed a tendency to be barely higher than those with the other irradiations of LEDs. The contents in the leaves of R and O treatments were shown to be lower. Chla/b showed a tendency to have significant difference in order of the light irradiations of RB, R, G, B, C, RBG and O. Leaf color of the plants grown under the irradiations of C, B, RB and RBG was dark green, while that grown under the irradiations of R, O and G was yellowish-green. The veins of the leaves under the irradiations of B, RB and RBG appeared as purple (Figure 3).

Photosynthesis

The Pn of leaves with the irradiations of R, B, RB and RBG was enhanced significantly, while that of O and G was suppressed as compared to that of C (Figure 4a). The enhancement under the irradiations of RB and RBG was greater than that under R and B. The light saturation point (LSP) under the irradiation of G showed the lowest PPFD (about 100 µmol m^{-2} s^{-1}), while that under RB and RBG showed the greatest PPFD (about 800 µmol m^{-2} s^{-1}). The LSP of R, C, B and O, was about 500 µmol m^{-2} s^{-1} (Figure 4a). The light compensation point (LCP) was shown to depend on the light quality of LEDs (Figure 4b). The LCP of leaves with the irradiations of RBG and RB was the highest (about 30 µmol m^{-2} s^{-1}) and that with R and B was about 20 and 16 µmol m^{-2} s^{-1}, respectively. On the other hand, the LCP with O and G was shown to be roughly 0 µmol m^{-2} s^{-1} (Figure 4b). The apparent quantum yield efficiency (AQY) was shown to have differences among the light irradiations of LEDs, that is, AQY values were shown to be great in order of B, RBG, RB, C, R, O and G (Figure 4b).

Gs-PPFD curves were completely similar to transpiration rate (Tr)-PPFD curves (Tr-PPFD curves not shown). Gs was high under the light irradiations of RB and RBG, when compared to that under the other light irradiations of LEDs (Figure 4c). The Gs values under the irradiations of RB and RBG increased in proportion to the intensity of PPFD, while the value under C decreased slightly in proportion to the intensity of PPFD. The Gs values under the other light irradiations of LEDs showed little change in proportion to the intensity of PPFD, but Gs under R increased slowly in proportion to the intensity of

Table 2. Effects of the LED light irradiation on photosynthetic pigments in leaves of cherry tomato plants.

Light treatment	Chla (mg.g^{-1})	Chlb (mg.g^{-1})	Chl(a+b) (mg.g^{-1})	Chla/b	Carotenoid (mg.g^{-1})
C	2.256^{ab}	1.075^{ab}	3.332^{ab}	2.117^{abc}	0.887^{ab}
R	2.098^{b}	0.950^{b}	3.048^{b}	2.209^{ab}	0.789^{b}
B	2.269^{ab}	1.067^{ab}	3.337^{ab}	2.130^{abc}	0.823^{ab}
O	2.006^{b}	0.980^{ab}	2.981^{b}	2.042^{c}	0.787^{b}
G	2.183^{ab}	1.009^{ab}	3.193^{ab}	2.172^{abc}	0.839^{ab}
RB	2.357^{ab}	1.045^{ab}	3.402^{ab}	2.259^{a}	0.876^{ab}
RBG	2.503^{a}	1.200^{a}	3.704^{a}	2.088^{bc}	0.948^{a}

C, Dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs; RB, red and blue LEDs; RBG, red, blue and green LEDs. Different letters indicate significant differences at $P<0.05$ (n=3).

Figure 3. Effects of LED light irradiations on leaf appearances of cherry tomato plants (C, dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs).

PPFD. Gs under G showed the lowest regardless of the intensity of PPFD. Pn and Gs showed positive correlation under RB, RBG and R, and their correlation coefficients were 0.921, 0.837 and 0.502, respectively. However, the relations showed negative correlation among the irradiations of C, G, B and O, and the correlation coefficients were 0.713, 0.477, 0.283 and 0.277, respectively.

Ci declined up to 800 µmol m^{-2} s^{-1} of PPFD and then increased gradually (Figure 4d). Ci under RB showed somewhat high values up to 800 µmol m^{-2} s^{-1}, as compared to that of the other light irradiations of LEDs.

