Effects of LED light spectrum on the growth and energy use efficiency of eggplant transplants

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Abstract: To enhance the transplants' growth and reduce energy use efficiency, Eggplant (*Solanum melongena* L.) transplants (*cv.* Jingqie 21) were cultivated in a plant factory laboratory under different LED light spectrums. The experimental treatments included white plus blue LED lights (R: B=0.5, WB0.5), white LED lights (R: B=0.9, W0.9), white plus red LED lights (R: B=2.7, WR2.7), white plus red plus UV lights (R: B=3.8, WRUV3.8), and red plus blue plus green LED lights (R: B=5.4, RBG5.4). The transplants were grown for 30 d under a light intensity of 250 μmol/m^2·s and a photoperiod of 16 h/d. The morphological indicators and biomass accumulation of eggplant transplants were significantly higher in the W0.9 treatment compared to the other experimental treatments. The photosynthetic quantum yield in the W0.9 treatment exhibited an increase of over 22% compared to that in the WR2.7 treatment. The shoot dry weight of the W0.9 treatment reached (381±41) mg/plant and the leaf area was (113.3±8.9) cm^2, indicating a higher health index compared to the other treatments. However, there were no significant differences in the net photosynthetic rate of the leaves among all treatments. The energy yield (EY) of the W0.9 treatment was (37.7±1.8) g/kW·h, which was higher than others. Therefore, considering the high quality of transplants and the maximization of energy use efficiency, the LED light spectrum in the eggplant transplants production was recommended to the white LED light with an R: B ratio of 0.9.

Keywords: eggplant transplants, LED light spectrum, growth, energy use efficiency
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1 Introduction

Eggplant (*Solanum melongena* L.) is widely planted in China, the total sown area of eggplant in China reached 8.698×10^4 hm^2, and the facility sown area reached 3.631×10^4 hm^2 in 2019[1]. With the annual demand fast increasing, high-quality eggplant transplants are in short supply because low temperatures and solar radiation in winter and early spring seriously affected the growth of transplants. The quality of transplants could be increased by factory seedling nurseries using plant factories with artificial light (PFAL), and the lighting environment is the most important influential factor of PFAL.

The light spectrum is one of the conditions affecting plant growth, which influences not only the yield and quality of crops but also the photosynthetic capacity due to the absorption of light by photosynthetic pigments[2]. Blue light has been demonstrated to enhance photosynthetic efficiency, whereas red light stimulates growth and development. These different effects could lead to different amounts of biomass accumulation under different light treatments. Red and blue lights are essential for plant growth and development, red light (600-699 nm) could activate photosynthesis because its wavelength is close to the absorption peak of chlorophyll[3], and blue light (400-499 nm) plays a vital role in the photomorphogenesis of plants, including CO_2 exchange in the leaves[4]. A small amount of UV (300-399 nm) and green light (500-599 nm) is beneficial for the accumulation of photosynthetic pigments and secondary metabolites.

The monochromatic light is not advantageous to the growth of plants, the cucumber seedlings grown had lower growth rates using monochromatic red and blue light[5]. The dry mass of tomato transplants under the R: B=9: 1 treatment was greater than under the R: B=5: 5 and 7: 3 treatments[6]. A certain proportion of blue light can increase the photosynthetic capacity of leaves, but the growth rate of seedlings will decrease with the increase in the proportion of blue light[7]. High R: FR ratio could inhibit the stem elongation of transplants[8]. Using full-spectrum (300-800 nm) distributed white LEDs or white plus red LEDs significantly improves the quality and yield of hydroponic lettuce[9]. Different light spectrum not only affects plant growth but are also related to energy consumption. Dry weight accounting for light energy use efficiency (LUE) and electrical energy use efficiency (EUE) based on economic plant production can be used to guide the management of the light environment in commercial plant production. Therefore, improving LUE and EUE has always been important for plant factories to solve high energy consumption[10]. EUE is related to the light spectrum, while EUE decreases gradually as R: B increases[11]. LUE decreased with increasing light intensity and was significantly lower for monochromatic light than for mixed light[12]. To further understand the economy of LEDs in plant factory production and its impact on plant merchantability, the photon yield (PY) and energy

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yield (EY) based on plant fresh weight were proposed. The PY can be used to evaluate the fit between plants and their growth light environment, and EY can be used to indirectly evaluate the luminous efficiency of LEDs. At the same time, the utilization of EY could assist cultivators in identifying the most suitable plant species for growth in plant factories, and infer productivity. Thus, this will enhance the efficiency of plant production and optimize overall plant yield.

