# Uncovering LED light effects on plant growth: new angles and perspectives

## LED Light for Improving Plant Growth and Energy Use Efficiency

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*Abstract: In controlled environment agriculture, energy is the predominant factor in production costs. Lighting is the one major consumers of energy. Commercial crop production in greenhouses can be enhanced by supplemental lighting which provides low moderate intensity light levels to increase photosynthesis and plant growth. Traditionally, horticultural lights were high-intensity discharge lamps such as high-pressure sodium (HPS), metal-halide (MH), and mercury (HPMV). The disadvantages of these lamps are high-energy costs, heat generation and suboptimal spectrum for photosynthesis.*

*LED (Light emitting-diode) lamps are a promising technology that has tremendous potential to improve irradiance efficiency and to replace traditionally used horticultural lighting (Kozai et al., 2015). LED provides precise light spectrum and close illumination. Their small size, durability, long lifetime, and cool emitting temperature are more suitable for plant-based uses than many other light sources.*

*This project aims to investigate energy use efficiency and photosynthesis with the evaluation and improvement of protected horticulture system. At the initial phase the effects of different supplemental light including LED light on plant growth and photosynthesis in lettuce have been studied, the higher luminous efficiency and positive impact for plant's growth showed the great potential of LED facilities compared with other artificial light and indicated that it is the most appropriate light resource at this stage. Claims of 50% energy savings for similar biomass yields are now obtained in the study. Further, extending the species of crops for LED faming system have been used for potential maximum efficiency during plant growth and development (Lu et al., 2015).The results also showed lettuce plants grown under the continuous combined red, green and blue LED light exhibited a remarkable decrease of nitrate contents at 24 h compared to other LED light treatments. In addition, red and blue light was more effective in facilitating lettuce plant growth than white LED light (Bian et ac., 2016). Moreover, continuous LED light at 24 h significantly increase phenolic compound concentrations.*

*Keywords: LED (Light emitting-diode) light, plant photosynthesis, plant growth, energy use efficiency*

## 1. INTRODUCTION

Use of greenhouses was introduced several decades ago to protect plants from weather conditions. Initially it was used from farmers at farmlands as alternative way to protect their yield. More recently greenhouses and roof gardens were introduced to city landscape initiating the idea of growing plants at the same place people live. Currently, small industrials and individuals have been involved in urban farming with success in producing fresh food, in a sustainable way, able to deliver to the final consumer in an instant, without transportation costs or storage needs. Also people that encounter those kinds of businesses and taste the products tend to prefer them because they are healthier, fresher and last way longer than the imported equivalents.

With the development of urban agriculture, artificial light has become the most important way to control the light conditions. For a long time people were using fluorescent lamp, filament lamp and high pressure sodium lamp and much research was carried out to test their effect. However, these kinds of light tend to consume large electric energy, release a lot of heat (which will also increase the cooling system's cost), and their some spectrums are not very suitable for plants, which leads to the excessive waste of energy (Yang, 2008).One of the most important elements in controlling the cost of artificial farming is the supply of low-cost light to supply energy for photosynthesis and growth. Light-emitting diodes (LEDs) have been proposed as alternate light sources in controlled agricultural environments as they have drastic advantages of traditional forms of horticulture lighting. These advantages include; superior lifetime, reduced size, cooler emitting temperature, and reduced energy consumption (Massa et al, 2008). An exciting potential of using LED lighting is the development of species specific light recipes comprised of the optimum proportion of specific narrow-band wavelengths light which can optimise growth, development and other desirable traits, whilst drastically reducing the energy input compared to traditionally used horticulture light sources.

## 2. MATERIALS AND MATHODS

### 2.1. Plant Material and Growth Conditions

The pak choi and tomato were grown in controlled growth room, which included two artificial lighting conditions: Fluorescence light used Unigro fluorescent lamp, light model 12/6N (54 wattage per tube), and the LED light used PHILIPS Green power research module which contained deep red (650nm~670nm, 10 wattage), blue (455nm~485nm, 14 wattage) and far red(725nm~750nm, 10 wattage). For tomato LED lighting module, it contained 10 lamp tubes, each tube refers to one kind of single light. The number of tubes for one module was 7 red light, 2 blue light and 1 far-red light. The photosynthetic photon flux density (PPFD) of fluorescent recipe was between 213.0~231.6μmol.$m^{-2}$.s-$^{1}$, and the PPFD of LED lighting module was between 100.6~262.0μmol.$m^{-2}$.$s^{-1}$. It was adjusted by changing the distance between lamp and plants, which was set to 31.2cm and 34.5cm for fluorescent lamp and LED module, respectively. The light intensity was measured by Skye Instruments spectr sense RS 232. The pak choi plants were grown under different LED lighting recipes. All LED treatments had same light intensity as 130 μmol.$m^{-2}$.$s^{-1}$changed red/blue ratio (table 1).

