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MODIFICATION OF GROWTH AND YIELD OF THE LEAFY VEGETABLE UNDER PHOSPHOR-CONVERTED LIGHT-EMITTING DIODE*

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Key words: phosphor converted-LEDs, leafy vegetable, ground biomass, R:B LED, Far-red radiation, yield.

Abstract

Leafy vegetable are desirable crops for daily consumption due to their nutritive value. This study aims to illustrate that the commercial phosphor converted-LEDs (pcH-LED) could improve the yield of the leafy greens in ground biomass and their morphological response of leaf and root. The experimental setup were set under three treatments which are pcH-LED, R:B LED and Fluorescent in the same environment. The results indicated that the Far-red radiation from pcH--LED can have positive effects on crop quality. It could promote the highest fresh weight, perfect leaf size, and nice leaf color of the Butterhead lettuce, Cos lettuce, Red oak and Green oak lettuce. The pcH-LED and R:B could produce the same quantity in leaf number, leaf length and root number, but R:B show negative effect to Cos lettuce resulting in shorter leaf and tiny size. Based on the growth and yield of leafy vegetable for indoor plantation, the pcH-LED is recommended to be a light source.

Introduction

Red (600–700 nm) and blue (400–500 nm) light are very interesting wavelengths for the growth and development of plants. Many previous studies have shown that plants can grow normally in combination with R and B radiation. This is especially the case for leafy vegetables where when exposed to a combination of R and B light, higher yield of the vegetable was observed than leafy vegetables under sole R (red) or sole B (blue)

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light (LI et al. 2017, SAITO et al. 2010). Moreover, the combination of R and B could promote the net photosynthesis and chlorophyll content of the plants (HE et al. 2017, LI et al. 2017).

The mixed-color method has been used to construct the R:B LED light for the horticultural applications. R and B LEDs can be mixed and assembled on the aluminum PCB (print circuit board). Subsequently, they can be installed on the heat sink. The LED drivers and the cooling system are also needed in the set up. Consequently, the PWM technique could be provided to control the level of the photon flux density.

Nowadays, the LED chip with phosphor converted (pc) technology was applied for the development of LED for horticultural purposes. These pc-LEDs are known fully as phosphor converted light emitting diodes. The red phosphor coated on the blue LED chip makes it possible for the R and B photon flux to be emitted from the single chip. This light source can appropriately be applied to the indoor plantation (LI et al. 2017).

The pc-LEDs has been commercialized, for example: LUXEON SunPlus (Lumileds) which is a full spectrum white-based horticulture light (white plus red light) from SAMSUNG and CREE. The pc-LEDs could produce the light spectrum to cover the photosynthetic active radiation (PAR) in the wavelength of 380–780 nm (MCCREE 1972). This is important because the FR light(701–780nm) could promote the highest fresh weight, dry weight, stem length, leaf length and leaf width of the lettuce (MICKENS et al. 2018, LI and KUBOTA 2009). The additional of far-red radiation has promotive effects on leaf expansion, which increases radiation capture and can increase the dry mass gain (PARK and RUNKLE 2017, 2018, ZOU et al. 2019).

The advantages of pc-LEDs are multifold. Firstly, pc-LEDs are easy to assemble. In some models, the LED driver circuit in the chip is included. PC-LEDs can be directly connected to AC power source and can be easily dimmed by using the simple AC voltage-dimmer. Therefore, this saves the time and human cost for specific equipment and installation. This study present a growth study of leafy green vegetables with the use of commercial pc-LEDs for horticultural purposes in comparison to a custom-built direct emission R:B LEDs. The goal is to determine whether the commercial pc-LEDs could improve the yield of the Butterhead lettuce, Cos lettuce (baby Cos), Red oak lettuce and Green oak lettuce. The above ground biomass and the morphological structure of their leaf and root were also investigated.

