

# Light Environment Optimization for Lettuce Growth in Plant Factory

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**Abstract:** Plant factory is a crop production system which is isolated from outside environment. Fluorescent lamp is popularly used in the plant factory, however, the spectrum of fluorescent light is broad and some portion of them is not necessary for photosynthesis. On the other hand, LED (light emitting diode) has narrow band width and is getting common these days. The final goal of this project was to develop a new light apparatus with LEDs optimized for vegetable production in plant factory. The specific objective was to investigate the effective light quality for growing plant more healthy and rapidly. The effect of light provided by various light qualities provided by the combination of LEDs (blue, green, red) on the photosynthesis rate, growth and morphogenesis of lettuce (*Lactuca sativa* L. "Greenwave".) were evaluated and the response compared with those of plant irradiated by fluorescent lamps. Photosynthesis rate of lettuce was greater in monochromic red light and the mixed light with red and blue LEDs. Stem length increased in monochromic red and blue light and decreased in mixed light. Fresh weight of lettuce was increased in monochromic red and fluorescent light.

**Keywords:** dry weight, environment control, fresh weight, LED, photosynthesis rate

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## 1. INTRODUCTION

Food safety concerns in Japan have stimulated interest in protected agriculture that is conducted in plant factories built with advanced technologies. Since this type of facility is completely isolated from the external environment, plants are grown without any agricultural chemicals. Additional characteristics of plant factories are process management and scheduled production. However, the initial and running costs for environmental control are very expensive. These issues are one of the factors which have barred spread widely. In running cost, the cost for lighting used plant growth is one of the large portions. Recently a light emitting diode (LED) has spread as a new light source. LED has good life performance, energy-saving ability and narrow bandwidth of wavelength. This narrow bandwidth characteristic enables to produce various light qualities, and the effects of light qualities on the growth and development of plant have been studied for a long time. Red light promotes germination and photosynthesis (Flint and McAllister 1937, Balegh and Biddulph 1970). Blue light effects stomatal opening and chloroplast development (Takemiya, Takahashi and Shimazaki 2007; Akoyunoglou and Anni 1984). Green light slow down or stop the plant development, but it brings positive effects in special conditions (Folta 2004, 2007; Terashima, Fujita, Inoue, Wah and Oguchi 2009). In many plants and wavelength, the absorbance of leaves or the quantum yield of photosynthesis have been studied. We consider LED can produce the best light quality for plant growth in plant factories by combining the characteristic of bandwidth and plant growth and development researches.

Photosynthesis rate and growth rate of plant grown under LED were reported (Mori and Takatsuji 2000, Mori, Takatsuji and Yasuoka 2002). The objective of this project was to investigate the effect of light quality on the growth of leafy vegetable which is one of the major items in the plant factory.

## 2. MATERIALS AND METHODS

### 2.1 Preparation of Plant Material

Leaf Lettuce (*Lactuca sativa* L. "Greewave") were sown in an urethane sponge absorbed enough water under fluorescent lamps provided PPF of 140 and 200  $\mu\text{mol s}^{-1} \text{m}^{-2}$  on the canopy level with a 14h photoperiod for one week. After one week, lettuce plants were transplanted to hydroponic system (GFM plant "M", M Hydroponic Research Co.,Ltd, Japan). Two experiments were planned, namely photosynthesis rate measurement and growth experiment. In photosynthesis rate measurements, plants were grown under fluorescent lamps for a month (11/26-12/27, 2009). In growth experiment, they were grown under six different light qualities from fluorescent lamps and LED systems for four weeks. All of the plants were grown in a growth chamber (KCLP-1000 I CT, NKsystem) set at a 16h/d light period and 25°C in light period and 18°C in dark period.

## 2.2 LED Lighting Apparatus

The light sources used in this projects were a fluorescent lamp (FLR20S • W/M, Toshiba, Japan) and a LED system. The LED system is consisted of blue, green and red LEDs (LUXEON Rebel, Philips Lumileds) and condenser lenses as shown in Figure 1. Photosynthetic photon flux (PPF) from the LEDs can be controlled by adjusting currents from a DC power supply.



Fig.1 Developed LED system

## 2.3 Environment Conditions

A hydroponic system constructed with a culture bed (730 wide mm × 665 length mm × 170 height mm) covered tarpaulin and a standard culture panel was employed in the project. The concentration of the nutrient solution was maintained at pH 5.9±0.2 and EC 2.00±0.10 by a fertilizer controller (CEMCO, Japan) with acidity regulator (Otsuka Chemical Co.Ltd., Japan).

