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Effects of Light-Emitting Diode (LED) Red and Blue Light on the Growth and Photosynthetic Characteristics of *Momordica charantia* L.

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Abstract

With andromonoecious *Momordica charantia* L. (bitter gourd) as material, three light qualities (50 μmol·m^{-2}·s^{-1}) including white LED light (WL), blue monochromatic light (B, 465 nm), and red monochromatic light (R, 650 nm) were carried out to investigate their effects on seed germination, physiological and biochemical parameters, sex differentiation and photosynthetic characteristics of bitter gourd. The results showed that compared to the WL treatment, the R treatment significantly promoted seed germination, seedling height elongation and soluble sugar content, the B treatment significantly increased seedling stem diameter, reducing sugar content and soluble protein content, the R and B treatments both significantly reduced sucrose content, but their POD activity showed no significant difference. Compared with the R treatment, the B treatment significantly increased the total female flower number and female flower nod ratio in 30 nods of main stems. The study of photosynthetic characteristics found that the R and B treatments could effectively increase the stomatal conductance (GS) of leaves, significantly improved the net photosynthetic rate (Pn) compared to the WL treatment, and the effect of the B treatment was better. Compared to the R and WL treatments, the B treatment increased the maximum photosynthetic rate (P_{max}), apparent quantum efficiency (AQE) and light saturation point (LSP), and reduced the dark respiration rate (Rd) and light compensation point (LCP) of the leaves. Fit light response curves showed that the adaptability and utilization of weak light in bitter gourd were middle or below, but it showed higher adaptability and utilization of strong light. Thus, it suggests that *Momordica charantia* is a typical sun plan with lower Rd. In summary, it is concluded that blue light has a positive effect on the seed germination, seedling growth, sex differentiation and improving the photosynthetic performance, and this will lay the foundation for artificially regulating optimum photosynthesis using specific LEDs wavelength, and help to elucidate the relationship how light quality influences the sex differentiation of plant.

Keywords

Light-Emitting Diode (LED), *Momordica charantia* L. (Bitter Gourd), Photosynthetic Characteristics, Light Response Curve, Sex Differentiation

1. Introduction

Light is a vital environmental factor regulating the growth, morphogenesis, photosynthesis, metabolism, and gene expression of plants (XU, K, *et al.*, 2005) [1]. Plants can use light as a signal to optimize growth and development for the ambient light conditions during their whole life cycle through sensing the quality, quantity, direction and duration of the incident light, then use it (Alfred, B, 1998) [2]. Many invents, such as seed germination, seedling development and induction of flowering are affected by light (Smith, T W, *et al.*, 1986; Chory, J, *et al.*, 1996; Chory, J, 1997) [3] [4] [5]. Generally, specific wavelengths are used in practice to optimize leaf photosynthesis and crop yield. Because in plants photosynthesis, the absorption spectrum of photosynthetic pigments mainly focuses on blue (400 - 500 nm) and red light spectrum (600 - 700 nm), blue and red light are the most effectively utilized wavelengths.

Physiological and biochemical approaches have given a broad foundation for the understanding of how blue and red light influence plant growth and development. Blue light strongly influences plant growth and development, such as the growth of the stem, the cotyledons and the leaves, stomatal opening, photosynthesis, flowering, and gene expression (Liscum, E, and Hangarter, R P, 1994; Short, T W, and Briggs, W R, 1994; Jenkins, G I, *et al.*, 1995; Briggs, W R, and Liscum, E, 1997) [6] [7] [8] [9]. Blue light stimulates “sun-type” characteristics such as high photosynthetic capacity on the chloroplast level. Plants generally exhibit higher photosynthetic characteristics under blue light than under red light (Savvides, A, *et al.*, 2012) [10]. Red light can influence the normal development of photosynthetic apparatus, increase leaf starch accumulation. Various plants showed differential physiological response to light quality changes. Blue light is more essential than red light for maintaining the activities of photosystem II and I and photosynthetic electron transport capacity in cucumber leaves (Miao, Y X, *et al.*, 2016) [11].

Momordica charantiais is a monoecious Cucurbitaceae plant, mainly cultivated as a vegetable for its medicinal and nutritional properties in tropical and subtropical Asia. It is used as a traditional medicine because it contains biologically active chemicals and has various medicinal properties (Raman, A, and Lau, C, 1996; Kosova, K, *et al.*, 2012) [12] [13]. Because the number of female flowers in bitter gourd is closely related to yield, thus how to improve the differentiation of female flower is vital in production. Now, bitter gourd is mostly cultivated in greenhouses, while artificial lights have been widely used in greenhouse production in order to increase both yield and quality of crops. LEDs have become an optimal light source for plants due to high electrical efficiency, small mass and volume (Bula, R, *et al.*, 1991) [14]. Moreover, LEDs can provide artificially regulated light spectrum for plant to optimize leaf photosynthesis and crop production. However, the regulation of different quality of LEDs on growth, development of bitter gourd remains largely unclear.