Carbohydrate content in organ of cherry tomato plants

As shown in Table 3, compared with C treatment, soluble sugar contents in leave of the B, G and RBG treatments significantly increased, and there was no significant difference between O, RB, R and C treatments. Sucrose content in leaves of the G treatment was significantly greater than that of the R, B, RB and RBG treatments, and sucrose content in leaves of the RB treatment was significantly less than that of other treatments. The starch content in leaves had no significant difference under light treatments.

Soluble sugar content in the stem of the B treatment was the greatest, followed by RB treatment. Compared with the C treatment, soluble sugar contents of B, O, G, RB and RBG treatments were significantly improved, while there were no effects under R. Sucrose contents in stem of the R, O and G treatment were more than that of other treatments, while there were less under RB, RBG and B. Starch contents in the stem of the B, RB and RBG treatments were more than that of the R, G and C treatments.

Soluble sugar content in root of the RB treatment was significantly more than that of other treatments, followed by B treatment. Soluble sugar contents in root of the R and O treatments were less than that of other treatments. Sucrose contents in root of the O treatment was significantly more than that of other treatments, while there were less under G and RBG treatments. Starch content in root of the O treatment was more than that of other treatments. Starch content in root of the R, B, RB and RBG treatments did not show significant differences

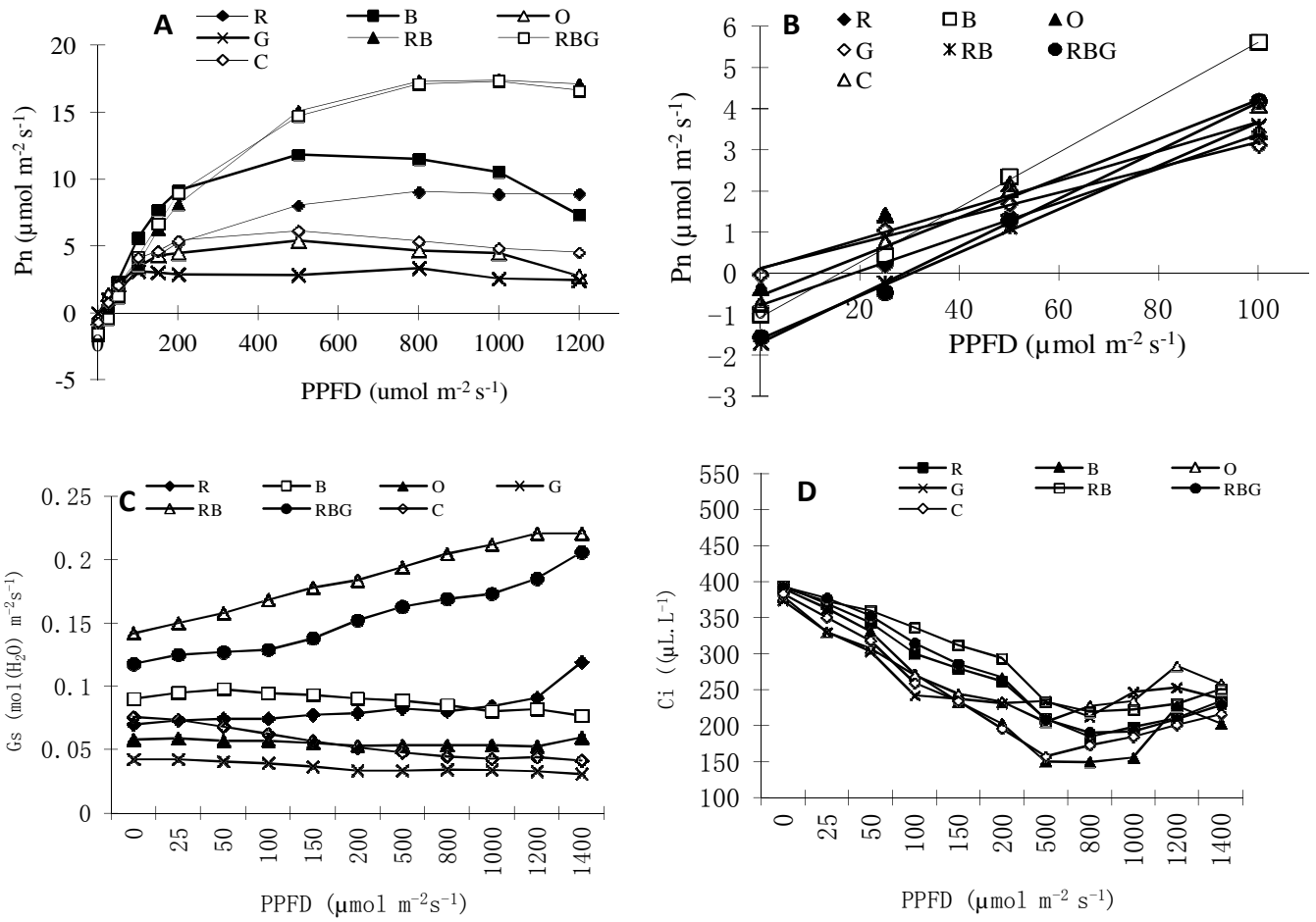

Figure 4. Effects of LED light irradiation on photosynthetic functions; a) response curve of photosynthesis (Pn), b) light compensation point and apparent quantum efficiency, the trend lines and coefficient R^2 are as follow respectively: yR=0.0415x-0.7896, R^2=0.9982, yB=0.0669x-1.071, R^2=0.9985, yO=0.0357x+0.1006, R^2=0.9297, yG=0.0307x+0.113, R^2=0.9854, yRB=0.0524x-1.5948, R^2=0.9981, yRBG=0.0586x-1.7052, R^2=0.9958, yC=0.0475x-0.5438, R^2=0.9521, c) response curve of stomatal conductance (Gs), d) Response curve of intercellular CO_2 concentration (Ci). C, Dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs.

among them.

Chlorophyll fluorescence