Material and Methods

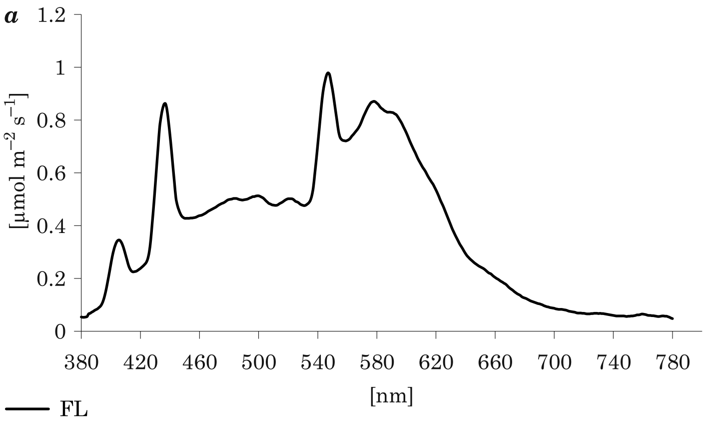
Plant and Growth Conditions

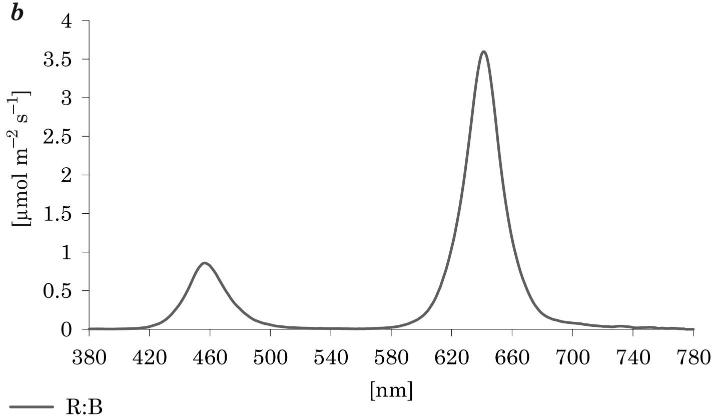
There are four different vegetable seeds used in this study: Butterhead lettuce (*Lactuca sativa var. capitata*), Cos lettuce (*Lactuca sativa var. longifolia,* L. *romana*), Red Oak *lettuce* (*Lactuca sativa var. crispa* L.), and Green Oak lettuce (*Lactuca sativa var. crispa* L.) (Chia Tai Co., ltd, Thailand). Firstly, after incubating the seeds at 4°C on moistened sponge for 5 days, the seeds of four vegetables were germinated into plastic pots (diameter is 10 cm). One seed was planted per one pot. Each pot contains loamy soil, compost, paddy husk charcoals, and coconut dust in the same quantity and was placed in the growth chamber (60 cm × 60 cm × 180 cm). The growth chamber is placed in the temperature control room. The temperature is maintained at 29/25°C (day/night) and the humidity is at 55% to 75% (day/night). There is one control group and two experimental groups. Each group consists of 12 pots per tray: 3 pots of Butterhead, 3 pots of Cos lettuce, 3 pots of Red oak, and 3 pots of Green oak lettuce. Twenty five milliliters of tap water was supplied to each pot once a day in the morning. The plants were irradiated with three treatments with different spectral of the light that is described in the next topic. Finally, the crops are harvested at 40 days after sowing (DAS).

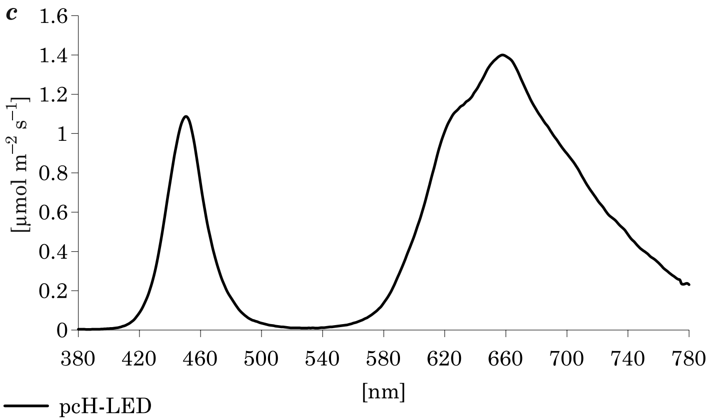
Treatments and LED Lighting System

The PPFD value presented to all experiments is at 150±3 μmol $m^{-2}s^{-1}$ with the light and dark hour of 14/10 h. The harvesting time is 40 DAS. The experimental designs are as follows:

FL light. Experiment 1: The FL light is a custom-made with the light area of 60 cm × 60 cm, consists of six 18 W, 2600 lm of warm white (Phillips Thailand). Six of FL was connected in parallel with 220 V 50 Hz AC power source, the total power is 108 W. The spectrum distribution of the FL is as show in Figure 1*a*. The FL was supplied on the top of the growing tray. The testing results of the spectrum distribution of FL determined that the percentage of B: G: R is about 31: 47: 22 and the photon flux of UV and FR were 2 and 5 μmol $m^{-2}s^{-1}$, R/B =1, R/FR = 6 (Fig. 1*d*).







d

	FL		R:B		pcH-LED	
	PPFD	% PAR	PPFD	%PAR	PPFD	%PAR
UV (380–399 nm)	2	1	0	1	0	0
B (400–399 nm)	45	31	54	19	35	23
G (500–599 nm)	69	47	3	2	8	5
R (600–700 nm)	32	22	93	79	110	72
PAR (400–700 nm)	147	100	152	100	153	100
FR (701–780 nm)	5		2		42	
R/B	1		2		3	
R/FR	6		38		3	
DLI	12.6		13.1		13.3	

