

Effects of supplementary lighting by natural light for growth of *Brassica chinensis*

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Abstract. This paper present a model of cultivated chamber with supplementary natural colour light. We investigate the effects of supplementary natural red light and natural blue light on growth of *Brassica chinensis* under natural white light illumination. After 4 weeks of supplementary colour light treatment, the experiment results shown that the weight of fresh leaf were not affected by supplementary natural blue light. However, those *Brassica chinensis* were cultivated in the chambers with supplementary natural red light obtained a significant increasing of fresh weight of leaf under both white light illuminate models. The combination of natural white light with supplementary natural red light illumination will be benefits in growth for cultivation and energy saving.

1. Introduction

Light quality is one of the most important variables affecting the efficiency for the growth of plants [1-5]. For example, blue light increased levels of anthocyanins in tomato [6], carotenoids in coffeea [7] and ascorbic acid in lettuce and Komatsuna [8], and red light seems to be most effective for anthocyanin production in cranberry fruits [9]. Li and Kubota investigated the effects of different supplemental light qualities on phytochemicals and growth of baby leaf lettuce grown at a high planting density inside a growth chamber, the results demonstrated that supplemental light quality could be strategically used to enhance nutritional value and growth of baby leaf lettuce grown under white light [2]. Those results have shown the viability of optimizing light quality in increasing phytochemical concentration.

In recent decades, light emitting diodes (LEDs) have been received attention as a light source with low power consumption for indoor illumination, plant cultivation and other many applications. Lin et al., demonstrate that supplemental light quality can be strategically used to enhance the nutritional value and growth of lettuce plants grown under RBW LED lights. Precise management of the irradiance and wavelength may hold promise in maximizing the economic efficiency of plant production, quality, and nutrition potential of vegetables grown in controlled environments. Lee et al., presents a high-performance LED agricultural luminaire that uses a beam-shaping diffuser to achieve high optical efficiency and energy saving. There are many studies demonstrated that the combination of red (R) and blue (B) LED light was an effective light source for plant growth and development, and the light spectra, intensities, and durations can easily be controlled by growers in artificial growing environments [8, 10, 11-14].

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In addition to agricultural production, energy saving is also an important issue for human life and reducing environment degradation. Artificial lighting systems can be one of the major electrical loads in a building. In recent decades, there are many research for the utilizing daylight for interior illumination can contribute to energy savings, daylight use of solar radiation is particularly beneficial as the natural light brought by the natural light illumination system can decrease energy consumption by reducing artificial lighting use [15-18].

The utilization of supplementary lighting by natural light for growth of plants with the benefits for improving the efficient of production of plant and energy saving. However, the research about the effect of supplementary light quality on growth of plant by natural light source is still rare. This paper present a model of cultivated chamber which supplementary the transmitted natural colour light by Sunshine illuminating on the area, where is filled with colour filter, of the roof for growth of plants. The experiment results of supplementary natural red light and blue light for growth of Brassica chinensis are also shown in this paper. We describe the plant material, experiment and measurement in section 2; the results of this experiment are shown in section 3, and the final section is the conclusions of this research.

2. Material and Methods

The assessment of the efficiency of supplementary natural red light and blue light for improving growth of plants is one of aims of this research. As a result of the spectrum of red and blue are most effectively use in visible light energy for photosynthesis, the growth chambers were illuminated either by combination of natural white light and red light or combination of natural white light and red light, respectively. Brassica chinensis was the experiment crop.

2.1. Plant material and growth conditions

Brassica chinensis (bok choy) is one of important vegetables, which is a good source of dietary fiber, vitamins A, B6, C, and K, calcium, folate and manganese, furthermore, it is applicable in hydroponics and in soil cultivation. In this research, 24 Brassica chinensis were cultivated into 6 growth chambers, which are illuminated by different supplementary natural light scheme, after the plants developed first true leaves. The plants were cultivated in the growth chambers for 4 weeks. The temperature and hours of Sunshine for the duration of experiment is shown in Fig. 1. In this period, the average temperature is 23°C, the maximum sunshine hours is 10 hours in a day. The climate is appropriate for Brassica chinensis cultivation.