The results regarding the effects of the irradiations of LEDs on the impact of the chlorophyll fluorescence of cherry tomato seedlings are shown in Table 4. ETR and ΦPSII under the irradiations of B, RB and RBG were higher than those under C, while those under R, O and G were lower than those under C. Moreover, qP showed no significant difference among respective irradiations of C, B, RB and RBG, while qP under G was significantly less than that of C, B, RB and RBG. qN under R was significantly greater than that under the other LEDs, and that under RB was significantly less than the other LED irradiations. qN under the other LED irradiations, except for R and RB, had no significant difference. The Fv/Fm under R was significantly less than that under the other LEDs, and the Fv/Fm under the respective irradiations of C, B, G, RB and RBG had no significant differences, that is, they were shown to be similar values. Compared with C treatment, Fv′/Fm′ under B, RB and RBG treatments were increased, and reduced under R and O, while there was no effect under G.

DISCUSSION

Plants are well known to perceive the subtle changes of light quality by photoreceptors. These photoreceptors stimulate signal transduction systems by various ways to change photomorphology of plants (Ward et al., 2005). Our results show that plants grown under such mono-chromatic lights as orange, red, and green light, compared with the control, show a reduction in growth, but under blue, red and blue, red and blue and green light, show promotion both in growth and assimilation rate

Table 3. Effects of the LED light irradiation on content of photosynthate in organ of cherry tomato plants.

Organ of plant	Light treatment	Soluble sugar content (mg.g^{-1})	Sucrose content (mg.g^{-1})	Starch content (mg.g^{-1})
Leave	C	31.344^{c}	13.511^{ab}	10.426^{a}
	R	29.052^{c}	11.092^{b}	9.878^{a}
	B	45.522^{a}	10.335^{b}	10.096^{a}
	O	36.061^{bc}	13.417^{ab}	8.516^{a}
	G	39.633^{ab}	15.107^{a}	10.119^{a}
	RB	35.004^{bc}	8.032^{c}	11.367^{a}
	RBG	38.926^{ab}	10.229^{b}	9.501^{a}
Stem	C	17.243^{c}	19.296^{b}	8.482^{bc}
	R	18.798^{c}	28.247^{ab}	6.332^{c}
	B	65.874^{a}	17.893^{bc}	10.305^{ab}
	O	31.955^{b}	33.246^{a}	9.220^{b}
	G	33.263^{b}	27.302^{ab}	8.571^{bc}
	RB	54.264^{ab}	15.263^{c}	12.127^{ab}
	RBG	36.407^{b}	16.795^{bc}	14.286^{a}
Root	C	35.071^{bc}	11.237^{b}	13.731^{b}
	R	31.220^{c}	12.099^{b}	18.624^{ab}
	B	40.551^{b}	9.220^{bc}	18.961^{ab}
	O	29.883^{c}	18.660^{a}	20.167^{a}
	G	33.049^{bc}	6.680^{c}	13.283^{b}
	RB	50.165^{a}	11.186^{b}	17.049^{ab}
	RBG	34.332^{bc}	9.332^{bc}	17.242^{ab}

C, Dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs; RB, red and blue LEDs; RBG, red, blue and green LEDs. Different letters indicate significant differences at $P<0.05$ (n=3).