This paper was projected to lay foundation for scientific light supplement and inducing sex differentiation in bitter gourd production, accordingly, the study mainly focused on the response of seed germination, physiological and biochemical change, as well as the photosynthetic performance to different LEDs light quality.

2. Materials and Methods

2.1. Materials

QX001, an andromonoecious bitter gourd variety, comes from the long-term breeding resources of our project group. Seed germination experiments started in February 2015 in the laboratory of LED light biology, Huizhou University. The environmental conditions were controlled as below, the temperature persisted in about 25˚C through day and night, the humidity was 60% - 80%. Screened full bitter gourd seeds were cleaned and soaked in cold water for 2 hours in advance, then transferred to 55˚C - 60˚C hot water soaking for 15 min with constant stirring, until all seeds cooled down to room temperature naturally, soaked them in clean water for 12 hours again. Lastly, all seeds were grouped and partitioned into culture dishes with a tile filter paper at the bottom, 25 grains sowed on a culture dish and 100 grains for a group.

Intensity test: at 25˚C ± 1˚C, dark treatment as the control, light intensity experiments set two treatments including 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ separately for seed germination. After 5 days, the intensity of 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ was selected in next study because seed germination rate was the highest under it. All seeds were sowed at 25˚C in LED illumination chamber, three treatments included white LED light treatment (WL), blue LED light treatment (465 nm, B) and red LED light treatment (650 nm, R), exposure time from 8:00 to 20:00.

All treatments were transplanted to seedling tray and cultured to two-leaf-one-heart stage after germination, then the seedlings with the uniform growth speed were transplanted into the experimental field. Each treatment set three experimental plots, 30 strains were planted in each plot with area of 15 m^2, and the general cultivation and management technical was applied in all plots. When the seedlings grew to six, twelve, and eighteen-leaf-one-heart, tested materials with the same growth speed were selected randomly from each plot for determining physiological and biochemical parameters as well as photosynthetic parameters. Left strains in field were in use for sex differentiation statistics until their nods above 30 in main stem.

2.2. Methods

2.2.1. Determination of Morphological Parameters

When bitter gourd seedling grew to two-leaf-one-heart, the ruler with precision of 0.001 m was used to measure the plant height, stem diameter was measured with vernier caliper with precision of 0.01 mm (measured position below the first leaf 1 cm near the base of the plant). For each treatment, 5 strains were selected and 3 times were repeated.

2.2.2. Determination of Physiological and Biochemical Parameters

Taking seedling apical bud and the first leaf below it as material, total soluble sugar content was determined by anthrone colorimetric determination method, 3,5-dinitrosalicylic acid colorimetric method for the determination of glucose content, Coomassie brilliant blue G250 staining method for the determination of soluble protein content, and guaiacol method for the determination of POD activity (Li, H S, 2007) [15].

2.2.3. Determination of Photosynthetic Parameters

Photosynthetic parameters were measured with LI-6400XT portable photosynthesis system from American company LI-COR when the seedling grew to the stage of six, twelve, and eighteen-leaf-one-heart, 5 strains, grew well with the same growth speed, without plant diseases and pests, were randomly selected from each plot. At 8:30 in a sunny morning, mature function leaves at the same position were clipped in the transparent leaf chamber of LI-6400XT for about 2 - 3 min, then began to record data until CO_2 concentration in the sample chamber persisted stable. Determined parameters included net photosynthetic rate (Pn), stomatal conductance (Gs), intercellular CO_2 concentration (Ci), and transpiration rate (Tr).

2.2.4. Determination of Light Response Curve

LI-6400XT portable photosynthesis system was continually used to determine the light response curve of bitter gourd. The 5 strains like above were randomly selected in each plot, the 18th *in vivo* mature functional leaf under normal growth situation was selected to determine light response curve in a sunny morning from 8:30 to 11:30. LED 6400-02B red and blue light source leaf chamber was used to measure instantaneous apparatus photosynthetic rate (IAPR) of attached leaf. In the process of determination, we switched LI-6400XT automatic "light-curve 2" function on, selected LED red and blue photosynthetic photo flux density (PPFD) gradients for 2000, 1800, 1500, 1200, 1000, 800, 600, 400, 200, 100, 50, 20, 0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for determination (Liu Y F, *et al.*, 2005) [16].

