



LED Light Spectrum Affects the Photosynthetic Performance of *Houttuynia Cordata* Seedlings

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Abstract: We investigated the effects of light-emitting diodes (LED) with various light spectrum (white, red, yellow, green and blue) on photosynthesis of *Houttuynia cordata* seedlings. The seedlings were either cultivated under florescent lamp or under various LED lights. The leaves were collected and chlorophyll fluorescence parameters, the contents of chlorophyll, soluble sugar and relative water were measured, chloroplasts were observed as well. The results showed chlorophyll fluorescence parameters as Fv/Fm, qP and qY values were the highest under blue LED light and the values were the lowest under green LED light. Red LED light resulted in the enhanced chlorophyll content compared with the other LED lights, and the chl a/chl b ratio did not change significantly among LED treatments. The soluble sugar content was not significantly different among the treatments. The red LED increased relative water content and the green LED decreased the water content. Observation of chloroplasts in the leaves of *Houttuynia cordata* seedlings showed chloroplast number and distribution were altered by various light spectrum where chloroplasts were smaller under blue LED, and appeared to be more scattered under red LED. Our results indicated that photosynthesis of *Houttuynia cordata* seedlings respond differently to various light spectrum emitted by florescent lamp and LED.

Keywords: *Houttuynia Cordata*, LED, Photosynthesis, Light Spectrum

1. Introduction

Among environmental conditions, light is a predominant source of energy for plant photosynthesis and also an important signal for plant growth and development [1]. It is known that not only are plants able to respond to the intensity of light but also to its quality (spectrum) or color [2-4]. Light spectrum plays an important role in morphogenesis and photosynthesis [5-8], influencing the way in which light is absorbed by the chlorophyll [9, 10]. The chlorophyll molecules in plants initiate photosynthesis by capturing light energy and converting it into chemical energy for transforming water and carbohydrate into the primary nutrient for living beings. The traditional light sources used for indoor agriculture are fluorescent lamps, metal halide and incandescent lamps.

The light-emitting diode (LED) is a unique type of semiconductor diode and has great advantages for indoor plant cultivation over above traditional light resources

including small size, specific wavelength, low thermal output, adjustable light intensity and quality, as well as high photoelectric conversion efficiency [11-14]. Such advantages make LEDs ideal for supporting plant growth in a controlled environment such as plant growth chamber. LEDs have been used for studies on chlorophyll biosynthesis in wheat [10], stem elongation and leaf expansion in lettuce [5], disease development in pepper and cucumber [15], and photosynthesis in kudzu [16].

Houttuynia cordata is one of authorized medical and edible plants by China's Ministry of Health. It is rich in nutrients for human consumption, including protein, amino acids, vitamin C, calcium, phosphorus, iron, etc [17]. To our knowledge, there are no studies to explore the LEDs on the photosynthesis of the *Houttuynia cordata* so far. The aim of the present study was to investigate the photosynthetic performance of the *Houttuynia cordata* seedlings under LED light with various light spectrum.

2. Materials and Methods

2.1. Plant Material and Light Treatments

Houttuynia cordata seedlings were from Yichang city, Hubei province, China, and were cultivated in growth chamber with room temperature of 25°C / 20°C during day / night, and air humidity of 75%. The *Houttuynia cordata* seedlings were cultured for 5 weeks to a height of about 2 cm, and then subsets of seedlings were treated with various LED lights. Six treatments were designed as following: fluorescent lamp (CK), white LED (W), red LED (wavelength 620-630nm, R), yellow LED (wavelength 585-590nm, Y), green LED (wavelength 515-520nm, G), and blue LED (wavelength 455-460nm, B). The photosynthetic photon flux density (PPFD) of the light was 40 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ which was determined by a quantum meter (HT-1318, HCIYET, CHINA). Thirty days later, chlorophyll fluorescence parameters and chlorophyll content were measured, and chloroplasts were observed as well.

2.2. Measurement

2.2.1. Chlorophyll Fluorescence Measurement

Chlorophyll fluorescence parameters were measured with a portable pulse modulation fluorometer (OS5p, Multi-Mode chlorophyll Fluorometer, OPTI-SCIENCES). Before measurement, the leaves in each group were adapted in

darkness for 15min. The maximal quantum yield of photosystem II (Fv/Fm), photochemical quenching coefficient (qP), light quantum yield (qY) and non-photochemical quenching coefficient (NPQ) were measured.