Table 4. Effects of LED light irradiation on the impact of chlorophyll fluorescence of cherry tomato plants.

Light treatment	ETR	ΦPSII	qP	qN	Fv/Fm	Fv′/Fm′
C	82.66^{ab}	0.437^{ab}	0.746^{a}	0.659^{ab}	0.818^{a}	0.576^{b}
R	43.03^{bc}	0.227^{bc}	0.422^{bc}	0.704^{a}	0.647^{b}	0.446^{c}
B	108.05^{a}	0.572^{a}	0.826^{a}	0.583^{ab}	0.828^{a}	0.691^{a}
O	31.75^{c}	0.168^{c}	0.286^{c}	0.633^{ab}	0.725^{ab}	0.528^{bc}
G	73.89^{abc}	0.391^{abc}	0.681^{ab}	0.654^{ab}	0.786^{a}	0.574^{b}
RB	108.93^{a}	0.576^{a}	0.849^{a}	0.549^{b}	0.815^{a}	0.679^{a}
RBG	99.60^{a}	0.527^{a}	0.801^{a}	0.584^{ab}	0.826^{a}	0.653^{ab}

ETR: Electron transport rate; ΦPSII, quantum efficiency of photosystem II photochemistry; qP, photochemical quenching; qN, non-photochemical quenching; Fv/Fm, maximal efficiency of Photosystem II; Fv′/Fm′, efficiency of excitation energy capture by open PSII reaction centers. C, Dysprosium lamp; R, red LEDs; B, blue LEDs; O, orange LEDs; G, green LEDs; RB, red and blue LEDs; RBG, red, blue and green LEDs. Different letters indicate significant differences at $P<0.05$ (n=3).

(Pn) (Table 1 and Figure 4a). Except monochromatic blue light, these effects of monochromatic lights on cherry tomato plants in this study have also been observed in other plants such as *Dendranthema grandiflorum*, *Triticum aestivum*, *Capsicum annum*, *Acacia mangium* and *Cucumis sativus* (Goins et al., 1997; McMahon et al., 1991; Schuerger et al., 1997; Wang et al., 2009). Yu and Ong (2003) reported that Pn of plants under monochromatic light was lower than that under broad spectral light. Moreover, Kim et al. (2004b) and Matsuda et al. (2004) have observed that supplemented blue light with red light significantly increased Pn and promoted the growth. This result was consistent with our study in which plants under RB and RBG got strong and Pn was enhanced greatly compared with other treatments (Figures 2 and 4a). According to some workers, Pn reduced under monochromatic red, yellow and green light could be as a result of the narrow transmission peaks of monochromatic light, leading to an imbalance of photons available to PSI and PSII and thus, changing the ratio of cyclic to whole chain electron transport (Tennessen et al., 1994). Moreover, utilization efficiency of photons from the

narrow red, blue, and yellow regions of spectrum by plants for photosynthesis would be lower than that of full spectrum radiation (Sager et al., 1982). In agreement with this, our results show that there is a reduction of relative quantum efficiency of PSII photochemistry (ΦPSII) in plants after exposure to monochromatic wavelength lights (Table 4). However, it seems that Pn under blue light can be promoted or inhibited by different synergistic interactions between blue/red light receptors and phytochrome according to species (Kim et al., 2004a). Blue light is well known to strongly influence the growth and development of higher plants. As described by Briggs and Huala (1999) and Lin (2000) about photomorphological responses mediated by blue light photoreceptors, blue light seems to participate in the photosynthetic acclimation in leaves irradiated during growth (Anderson et al., 1995; Senger and Bauer, 1987; Walters, 2005). Furthermore, according to Matsuda et al. (2008), blue light helps to boost the acclimation responses to energy partitioning in PSII and CO_2 assimilation due to high irradiance. The evidence as aforementioned seems to imply that photosynthesis and growth under blue light are better than those under white light in our experiment.