*Table 1: Light treatments with different light recipes*

| Treatments | Red light proportion | Blue light proportion |
|---|---|---|
| CK | 50% | 10% |
| Recipe 1 | 100% | 0% |
| Recipe 2 | 77% | 23% |
| Recipe 3 | 73% | 27% |
| Recipe 4 | 70% | 30% |
| Recipe 5 | 62% | 38% |
| Recipe 6 | 0% | 100% |

The plant growth was set to 18 hours lighting length, 6 hours dark cycle with temperature of 24 $^{o}$C for day time and a temperature of 20 $^{o}$C for dark time. For the testing experiment, we used lettuce as the experimental plant material, as it is a common vegetable for salad, and also sensitive to light conditions with short growth period. The measurements of plant growth was carried out at 70 days after seeds germination.

### 2.2. Gas Exchange and Chlorophyll Fluorescence

On day 12 of the differential light treatments, gas exchange and chlorophyll fluorescence measurements were taken using a Li-COR-6400XT [Lincoln, Nebraska, USA]. CO2 = 400umol m2 s-1; Flow rate= 400. Prior to measurement, tested leaves were dark-adapted for 1 hour for dark-adapted Fo and Fm references. Photosynthesis, stomatal

conductance and chlorophyll fluorescence measurements were taken after the leaf reached steady-state photosynthesis at 150umol m2 s-1 of light of the same red/blue proportion as its growth conditions during treatment.

Fv = Fm-Fo/Fm

PhiPSII = Fm=Fs/Fm'

Fm is the maximum fluorescence emitted by chlorophyll of a dark-adapted leaf generated through excitation by brief light pulse, Fo is the minimum fluorescence emitted by chlorophyll of dark-adapted leaf. Fs is the stead-state fluorescence emitted from chlorophyll during photosynthesis under designated light conditions. Fm' is the maximum chlorophyll fluorescence emitted by chlorophyll during photosynthesis excited to maximum fluorescence by brief light pulse.

### 2.3. Chlorophyll Content Measurements

After 12 days of treatment, and following the taking of gas exchange measurements and chlorophyll fluorescence, leaf chlorophyll concentration was measured using the Minolta SPAD-502PLUS [Spectrum technologies, Illinois, USA]. Each leaf measurement is an average 20 technical replicates per leaf and 6 biological replicates. Measurements are given in relative SPAD-units, with higher values indicating higher chlorophyll content.

### 2.4. Data analysis and statistical evaluation

All data was processed and graphs were generated using Microsoft Excel 2013. In all case, error bars correspond to ± 1 standard deviation (SD). Statistical analysis was undertaken using IBM SPSS Statistics 22, with one-way Analysis of Variance (ANOVA) (α=.05, p≤.05), with homogenecity of variance implemented to ensure appropriateness of all tests. In order to evaluate significant difference found by one-way ANOVA, Bonferonni Post-Hoc test (α=.05, p≤.05) was utilised and significant differences are reported on each graph. Key for understanding statistical differences is that above each error bar is a letter, if two treatments share same letter, there are no significant differences between means, if not then differences between means are significant to p<.05.

## 3. RESULTS

### 3.1. Pak choi plant growth and energy use under different light intensity conditions

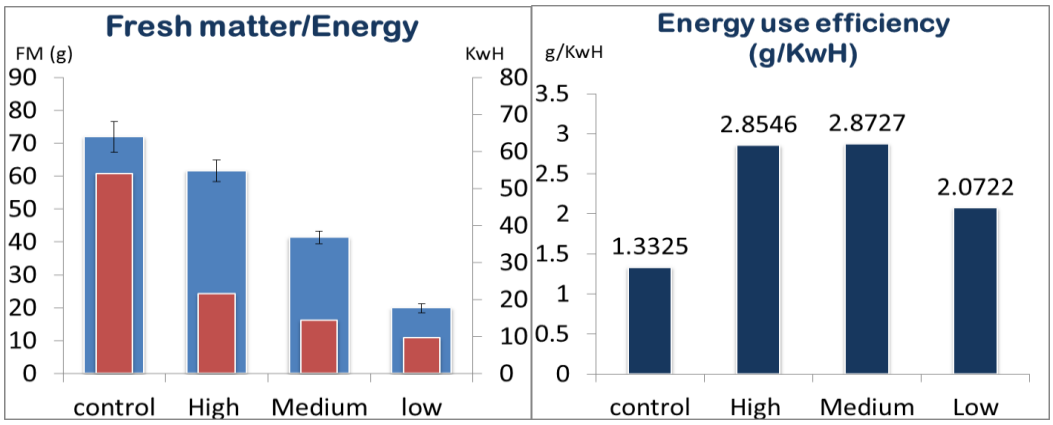


*Figure 1: Plant fresh matter and energy use efficiency under different light intensity conditions*