To further investigate the different LED light spectrum influence on the growth of eggplant transplants and analysis of the energy use efficiency, the morphological indexes, biomass accumulation, chlorophyll content, photosynthetic characteristics, chlorophyll fluorescence parameters, and energy utilization of eggplant transplants were identified in this study. It could provide a theoretical basis for the industrialized seedling raising of eggplant.

2 Materials and methods

2.1 Plant materials and growth conditions

Seeds of eggplant (*Solanum melongena* L., cv. Jingqie 21) (Jingyan Yinong Seed Sci-Tech Co., Ltd., China) were sown into the 72-cell trays (540 mm×280 mm) with a substrate blending vermiculite, peat, and perlite (1V: 2V: 1V), and the EM microbial environmental improver (EM Research Institute, Aimule environmental protection Biotechnology Co., Ltd., and Jiangsu Yimu Biotechnology Co., Ltd., China) was added. The experiment was conducted in the Plant Factory Laboratory (China Agricultural University, Beijing, China). The ambient temperature of the plant factory was set at (28±1)°C before seed germination, and the relative humidity and CO_2 were not controlled. The eggplant seeds were sprayed with water twice a day before germination. After sprouting, the temperature was adjusted to (26±1)°C and (20±1)°C in the light and dark periods, respectively, the relative humidity was 65%±5% in the light period and 75%±5% in the dark period, and the CO_2 concentration was set at (800±50) μmol/mol. The formula of the nutrient solution was the Japanese garden experimental seedling solution (Table 1). The EC was controlled at 2.2-2.5 mS/cm and the pH at 6.0-6.5. 1/3 strength of the Japanese garden experimental seedling solution was used between seed emergence and true leaf unfolding, and 2/3 strength of the solution was used before cotyledon unfolding and true leaf growth. The full strength of the Japanese garden experimental seedling solution was used after true leaf growth. The nutrient solution was irrigated by bottom irrigation. After the 30^{th} day of full cotyledon expansion of the transplants and with 6-7 true leaves, the six transplants of constant growth were randomly selected in each treatment as the sample to be tested.

Table 1 Japanese garden experimental seedling solution

Major element	Mass concentration/ mg·L^{-1}	Trace element	Mass concentration/ mg·L^{-1}
$Ca(NO_3)_2·4H_2O$	944	Na_2Fe_7-EDTA	30.00
KNO_3	808	H_3BO_3	2.86
$MgSO_4·7H_2O$	492	$MnSO_4·4H_2O$	2.13
$NH_4H_2PO_4$	152	$ZnSO_4·7H_2O$	0.22
		$CuSO_4·5H_2O$	0.08
		$(NH_4)_6Mo_7O_{24}·4H_2O$	0.02

2.2 Treatment design

The light spectrum treatment on eggplant transplants was divided into five experimental areas based on different R: B ratios (Figure 1), white plus blue LEDs (R: B=0.5, noted as WB0.5), white LEDs (R: B=0.9, W0.9), white plus red LEDs (R: B=2.7, WR2.7), white plus red plus UV lamps (R: B=3.8, WRUV3.8), and red plus blue plus green LEDs (R: B=5.4, RBG5.4) (Beijing Lighting Valley Technology Co., Ltd., China), respectively. The light intensity is 250 μmol/m^2·s, the photoperiod is 16 h/d (the light period is 08:00-00:00), and the light intensity is measured by a portable light quantum meter (LI-250, LI-COR Inc., USA) in the plane 15 cm below the lamps. The spectral distribution of lamps in each treatment was measured by an optical fiber spectrometer (AvaSpec-ULS2048, Avantes Inc., Netherland) at the wavelength of 300 to 800 nm on the plane 15 cm below the lamps. The photon fluxes of ultraviolet (UV, 300-399 nm), blue (B, 400-499 nm), green (G, 500-599 nm), red (R, 600-699 nm), and far-red (Fr, 700-800 nm) were calculated from the spectral distribution. The R: B ratio was calculated from the photon fluxes of red and blue wavelengths (Figure 1).

