Optimal red:blue ratio of full spectrum LEDs for hydroponic pakchoi cultivation in plant factory

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Abstract: Pakchoi, a popular leafy vegetable in China, is expected to be planted in plant factories with artificial lighting (PFALs). In order to examine the effects of different red and blue light ratios (R:B ratio) on growth, photosynthesis, and absorption spectrum of plant leaves, and to analyze the energy use efficiency, the pakchoi (Brassica Chinensis L. cv. Xiazhijiao) was cultivated hydroponically under white LEDs with R:B ratios of 0.9 (L0.9) and 1.8 (L1.8), white plus red LEDs with R:B ratios of 2.7 (L2.7) and 4.0 (L4.0) for 40 d, respectively. The results showed that the leaf length and width were significantly greater in the L0.9 treatment than in other treatments, and the dry weight per plant increased by over 33% when R:B ratio decreased from 4.0 to 0.9. The net photosynthesis rates of pakchoi leaves ranged from 9.2 to 9.6 μmol/(m²·s) under different lighting conditions, which had no significant difference. The biggest difference in the spectrum absorptance of pakchoi leaves was expressed in green light waveband, and the highest absorption of plant leaves was under L0.9 and L1.8 treatments. The light energy use efficiency (LUE), photon yield (PY), and energy yield (EY) in L0.9 were over 25% higher than that in the other treatments, while there was no significant difference in the electrical energy use efficiency (EUE). In conclusion, an optimal light quality to cultivate pakchoi in PFALs was the white LEDs with R:B ratio of 0.9, and this finding could provide a promising lighting environment to hydroponic pakchoi yield and energy use efficiency.

Keywords: pakchoi, R:B ratio, yield, absorption spectrum, energy use efficiency

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1 Introduction

As the living standards of Chinese people have improved, fresh and nutritious vegetables have become a preferable option for more and more consumers. Pakchoi (Brassica chinensis L.), a vegetable species of Brassicaceae, is one of the favorite leafy vegetables of the Chinese, especially in North China[1]. The pakchoi is rich in dietary fiber, vitamins C and carotenoid, making it an ideal choice for leafy vegetables. Because of its unstable supply, uneven quality, and difficulties in storage and transportation, it is necessary to provide a new way for high yield and quality pakchoi production. Plant factory with artificial lighting (PFALs) is expected to realize year-round clean cultivation of high-quality leafy vegetables[2]. It was reported that there were currently more than 500 PFALs worldwide in production, and most of them were used to plant leafy vegetables, mainly lettuce[3]. Pakchoi is a leafy vegetable with a short growth cycle, which has a large potential to be cultivated in PFALs. A suitable lighting environment could be favorable for producing hydroponic pakchoi with high yield and quality in PFALs.

Lighting is an important factor that could influence plant morphology, photosynthesis, and growth. Therefore, it is vital to explore the most efficient lighting environment for growing plants. Moreover, light quality as a signal could impact leaves shape, chlorophyll content, secondary metabolic products accumulation, etc.[4] In previous studies, the research on the effect of light quality on the growth of leafy vegetables has been mainly focused on red and blue light. The suitable R:B ratio of LED light varies among different leafy vegetables. Agarwal et al.[5] proved that R:B ratio of 3 could improve the growth, physiological, metabolic functions, and resource use efficiency of sweet basil. R:B ratio of 12 could improve the growth of lettuce by stimulating morphological and physiological responses[7]. However, in recent years some researchers have revealed that long hour lighting of monochromatic red light, monochromatic blue light, and the mixture of red LEDs and blue LEDs with ratios of red light to blue light (R:B ratio) of 3, 1, and 1/3 on spinach, which revealed that too much blue light or red light were both to the disadvantage of biomass accumulation and photosynthesis. Pennisi et al.[6] proved that R:B ratio of 3 could improve the growth, physiological, metabolic functions, and resource use efficiency of sweet basil. R:B ratio of 12 could improve the growth of lettuce by stimulating morphological and physiological responses[7]. However, in recent years some researchers have revealed that long hour lighting of monochromatic red light, monochromatic blue light, and the mixture of red and blue LEDs with different R:B ratios often affect the growth of plants, which may cause the reduction of output of leafy vegetables comparing with full spectrum LEDs[8-10]. Although chlorophyll mainly absorbed blue and red light to supply energy for photosynthesis, green light was observed to reach deeper mesophyll[11], which might contribute to enhancing photosynthesis and biomass accumulation[12-14]. Compared with blue and red light, white LED has higher color rendering, which supported the identification of plant diseases and reduced the difficulty of plant management[15-18], besides, the cost of white LED packages is now...
80% lower than that of the red LEDs. As a result, the proportion of white LEDs in horticultural fixtures was increased to 60%\[^{[19]}\]. Similarly, a rising number of PFALs are also using full spectrum LEDs in practice, but which kind of spectral composition of full spectrum LEDs is suitable for the cultivation of leafy vegetables remains to be discussed\[^{[20-21]}\].