2.3. Statistic Analysis

Microsoft Office 2013 Excel software was used for data processing and mapping, SPSS17.0 software was for variance analysis, Dunan multiple comparison, significant test $P < 0.05$. The Photosynthetic light response curve was simulated when the data were processed by the nonlinear statistical regression function of

SPSS17.0 software and combined with linear regression in the low light period of 0 - 200 μmol·m^{-2}·s^{-1}. Calculating A and X axis lines intersect, the X axis numerical point of intersection is for LCP when A equaled to 0, while the numerical point of intersection of Amax in X axis is for LSP (Liu, Y F, *et al.*, 2005; Farqubar, G D, *et al.*, 1980) [16] [17].

The theoretical formula of the non-rectangular hyperbola model is as follows:

$$x = \frac{\varphi Q + A_{\max} - \sqrt{\left(\varphi Q + A_{\max}\right)^2 - 4\varphi Q A_{\max}}}{2k} - \mathrm{R}day$$

In this formula, A represents Pn, φ represents AQE, $A_{\max}$ is $\mathrm{P}_{\max}$, Q is the photosynthetic active radiation (PAR), k is the angle of light response curves, R*day* is dark respiration rate.

3. Results

3.1. Seed Germination and Growth Parameters

The results in **Table 1** showed that different LED light treatments influenced seed germination. Germination rate and germination potential of seeds varied with different LED treatments. The R treatment significantly promoted the seed germination, the germination rate and germination potential of the seeds increased by 5.71% and 5.73% compared to the WL treatment. Compared to the WL and R treatments, the B treatment significantly reduced the seed germination rate and increased germination potential, and the germination rate decreased by 6.80% and the germination potential increased by 12.40% compared to the WL treatment separately. This suggested that red light promoted the seed germination, while blue light is conducive to the improvement of germination potential in bitter gourd.

Different LED light treatments affected the growth of bitter gourd seedlings. The R treatment significantly promoted seedling elongation compared to the WL and B treatments, and increased by 33.51% compared to the WL treatment. The B treatment significantly increased the stem diameter by 22.49% compared to the WL treatment, but there was no difference between the WL and R treatment. This implied that blue light was conductive to breed strong and dwarf bitter gourd seedlings.

3.2. Physiological and Biochemical Parameters

3.2.1. Soluble Sugar Content

The change of soluble sugar content of apical buds during the period of six, twelve and eighteen-leaf-one-heart was shown in **Figure 1(a)**. The results showed that along with the increase of seedling age, soluble sugar content presented an increase trend. The R treatment significantly increased soluble sugar content compared to the WL and R treatment, and increased by 51.11%, 34.82% and 79.55% respectively during the stage of six, twelve and eighteen-leaf-one-heart compared with the WL treatment. While in the B treatment, soluble sugar content decreased

Table 1. Seed germination and growth parameters of bitter gourd under different LED light treatments.

Treatment	Germination rate (%)	Germination potential (%)	Plant height (cm)	Stem diameter (mm)
WL	93.68 ± 0.06^{b}	78.86 ± 0.01^{c}	9.31 ± 0.21^{a}	2.49 ± 0.16^{a}
B	87.31 ± 0.09^{c}	88.64 ± 0.01^{a}	8.31 ± 0.28^{a}	3.05 ± 0.07^{b}
R	99.03 ± 0.09^{a}	83.38 ± 0.02^{b}	12.43 ± 0.53^{b}	2.65 ± 0.18^{a}

Letter (a)-(c) represent significant difference among results of Dunan multiple comparison, the same as below.