Fig. 1. Spectral distribution of the light treatment: *a* – the 1st experiment group (FL); *b* – the 2nd experiment group (R:B); *c* – the 3rd experiment group (pcH-LED); *d* – comparison of the percentage of the distribution spectrum of FL, R:B and pcH-LED in PAR range (400–700 nm), UV (380–399 nm), and FR (701–780 nm) measured by a spectroradiometer "Lighting Passport Pro Essence"

R:B artificial light. Experiment 2: This study used a custom-made R:B LED light. The input voltage is 220 V 50 Hz and two 24 V 100 W of LED drivers to drive the group of R and B LED. The dimension is 27.5 cm × 16.5 cm. The R:B LED consists of two colors of narrow band spectral LED and the number was 42 of 645 nm red(R) LEDs, and 28 of 446 nm of blue (B) LEDs. The total number of LED is 70 with the total power of 200 W. The spectrum distribution of the R:B LED artificial light is as shown in Figure 1*b*. The testing results of the spectrum distribution of R:B indicated that the percentage of B: G: R is about 19: 2: 79. There is zero UV and the FR is about 2 μmol $m^{-2}s^{-1}$, R/B = 2, R/FR = 38 (Fig. 1*d*).

pcH-LED artificial light. Experiment 3: The author applied the phosphor converted LED for horticultural (pcH-LED) purposes with YXO-GLC-8001, Dimension: 78 mm × 44 mm × 1.6 mm, the spectrum range is 380–840 nm, LED chips from Bridgelux: 20W, (Shenzhen Yuxinou Technology Co., Ltd, Guangdong, China). The author designed and assembled the prototype of the pcH-LED artificial light. It consists of 6 of LED connected in parallel. The total power is 120 watts, installed on the aluminum heat sink with the dimension of 27.5 cm × 27.5 cm × 1.5 cm. The supply voltage is 220 V 50 Hz with dimming control. Moreover, the supply voltage could be applied to the LED chip without the need of an external LED driver. The spectrum distribution of the pcH-LED is as shown in Figure 1*c*. The testing results of light quality concluded the percentage of B: G: R at 23: 5: 72. No UV radiation was detected but the FR photon flux is about 41 μmol $m^{-2}s^{-1}$, R/B = 3, R/FR = 3 (Fig. 1*d*).

Measurements

The PPFD spectrum distribution of all light sources was measured by the spectroradiometer from Lighting Passport Pro Essence (Asensetek Incorporation, Taiwan). The growth of leafy vegetable was recorded at the 40^{th} day of the treatment. The yield of the leafy vegetable was investigated along with the fresh weight [g] which is measured by a digital weight scale 0.01 g to 500 g (TWK, China). The leaf number, leaf length, root number, and the root length were measured by a digital venire caliper 0–200 mm (Mitutoyo Crop., Kanagawa, Japan). The morphological investigation were described and compared. This was conducted by the observation of the plant color, tip burn and the plant shape.

Data Collection and Analysis

There are three treatment groups of the plants. Each group consists of 3 Butterhead lettuces, 3 Cos lettuces, 3 Red oak lettuces, and 3 Green oak lettuces. The plants population in each group is 12 (n = 12). Plants sample will be taken from the plants of each group for the investigation of the leaf number, leaf length, root number, root length, and the fresh weight. The results were submitted to analysis of variance in an IBM SPSS statistics software package. Tukey's test at the significance level of 0.05 was run to evaluate the significance of differences.

Results and Discussion

Fresh Weight

Figure 2*a* shows that the average fresh weight of Butterhead lettuce under pcH-LED was highest at 12.78 g, and 11.18 g under the R:B. The Butterhead lettuce under FL shows the lowest fresh weight at about 2.47 g. There is no significant difference ($p > 0.05$) of average fresh weight under all difference light sources.

The Cos lettuce under pcH-LED indicated the highest fresh weight of 18.75 g, and is significantly different ($p \leqslant 0.05$) from under R:B and FL. However, the average fresh weight of Cos lettuce under R:B (1.88 g) and under FL (3.86 g) are not significantly different ($p > 0.05$).

The fresh weight of red oak lettuce under pcH-LED was indicated the highest at 20.13 g, but not significantly different ($\alpha < 0.05$) from under the R:B (12.02 g). The fresh weight of red oak under FL was lowest at 2.75 g and is significantly different ($p \leqslant 0.05$) by red oak under pcH-LED, but not significantly different ($p > 0.05$) from R:B.

The fresh weight of the Green oak lettuce was indicated the highest at 16.42 g under pcH-LED, and 11.40 gm under R:B. The lowest fresh weight is under FL at 6.27 g. However, there are not significantly different ($p > 0.05$) from other treatments.