The light energy absorbed by the plant will eventually be converted partially into chemical energy. Thus, the increased chemical energy of plants is all provided by electric energy, as artificial lighting is the only source of plant photosynthesis in PFALs. Although using PFAL could improve plant productivity to generate profit, it is still hard to cover the extreme capital and operation cost in commercial production. In order to cosmically extend the PFAL application, the electricity consumption of artificial lighting which currently takes 70%-80% of total consumption for year-round cultivation should be reduced\[^{[24-26]}\].

An optimal lighting environment could decrease the electricity consumption accounts by increasing the yield and nutritional value of plants. Besides, R:B ratio is not only a significant index for studying the physiological response of plants, but it also means that the efficacy of the luminaire is different. Thus, the impact of R:B ratio on the consumption of electricity for lighting is worth exploring and it is a key issue for its commercial prospect.

The purpose of this study was to determine the effects of different R:B ratios in full spectrum LED fixtures on the photosynthesis and the growth of hydroponic pakchoi by researching photosynthetic rate, chlorophyll content, spectral characteristics of leaves, and energy use efficiency. The results of this study would be used to give guidance on the management of light conditions for hydroponic pakchoi production in PFALs.

## 2 Materials and methods

### 2.1 Plant materials

Seeds of pakchoi (Brassica chinensis L. cv. Xiazhijiao) were soaked in 10% (V/V) sodium hypochlorite solution for 30 min to sterilize, followed by a rinse with water. Solid and plump seeds were selected and sown in moist sponge cubes (L25 mm × W25 mm × H25 mm). All the cubes were placed in plastic containers (L520 mm × W360 mm × H90 mm) which were held with holes for moisturization. Two days after sowing, the deionized water was replaced by Japanese horticultural nutrient solution at standard concentration when buds emerged. Japanese horticultural experimental nutrient solution at standard concentration when bubs emerged. Japanese horticultural experimental nutrient solution was used with pH of 6.0-6.5 and EC of 2.2-2.5 mS/cm and provided by the following components, mg/L: Ca(NO\(_3\))\(_2\)-4H\(_2\)O, 944; KNO\(_3\), 808; MgSO\(_4\)·7H\(_2\)O, 492; NH\(_4\)H\(_2\)PO\(_4\), 152; Na\(_2\)Fe-

### 2.2 Environmental conditions

All experiments were performed in small PFAL rooms. Four multistory stainless steel cultivation shelves were set to cultivate plants. Each cultivation shelf held five Acrylonitrile-butadiene-styrene (ABS) cultivation beds (L1200 mm×W900 mm×H70 mm) with 54 uniform holes (Φ20 mm) for transplanted pakchoi.

During the pregermination stage, air temperature and relative humidity were set as (25±1)°C and 75%±5% without lighting. During the cultivation stage, air temperature and relative humidity were turned to (25±1)°C/(20±1)°C and (65±5)%/(75±5)% respectively during the light period/dark period. Meanwhile, CO\(_2\) concentration was maintained at (800±50) μmol/mol during the light period and uncontrolled during the dark period.