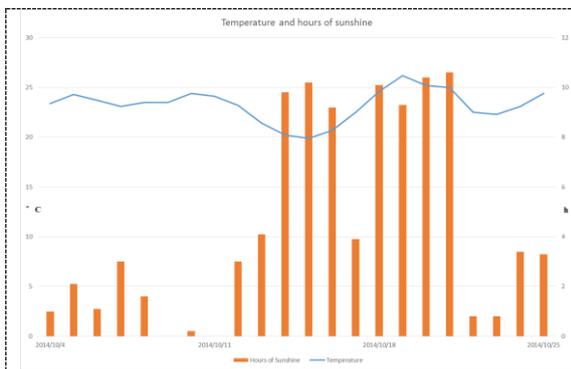


Figure 1. Temperature and hours of Sunshine for the duration of experiment.



Figure 2. An illustrated for the growth chamber.

2.2. Growth chamber

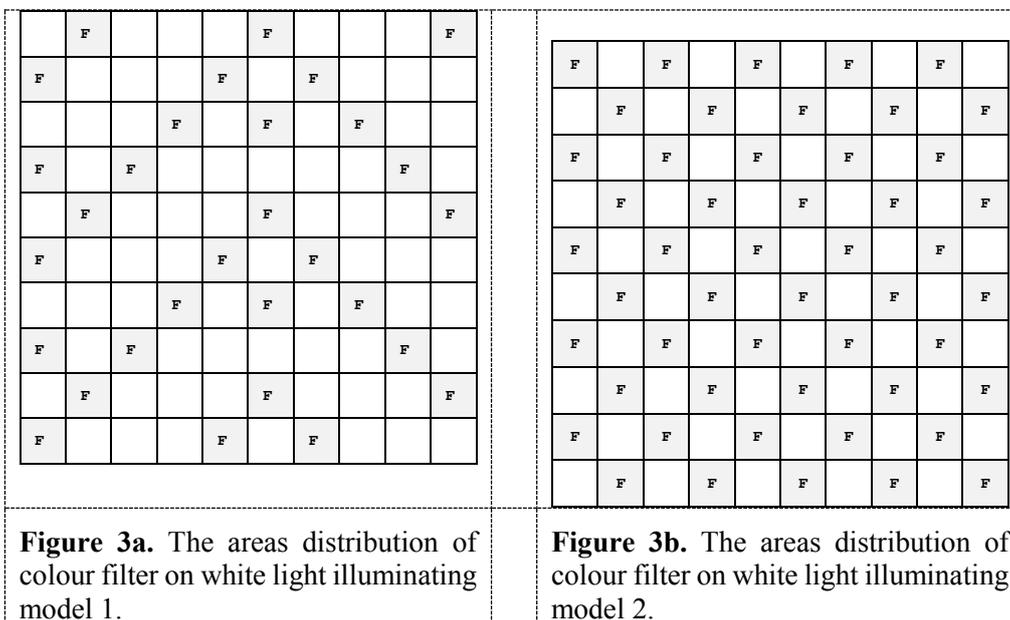
In this research, natural white light as the control treatment. Two natural white light illuminating models are used in this experiment, that the ratio of white light areas are 70% (W1) and 50%(W2) of total area of the roof of the chamber respectively. The growth chambers were illuminated either by combination

of natural white light and red light or combination of natural white light and red light, respectively. Both of the natural white light source and the supplementary colour light are obtained by Sunshine illuminating on the areas of transparent and colour filter of the roof respectively. Fig. 2 is an illustration for the growth chamber. The ratio of areas of colour filter on the chambers are described in table 1, where the ratio (W: B: R: K) means the relative areas of the regions where without colour filter, where is filled with blue filter, red filter and black (T=0) respectively. The areas distribution of colour filter are designed for uniformly illumination on the chambers during a day, illuminating model 1 and model 2 are shown in Fig. 3a and Fig. 3b respectively. The transmitted spectrum of blue and red colour filters are shown in Fig. 4a and Fig. 4b respectively.