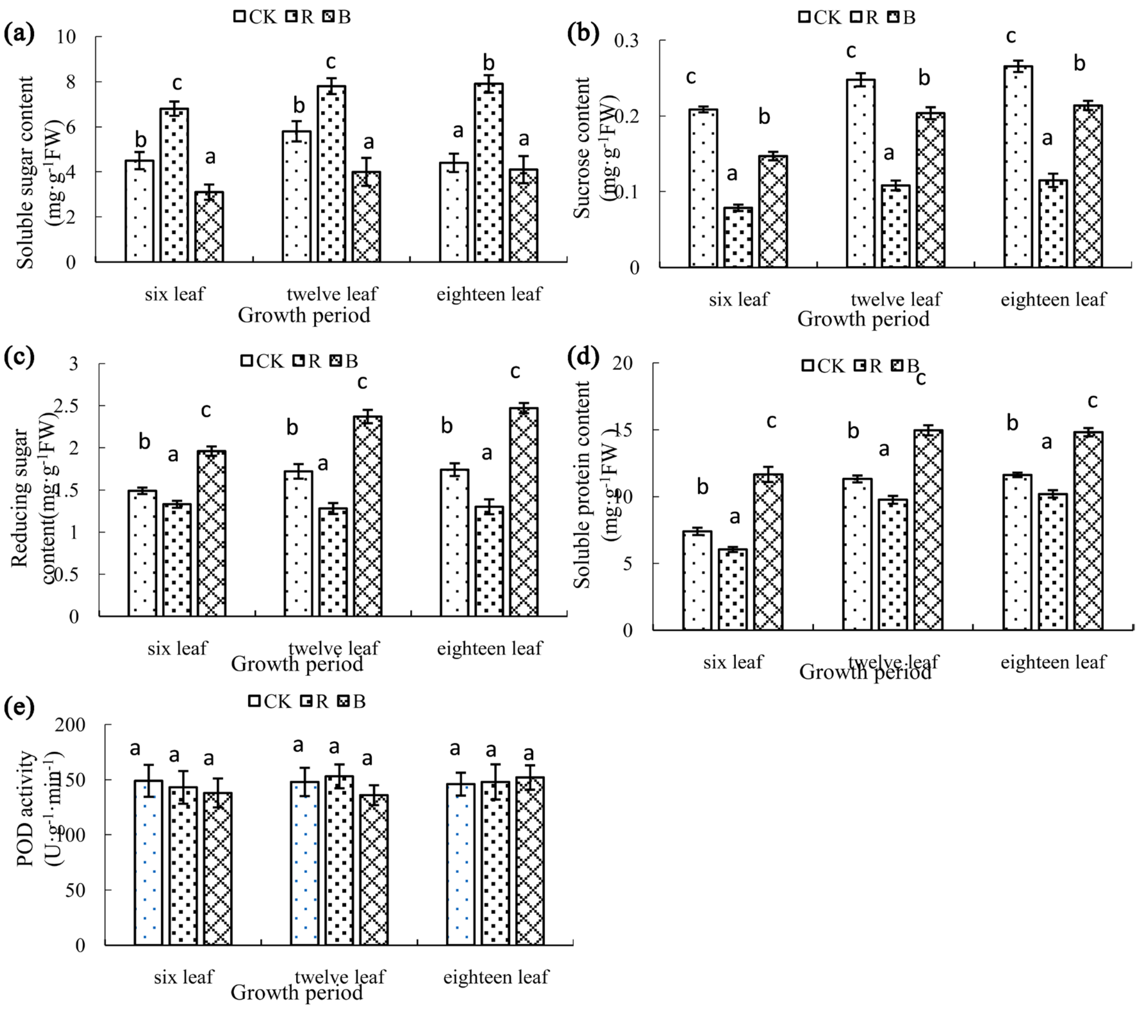

Figure 1. Physiological and biochemical parameters of bitter gourd under different LED light treatments. Note: (a) soluble sugar content; (b) sucrose content; (c) reducing sugar content; (d) soluble protein content; (e) POD activity.

significantly by 31.11%, 31.03% and 6.82% respectively during three periods compared with the WL treatment.

3.2.2. Sucrose Content

The change of sucrose content of apical bud during the period of six, twelve and eighteen-leaf-one-heart was shown in Figure 1(b). The results found that sucrose content increased gradually along with the increase of seedling age, the R and the B treatments both significantly decreased sucrose content compared to the WL treatment during 3 periods, it decreased by 62.27%, 56.30% and 56.70% in the R treatment, 29.48%, 17.79% and 19.47% in the B treatment respectively.

3.2.3. Reducing Sugar Content

The change of reducing sugar content of apical bud during three periods was shown in **Figure 1(c)**. Similar to the change of soluble sugar and sucrose above, reducing sugar content also presented increase trend along with the increase of seedling age. During three periods, compared to the WL treatment, reducing sugar content significantly increased by 31.54%, 37.79% and 41.95% in the B treatment, adversely, it significantly decreased by 10.74%, 25.58% and 25.28% in the R treatment. This indicated that blue light was conductive to the accumulation of reducing sugar, while red light had the opposite effect.

3.2.4. Soluble Protein Content

The change of soluble protein content of apical bud during the period of six, twelve and eighteen-leaf-one-heart was shown in **Figure 1(d)**. During three period, compared to the WL and R treatments, soluble protein content in the B treatment had a significant increase, the B treatment increased by 57.66%, 32.21% and 27.57% and the R treatment decreased by 18.31%, 13.77% and 12.29% accordingly Comparing to the WL treatment.

3.2.5. Peroxidase (POD) Activity

The change of POD activity of apical bud during the period of six, twelve and eighteen-leaf-one-heart was shown in **Figure 1(e)**. Both red and the B treatment showed no significant difference in the POD activity of apical bud in bitter gourd among three treatments during three periods.

3.2.6. Sex Differentiation Statistics in Field

Statistical results of sex differentiation of different treatments were shown in **Table 2**. Results found that three light qualities had no significant influence on first female flower node of tested plants, the B treatment significantly increased the total female flower quantities and female flower node ratio of 30 nodes in main stem compared to the R treatment, but both showed no significant difference from the WL treatment.