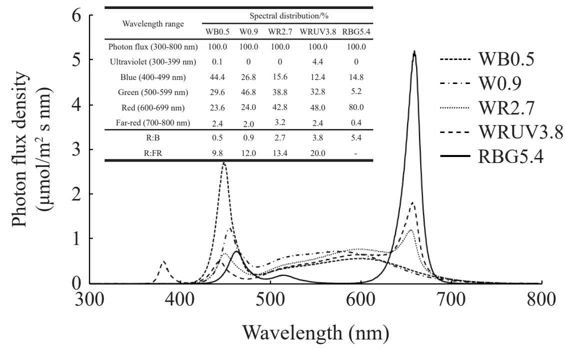


Figure 1 Spectral distribution of LEDs with the light intensity of 250 μmol/m^2·s, R: B ratios of 0.5, 0.9, 2.7, 3.8, and 5.4 (WB0.5, W0.9, WR2.7, WRUV3.8, and RBG5.4), respectively

2.3 Growth measurements

2.3.1 Plant morphology and growth characteristics

The plant height from the root to the growth point of the seedling was measured with a straightedge. The stem diameter at the middle of the hypocotyl was measured with an electronic vernier caliper (573-605/705, Sanfeng Measuring Tools Precision Co., Ltd., Japan). The number of leaves includes all mature leaves. All true leaves of the sample were scanned with a scanner (LiDE 110, Canon (China) Co., Ltd.), and the leaf area was calculated in Adobe Photoshop CC 2014. The shoot and root fresh weights of the transplants were weighed using a one percent analytical balance (AX622ZH, OHAUS Instruments (Changzhou) Co., Ltd. USA). The shoot and root parts of the transplants were placed in paper bags and dried in an oven at 80°C for 72 h to a constant weight and weighed on a one over ten-thousand analytical balance (AX224ZH, OHAUS Instruments (Changzhou) Co., Ltd., USA).

The health index, G value (Growth of daily average dry weight, mg/d), and dry weight root shoot ratio were calculated according to Equations (1)-(3).

$$\text{Health index} = S_d/h_p \times DW_T \quad (1)$$

$$\text{G value} = DW_T/DAT \quad (2)$$

$$\text{Dry weight root shoot ratio} = DW_R/DW_S \quad (3)$$

where, S_d is the stem diameter, mm; h_p is the plant height, cm; DW_T is the total dry weight, mg; DAT is the transplanting days, d; DW_R is the root dry weight, mg; DW_S is the shoot dry weight, mg.

2.3.2 Chlorophyll content

The third functional leaf was cut and weighed to 0.1 g, extracted with 95% ethanol, and the absorbance of chlorophyll extract at 665 nm, 649 nm, and 470 nm was measured by UV spectrophotometer (UV1700PC, Shanghai Aucy Scientific Instrument Co., Ltd. China), Chlorophyll content measurements of eggplant transplants using additive effects of absorbance (the total absorbance of the measured liquid at a certain wavelength is equal to the sum of its absorbance of each component), the contents of chlorophyll a and chlorophyll b are finally calculated[13].

2.3.3　Photosynthetic characteristics

The photosynthetic parameters include net photosynthetic rate (*Pn*), μmol/m^2·s; stomatal conductance (*Gs*), mol/m^2·s; intercellular CO_2 concentration (*Ci*), μmol/mol; transpiration rate (*Tr*), mmol/m^2·s. Measurements were carried out using a portable photosynthesis system (LI-6400XT, LI-COR, Inc., USA). The parameters are set as follows: the airflow rate in the sample room is 500 μmol/s, the light intensity is 350 μmol/m^2·s, the temperature of the blade chamber is 25°C, the CO_2 concentration in the reference chamber is 800 μmol/mol.

2.3.4　Chlorophyll fluorescence characteristics

Chlorophyll fluorescence parameters were measured using a chlorophyll fluorescence imaging system (CF Imager, Technologica, Inc., UK) and a multifunctional plant efficiency analyzer (M-PEA, Hansatech, Inc., UK). The fluorescence parameters used in this research include effective quantum yield of electron transport of PS Ⅱ ($\Phi_{PS\,II}$), maximal photochemical efficiency of PS Ⅱ in the dark (F_v/F_m), light energy absorbed by unit PS Ⅱ reaction center (ABS/RC), energy dissipated by unit PS Ⅱ reaction center (DIo/RC) and performance index based on absorbed light energy (PI_{abs}) and the transplants need to be dark adaptation before experiments. The activated light intensity when using CF Imager is consistent with the treatment.