On the other hand, Chl content is one of the most important factors to estimate Pn (Mao et al., 2007) and dry matter production (Ghosh et al., 2004). According to Naidu et al. (1984), suppression of photosynthesis is due to reduction of Chl levels, particularly Chla, which is directly involved in determination of photosynthetic activity (Sestak, 1996). Our experiment results are evidence of the former conclusion. The higher contents of Chla in leaves under RB and RBG seem to be relevant to the higher photosynthetic rates caused under these two LEDs such as RB and RBG (Table 3). Carotenoid is the auxiliary pigment of antenna Chls in chloroplasts and can help Chl to receive light energy (Zheng et al., 2008). Red light reduced the carotenoid content in callus of hyacinth plants (Anna and Alicja, 2001). The carotenoid content in leaves of lettuce plants under different light irradiations showed to be high in order of white, yellow, blue and red (Xu et al., 2007). In the present study, the carotenoid content of cherry tomato leaves under RBG was the highest, and that under RB, B, G and C showed no significant difference, while that under O and R was the lowest (Table 3). The difference between the result of Xu et al. (2007) and Table 3 may be due to qualitative and quantitative differences between various spectral irradiations and plant species.

Light quality regulates carbohydrate of plants and affects growth of plant (Kowallik, 1982). Red light can promote the accumulation of carbohydrates (Zheng et al., 2008). Zhang et al. (2010) indicated that red light is conducive to the accumulation of photosynthetic products of plants and that fresh weight, soluble sugar, starch and carbohydrates in tomato seedlings were significantly higher under red light than those of white light. Results of Pu et al. (2005) and Chu et al. (1999) were similar to Zhang et al. (2010). Zhang et al. (2010) also reported that supplement red light with blue light was more conducive to the accumulation of carbohydrates in lettuce seedlings. However, our results are not all consistent with Zhang et al. (2010). In our studies, content of soluble sugar in cherry tomato was higher under blue light than that of under red and combination of red and blue light (Table 3). This difference is probably related to different plant species and difference of light treatment.

Light quality influenced Gs of plants, and then changed photosynthesis. Pn was controlled by stomatal or non-stomatal limitation factors. Positive correlation between Gs and Pn seems to be a criterion of photosynthesis by stomatal limitation. While Ci decreased up to a certain extent of PPFD due to indispensable conditions, and then increased, Ci is the most reliable criterion of photosynthesis by non-stomatal limitation (Xu, 1997). The Pn and Gs positively correlated with PPFD within 800 µmol m^{-2} s^{-1} together with Ci decline (Figure 3d). This phenolmenon suggests that the change of Pn under RB, RBG and R is mainly probably caused by stomatal limitation and the change under C, G, B and O by non-stomatal limitation factors. Non-stomatal limitation factor is probably due to the decrease in the quantity of Rubisco (Wang et al., 2009).

LCP and LSP are involved in the light energy ability of leaves and are even two key indicators of photosynthesis. Therefore, LCP and LSP will change under different conditions of the light environment. Under unsuitable conditions of the environment, the LCP and LSP seem to change frequently (Du et al., 2005). Different light conditions had an impact on the LCP and LSP of cherry tomato seedlings (Figure 4a and b). LSP of plants under R, RBG and RB was enhanced and that under G was suppressed, compared with the C treatment (Figure 4a). The result seems to induce the high light ability of cherry tomato plants under R, RBG and RB and the low ability of the plants under G. Furthermore, LCP of plants under RBG and RB was enhanced and that of R and B was somewhat enhanced. However, that under O and G was suppressed (Figure 4b). The result suggestes that light quality could influence LCP and LSP of cherry tomato, and LCP under LED would be lower than that under solar light. However, the reason is still not understood.

Conclusion

In conclusion, for lower Chl level, Gs, ETR, ΦPSII and qP, monochromatic red, yellow and green light irradiations caused lower Pn which resulted in unfavorable growth of cherry tomato in roots, stems, leaves and dry mass, but RB and RBG light irradiations enhanced the photosynthesis to significantly promote the growth and development of cherry tomato seedlings. Besides, light quality controls LCP of cherry tomato seedlings, and it is

different under the light source adopted in our experiment and under solar irradiation.