For light quality, six experimental conditions were set up. One was fluorescent light (FL) and the others were LED light sections provided by the LED systems. The light qualities set by the LED systems were monochromic red light (R), monochromic blue light (B), the light mixed with red and blue light (RB), the light imitated sunlight (SL-L), the light imitated fluorescent lamp light (FL-L). Table 1 shows light intensity rates of blue, green and red LEDs about these five light qualities. We referred to the spectrum data of sunlight (Air Mass 1.5: ASTM G173, NREL) and a fluorescent lamp (FLR20S • W/M, TOSHIBA) to set SL-L and FL-L.

The reason why we chose these six light condition was based on the previous reports as follows. Fluorescent lamps are popularly used in plant factories, so FL was used to reproduce plant growth in plant factories as standard. The effect of R light was reported that monochromic red light irradiation showed the highest photosynthesis rate in many monochromic light irradiations (Balegh and Biddulph 1970;

Björkman 1973). Previous research pointed out dry weight of plant grown under blue light increased (Hirai, Amaki and Watanabe 2006). For RB, it is reported that the light mixed with red and blue light promoted plant growth and photosynthesis. To reproduce plant growth in sunlight which plants have adapted, SL-L was used. FL-L was used to research the effect of removing ultraviolet and infrared rays from fluorescent light.

Table 1. Light intensity rates of blue, green and red LEDs for five light qualities using LED systems (%)

	blue LED	green LED	red LED
1. R	0.0	0.0	100.0
2. RB	16.7	0.0	83.3
3. B	100.0	0.0	0.0
4. SL-L	33.4	33.9	32.7
5. FL-L	29.8	39.6	30.6
6. FL	Flourescent Lamp		

## 2.4 Photosynthesis rate Measurement

A LI-6400 (LI-COR) was used for photosynthesis rate measurement. Plant leaf was fastened with the leaf chamber of LI-6400 in which CO<sub>2</sub> concentration set at 400 ppm and applied one light quality whose light intensity was set at 300  $\mu\text{mol m}^{-2} \text{s}^{-1}$  for an hour. After confirming photosynthesis rate was stable, the measurement was begun. The light intensity was set at 300 (250 in FL)  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at first, followed 200, 150, 100, 80, 60, 40, 20, 10  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . In each light intensity, CO<sub>2</sub> concentration was increased from 0 ppm to 1500 ppm for every 100 ppm, and photosynthesis rate was measured and stored at every condition. After measurement was completed to 10  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , light quality was changed to the next and the same measurement procedure was repeated. In all measurement, the same area of the same leaf of the same plant was used.

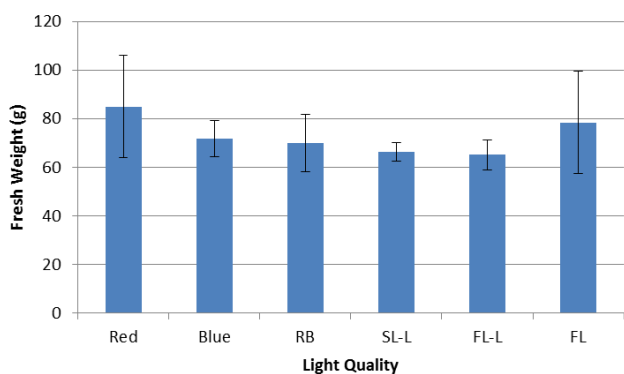
## 2.5 Growth Experiment

Six treatments with six light qualities were planned for growth experiment. Nine plants were grown in one treatment as a replication. However, one plant in R treatment and two plants in FL treatment were not grown well, the number of replication in these treatments were eight and seven, respectively. Growth response to the light quality was quantified by fresh weight, dry weight and number of leaves per plant. The dry weight was measured after drying in a hot air oven at 70 °C for 4 days, and the number of leaves was measured all leaves contained even very small new leaves.