2.2.2. Contents of Chlorophyll, Soluble Sugar and Relative Water

Chlorophyll and relative water contents were measured according to Lee [18]. The content of soluble sugar in the leaves was determined by the anthrone-sulfuric acid method [19] with glucose reagent as a standard sample.

2.2.3. Observations of the Chloroplast

The chloroplasts in mesophyll cells were observed from the same position of the leaves under a light microscope (OLYMPUS-DP71).

2.3. Statistical Analysis

Statistical significance was estimated at $P < 0.05$ according to Duncan's multiple range test and a one-way ANOVA with SPSS software program. All data were given as mean \pm SD.

3. Results

3.1. Effects of Various LEDs on Chlorophyll Fluorescence Parameters

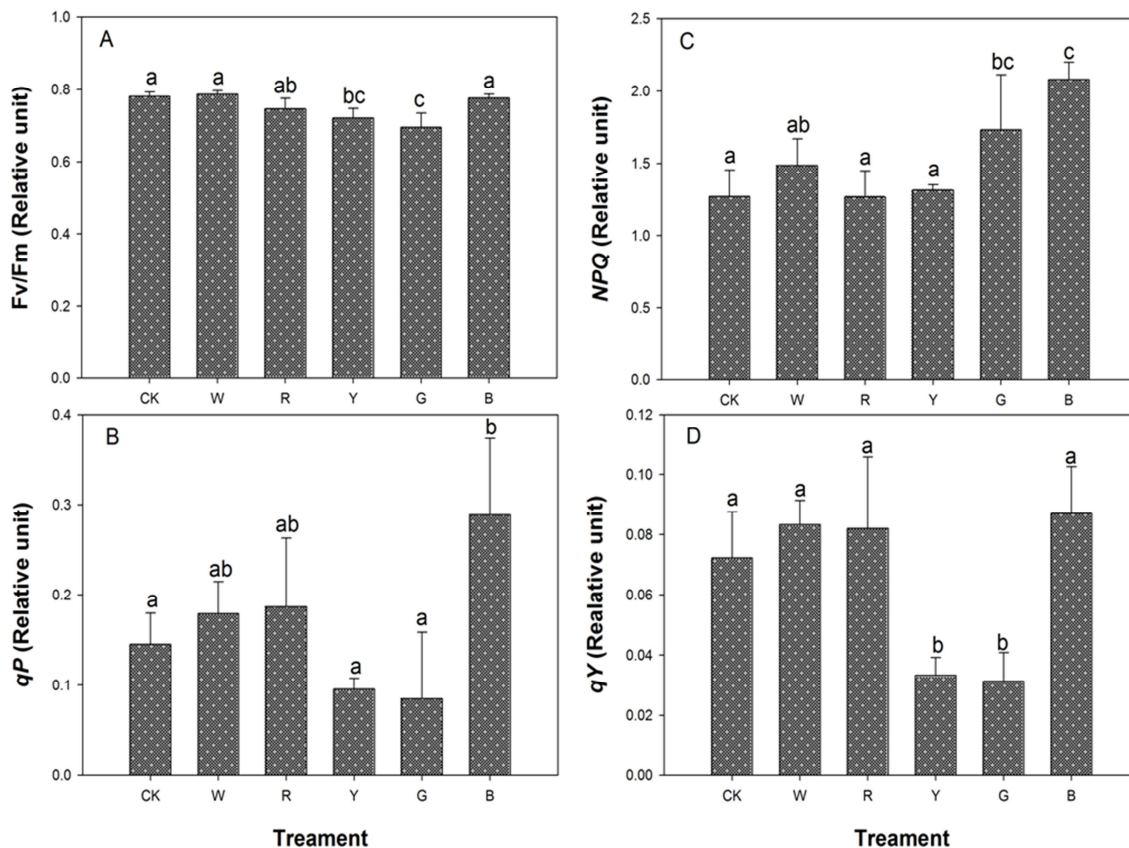


Fig. 1. Effects of various LEDs on chlorophyll fluorescence parameters of *Houttuynia cordata* seedlings. Data given as means \pm SD (n = 5). Different letters indicate significant differences at 95% level.