From this experiment, the fresh weight of the Butterhead, Cos lettuce, Red oak and Green oak lettuce was highest under pcH-LED, and the fresh weight of Butterhead, red oak and green oak was lowest under FL treatment. This could be because the pcH-LED could exhibit the highest quantum yield of the FR is about 41 μmol $m^{-2}s^{-1}$, while FL and R:B LED produce very low FR radiation. Accordance to study of Mickens et al. (2018) report that the FR light (700–800 nm) could increase the highest fresh mass [g] and shoot diameter of the lettuce. Confirm with the study of

ZHANG et al. (2019) R:B with FR (735 nm) with 43 µmol m^{-2}s^{-1} altered leaf area and total biomass of Tomato plants when compare to R:B LED without FR. Similar to the report of ZOU et al. (2019) who have shown that red: blue light (7:1) with FR 50 µmol m^{-2}s^{-1}during day could increase the total biomass of the lettuce 'Tiberius' by 39% than that of red: blue (7:1) light without FR. Relative to the experimental result of MENG and RUNKLE (2019) who reported that the shoot fresh weight [g] and dry weight of lettuces 'Rex' and 'Rouxai' under R:B = 1 at 180 µmol m^{-2} s^{-1} with adding FR of 30 and 70 µmol m^{-2} s^{-1} increased more than the weights under R:B without FR; moreover, if FR is increased, the shoot fresh weight and dry weights will be linearly increased as well.

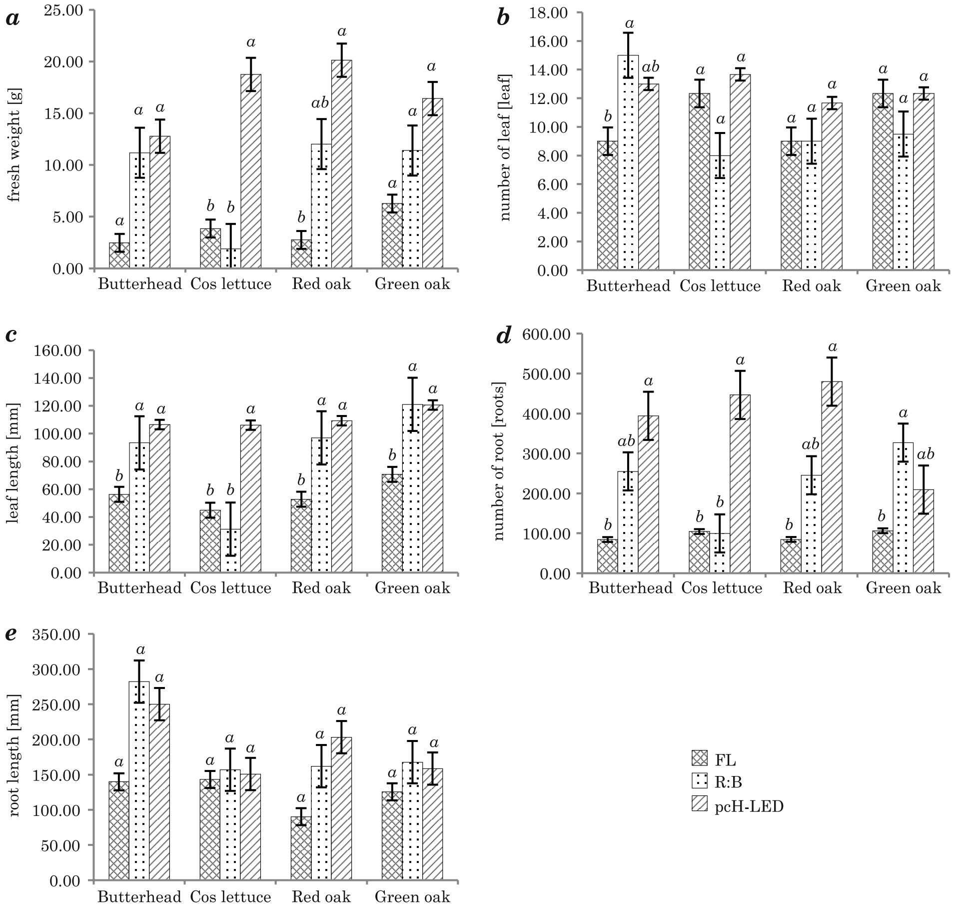


Fig. 2. Effect of three different types of the light source on: *a* – the fresh weight; *b* – number of leaf; *c* – leaf length; *d* – number of root; *e* – root length of the Butterhead lettuce, Cos lettuce, Red oak and Green oak lettuce

Leaf Number and Leaf Length

The number of leaf under all treatments is as shown in Figure 2*c*. The average leaf number of Butterhead lettuce under R:B was highest at 15 leaves, 13 leaves under the pcH-LED, and 9 leaves under FL. The leaf number of Butterhead lettuce under R:B is not significantly different ($p > 0.05$) from pcH-LED, but showed significant difference ($p \leqslant 0.05$) from the leaf number under FL.