Figure 1 shows no significant difference between high light intensity treatment and medium light treatment. It needs to consider a balance between cost and plant growth benefits when change the light level from 100 µmol/$m^2s^{-1}$ (low), 150 µmol/$m^2s^{-1}$ (medium) to 220 µmol/$m^2s^{-1}$ (high). The daily energy cost increased from 0.026 to 0.040 (KwH) (by 54%). Blue colour represents plant fresh matter; Red colour represents energy use and dark blue represents energy use efficiency (fresh matter/energy use).

### 3.2. Evaluation of photosynthetic parameters between light treatments in pak choi and tomato

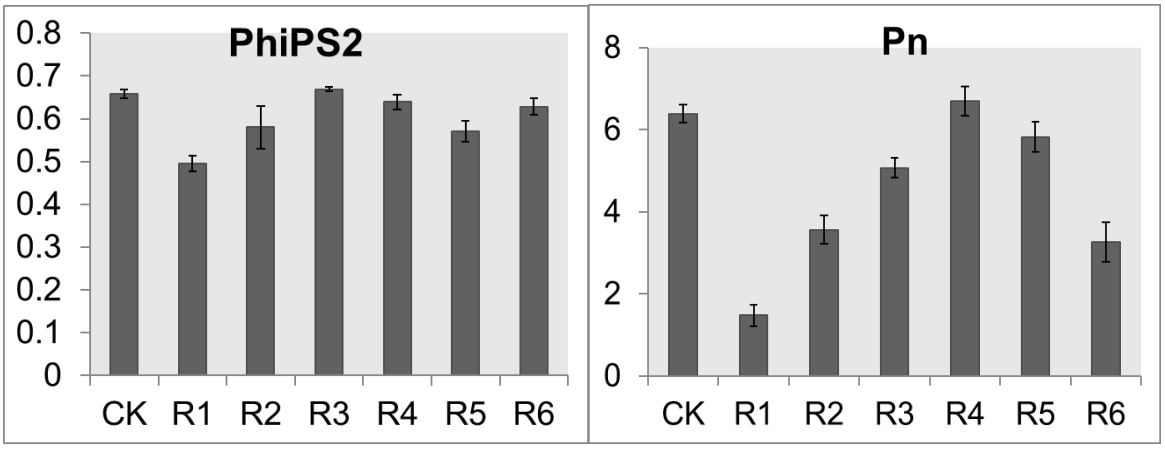


*Figure2: PSII operating efficiency (PhiPS2) and of Net photosynthetic rate (Pn) in pak choi under different LED light recipes (R1-R6 =Recipes 1 to recipes 6, CK= fluoresces light)*

From Figure 2, we have found that R3 and R4 have higher PSII operating efficiency, and R4 and R5 have higher net photosynthetic rate compared with other LED light recipes. Also it shows fluorescent light results a higher PhiPS2 and Pn compared with LED lighting conditions.