Table 1. Ratio of areas of colour filter region .

chamber	Ratio(W:B:R:K) ^a
W1	7:0:0:3
WB1	7:3:0:0
WR1	7:0:3:0
W2	5:0:0:5
WB2	5:5:0:0
WR2	5:0:5:0

^a Where W,B,R and K refers to white, blue, red and black respectively.



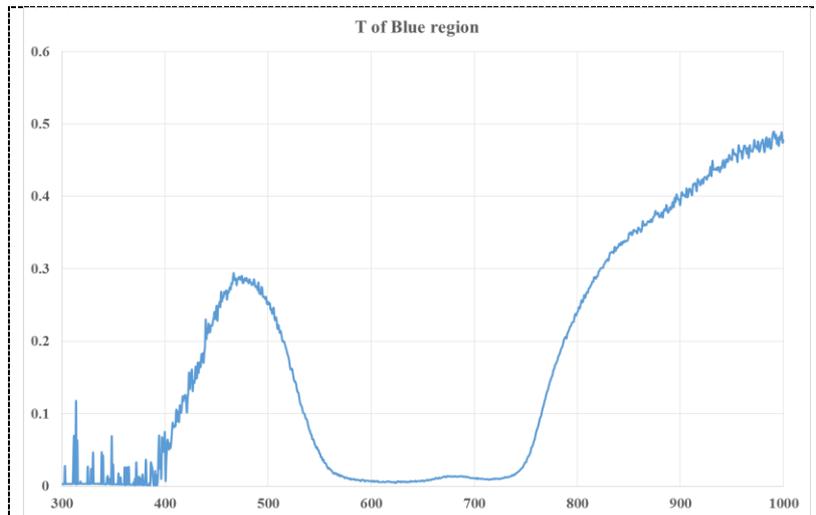


Figure 4a. The transmitted spectrum of the colour filter for blue.

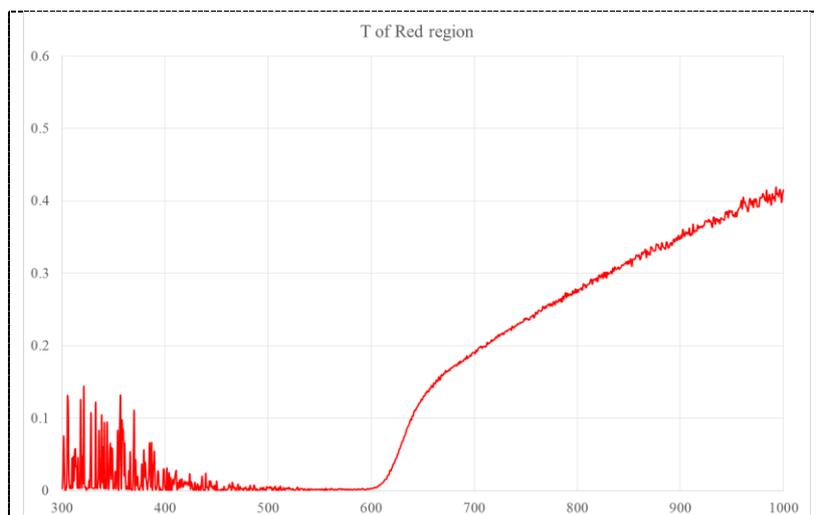


Figure 4b. The transmitted spectrum of the colour filter for red.