The Cos lettuce under pcH-LED indicated that the highest number of leaf is at 13.66, under FL is 12.33 leaves, and lowest at 8 leaves from the R:B treatment. Although, the leaf number of the Cos lettuce are different, but the statistical results is not significantly different ($p > 0.05$) from all treatments. The number of leaf of red oak lettuce under pcH-LED was indicated the highest at 11.66, but showed as not significantly different ($p > 0.05$) under the R:B (9.00), and under FL (9.00). The Green oak lettuce under pcH-LED and FL resulted in the highest number of leaf equally at 12.33, but only 9.50 leaves when under FR. The statistical results are not significantly different ($p > 0.05$) from other treatments.

From this experiment, the number of leaf of the Cos lettuce, Red oak and Green oak lettuce were not significantly different ($p > 0.05$) under all treatments. This has been shown to be similar to the study of SAITO et al. (2010) where the leaf number of the Green-oak lettuce under R:B and FL are not different statistically (LI and KUBOTA 2009). But the leaf number of the Butterhead lettuce was lowest under FL and showed significant difference from other treatments.

The leaf length under all treatments is as shown in Figure 2*b*. The average leaf length of Butterhead lettuce under pcH-LED was highest at 106.51 mm, 93.35 mm under the R:B, and 56.32 mm of leaf length is under the FL treatment. The leaf length of Butterhead lettuce under FL was lowest and it showed significant difference ($p \leqslant 0.05$) from under pcH-LED and R:B.

The Cos lettuce under pcH-LED indicated the highest leaf length of 106.10 mm. This result is the significantly different ($p \leqslant 0.05$) from the leaf length that was under R:B (31.27 mm) and under FL (44.89 mm). The Cos lettuce under R:B indicated the lowest leaf length when compared to the other treatments. The leaf length of Red oak lettuce under pcH-LED was indicated the highest as 109.28 mm, and not significantly different ($p > 0.05$) from the R:B (96.94 mm). The leaf length of Red oak lettuce under FL is lowest of 52.80 mm and shows the significant difference ($p \leqslant 0.05$) from other treatments. The leaf length of the Green oak lettuce under R:B was indicated the highest at 121.05 mm, but showed no significant difference ($p > 0.05$) from pcH-LED (120.57 mm). The leaf length of Green oak lettuce under FL is lowest at 70.67 mm and shows the significant difference ($p \leqslant 0.05$) from pcH-LED and R:B treatments.

From this experiment, the author concluded that the pcH-LED and R:B could promote the leaf length of the Butterhead lettuce, Red oak and Green oak lettuce better than from the FL treatments. This finding can also be confirmed by LI and KUBOTA (2009) who reported that the leaf length and leaf width significantly increased by 44% and 15%, respectively, with supplemental FR light when compared to white light, and the report of ZHANG et al. (2019) describe the Tomato seedling plants under R:B with FR (735 nm) as 43 µmol $m^{-2}s^{-1}$ altered leaf area when compare to R:B LED without FR. This is in agreement with the results of ZOU et al. (2019) who reported that the lettuce under red: blue light with FR 50 µmol m^{-2} s^{-1} provided a higher leaf area than the lettuce under red: blue light without FR. The adding of FR at 30 and 70 µmol m^{-2} s^{-1} on the RB = 1 at 180 and 360 µmol m^{-2} s^{-1} will increase the leaf length [cm] but not in leaf number of the lettuces 'Rex' and 'Rouxai' when compared to not adding FR (MENG and RUNKLE 2019).

Root Number and Root Length

The number of roots of the leafy vegetable under all treatments is shown in Figure 2*d*. The average root number of Butterhead lettuce under pcH-LED was the highest at 394.00 roots, 255.00 root under the R:B, and 89.33 roots of the Butterhead lettuce under the FL. The root number of Butterhead lettuce under FL was the lowest and shows significant difference ($p \leqslant 0.05$) under pcH-LED, but did not show a significant difference ($p \leqslant 0.05$) under the R:B.

The Cos lettuce under pcH-LED indicated the highest root number of 446.33 roots and shows a significant difference ($p \leqslant 0.05$) from those under R:B (99.66 roots) and under FL (104.33 roots). The Cos lettuce under R:B was shown to have the lowest root number when compared to the others but does not show a significant difference ($p > 0.05$) with the number of roots under the FL. The root number of the Red oak lettuce under pcH-LED was indicated as the highest at 479.66 roots, but did not show a significant difference ($p > 0.05$) from the root number under the R:B (245.33 roots). The root number of Red oak lettuce under FL is the lowest at 84.66 roots and shows a significant difference ($p \leqslant 0.05$) under the pcH-LED treatments. The root number of the Green oak lettuce under R:B was the highest at 327.00 roots, and did not show a significant difference from the root number under the pcH-LED (209.33 roots). The root number of Green oak lettuce under FL is the lowest at 106.33 roots and shows a significant difference ($p \leqslant 0.05$) under pcH-LED.