3.3. Photosynthetic Parameters of Bitter Gourd

Figure 2 shows the fluctuation trend of Pn, Gs, Ci, and Tr was similar during

Table 2. Sex differentiation statistics of bitter gourd in field.

Treatment	First female flower node (node)	Female flower quantity of 30 nodes (node)	Female flower node ratio of 30 nodes (%)
WL	19 ± 2.61^{a}	2.5 ± 0.37^{ab}	8.33^{ab}
B	21 ± 2.27^{a}	3.0 ± 0.23^{a}	10.00^{a}
R	20 ± 1.83^{a}	2.0 ± 0.34^{b}	6.67^{b}

six, twelve and eighteen-leaf-one-heart periods, their lowest value all occurred during twelve-leaf-one-heart compared with other two periods. During six and twelve-leaf-one-heart periods, the B treatment significantly promoted Pn increased by 15.89% and 26.78% compared with the WL treatment, while during eighteen-leaf-one-heart period, there was no significant difference in Pn of all plants. The R and B treatment significantly promoted Gs increased by 13.16% and 21.05% compared to the WL treatment during six-leaf-one-heart period, but it showed no difference among three treatments during the later twelve and eighteen-leaf-one-heart periods. Ci and Tr showed no differences among three treatments during three periods.

3.4. Light Response Curve of Bitter Gourd

Light response curve was fitted with the non-linear hyperbolic model (**Figures 3(a)-(c)**), and related photosynthetic parameters of different treatments were calculated through 0 - 200 μmol·m^{-2}·s^{-1} Pn-PPFD linear regression (**Figures 3(a')-(c')**), **Table 3**).

Previous study found that the maximum value of plant AQE varies from 0.08 to 0.125, but in natural environment, its value is much smaller than the theoretical upper limit and varies from 0.03 to 0.07 in well grown plants (Qiu, G W, 1992) [18]. From **Table 3**, we knew that the AQE of bitter gourd varied from 0.063 to 0.071, the average was 0.066, which suggested that bitter gourd had higher light energy utilization rate. The B treatment significantly increased the AQE compared with the WL and the R treatment, it implied that blue light could

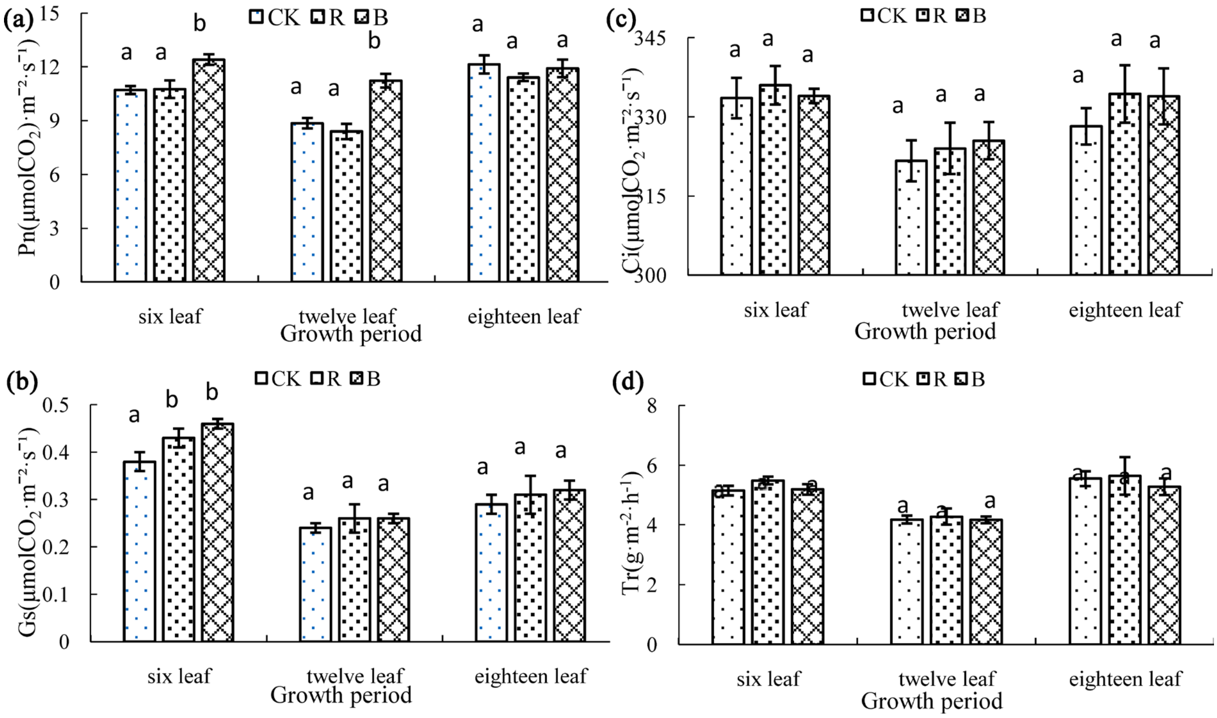

Figure 2. Photosynthetic parameters of bitter gourd under different LED light treatments. (a) changes of Pn; (b) changes of Gs; (c) changes of Ci; (d) changes of Tr.