The ratio of supplementary light compare to natural white light can be determined by Eq. (1)~(3), where I_F , I_S , R_F , T_F and A_F are refer to the relative transmitted intensity of natural colour light, the relative intensity of natural white light, ratio of supplementary natural colour light, the average transmittance of colour filter which corresponding to active spectrum and the ratio of colour filter on the growth chamber. The ratio of supplementary colour light is described in Table 2, where A_F is obtained by the total area where the region with colour filter relative to the total area where is sunshine illuminated, T_F is the average transmittance which corresponding to the action spectrum.

$$I_F = \int I_S(\lambda)d\lambda \cdot T_F(\lambda) \quad (1)$$

$$I_W = \int I_S(\lambda)d\lambda \quad (2)$$

$$R_F = \frac{I_F A_F}{(1 - A_F) I_W} \quad (3)$$

Table 2. The ratio of supplementary colour light

Chamber	A_F	T_F	I_F
W1	30%	0	0%
WB1	30%	0.1	4%
WR1	30%	0.2	9%
W2	50%	0	0%
WB2	50%	0.1	10%
WR2	50%	0.2	20%

2.3. Measurement

We investigate the effects of supplementary natural red light and natural blue light on growth of *Brassica chinensis* which were grown under natural white light illumination. The stem length, length of leaf and width of leaf of each plant were measurement per week after the plants were cultivated in the growth chamber by supplementary natural colour light. After 4 weeks of supplementary colour light treatment, the leaf fresh weight was also measured in the finally measurement.

3. Results

The stem length, length of leaf and width of leaf of each plant were measurement per week after the plants were cultivated in the growth chamber, which were cultivated in the chambers with different natural light treatment. The average length of leaf and the average of leaf during experiment are described in Table 3 and Table 4 respectively. Fig. 5 and Fig. 6 shows the average values of product of leaf length and width of leaf, which is related to the area of leaf. The results shown that the *Brassica chinensis* which were cultivated in chambers WR1 and WR2 can be Maximum increased to about 25% and 26% relative to those were cultivated in chambers W1 and W2 during this period respectively. The values of products shown that the *Brassica chinensis* which were cultivated in chamber WB1 and WB2 can be increased to about 26% and 6% relative to W1 and W2 respectively.

Fig. 7 and Fig. 8 are the latest measurements in this experiment for supplementary natural colour lighting illuminated on *Brassica chinensis* growth. Fig.7 shows that the harvest total fresh weight of leaf was 70g, which is obtained by those *Brassica chinensis* were cultivated in chamber WR1. The total fresh weight of leaf which were cultivated in Chamber WR1 got an increase of about 37% and 32% relative to those were cultivated in chamber WB1 and W1 respectively. The average length of leaf of *Brassica chinensis* which were cultivated in Chamber WR1 got an increase of about 13% relative to those were cultivated in chamber W1. The average length of leaf of *Brassica chinensis* which were cultivated in Chamber WB1 got an increase of about 8% relative to those were cultivated in chamber W1. The average width of leaf of *Brassica chinensis* which were cultivated in Chamber WR1 got an increase of about 11% relative to those were cultivated in chamber W1. The average length of leaf of *Brassica chinensis* which were cultivated in Chamber WB1 got an increase of about 17% relative to those were cultivated in chamber W1.

Fig. 8 shown that the harvest total fresh weight of leaf is 58.8g, which *Brassica chinensis* were cultivated in chamber WR2. The fresh weight of *Brassica chinensis* which were cultivated in Chamber WR2 got an increase of about 14% and 21% relative to those were cultivated in chamber WB2 and W2 respectively. The average length of leaf of *Brassica chinensis* which were cultivated in Chamber WR2 got an reduction of about 5% relative to those were cultivated in chamber W2. The average length of leaf of *Brassica chinensis* which were cultivated in Chamber WB2 got an increase of about 8% relative to those were cultivated in chamber W2. The average width of leaf of *Brassica chinensis* which were

cultivated in Chamber WR2 got an reduction of about 9% relative to those Brassica chinensis were cultivated in chamber W2. The average length of leaf of Brassica chinensis which were cultivated in Chamber WB2 got an reduction of about 1% relative to those were cultivated in chamber W2.