2.3.5　Energy use efficiency

The energy consumption index adopts four indexes: LUE, EUE, photon yield (PY), and energy yield (EY)[14-16]. According to Equations (4)-(7).

$$\mathrm{LUE} = f \times D/\mathrm{PAR} \tag{4}$$

$$\mathrm{EUE} = f \times D/W \tag{5}$$

$$\mathrm{PY} = \mathrm{FW}_T/\mathrm{OTLI} \tag{6}$$

$$\mathrm{EY} = \mathrm{FW}_T/W \tag{7}$$

where, f is the chemical energy that transplants convert into dry matter, 20 MJ/kg; D is the dry weight increase of the available part of the transplant, kg/m^2; PAR is the acceptable effective photosynthetic radiation of transplants, MJ/m^2; W is the electric energy consumed by the LEDs, MJ/m^2; FW refers to the fresh weight of a single transplant, g; OTLI refers to the total accumulated light of transplants, mol/plant.

2.4　Data processing and analysis

The data were calculated by Microsoft Excel 2019, and the statistical analysis was carried out by IBM SPSS Statistics 26. The data analysis of variance was based on Duncan's new multiple range test (α<0.05).

3　Results and discussion

3.1　Effects of light spectrum on morphology and growth of eggplant transplants

There were significant differences in plant height, stem diameter, leaf numbers, and leaf area of eggplant transplants in different treatments (Table 2 and Figure 2). The plant height of WR2.7, WRUV3.8, and RBG5.4 treatments was higher than that of the other two treatments, and the plant height of WR2.7 treatment was up to (9.1±0.5) cm, indicating that the high proportion of red light could promote stem elongation, which is the same as that of Ouyang et al.[17] The stem diameter of eggplant transplants under W0.9 treatment was the largest, which was (3.1±0.4) mm, there was no significant difference in stem diameter between WB0.5, WR2.7, and RBG5.4, but the stem diameter of transplants under WRUV3.8 was the smallest, only (2.5±0.1) mm. The leaf area of W0.9 was (110.7±6.8) cm^2, which was 24.7% higher than that of WRUV3.8. Leaf area is an important indicator of transplant growth and affects photosynthesis and transpiration rates[18], showing that the transplants in W0.9 treatment have better photosynthetic capacity than the others. It is encouraging to compare this conclusion with that found by Kim[19], who found that increasing the proportion of green light in R: B ratio lights could increase the leaf area of lettuce significantly. This outcome is contrary to the research of Mickens et al.[20], who found that there was no significant difference in plants when increasing the proportion of green light. A possible explanation for this might be that different plants have different green light needs. Far-red light promotes the accumulation of biomass by increasing the leaf area and then increasing the light energy interception area[21]. Some researchers found that a high R: FR value could inhibit the growth of internode and the increase leaf area of bell pepper transplants[22], but others have exactly the reverse effect that a low R: FR value can increase the leaf area of trifolium[23]. All kinds of signs showed that there are great

Table 2　Effects of light spectrum on the morphology of eggplant transplants

Treatment	Plant height/cm	Stem diameter/mm	Leaf numbers	Leaf area/cm^2
WB0.5	7.8±0.6^{bc}	2.7±0.3^b	3.2±0.4^a	90.0±6.5^b
W0.9	7.3±0.9^c	3.1±0.4^a	3.0±0.0^b	110.7±6.8^a
WR2.7	9.1±0.5^a	2.9±0.2^b	3.0±0.0^b	104.2±9.6^a
WRUV3.8	7.9±0.4^{bc}	2.5±0.1^c	3.2±0.4^a	88.8±8.6^b
RBG5.4	8.2±0.6^b	2.8±0.2^b	3.0±0.0^b	104.6±2.6^a

Note: Means with the different letters in the same column were significantly different at α = 0.05 level (n=6), according to Duncan's test.

Figure 2　Growth of eggplant transplants under different R: B ratios

differences in the sensitivity of plant growth and development to R: FR value, there are different threshold ranges for plant response to R: FR[24]. In this study, the R: FR values for W0.9 and WR2.7 were similar at 12 and 13.4 respectively, and the leaf area of eggplant transplants in these two treatments was (110.7±6.8) cm^2 and (104.2±9.6) cm^2 respectively. The proportion of far-red light in the RBG5.4 treatment was very small, but the high proportion of red light also could increase the leaf area of the transplants.