ACKNOWLEDGEMENT

The authors wish to thank the Chinese National Natural Science Foundation (2006AA03A165) and (30972035) for assistance rendered.

REFERENCES

Anderson JM, Chow WS, Park YI (1995). The grand design of photosynthesis: acclimation of the photosynthetic apparatus to environmental cues. J. Photosynth. Res. 46: 129-139.

Anna B, Alicja K (2001). Effect of light quality on somatic embryogenesis in *Hacinthus orientalis* L.'Delft's blue'. J. Biol. Bull. Poznan. 38: 103-107.

Arnon DI (1949). Copper enzymes in isolated chloroplasts polyphenoloxidase in beta vulgaris. Plant Physiol. 24 :1-15.

Banerjee R, Batschauer A (2005). Plant blue-light receptors. Planta, 220: 498-502.

Briggs WR, Huala E (1999). Blue-light photoreceptors in higher plants. J. Annu. Rev. Cell Dev. Biol. 15:33-62.

Buysse J, Merckx R (1993). An improved colorimetric method to quantify sugar content of plant tissue. J. Exp. Bot. 44: 1627-1629.

Chu ZX，Tong Z，Feng LJ (1999). Effect of different light quality on photosynthetic characteristics of cucumber leaves. *Acta Botanica Sinica* 41(8): 867-870. (in Chinese).

Du HT, Liu SQ, Pu GB (2005). Effects of light qualities on growth and chlorophyll fluorescence parameters in leaves of color pepper seedling. J. Acta Agriculturae Boreali-occidentalis Sinica, 14: 41-45.

Ghosh PK, Ramesh P, Bandyopadhyay KK, Tripathi KM (2004). Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. II. Dry matter yield, nodulation, chlorophyll content and enzyme activity. Bioresour. Technol. 95: 85-93.

Goins GD, Yorio NC, Sanwo MM, Brown CS (1997). Photo-morphogenesis, photosynthesis, and seed yield of wheat plants grown under red light-emitting diodes (LEDs) with and without supplemental blue lighting. J. Exp. Bot. 48: 1407-1413.

Hogewoning SW, Trouwborst G, Maljaars H, Poorter H (2010). Blue light dose-responses of leaf photosynthesis,morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light. J. Exp. Bot. 132: 1-11.

Hiroshi H, Yoshihiro S, Toshiko U, Hiroshi K (2000). Effects of low light intensity on growth, photosynthesis and distribution of photoassimilates in tomato plants. Environ. Control Biol. 38(2): 63-69.

Jiao Y, Lau OS, Deng XW (2007). Light-regulated transcriptional networks in higher plants. Nat. Rev. Genet. 8: 217-230.

Kim HH, Goins GD, Wheeler RM (2004a). Stomatal conductance of lettuce grown under or exposed to different light qualities. J. Ann. Bot. 94: 691-697.

Kim SJ, Hahn EJ, Heo JW, Paek KY (2004b). Effects of LEDs on net photosynthetic rate, growth and leaf stomata of chrysanthemum plantlets *in vitro*. Scientia Horticulturae, 101: 143-51

Kinet JM (1977). Effect of light conditions on the development of the inflorescence in tomato. Scientia Horticulturae, 6(1): 15-26.

Kowallik W (1982). Blue light effects on respiration. Annu. Rev. Plant Physiol. 33: 51-72

Lin C (2000). Plant blue-light receptors. J. Trends Plant Sci. 5: 337-342.

Liu XY, Xu ZG, Chang TT, Guo SR (2010). Growth and Photosynthesis of Cherry Tomato Seedling Exposed to Different Low Light of LED Light Quality. Acta Bot. Boreal. Occident. Sin. 30(4): 0645-0651. (in Chinese).

Matsuda R, Ohashi-Kaneko K, Fujiwara K, Goto E, Kurata K (2004). Photosynthetic characteristics of rice leaves grown under red light with or without supplemental blue light. Plant Cell Physiol. 45: 1870-1874.

Matsuda R, Ohashi-Kaneko K, Fujiwara K, Kurata K (2008). Effects of blue light deficiency on acclimation of light energy partitioning in PSII and CO_2 assimilation capacity to high irradiance in spinach leaves. Plant Cell Physiol. 49: 664-670.