### 3. RESULTS AND DISCUSSIONS

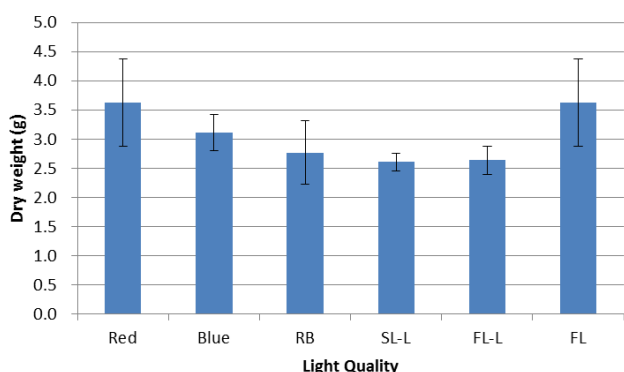
#### 3.1 Fundamental Characteristics

Figure 2 shows the relation between light quality and fresh weight. Unevenness of fresh weight can be seen in R and FL treatments. The unevenness was caused by the difference of light environment or competition among individuals as seen in number of leaves. The higher photosynthesis rate under a certain light quality makes the greater fresh weight. Figure 3 indicates the relation of photosynthesis rates and fresh weights every light quality. In fluorescent lamp environment, the plants were exposed to the diffused and uniform light. On the other hand, direct light was irradiated on the plants and the leaves in the lower position was not able to received the enough light intensity in LED environment. So, it might be difficult to quantitatively discuss the photosynthesis in both fluorescent and LED environment together. Figure 3 indicates the relation between light quality and dry weight. In LED light environment, the result of the dry weight gives similar tendency as the result of fresh weight shown in Figure 2 qualitatively.



Error bar indicates SD.

Fig.2 Relation between light quality and fresh weight

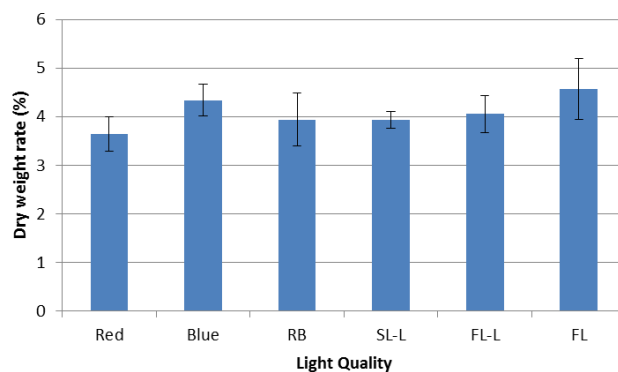


Error bar indicates SD.

Fig.3 Relation between photosynthesis rate and dry weight

Figure 4 shows the relation between light quality and dry weight rate which means dividing dry weight by fresh weight.

Dry weight rate increased a little in FL and B and reduced in R. Although Hirai et al.(2006) reported that lettuce grown under red light had the smallest dry weight among that under monochromic blue, blue-green, green and red light, the lettuce crop in R treatment had as big dry weight as that in B treatment had in our experiment. However, the dry weight rate was much lower in R.



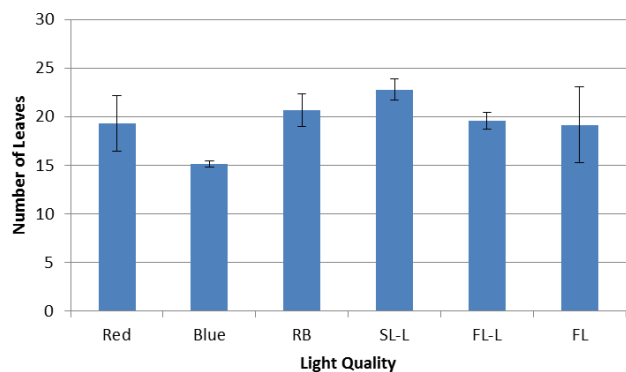
Error bar indicates SD.

Fig.4 Relation between light quality and dry weight rate

It is considered R treatment could suppress dry matter production. We think the reason why dry weight rate decreased in R could be a bad plant posture of light absorption caused by overlapping of leaves and hanging down leaves. Figure 4 also shows that the higher rate of red light a light quality had, the less dry weight of plant grown under the light quality became.

#### Number of Leaves

Figure 5 shows the relation between light quality and number of leaves. It was observed that plants grown under R have long leaves and petioles, and that overlapping of leaves happened more frequently than other light qualities. The overlapping makes difference to the light quantity supplying plants and plant growth. The light intensity of the FL treatment is different among transplanted position because the edge of the FL tube had the relatively lower light intensity. This difference could cause the difference of individual growth under FL. Other light qualities happened less overlapping of leaves than R and had the same light environment among individuals because light sources set right above. So standard errors in their treatment were significantly low.



Error bar indicates SD.