Different light spectrum treatments could significantly affect biomass accumulation (Table 3). The shoot fresh weight of eggplant transplants in the RBG5.4 treatment was (4.3±0.4) g/plant, second only to the W0.9 treatment at (4.9±0.3) g/plant. The dry weight of the shoot and root of W0.9 was higher than that of other treatments, which were (0.89±0.12) g/plant and (44.6±3.1) mg/plant, respectively. These findings are consistent with the results reported by Yorio et al.[25], which demonstrated that the dry weight of radish and spinach was significantly higher under R: B ratio lights treatment than under the monochromatic light treatment. Previous studies have indicated that compared with monochromatic light, the combination of red light and blue light can promote the growth rate of hydroponic lettuce and pepper and increase the accumulation of dry mass[26]. The shoot fresh weight and dry weight of eggplant transplants in WB0.5 were 64.0% and 23.3% lower than those in W0.9, respectively, and there was no significant difference among the other three treatments. This study confirmed that the root fresh weight and dry weight of eggplant transplants were related to the light spectrum. The treatment of full-spectrum LEDs is conducive to the accumulation and transformation of assimilates and the absorption of nutrients by plants[27].

Table 3 Effects of light spectrum on the biomass of eggplant transplants

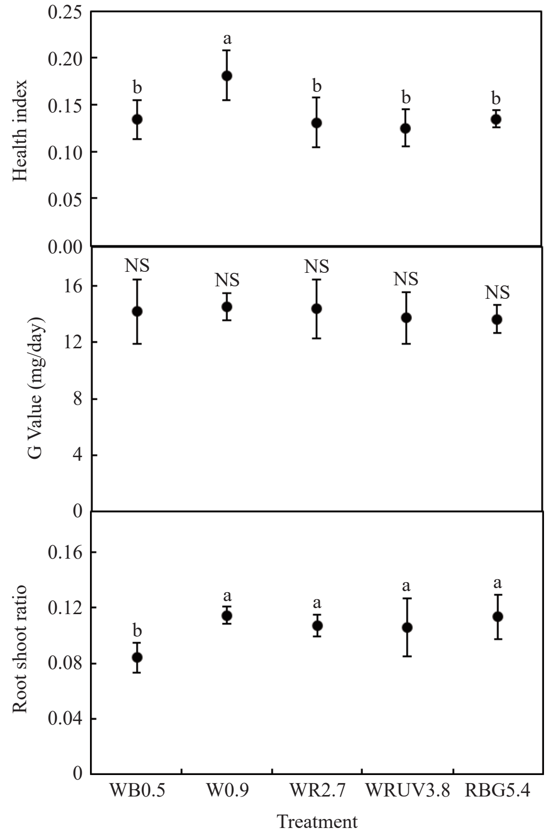
Treatment	Shoot fresh weight/ g·plant^{-1}	Shoot dry weight/ mg·plant^{-1}	Root fresh weight/ g·plant^{-1}	Root dry weight/ mg·plant^{-1}
WB0.5	3.9 ± 0.4^{bc}	377.6 ± 63.1^{b}	0.32 ± 0.04^{c}	34.2 ± 6.7^{b}
W0.9	4.9 ± 0.3^{a}	381.5 ± 41.4^{a}	0.89 ± 0.12^{a}	44.6 ± 3.1^{a}
WR2.7	4.1 ± 0.5^{bc}	372.2 ± 73.8^{b}	0.65 ± 0.14^{b}	41.9 ± 2.7^{a}
WRUV3.8	3.7 ± 0.4^{c}	356.1 ± 69.0^{c}	0.54 ± 0.10^{b}	36.5 ± 4.3^{b}
RBG5.4	4.3 ± 0.4^{b}	352.8 ± 28.3^{c}	0.54 ± 0.09^{b}	43.7 ± 6.5^{a}

Note: Means with the different letters in the same column were significantly different at α = 0.05 level (n = 6), according to Duncan's test.

The health index of eggplant transplants with W0.9 was 0.181, which was 38.5% higher than other treatments (Figure 3). A previous study has shown that red and blue light treatment could promote the growth of cucumber seedlings, the plant height, health index, and plant dry weight is significantly higher than under monochromatic light treatment[28], which is consistent with the results of this study. There was no significant difference in the G value of eggplant transplants in different light spectrums, but W0.9 was slightly higher. The root shoot ratio of W0.9, WR2.7, WRUV3.8, and RBG5.4 was significantly higher than WB0.5, which was positively correlated with R: B ratio due to the inhibitory effect of high blue light proportion on eggplant transplant root growth under WB0.5 treatment, similar findings were reported by Son et al.[29]

3.2 Effects of light spectrum on chlorophyll content of the leaves of eggplant transplants

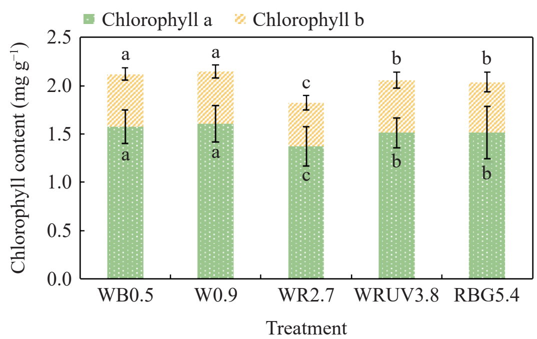
Chlorophyll is a crucial component, as the level of its content directly impacts the amount of light energy captured. It has been shown that the light spectrum can regulate photosynthesis in plants by affecting the synthesis of photosynthetic pigments[30]. The higher



Note: Means with the different letters in the same column were significantly different at α=0.05 level (n=6), according to Duncan's test. NS represents no significant difference.