Table 3. The average length of leaf during experiment (cm)

Chamber	10/4	10/11	10/18	10/25
W1	4.0	7.6	11.5	13.5
WB1	4.0	8.2	13.1	14.0
WR1	4.0	8.6	12.6	14.8
W2	4.0	7.6	12.4	13.8
WB2	4.0	8.2	11.3	12.5
WR2	4.0	7.8	12.6	14.6

Table 4. The average width of leaf during experiment (cm)

Chamber	10/4	10/11	10/18	10/25
W1	4.0	7.6	11.5	13.5
WB1	4.0	8.2	13.1	14.0
WR1	4.0	8.6	12.6	14.8
W2	4.0	7.6	12.4	13.8
WB2	4.0	8.2	11.3	12.5
WR2	4.0	7.8	12.6	14.6

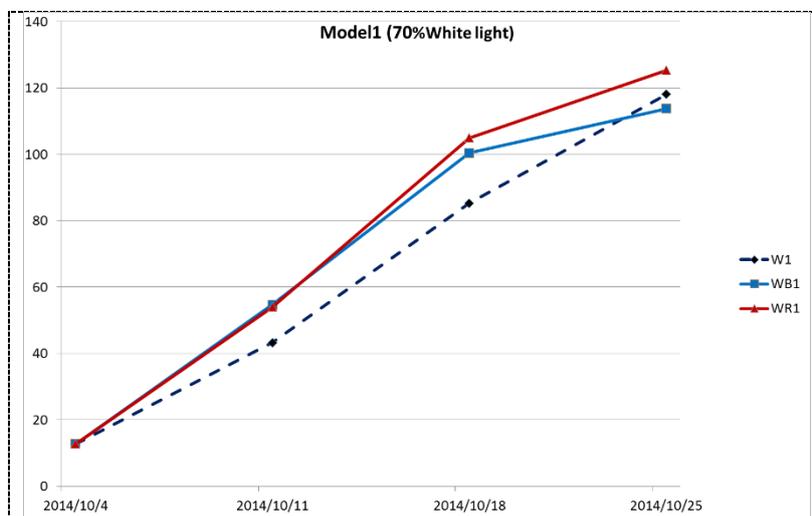


Figure 5. The average values of products of length and width of leaf which were cultivated in illuminated model 1.

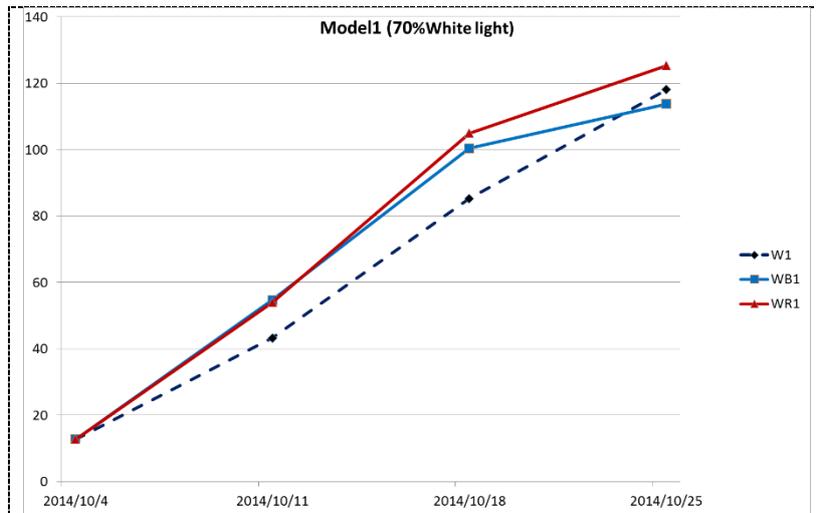


Figure 6. The average values of product of length and width of leaf which were cultivated in illuminated model 2.