McMahon MJ, Kelly JW, Decoteau R, Young RE, Pollock RK (1991). Growth of Dendranthema grandiflorum (Ramat.) Kitamura under various spectral filters. J. Am. Soc. Horticultural Sci. 116: 950-954.

Miyamoto Y, Nisbett RE Masuda T (2006). Culture and the physical environment. Holistoc versus analytic perceptual affordances. Psychol. Sci. 17: 113-119.

Naidu RA, Krishnan M, Nayudu MV, Gnanam A (1984). Studies on peanut green mosaic virus infected peanut (*Arachis hypogaea* L.) leaves. II. Chlorophyll-protein complexes and polypeptide composition of thylakoid membranes. Physiol. Plant Pathol. 25: 191-198.

Neff MM, Fankhauser C, Chory J (2000) Light: an indicator of time and place. Genes Dew. 14: 257-271.

Pu GB, Liu SQ, Liu L (2005). Effects of different light qualities on growth and physiological characteristics of tomato seedlings.*Acta Horticulturae Sinica* 32(3):420-425 (in Chinese).

Sager JC, Edwards JL, Klein WH (1982). Light energy utilization efficiency for photosynthesis. Trans. amer. Soc. agr. Eng. 25: 1737-1746.

Schuerger AC, Brown CS, Stryjewski EC (1997). Anatomical features of pepper plants (*Capsicum annuum* L) grown under red light-emitting diodes supplemented with blue or far-red light. J. Ann. Bot. 79: 273-282.

Senger H, Bauer B (1987). The influence of light quality on adaptation and function of the photosynthetic apparatus, J. Photochem. Photobiol.B: Biol. 45: 939-946.

Sestak Z (1996). Liminations for finding linear relationship between chlorophyll content and photosynthetic activity. J. Biol. Plant, 8: 336-346.

Smith H (1994). Sensing the light environment: the functions of the phytochrome family. In: Kendrick RR, Kronemberg GHM, editors. Photomorphogenesis. The Hague:Kluwer Academic Publishers, pp. 374-416.

Tanaka Y, Kimata K, Aiba H (2000). A novel regulatory role of glucose transporter of *Escherichia coli*: membrane sequestration of a global repressor Mic. EMBO J. 19: 5344-5352.

Tennessen DJ, Singsaas EL, Sharkey TD (1994). Light-emitting diodes as a light source for photosynthesis research. Photosynth. Res. 39: 85-92.

Van KO, Snel JFH (1990). The use of chlorophyll fuorescence nomenclature in plant 7 stress physiol. Photosynthesis Res. 25: 147-150.

Walters RG (2005). Towards an understanding of photosynthetic acclimation. J. Exp. Bot. 411: 435-447.

Wang H, Gu M, Cui J, Shi K, Zhou Y, Yu J (2009). Effects of light quality on CO2 assimilation, chlorophyll-fluorescence quenching, expression of Calvin cycle genes and carbohydrate accumulation in Cucumis sativus. J. Photochem. Photobiol. B: Biol. 96:30-37.

Ward JM, Cufr CA, Denzel MA (2005). The D of transcription factor OBP3 modulates phytochrome and cryptochrome signaling in Arabidopsis. Plant Cell, 17: 475-485.

Wu JS，Fu S, Zheng J，Zhou GQ (2008). Epipremnum aureum：growth and photosynthetic response to light-emitting diodes (LED). J. Zhejiang Forestry College 25(6): 739-742. (in chinese).

Xu DQ (1997). Some problems in stomatal limitation analysis of photosynthesis. Plant Physiol. Commun. 33: 241-244. (in Chinese).

Xu L, Liu SQ, Qi LD, Liang QL, Yu WY (2007). Effect of light quality on leaf lettuce photosynthesis and chlorophyll fluorescence. Chinese Agric. Sci. Bull. 23: 96-100. (in Chinese).

Yu H, Ong BL (2003). Effect of radiation quality on growth and photosynthesis of Acacia mangium seedlings. Photosynthetica, 41: 349-355.

Zheng J, Hu MJ, Guo YP (2008). Regulation of photosynthesis by light quality and its mechanism in plant. Chinese J. Appl. Ecol. 19: 1619-1624. (in Chinese).