From this experiment, it is possible to conclude that the effects of pcH-LED could promote the root number of the Butterhead lettuce, Cos lettuce, and Red oak lettuce. On the other hand, the R:B could promote the root number of the Green oak lettuce better than from the other treatments. According to the study of ZOU et al. (2019) who found that the effect of red: blue (7:1) light with FR (740 nm) of PPFD 50 µmol m^{-2} s^{-1} during day and at the end of the day has significantly increase the shoot/root ratio of lettuce 'Tiberius' than under red: blue (7:1) light without FR.

Figure 2*e* shows the root length of the leafy vegetable under all treatments. The average root length of the Butterhead lettuce under R:B was the highest at 282.15 mm, the root length of 250.15 mm was observed for under the pcH-LED, and 139.79 mm was obtained as the root length under the FL treatment. The root length under R:B, pcH-LED and FL were not significantly different ($p > 0.05$).

The Cos lettuce under R:B was observed to have the highest root length of 156.95 mm. The root length under pcH-LED is about 150.89 mm and 143.10 mm of the root length under FL. However, the root length under R:B, pcH-LED and FL did not show a significant difference ($p > 0.05$). The root length of the Red oak lettuce under pcH-LED was the highest at 203.22 mm, but did not show a significant difference between the root number of the Red oak under the R:B (162.02 mm), and under FL (90.26 mm). The root length of the Green oak lettuce under R:B was the highest at 167.72 mm, but did not show a significant difference ($p > 0.05$) from the root length of the Green oak under the pcH-LED (158.60 mm), and under the FL (125.60 mm).

The author can conclude that the different light treatments (pcH-LED, R:B and FL) could not have affected the root length of the Butterhead lettuce, Cos lettuce, Red oak, and Green oak lettuce. However, there are a few study of the lettuce roots and development under FR radiation, this is an interesting point for study in the future.

Morphological Observation

Under FL. Figure 3 shows the morphological response of the 4 types of leafy vegetable in this experiment at harvest time (40 DAS) under different supplemental lights. There are obvious morphological changes under pcH-LED, FL, and R:B. For example, the Butterhead lettuce (Fig. 3*a*) under FL appeared to have a short and narrow leaf. The fresh weight was also the lowest when compared to the other supplemental light.