### 2.3 Lighting treatments

The lighting environment was provided by four types of LED luminaires (Beijing Lighting Valley Technology Co., Beijing, China), white LEDs with R:B ratios of 0.9 (L0.9) and 1.8 (L1.8), white plus red LEDs with R:B ratios of 2.7 (L2.7) and 4.0 (L4.0). The color temperatures of white LEDs in L0.9 and L2.7 were 6500 K, and those in L1.8 and L2.7 were 4000 K. The photoperiod was set to 12 h/d with photon flux density (PFD) of 250 μmol/(m\(^2\)·s). The light intensity and spectral distributions were tested by a fiber spectrometer (Avaspec-ULS2048, Avantes Inc., Apeldoorn, The Netherlands) at 15 cm under the lamps (Figure 1) varying from 300-800 nm. The analysis of light quality was based on the photon flux of ultraviolet light (UV, 300-399 nm), blue light (B, 400-499 nm), green light (G, 500-599 nm), red light (R, 600-699 nm) and far-red light (FR, 700-800 nm), and the R:B ratio was integrated by the photon flux of red light waveband to light blue waveband (Table 1).

![Figure 1](image)

**Figure 1** Spectral distributions of LED lighting environment at light intensity of 250 μmol/(m\(^2\)·s) provided by white LEDs with R:B ratio of 0.9 and 1.8, white plus red LEDs with R:B ratio of 2.7 and 4.0, respectively.

<table>
<thead>
<tr>
<th>Wavelength/mm</th>
<th>Spectral distribution/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0.9</td>
<td>100.0</td>
</tr>
<tr>
<td>L1.8</td>
<td>100.0</td>
</tr>
<tr>
<td>L2.7</td>
<td>100.0</td>
</tr>
<tr>
<td>L4.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Note: Data are flux-based composition of ultraviolet, blue, green, red, and far-red lights. R:B, red light to blue light ratio.

### 2.4 Growth measurements of hydroponic pakchoi

#### 2.4.1 Growth characteristics

All the fully expanded true leaves were counted as leaf number, and stem length, leaf length and leaf width of hydroponic pakchoi (fifth or sixth fully expanded leaf from the apical shoot) were measured from each treatment at 40 d. The fresh weights of the
shoots and roots were measured by centesimal balance, and all these material was de-enzyme in an oven at 105°C for 3 h, then dried to constant weight at 80°C, and the dry weights were measured by an electronic analytical balance (FA1204B, Bion Group, China).

### 2.4.2 Photosynthetic characteristics

A portable photosynthesis system (LI-6400XT, LI-COR Biosciences Corporation, Lincoln, NE, USA) was used to measure the stomatal conducance, intercellular CO₂ concentration, transpiration rate, and net photosynthesis rate (Pₐ) of hydroponic pakchoi leaves. Relevant parameters of 6400-02B leaf chamber including PFD, leaf temperature, CO₂ concentration, and air flow were set at 250 μmol/(m²·s), 25°C, 800 μmol/mol, and 500 μmol/s, respectively.

### 2.4.3 Chlorophyll contents

Pakchoi leaves from the same leaf position were selected and cut up as samples. Around 0.1 g of sample was weighed and then put into 10 mL 95% ethanol extract. After extracting in dark conditions, the solution was detected for absorbance at the wavelength of 470 nm, 649 nm, and 665 nm by an ultraviolet spectrophotometer (UV-1700, AUCY Scientific Inc., Shanghai, China), respectively. The chlorophyll contents were calculated according to the method in reference[27].

### 2.4.4 Plant leaves spectral characteristics

The spectra of light reflection and transmission were measured from the adaxial and abaxial surfaces of pakchoi leaves by an integrating sphere of UV-VIS spectrophotometer (UV3150, Shimatsu Corporation, Japan), and the wavelength was set from 300 nm to 800 nm when the wavelength interval was set at 1 nm. The measurement positions were chosen to be in the middle of the leaf blade beside the main leaf vein for 4 scans and the average values were taken as the measurement results. Absorbance was calculated as subtraction of reflectance and transmittance from 100%.