Figure 3 Effects of different light spectrum on health index, G value, and root shoot ratio of eggplant transplants

the chlorophyll content of leaves, the more light energy is captured by leaves, which could improve the net photosynthetic rate of plants[31]. The contents of chlorophyll a and chlorophyll b in WB0.5 and W0.9 treatments have no significant difference, while the total chlorophyll content was 16.4% and 18.1% higher than that of WR2.7, respectively (Figure 4). The absorption peak of chlorophyll in red and blue light is significant, adding far-red light to red LED could not affect the chlorophyll content of plants significantly, but increasing the proportion of blue light can enhance the synthesis of chlorophyll content in leaves[32].



Note: Means with the different letters in the same column were significantly different at α = 0.05 level (n = 6), according to Duncan's test.

Figure 4 Chlorophyll content of the leaves of eggplant transplants grown under different lighting treatments

3.3 Effects of light spectrum on photosynthetic characteristics and chlorophyll fluorescence parameters of eggplant transplants

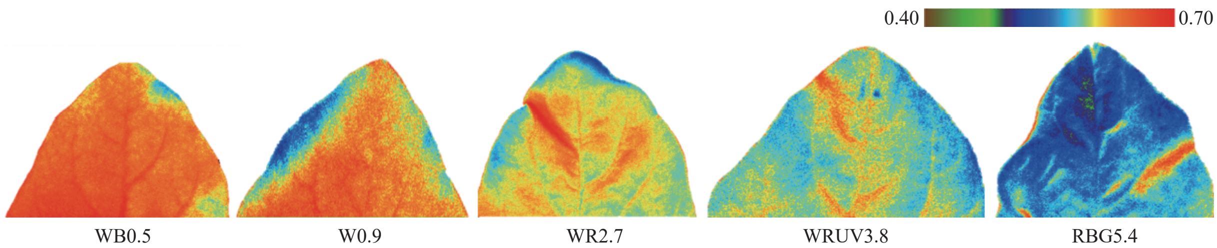
The light spectrum had a significant effect on the photosynthetic characteristics of the leaves of eggplant transplants except the net photosynthetic rate (*Pn*) (Table 4). This result may be because the instant *Pn* of a single leaf could not reflect the photosynthetic capacity of the whole plant, the accumulation of biomass was not positively correlated with *Pn* of a single leaf but also related to the number of leaves and leaf area of the plant[33]. The stomatal conductance (*Gs*) and intercellular CO_2 concentration (*Ci*) of eggplant transplants cultured with different light spectrum were the largest under WR2.7, which were (0.481±0.064) mol/m²·s, and (719±7) μmol/mol, respectively. The right amount of blue light could promote stomatal opening effectively[34], and a certain proportion ofred and blue light can enhance *Gs*[35]. The proportion of blue light in WR2.7 is 15.6% while red light is 42.8% in this study, which could promote the *Gs*. The transpiration rate (*Tr*) was directly proportional to *Gs*, the *Tr* of W0.9 and WR2.7 treatments was significantly higher than that of other treatments.

Table 4 Effects of different light spectrum experimental areas on photosynthetic characteristics of eggplant transplants