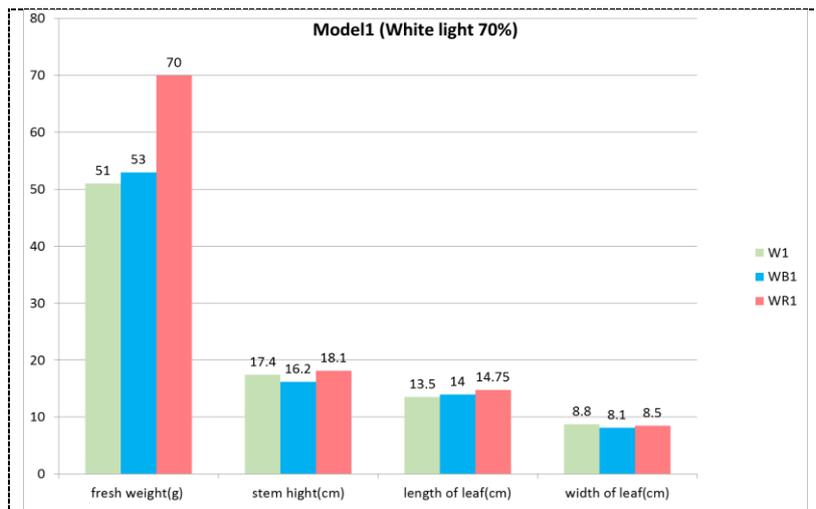
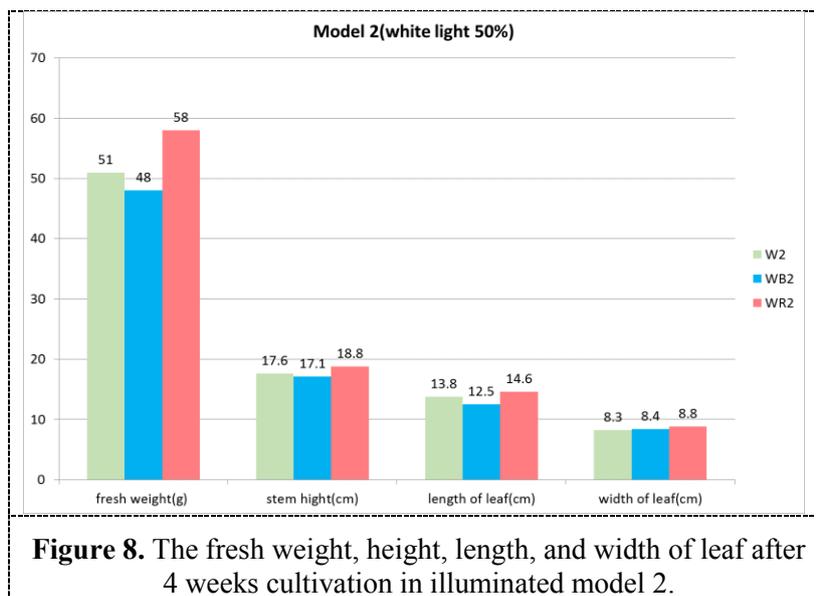


Figure 7. The fresh weight, height, length, and width of leaf after 4 weeks cultivation in illuminated model 1.



4. Conclusion

In this research, we investigate the effects of supplementary natural red light and natural blue light on growth of *Brassica chinensis* grown under natural white light illumination. After 4 weeks of combination of natural white light and supplementary natural red light treatment and supplementary natural blue light treatment, the experiment results shown that the weight of fresh weight were not affected by supplementary natural blue light. However, those *Brassica chinensis* were cultivated in the chamber with supplementary natural red light obtained a significant increasing of fresh weight of leaf under both white light illuminate models. The combination of natural white light with supplementary natural red light illumination will be benefits in growth for cultivation and energy saving.

5. References

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