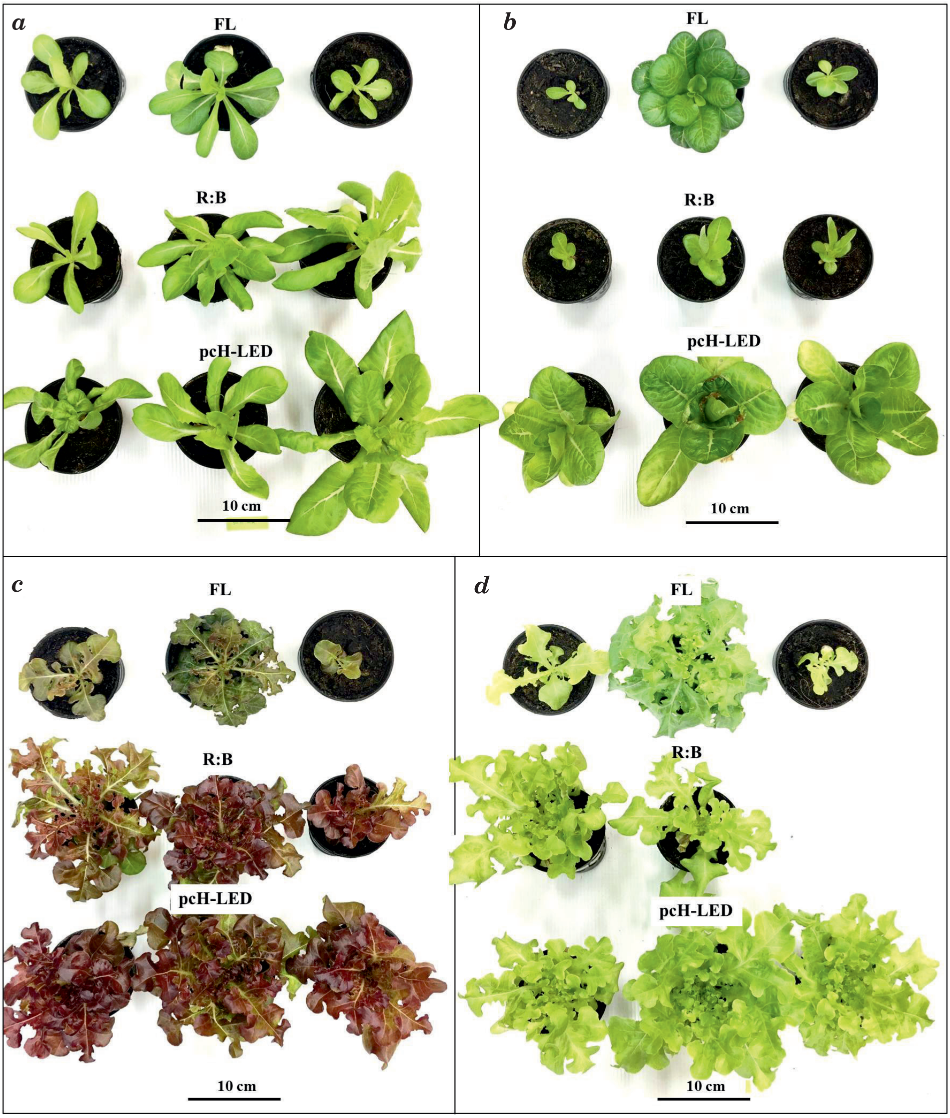


Fig. 3. Comparison of the four leafy vegetables at 40 days on land biomass under FL, R:B LED and pcH-LED: *a* – Butterhead lettuce; *b* – Cos lettuce; *c* – Red oak lettuce; *d* – Green oak lettuce

The Cos lettuce (Fig. 3*b*) growth and development under FL resulted in compact and short leaf which looks like a baby leaf. The average fresh weight is low, but has a normal leaf color. However, the Cos lettuce at the center pot shows a high number of leaves, but the leaf length was shorter than the Cos lettuce under pcH-LED. The Red oak lettuce under FL has compact leaves that looked severely dwarfed. The leaf color did not show the red color, but moss green color (Fig. 3*c*). Green oak lettuce under FL shows the same results as the Red oak lettuce, but they contain normal green leaf color (Fig. 3*d*).

The observations were in accordance to the report of CHEN et al. (2014) where the fresh weight of green oak leaf lettuce under warm white FL shows a significant difference ($p \leqslant 0.05$) from the fresh weight of the lettuce under FL + red LED light.

According to the report of SANOUBAR et al. (2018) refers to the study of the seedling of some aromatic plants such as *Artemisia absinthium*, *Artemisia vulgaris*, *Atriplex halimus*, and more, in total of nine species under LED mixed between red (655 nm) and blue (456 nm) versus fluorescent warm-white light (5300 K) in a growth chamber. The PPFD is 150 μmol m^{-2} s^{-1}, with an experiment period of 20 days. Both growth chambers were set at 22 ± 1 °C, 70% air humidity and 16/8 h light/dark period. At the end of the day, the shoot's fresh weight and length are as short and small as those obtained under fluorescent lights, but those under red/blue LED indicate significant differences.

The spectrum of the FL light revealed too much green light (69 μmol $m^{-2}s^{-1}$) when compared to the amount of green light from other light sources within this study. On the other hand, it is found that the FL light gives out blue light that is no different than what is seen from the other light sources used within this study and the lowest amount of red light (Fig. 1*a*, *d*). With that said, the FL light then does not fully support plant development; the plants grown under FL light in this experiment did not show very good development when compared to those grown under R:B and pcH-LED (R:B+FR). Previous studies report the effects of green light which tend to reverse the processes established by red and/or blue light. In this way, green light may be informing the plant of photosynthetically unfavorable conditions (FOLTA and MARUHNICH 2007). Therefore, when the PAR spectrum was compared, it can be seen that the green light does not contribute to photosynthesis, but red and blue light will induce higher photosynthesis efficiency.

In accordance to the report of UENO and KAWAMITSU (2017), it was confirmed that the lettuce under red and blue light in the plant factory Okinawa showed the highest yield than lettuce under FL light and white LED light. Therefore, indoor agriculture favors light with mainly blue and red spectrums.

In conclusion the warm white FL is not appropriate for the application to grown the Butterhead lettuce, Cos lettuce, Red oak and Green oak lettuce, because the results obtained showed the lack of response to the shape and color of the leafy vegetable growth and development.

Under R:B. It is well known LEDs now offer controllable sources of light that can selectively and quantitatively provide specific wavelengths for indoor horticultural. Previous studies have demonstrated that the combination of red (600–700 nm) and blue light (400–500 nm) is an effective lighting source for plant growth (BIAN et al. 2015). The morphological observation results is in Figure 3*a* shows the images of the Butterhead lettuce at harvest time (40 DAS) under different supplemental lights. The Butterhead lettuce under R:B indicated that the leaf number and leaf length is higher than under FL. The fresh weight of Butterhead lettuce under R:B was lower than from under pcH-LED. But the Butterhead lettuce in all samples looked dwarfed with very short leaf and tiny size (Fig. 3*b*). However, the R:B promotes the leaf and fresh weight of the Red oak and Green oak lettuce (Fig. 3*d*). But the color of the leaf of the Red oak lettuce under R:B appeared light red in some leaves (Fig. 3*c*). However, in this study indicated that the R:B is not appropriate for the growth and development of the Cos lettuce.