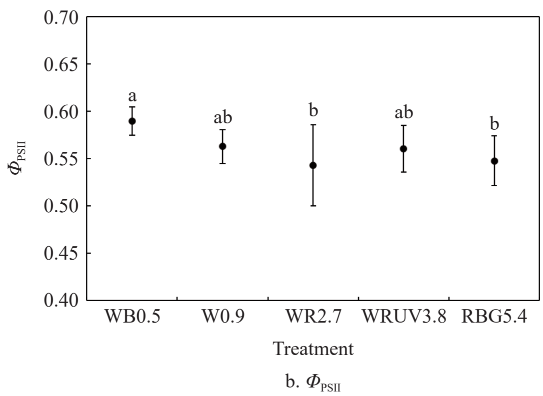
Treatment	*Pn*/μmol·m⁻²·s⁻¹	*Gs*/mol·m⁻²·s⁻¹	*Ci*/μmol·mol⁻¹	*Tr*/mmol·m⁻²·s⁻¹
WB0.5	12.5±0.8^{NS}	0.392±0.040^{b}	708±9^{a}	4.58±0.35^{b}
W0.9	11.4±0.5^{NS}	0.394±0.043^{b}	709±8^{a}	5.81±0.38^{a}
WR2.7	12.0±0.9^{NS}	0.481±0.064^{a}	719±7^{a}	5.57±0.42^{a}
WRUV3.8	11.6±0.9^{NS}	0.289±0.033^{c}	696±9^{b}	3.86±0.31^{c}
RBG5.4	12.2±0.7^{NS}	0.312±0.050^{c}	696±12^{b}	3.98±0.42^{c}

Note: Means with the different letters in the same column were significantly different at $\alpha = 0.05$ level ($n = 6$), according to Duncan's test. NS represents no significant difference.

The effective quantum yield of electron transport ($\Phi_{PS\,II}$) is the actual photochemical efficiency of plant leaves when the PS Ⅱ reaction center is closed under the light. The $\Phi_{PS\,II}$ of PS II of eggplant transplants is significantly affected by the light spectrum (Figure 5). Chlorophyll fluorescence imaging changes from red to blue, indicating that $\Phi_{PS\,II}$ decreases with the R: B ratio increase. F_v/F_m reflected the potential maximum photosynthetic rate of plants and was mainly used to measure the potential activity of PS Ⅱ in plant leaves[36]. In this study, the F_v/F_m of eggplant transplant leaves under all treatments showed a good trend, indicating that the leaves of eggplant transplants have good photosynthetic efficiency. The ABS/RC and DIo/RC of eggplant transplants also increased with the increase of the R: B ratio. Compared with W0.9 and WR2.7, the ABS/RC value of WB0.5 treatment decreased significantly, which was 1.83±0.16. There was no significant difference in DIo/RC values among the four treatments. Di et al.[37] reported that with the increase of the R: B ratio, the ABS/RC and DIo/RC of eggplant leaves also increased, which was generally consistent with



a. Φ_{PSII} of PS II in leaves of eggplant transplants



b. Φ_{PSII}

Figure 5 Determination of the actual photochemical quantum efficiency ($\Phi_{PS\,II}$) of PS Ⅱ in leaves of eggplant transplants using chlorophyll fluorescence imaging and changes in $\Phi_{PS\,II}$ under different light spectrum treatments

theresults of this study. PI_{abs} is a comprehensive performance index of PS II activity that more quickly reflects the effects of stress on PS II. If PS II activity is reduced, it severely interferes with photosynthesis in leaves, alters the fatty acid composition of the cytoplasmic membrane, and causes membrane lipid peroxidation through reactive oxygen species, damaging the integrity of the cytoplasmic membrane and leading to cell or plant death in severe cases[38]. In different light spectrum treatments, the PI_{abs} of WRUV3.8 treatment was significantly lower than that of other treatments, 55.2% lower than that of W0.9 treatment. In this study,PI_{abs} had no abnormal values, indicating that all the eggplant transplants were not under pressure (Table 5).