Fig.5 Relation between light quality and number of leaves

Number of leaves was increased in SL-L treatment and significantly decreased in B. Plants grown in SL-L treatment had more new and small leaves than other treatments. Decreasing leaves of lettuces grown under blue light has been reported previously (Hirai 2006). We also observed the effect of blue light on decreasing number of leaves has the significant difference among monochromatic blue, blue-green, green and red light treatment. And in our research, this effect of blue light has the significant difference among B, R, RB, SL-L, FL-L and FL treatments. From these researches, it is considered that blue light could decrease number of leaves and green and red lights could suppress this decreased effect of blue light.

### 3.2 Photosynthesis rate

Figure 6 shows the relation between light qualities and photosynthesis rates. The photosynthesis rate was increased in monochromatic red light (R) and RB. These light qualities contained more red light than others, so it was considered that red light could hasten photosynthesis. This response has been reported previously in many species (Emerson and Lewis 1943; Balegh and Biddulph 1970; Björkman 1973). Mori and Takatsuji (2000) reported that photosynthesis rate of R treatment was lower than that of RB treatment. However, our result which photosynthesis rate of R treatment was higher than that of RB treatment was different from the previously reported results. This difference could be due to the difference of plant specie, experiment environment and growth condition. The difference of photosynthesis rates under SL-L, FL-L and FL were small. This could be due to little difference among their light qualities. In spite of light intensity or CO<sub>2</sub> concentration, the result that the highest photosynthesis rate is in R, followed in RB and in the others in this order was not changed.

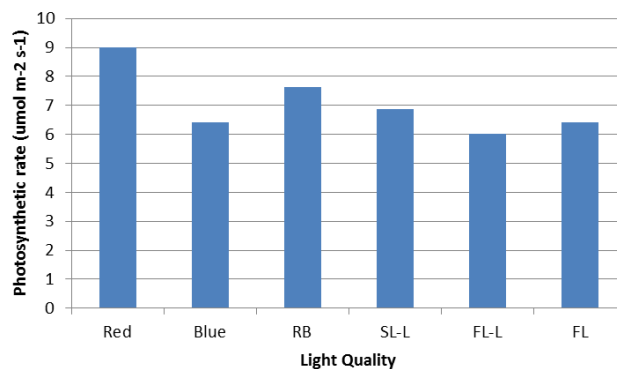


Fig.6 Relation between light qualities and photosynthesis rates

### 3.3 Comparison of Electric Power Consumption

Figure 7 shows the relation among light quality, production efficiency and electric power consumption. Production efficiency means the value dividing average fresh weight by power consumption. R and B treatment using LED systems had much lower power consumption and higher production efficiency compared to FL. Production efficiency of B, which was the smallest in that of other light qualities using LED systems, was approximately 1.8 times higher than that of FL. One of the most important reasons of this result could be the difference of ability between LEDs and fluorescent lamps. On the other hand, the large difference among light qualities using LEDs was also observed. Production efficiency of R treatment was about 1.7 times higher than that of B treatment. This difference is because red light has lower power consumption than blue light. However, power consumption differs from light sources, so if LED differs, it must be cautious of these values differing.

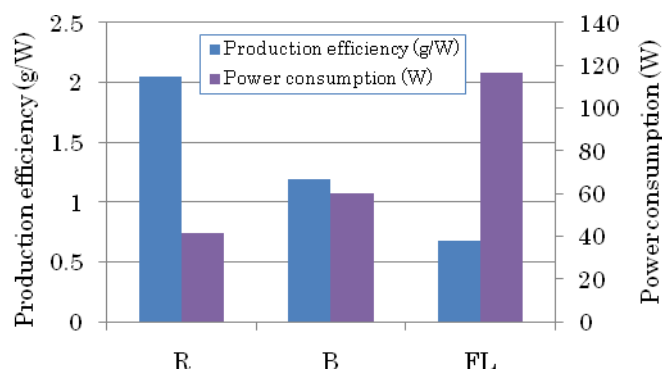


Fig.7 Relation among light quality, production efficiency and power consumption

## 4. CONCLUSIONS

In conclusion, monochromatic red light might be the most effective for photosynthesis and growth in *Lactuca sativa* L. "Greenwave". In addition, production efficiency in

monochromic red light is more than twice in comparison with in florescent lamps. There were couple of reports described the plant shape looked bad in monochromic red light condition. Although stem length in monochromic red light was surely a little bit longer than in monochromic blue, we judged product value of lettuce did not fall.

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