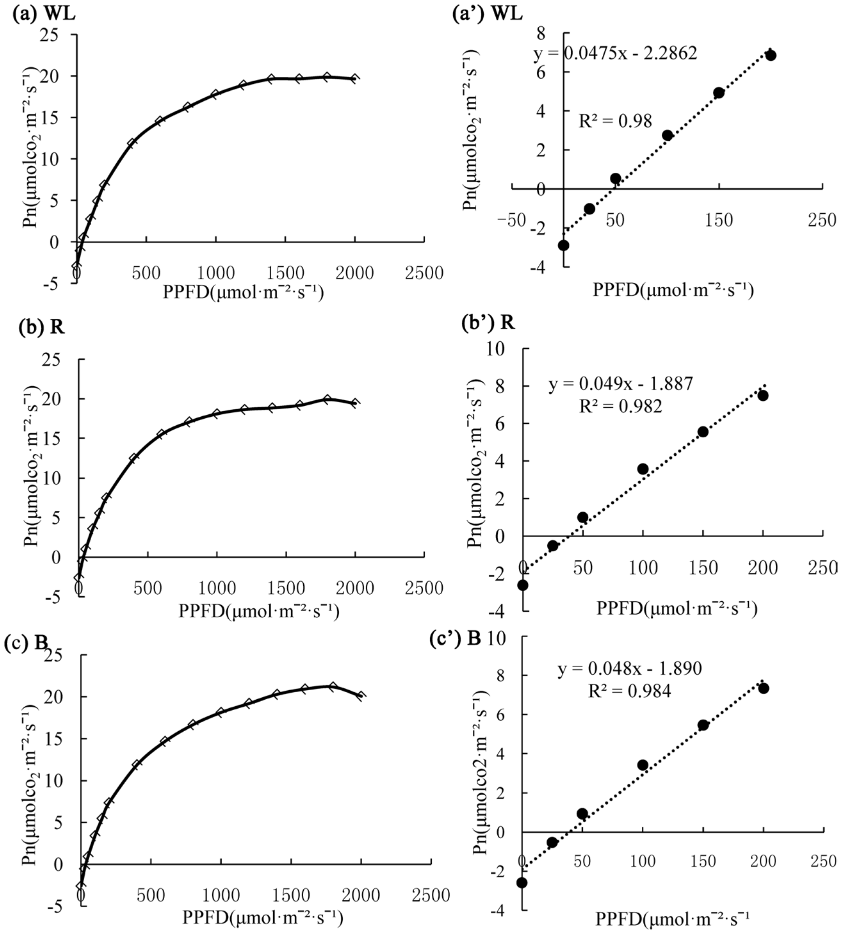

Figure 3. Light response curves of bitter gourd fit by non-linear hyperbolic model and Pn-PPFD linear regression based on 0 - 200 μmol·m^{-2}·s^{-1}. Note: (a) WL, Light response curve of the WL treatment; (a') WL, Pn-PPFD linear regression of the WL treatment; (b) R, Light response curves of the R treatment; (b') R, Pn-PPFD linear regression of the R treatment; (c) B, Light response curves of the B treatment; (c') B, Pn-PPFD linear regression of the B treatment. (Note: Pn, net photosynthetic rate; PPFD: photosynthetic photon flux density).

Table 3. Related photosynthetic parameters of light response curve of bitter gourd

Treatment	AQE	P_{max} (μmol·m^{-2}·s^{-1})	Rd (μmol·m^{-2}·s^{-1})	LCP (μmol·m^{-2}·s^{-1})	LSP (μmol·m^{-2}·s^{-1})
WL	0.063 ± 0.005^{a}	25.71 ± 0.670^{a}	−2.64 ± 0.03^{a}	48.13 ± 4.10^{b}	589.39 ± 11.34^{b}
R	0.064 ± 0.004^{a}	24.00 ± 0.465^{a}	−2.60 ± 0.20^{a}	38.36 ± 3.06^{a}	526.17 ± 15.48^{a}
B	0.071 ± 0.001^{b}	27.74 ± 1.237^{b}	−2.37 ± 0.37^{b}	39.14 ± 3.50^{a}	613.47 ± 10.87^{c}

improve the light energy utilization rate of bitter gourd.