The maximal photochemical yield (Fv/Fm), photochemical quenching (qP), non-photochemical quenching (NPQ) and the light quantum yield (qY) represent the photosynthetic function of the photosystem II (PS II). At the present study, Fv/Fm (Fig.1A) decreased in W, R, Y, G groups gradually, but their differences were not significant ($p>0.05$); the values under Y and G treatments were significantly lower compared with those under W, B groups and CK ($p<0.05$). The qP in B

group was significantly higher than those in Y and G groups and CK ($p<0.05$), among which it was the lowest in G group (Fig.1B). The NPQ was the highest in B group and it was the lowest in R group. Green and blue light enhanced the NPQ significantly than the rest LED light treatments and the CK (Fig.1C). The qY values showed the similar tendency as the qP (Fig.1D).

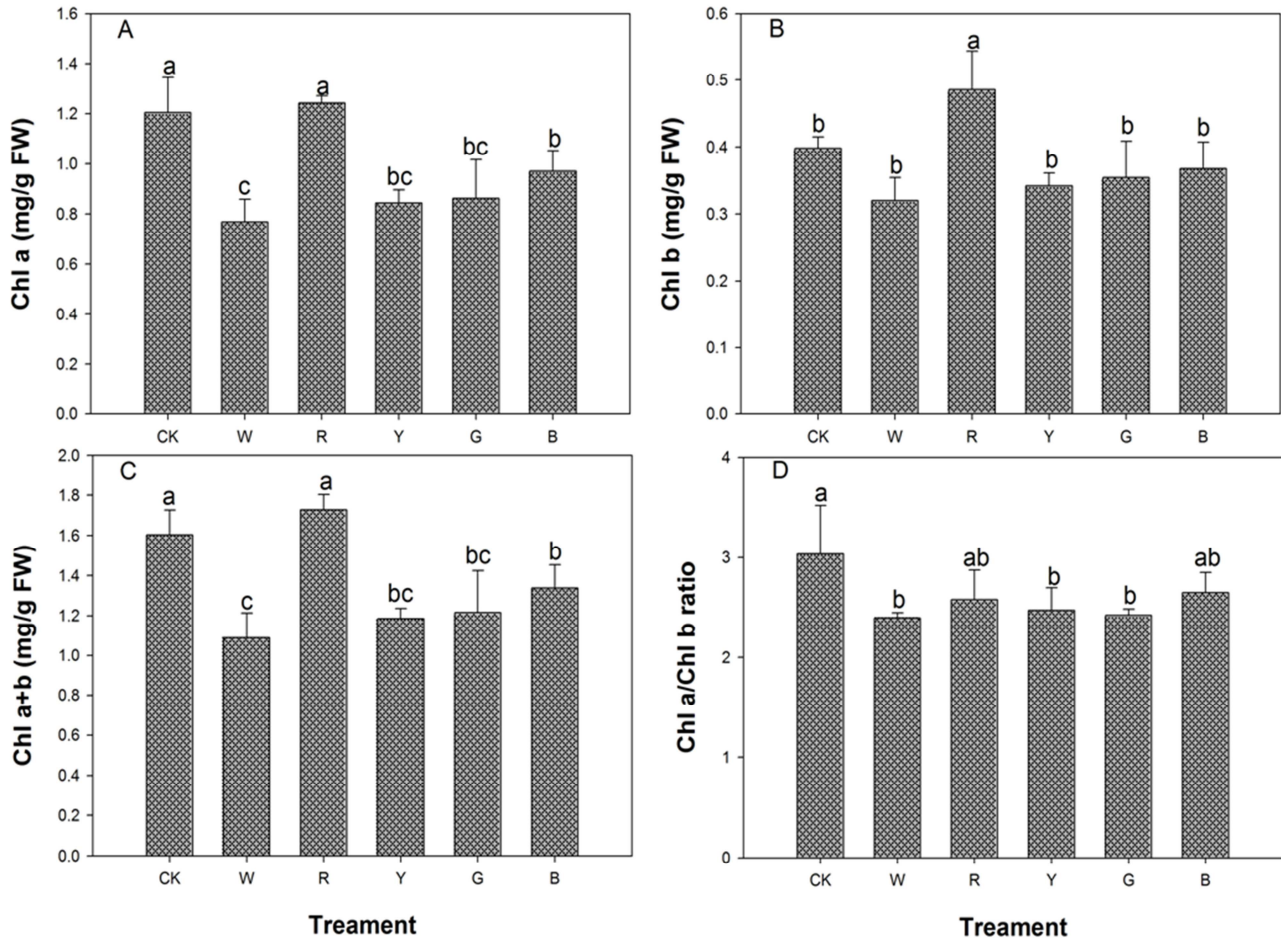


Fig. 2. Effects of various LEDs on chlorophyll (chl) content and ratio of chl a/chl b in the leaves of *Houttuynia cordata* seedlings. Different letters indicate significant differences at 95% level. Data given as means \pm SD ($n = 3$).