In this study, the author provided R:B ratio at about 79:19 which showed good morphological and biomass of Butterhead lettuce, Red oak and Green oak lettuce. Similar to MICKENS et al. (2018) report, the red pak choi showed the greatest yield (biomass), leaf area, and relative anthocyanin accumulation under a spectrum provided by R:B (R75% B25%) LEDs. The findings suggest that for pak choi, partitioning more biomass into leaf expansion over petiole elongation had a higher influence on the overall yield. This was better than red pak choi under white, white-red, white--green and white-far-red LED at the same level of PPFD and in the same light hours. However, PAR spectrum of the sun light contains around 31% of B light. It appears that around 30% may be the maximum blue light percentage to produce plant biomass efficiently and keep appearance quality in an acceptable range (YING et al. 2020). In summary, R and B light is a major common light for indoor plant production such as lettuce, cabbage, kale, arugula and mustard, microgreens, broccoli, cucumber and so on. Each species responds to the different radiation of R and B ratio, and growth well in different level of PPFD.

Under pcH-LED. In vegetable horticulture, biomass production and product quality are important features that determine the quality of the crop yield. These features are directly correlated to photosynthesis efficiency: biomass production is dependent on the quantity of the active radiation obtained by the leaves, whereas the product quantity is dependent on the wavelengths of the light used in photosynthesis. Therefore, manipulating the blue-red light and R:FR ratio of the light can lead to an improvement of the biomass production and product quality, which then translates to better crop yield (MAINARD et al. 2016).

In this experiment on Figure 3*a* shows the growth and development of the Butterhead lettuce at 40 DAS under FL, R:B, and pcH-LED (R:B+FR radiation). The results clearly indicated that the Butterhead lettuce under pcH-LED was perfectly beneficial. The pcH-LED could promote the increase in fresh weight, leaf size, and normal leaf color. The effect of pcH-LED that was supplemented to the Cos lettuce, Red oak and Green oak lettuce (Fig. 3*b*, 3*c*, 3*d*) shows the same results to the Butterhead lettuce. Consequently, the pcH-LED could be applied to be an artificial light for the indoor cultivation. pcH-LED could promote the good quality of leafy vegetable such as having perfect leaf size, big plants, good shape and nice leaf color of the Butterhead lettuce, Cos lettuce, Red oak and Green oak lettuce. This is because the pcH-LED could produce the FR light at a high PPFD (41 μmol m^{-2} s^{-1}) when compared to the R:B and FL. Based on literature, the light spectrum of FR range (700–800 nm) can boost lettuce yields, fresh weight, dry weight and leaf number (LI and KUBOTA 2009). Some of previous study was show that the Tomato seedling plants under R:B with FR (735 nm) at 43 μmol $m^{-2}s^{-1}$ altered leaf area and total biomass more that tomato seedling under the R:B LED without FR (ZHANG et al. 2019). Adding 110 μmol $m^{-2}s^{-1}$ of FR light (735 nm) after supplement the red: blue (ratio 76:24) and white light immediately increased the quantum yield of photosystem II (ΦPSII) of lettuce (*Lactuca sativa*) by an average of 6.5 and 3.6% under red: blue and warm-white light, respectively (ZHEN and VAN IERSEL 2017). The acclimation process of plant morphology triggered by additional FR light plays a pivotal role for improving the production of indoor cultivated lettuce, and the enhanced production by additional FR light cannot be achieved by adding similar amount of red and blue light (ZOU et al. 2019). Including FR in a light spectrum increased plant size and photosynthesis (PARK and RUNKLE 2017). These confirm that the FR light is needed for the photosynthesis efficiency of lettuce. Usually, plants grown under light with efficient photosynthesis could produce good quality and high yield of 4 leafy vegetable in this study.

Conclusion

Based on growth and yield of leafy vegetable for indoor plantation, we recommend the pcH-LED to be a light source. The yields obtained under pcH-LED treatment indicates that the phosphor conversion could generated the combination of R and B with high amount of FR spectral that can have the positive effects on crop quality. It could promote the highest yield of leafy vegetable such as highest fresh weight and root number, perfect leaf size, good shape and nice leaf color of the Butterhead lettuce, Cos lettuce, Red oak and Green oak lettuce. The pcH-LED and R:B could produce the same quantity in leaf number, leaf length and root number, but the R:B light shows negative effect to Cos lettuce resulting in short leaf and tiny size. Therefore, the growth was substantially affected by the combination of R and B lights, with and without FR. The presence of both lighting spectrums is essential for expanding and elevating the lettuce quality. On a large scale, this technology could improve the commercial greenhouse production while helping farmers achieve maximum products.

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