### 2.4.5 Energy use efficiency

Light energy use efficiency (LUE) was defined as the ratio of the increase in chemical energy of the whole plant to the total amount of light energy received at the plant community surface by the plant in a unit of time (a week or a cultivation cycle)[28]. Electrical energy use efficiency (EUE) was referred to as the ratio of the increase in chemical energy of the whole plant to the total amount of photons (300-800 nm) received at the plant community surface by the plant in a unit of time (a week or a cultivation cycle). Photonic yield (PY) was the conversion factor from dry mass to chemical energy (about 20 MJ/kg)[25]; D is the dry mass accumulation rate of unit area, kg/(m²·h); R is the light radiation (300-800 nm) at 15 cm under the lamps, MJ/(m²·h), which was measured by a fiber spectrometer (AvaSpec-ULS2048, Avantes Inc., Apeldoorn, The Netherlands); E is the total consumption of electricity for lighting, MJ/(m²·h), which was measured by smart metering (TP9004, Shenzhen Northmeter Co., Ltd., China); FW is the fresh weight of the vendible part of one plant, g; OTLI is the average energy consumption of lighting by a single plant during growth per plant, kW·h.

### 2.5 Statistical analysis

IBM SPSS Statistics 26 (IBM Corporation, Chicago, IL, USA) was used for statistical analysis. The comparisons were conducted by Duncan’s multiple range test selected from significant one-way ANOVA (p<0.05). The results were recorded as mean±standard deviation values (n=6).

### 3 Results and discussion

#### 3.1 Growth characteristics of hydroponic pakchoi

Different R:B ratio of LED could affect the morphology and biomass accumulation of hydroponic pakchoi (Figure 2). The results indicated that the leaf number, stem length, leaf length, and leaf width were significantly greater in L0.9 than in other treatments after 40 d of cultivation, which was 10.2%-28.8% higher (Table 2). L1.8, L2.7, and L4.0 treatments did not show significant difference in hydroponic pakchoi morphology. Pakchoi grown under L0.9 treatment were higher than ones grown under L1.8, L2.7, and L4.0 in shoot/root fresh and dry weights, especially in shoot weights. Therefore, L0.9 treatment was beneficial to the organic accumulation of hydroponic pakchoi.

![Figure 2](image)

**Figure 2** Effect of LED light quality on the morphology of hydroponic pakchoi after 40 d cultivation

### Table 2 Morphology and biomass of hydroponic pakchoi grown under LED lighting environment at light intensity of 250 μmol/(m²·s) provided by white LEDs with R:B ratios of 0.9 and 1.8, white plus red LEDs with R:B ratios of 2.7 and 4.0, respectively, for 40 d after sowing

<table>
<thead>
<tr>
<th>Lighting treatment</th>
<th>Leaf number</th>
<th>Stem length/cm</th>
<th>Leaf length/cm</th>
<th>Leaf width/cm</th>
<th>Shoot fresh weight/g</th>
<th>Root fresh weight/g</th>
<th>Shoot dry weight/g</th>
<th>Root dry weight/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0.9</td>
<td>13±1.0</td>
<td>6.6±1.1</td>
<td>12.7±0.7</td>
<td>8.8±0.7</td>
<td>47.4±1.7</td>
<td>2.27±0.2</td>
<td>2.27±0.31</td>
<td>0.18±0.05</td>
</tr>
<tr>
<td>L1.8</td>
<td>12±1.0</td>
<td>4.8±0.3</td>
<td>10.9±0.5</td>
<td>7.6±0.3</td>
<td>29.12±3.4</td>
<td>1.79±0.34</td>
<td>1.68±0.26</td>
<td>0.15±0.02</td>
</tr>
<tr>
<td>L2.7</td>
<td>11±1.3</td>
<td>4.7±0.3</td>
<td>11.0±0.8</td>
<td>7.9±0.4</td>
<td>25.17±3.2</td>
<td>1.56±0.35</td>
<td>1.74±0.20</td>
<td>0.16±0.03</td>
</tr>
<tr>
<td>L4.0</td>
<td>12±1.1</td>
<td>5.0±0.4</td>
<td>10.9±1.0</td>
<td>7.7±0.5</td>
<td>25.91±4.4</td>
<td>1.58±0.34</td>
<td>1.50±0.21</td>
<td>0.14±0.02</td>
</tr>
</tbody>
</table>