3.2. Effects of Different LEDs on Chlorophyll Content

Chlorophyll a (chl a) is essential for most photosynthetic organisms to convert chemical energy though it is not the only pigment that used for photosynthesis. All oxygenic photosynthetic organisms use chlorophyll a, but differ in accessory pigments like chlorophyll b (chl b) [20]. The contents of chlorophyll a were higher than chlorophyll b in both CK and LED light treatments. At the present study, all types of the LED lights except red LED decreased the contents of chlorophyll a and chlorophyll b, where the chlorophyll a showed more sensitive to LED lights ($p<0.05$) (Fig.2A, 2B). As for Chl a / Chl b ratios, there were not significantly different among LED treatments, and the values were lower than CK (Fig.2D).

3.3. Effects of Various LEDs on Soluble Sugar and Relative Water Content (RWC)

Carbohydrates are not only photosynthetic products but also energy substance. The content of soluble sugar is the highest in Y group and it was the lowest in G group, and no significant difference were observed among those under CK, W, R, Y and B groups ($p>0.05$), except the G treatment ($p<0.05$) (Fig.3A).

RWC is a good index for leaf water status especially for turgor potential. The value was significantly higher in CK than the values under LED treatments except that in R group ($p<0.05$) which was the highest among LED treatments (Fig.3B), Green LED light resulted in the lowest RWC.

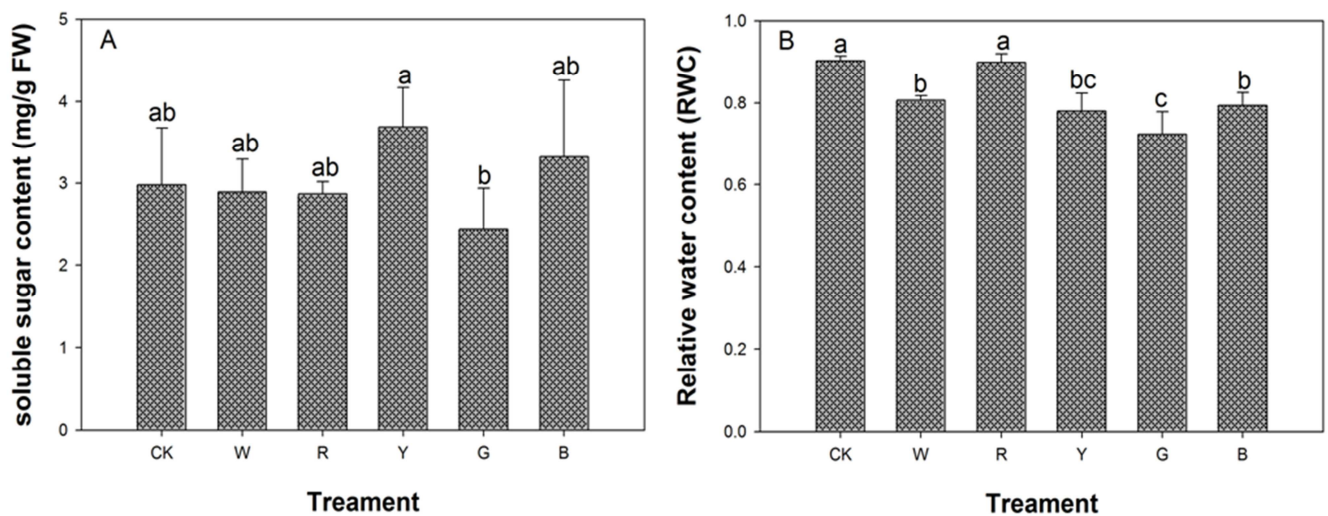


Fig. 3. Effects of various LEDs on soluble sugars (A) and relative water content (B) in the leaves of *Houttuynia cordata* seedlings. Different letters indicate significant differences at 95% level. Data given as means \pm SD ($n = 3$).