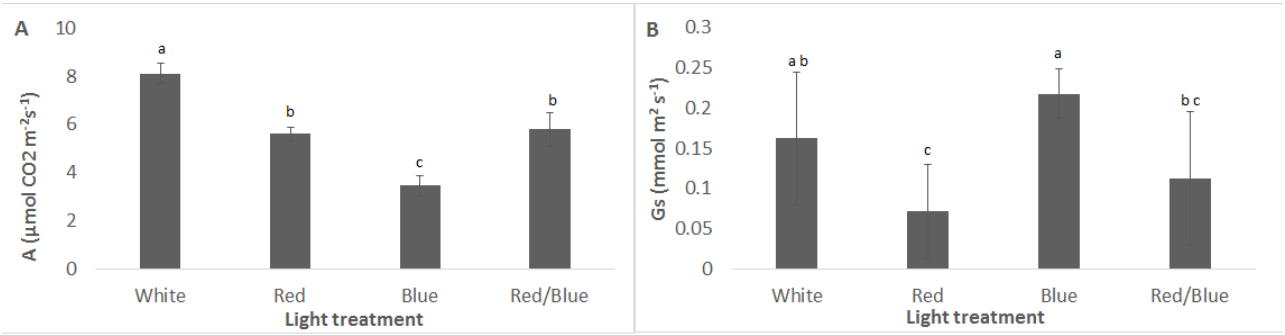


*Figure 3: Photosynthesis and stomatal conductance measurements of tomato leaves after 12 days treatment under different light qualities. Measurements were taken using Li-COR 6400XT after leaf photosynthesis reaches steady-state at 150umol m2 s-1, with proportion of red/blue light varied depending on treatment in order to match treatment conditions. (A) Shows net carbon assimilation measured as umol C02 m2 s-1. (B) Shows stomatal conductance measured in mmol m2 s-1. Biological replicates n=5. Error bars are to ± 1 SD. The letter system indicates Bonferonni Post-hoc test for evaluating significant difference in mean at .05 level, with two groups not containing same letter as an indication of significant difference.Photosynthesis and stomatal conductance measurements of tomato leaves after 12 days treatment under different light qualities. Measurements were taken using Li-COR 6400XT after leaf photosynthesis reaches steady-state at 150umol $m^2$ $s^{-1}$, with proportion of red/blue light varied depending on treatment in order to match treatment conditions. (A) Shows net carbon assimilation measured as umol C02 $m^2$ $s^{-1}$. (B) Shows stomatal conductance measured in mmol m2 s-1. Biological replicates n=5. Error bars are to ± 1 SD. The letter system indicates Bonferonni Post-hoc test for evaluating significant difference in mean at .05 level, with two groups not containing same letter as an indication of significant difference.*

Tomato plants grown under the white light displayed significantly higher rates of photosynthesis than the leaves of plants grown under any of the LED light conditions (figure 3a). Within the LED treatments, the monochromic-red and the mixed red/blue light-grown plants exhibited similar photosynthetic rates, whilst the plants grown under monochromic-blue light displayed significantly impaired rates of photosynthesis compared to all other groups. The stomatal conductance (figure 3b) was shown to be significantly higher in the blue-light grown plants than the red-light grown plants, which showed the lowest rate of stomatal conductance, while the mixed red/blue LED-grown plant displayed an intermediate value of stomatal conductance.

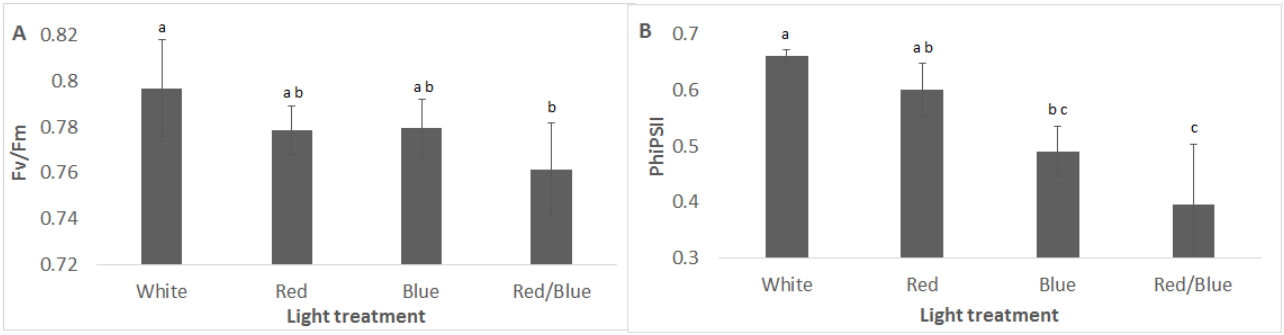


*Figure 4: Chlorophyll fluorescence measurements of tomato leaves under different light qualities after 12 days light treatment.*

There were no significant differences between the plants grown under white, and monochromic red and blue light treatments, all indicating a healthy leaf status. However, the red/blue treatment group exhibited a lowered Fv/Fm averaging around 0.76 and significantly lower than those plants grown under white light control conditions. Once again, the white light treatment exhibited the highest PhiPSII, significantly greater than blue and mixed LED treatment.

## 4. CONCLUSION

Spectral quality drastically effect growth and development. The results clearly indicate that there are significant developmental differences between tomato plants grown under traditionally used fluorescent tubes providing wide-spectrum white light, and those grown under narrow-band LED lights. It will likely take several iterations of testing a wide-range of light recipes in order to identify the optimum light regime for growth and development to maximise yield in tomato, and furthermore this will likely be separated into distinct growth phases in which the optimum light recipes differ. The similarities between the white light and monochromatic red-light grown tomato plants in terms of photosynthesis and dry weight are promising, as with such a low stomatal conductance observed in the latter treatment gives huge potential for increasing overall photosynthesis through additions of small proportion of blue-light. Also, the many different phenotypes already observed between treatments offer a many different avenues of exploration, to identify the key down-stream regulators which are being regulated by specific light signals.

## 5. REFERENCES

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