The P_{max} reflected the utilization ability of plant to strong light. P_{max} measured in our study ranged from 24 to 27.74 μmol·m^{-2}·s^{-1}, and it was significantly higher in the B treatment than that of the WL and the R treatments.

Rd, to a certain extent, reflected the consumption rate of photosynthetic products in plant. In our study, Rd of bitter gourd was more than −3 μmol·m^{-2}·s^{-1} (Qiu, G W, 1992) [18], varied from −2.37 to −2.64 μmol·m^{-2}·s^{-1}, which indicated that bitter gourd had smaller Rd, namely it consumed less organic matter. The B treatment significantly decreased Rd compared with other two treatments.

LCP is an important parameter reflecting the ability of plants have to make use of weak light, the smaller the value, the stronger ability plants making use of light energy, generally it varies from 30 to 70 μmol·m^{-2}·s^{-1} (Qiu, G W, 1992) [18]. The LCP of all the tested bitter gourd ranged from 38.36 to 48.13 μmol·m^{-2}·s^{-1}, which suggested that bitter gourd had stronger ability to make use of light energy.

LSP reflects the plants' adaptability to strong light. The LSP of three treatments was ranged from 526.17 to 613.47 μmol·m^{-2}·s^{-1}, the average was 576 μmol·m^{-2}·s^{-1}, it implied that bitter gourd is a typical sun plant.

4. Discussion

4.1. Monochromatic Light Positively Affects Seed Germination and Seedling Growth

Light can not only provide energy to green plants for growth, but also regulate their morphological development, and these two functions coordinate each other. Some events of growth and development, such as seed germination, seedling development and induction of flowering are affected by light (Smith, M A, *et al.*, 1986; Chory, J, *et al.* 1996; Chory, J, 1997) [3] [4] [5]. Red light promoted the seed germination of bitter gourd, and kept the germination potential at a high level. Although blue light reduced the seed germination rate, but seed germination potential significantly increased. It suggests that seed germination of bitter gourd differentially responses to different light quality.

Blue light strongly influences the growth of the stem and flowering, red light promotes seedling elongation and leaf expansion. This study confirmed that red and blue light had a directional effect on the morphology of bitter gourd, red light is conducive to the seedlings elongation, while blue light promotes the cultivation of dwarf and strong bitter gourd seedling.

4.2. Blue and Red Light Induces the Differential Physiological and Biochemical Response and Sex Differentiation of Bitter Melon

Previous study showed that monochromatic light has a significant impact on the growth morphology, physiological and biochemical parameters during seedlings stage, red light is in favor of the accumulation of soluble sugar in plants, blue light has been conducive to the synthesis of soluble protein (Zhang, R H, *et al.*, 2008) [19]. The photoinhibition of PSII induced by red light might due to the imbalance between degradation and replacement of D1 protein, or the lack of PSII core antenna proteins CP47 and CP43 (Melis, A, 1999; Rajagopal, S, *et al.*, 2000) [20] [21]. This study also found red light promoted soluble sugar content significantly increased, blue light promoted reducing sugar and soluble protein content increased significantly, decreased soluble protein may further affect photosynthetic performance.

Research pointed out that in leaves higher photosynthetic capacity, soluble protein, chlorophyll and soluble sugar content were in favor of male flower differentiation, while high sucrose and reducing sugar content was conducive to female flower differentiation, plant antioxidant enzyme activity and sexual type are closely related, high POD activity is conducive to female differentiation. In our study, blue light could increase female flower quantity and nod ratio compared with red light, to some extent, this is in accordance with their physiological and biochemical response to different quality. It is worth mentioning that the POD activity of three treatments showed no significant difference, this is not well consistent with the previous viewpoint.

Since LEDs light can influence the physiological and biochemical parameters of bitter gourd, and act on the sex induction, it means that optimum light spectrum can be explored for artificial culture. Maybe we should have a further supplement study through prolonging illumination time (until six-leaf-one-heart, sex differentiation of bitter gourd mostly ends), increasing light intensity (only 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ weak light applied in this paper) or using complexed LEDs light.