3.4. Effect of Different LEDs on Chloroplasts

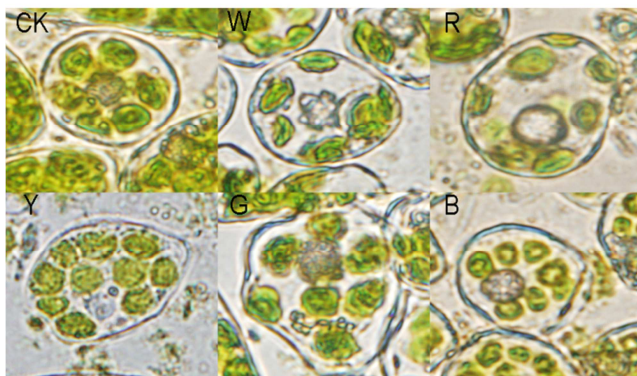


Fig. 4. Effects of various LEDs on the chloroplast status in the leaves of *Houttuynia cordata* seedlings ($100\times$).

Chloroplast number and distribution were altered by various light spectrum where they were smaller under blue LED, and appeared to be more scattered under red LED.

4. Discussion

Chlorophyll is vital for photosynthesis, which allows plants to absorb energy from light. Interestingly, we observed that *Houttuynia cordata* seedlings under florescent lamp, red and yellow LED lights had higher Chl a/b ratios compared with those under white, green and blue LED lights. Changes in Chl a/b ratio have been suggested as an indicator for relative photosystem stoichiometry [21]. The observed changes in the Chl a/b ratio usually correlate to the changes in the size of the PSII light-harvesting antenna [22] and PSII: PSI content. The present study shows that the relative photosystem stoichiometry was reduced under the LED lights compared with florescent lamp, though no significant difference showed among florescent lamp, red and blue light groups.

Yellow and blue LED resulted in the higher soluble sugar contents in *Houttuynia cordata* seedlings compared with the CK group. It is easy to understand for blue LED, since it is a major absorption spectrum for chlorophyll used for photosynthesis, but interestingly, yellow light showed more favorable effect for carbohydrate biosynthesis compared with red LED light, the mechanism underlying need further investigation. The green LED light showed negative effect on carbohydrate biosynthesis since the least utility for photosynthesis. Wang [23] concluded the carbohydrates contents were consistent with the transcript levels of enzymes genes that are involved in the Calvin cycle. The yellow and blue LED light may, on the other hand, up-regulate the related genes contributing to carbohydrates biosynthesis, and it is not the case for green LED light.

Stomatal opening was induced by blue and red lights [24]. At the present study, the relative water content was higher in CK and red LED group, then the white, yellow and blue light, and it was the lowest under green LED. The present study showed green light induced the largest stomatal conductance, then the white, yellow and blue LED, red and CK showed the least effects on stomatal conductance. Consequently, CO₂ assimilation rate under yellow and blue LED is higher than CK and red light. Previous study also observed that plants grown under red or yellow light had reduced photochemical quenching (qP) and they claimed that blue light was more crucial for the efficient function of PSII than red and yellow lights [25].

Fv/Fm, as one of the most important fluorescence parameters, reflects the maximal photochemical efficiency of the active center of PSII in the dark. Plants had higher absorption in blue and red light than green and yellow light. The different absorption for different lights might partially explain the difference in the CO₂ assimilation rate of plants grown under different wavelength lights. UV could induce PSII photoinhibition [26, 27] and qP reflects the proportion of

open PSII reaction center. Thus, we speculate that the yellow and green light may induce PSII photoinhibition.

Chloroplast is a kind of light-induced organelle. Extremely strong light often decreases chlorophyll content owing to inhibition of chloroplast generation. In contrast, the number of chloroplasts per unit leaf area drops under weak light, but the larger chloroplasts results in increased chlorophyll content in plant leaves. The present study found that chloroplasts were larger and more scattered under red light; smaller under blue light but with more number; the utility of yellow and green are the best, thus bigger and more chloroplasts appeared.

5. Conclusion

In this work, LEDs with various wavelengths showed various effects on photosynthesis of *Houttuynia cordata* seedlings via regulation the relative water content which is correlated with stoma and CO₂ assimilation rate, so altered the chloroplast number and size. According to the light quantum yield, our study verified that the light absorption was altered with the various wavelength lights. This self-adjustment capacity is important to adapt various environment conditions.

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