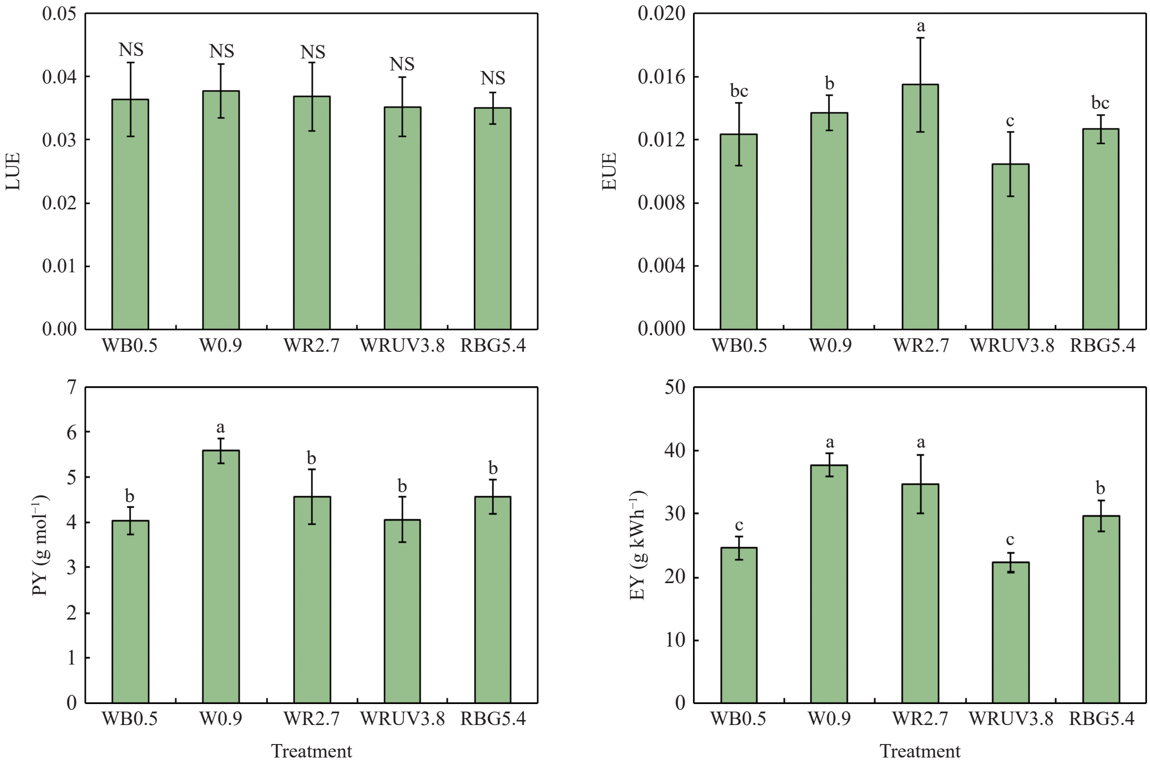
Table 5 Effects of different light spectrum experimental areas on chlorophyll fluorescence parameter of eggplant transplants

Treatment	Chlorophyll fluorescence Parameter			
	F_v/F_m	ABS/RC	DIo/RC	PI_{abs}
WB0.5	0.83±0.004^{b}	1.83±0.16^{b}	0.32±0.03^{NS}	2.58±0.27^{b}
W0.9	0.83±0.006^{a}	2.06±0.28^{a}	0.34±0.04^{NS}	3.15±0.31^{a}
WR2.7	0.84±0.005^{a}	2.10±0.24^{a}	0.34±0.05^{NS}	2.80±0.21^{a}
WRUV3.8	0.82±0.005^{b}	2.04±0.10^{b}	0.37±0.02^{NS}	2.03±0.31^{c}
RBG5.4	0.82±0.010^{b}	2.00±0.10^{b}	0.35±0.03^{NS}	2.31±0.36^{b}

Note: Means with the different letters in the same column were significantly different at $\alpha = 0.05$ level ($n = 6$), according to Duncan's test. NS represents no significant difference.

3.4 Energy use efficiency

Yokoi et al.[14] and Kozai[15] proposed that light energy use efficiency (LUE) and electric energy use efficiency (EUE) should be calculated based on the biomass accumulation of plants. The dry matter accumulation of plants is closely related to the absorption and transformation of light energy. Therefore, the lighting of artificial light plant factories must meet the light environment required for plant growth. There was no significant difference in LUE in this study under different light spectrum treatments, but the LUE under W0.9 was slightly higher, which was 0.038±0.004. The WR2.7 treatment had the highest EUE, which was 13.1% higher than the W0.9 treatment, while WRUV3.8 had the smallest EUE of all treatments, which was 32.3% lower than WR2.7 and 23.4% lower than W0.9. The photon yield (PY) and energy yield (EY) were calculated based on plant fresh weight[16]. PY and EY were ahead of the remaining treatments at W0.9, with PY over 22.1% higher and EY over 8.6% higher (Figure 6).



Note: Means with the different letters in the same column were significantly different at α = 0.05 level (n = 6), according to Duncan's test. NS represents no significant difference.

Figure 6 Accounts of energy efficiency of eggplant transplants production under the different light spectrum

4 Conclusions

The different light spectrum had significant effects on the morphological and biomass accumulation of eggplant transplants. The total dry weight of eggplant transplants under W0.9 reached 426.1 mg/plant, and the health index was 38.5% higher than other treatments. There was no significant difference in net photosynthetic rate, while the photon yield (PY) and energy yield (EY) were significantly higher in W0.9 treatment than in other treatments. Thus, it is suggested that white LEDs with an R: B ratio of 0.9 should be selected as light environments for eggplant transplant production in plant factories.

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