4.3. Blue and Red Light Differentially Regulates Photosynthetic Characteristics of Bitter Gourd

Light quality affects photosynthesis both through influence on the composition of the photosynthetic apparatus, and on translocation of carbohydrates from chloroplasts, birch leaf P_{max} appeared under blue light treatment (Saebo, A, *et al.*, 1996) [22]. Blue and red light strongly affect leaf photosynthesis, photomorphogenesis and plant physiology (Hogewoning, S W, *et al.*, 2010) [23]. Blue light strongly influences stomatal opening, photosynthesis, flowering and gene expression. Red light depressed leaf photosynthesis and blue light exhibited relative positive effect (Cope, K R, *et al.*, 2014; O'Carrigan, A, *et al.*, 2014) [24] [25], because blue light plays a vital role in maintaining photosystems activity and photosynthetic electron transport capacity. Under the same light intensity, supplementary blue light to red light can promote Pn in spinach (Matsuda R, *et al.*, 2008) [26] and cucumber (Hogewoning, S W, *et al.*, 2012) [27]. The apparent quantum yield is also strongly affected by light quality, phytochrome and a possible cryptochrome, can regulate photosynthetic performance [1]. Light quality regulated the ratio of PSII to PSI in cucumber (Hogewoning S W, *et al.*, 2012) [27], and affects plant morphology and physiology mainly through photoreceptors signal transduction (Lin, C, and Todo, T, 2005) [28].

In this paper, the B treatment had higher Pn in six and twelve-leaf-one-heart period, related photosynthetic parameters of light response curve involving Pn_{max}, AQE, LCP were also significantly higher than that of the R and WL treatments, whereas Rd and LCP were lower. This is in accordance with the study of blue light can lead to an increase of maximum and effective photochemical quantum yield of PSII (Fv/Fm and ΦII) whereas red light was the opposite (Hogewoning, S W, *et al.*, 2012) [27].

Stomata is the channel of CO_2 exchange in the leaf, high stomatal light sensitivity is important for the efficient use of light energy in photosynthetic CO_2 fixing. stomatal conductance increases in response to a rapid increase in white light intensity (Shimazaki, K I, *et al.*, 2007) [29]. stomata are especially sensitive to blue light (Dumont, J, *et al.*, 2013) [30], but the rate of stomatal opening in response to red light is also remarkable (Boccalandro, H E, *et al.*, 2012) [31]. Red light affects stomata mainly through photosynthesis, the subsequent decrease in Ci (Araújo, W L, *et al.*, 2011) [32] and increase in balance between photosynthetic electron transport and carbon assimilation (Busch, F A, 2014) [33] are signals for stomata opening. Beside the similar stomata response to red light, absorption of blue light by the non-photosynthetic receptors is a much more efficient signal for stomatal opening (Shimazaki K I, *et al.*, 2007) [29]. Green light affects stomata in two ways (Wang, Y, and Folta, K M, 2013) [34].

The R and B treatment both significantly increased Gs during the period of six-leaf-one-heart, blue light strongly affected the stomata opening, this is consistent with previous study. During the period of twelve and eighteen-leaf-one-heart, stomatal light response reduced and acclimated to natural light environment gradually. White light is a complexed light of monochromatic lights, of which green light acts reversal of blue light response (Aasamaa, K, and Aphaloa, P J, 2016) [35], Gs increases only slightly (Wang, Y, and Folta, K M, 2013) [34] or even decreases. There was no significant difference in Ci and Tr of all treatments, although they had the similar fluctuation trend to Pn, which implied they are not a key limitation to Pn. In addition, bitter melon plants may need close stomata transiently in order to adapt the natural strong light environment (only 50 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in treatments), their photosynthetic parameters all decreased during twelve-leaf-one-heart.

Lastly, fit Light response curve of bitter gourd indicated that AQE, P_{max}, Rd, LCP and LSP value all followed the plant physiological law. Based on these parameters, it is concluded that not only can *Momordica charantia* make use of weak light at a high level, but also had strong adaptability to high light intensity, it suggests that *Momordica charantia* is a typical sun plant. Moreover, the Rd of *Momordica charantia* is much low, thus may we say *Momordica charantia* have high efficiency for solar energy utilization.

5. Conclusions

1) Red light treatment promoted the seed germination, kept the germination potential at a high level, as well as promoted seedling elongation and leaf expansion. Blue light treatment reduced the seed germination rate, but significantly increased seed germination potential, and strongly affected the growth of the stem and flowering.

2) Physiological and biochemical parameters of *Momordica charantia* response to blue and red light differently. Soluble sugar content of apical buds significantly increased under red light treatment, whereas blue light treatment

promoted reducing sugar and soluble protein content increased significantly, but POD activity of three treatments showed no significant difference. Blue light is more efficient to regulate the photosynthetic parameters of bitter melon and improves photosynthetic performance. Moreover, Blue light could increase female flower quantity and nod ratio compared with red light, to some extent, it is in accordance with their physiological and biochemical response to different light quality.

3) Under blue light treatment, related photosynthetic parameters of light response curve involving Pn_{max}, AQE, LCP were also significantly higher than that of the R and WL treatments, whereas Rd and LCP were lower. Related results indicated that *Momordica charantia* is a typical sun plant, the Rd of *Momordica charantia* is much low, and may we say *Momordica charantia* have high efficiency for solar energy utilization.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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