Note: Different letters in the same column indicate significant differences (p<0.05). NS represents no significant difference in the same column.
products, which conforms with the previous studies.[17,29] Meanwhile, the responses of plant morphology and biomass accumulation to R:B ratio were related to species, and the suitable percentage of red and blue light varied among different brassicaceous vegetables. Mickens et al.[30] observed that the shoot fresh weight of red pakchoi had no significant difference between the white LEDs treatments and the white plus red LEDs treatments. Ying et al.[31] explored the influence of blue light fraction in red and blue LEDs on yield of four Brassicaceae microgreens including cabbage, kale, arugula, and mustard, and no significant difference was observed in fresh and dry yield of kale, arugula, and mustard under different percentages of blue light from 0-30%, while, the fresh and dry weight reached a plateau at 15% blue light in cabbage planting.[31]

3.2 Photosynthesis of hydroponic pakchoi leaves

Although the morphology of hydroponic pakchoi showed different responses to R:B ratio, there was no significant difference among Pn of hydroponic pakchoi leaves under varied treatments, which were at 9.2 to 9.6 μmol/(m²·s) (Figure 3). The highest stomatal conductance was observed under L0.9 treatment at 421 mmol/(m²·s) which was 12.8% higher than L1.8 treatment. Intercellular CO₂ concentration is another important issue having an impact on photosynthesis, and the intercellular CO₂ concentration was lower at 535 μmol/mol under L4.0 treatment while the results were similar under L0.9, L1.8, and L2.7 treatments in this study. Transpiration rate was also the highest under L0.9 treatment and 8% higher than L1.8 and L4.0 treatments approximately. Hernández et al.[32] found that with the fraction of blue light increased from 10% to 80%, the Ps of cucumber leaf showed an increasing tendency. Yan et al.[20] reported that Pn of hydroponic lettuce was higher as the R:B ratio decreased from 3.6 to 0.9 with the same daily light integrals. Chang et al.[33] gave a contrary result, as they found that the Ps of Brassica napus L. decreased with the increase of the blue light fraction from 25% to 100%.

3.3 Chlorophyll contents and spectral characteristics of hydroponic pakchoi leaves

The pigment contents of hydroponic pakchoi leaves had no obvious response to light quality. The total chlorophyll and carotenoid contents of hydroponic pakchoi leaves reached the highest level under L2.7, respectively, and there was no significant difference in chlorophyll b content. Meanwhile, carotenoid content of pakchoi leaves under L2.7 treatment was observed around 20% higher than in other treatments. The total chlorophyll contents of pakchoi were the highest under blue light followed by that under white light[34], while the highest contents of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids of Brassica napus were all observed under red light followed by those under white light.[35]

Table 3  Pigment contents of hydroponic pakchoi leaves grown under LED lighting environment at a light intensity of 250 μmol/(m²·s) provided by white LEDs with R:B ratios of 0.9 and 1.8, white plus red LEDs with R:B ratios of 2.7 and 4.0, respectively

<table>
<thead>
<tr>
<th>Lighting treatment</th>
<th>Chlorophyll a content/mg·g⁻¹</th>
<th>Chlorophyll b content/mg·g⁻¹</th>
<th>Total chlorophyll content/mg·g⁻¹</th>
<th>Chlorophyll a/b</th>
<th>Carotenoid content/mg·g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0.9</td>
<td>1.41±0.15²</td>
<td>0.52±0.06²</td>
<td>1.93±0.20²</td>
<td>2.70±0.04²</td>
<td>0.26±0.04²</td>
</tr>
<tr>
<td>L1.8</td>
<td>1.51±0.16⁴</td>
<td>0.57±0.08⁴</td>
<td>2.08±0.25⁴</td>
<td>2.65±0.09⁴</td>
<td>0.26±0.05⁴</td>
</tr>
<tr>
<td>L2.7</td>
<td>1.63±0.12⁶</td>
<td>0.61±0.07⁶</td>
<td>2.24±0.18⁶</td>
<td>2.67±0.15⁶</td>
<td>0.32±0.03⁶</td>
</tr>
<tr>
<td>L4.0</td>
<td>1.43±0.12⁸</td>
<td>0.53±0.05⁸</td>
<td>1.97±0.17⁸</td>
<td>2.69±0.08⁸</td>
<td>0.25±0.04⁸</td>
</tr>
</tbody>
</table>

Note: Different letters in the same column indicate significant differences (p<0.05), NS represent no significant difference in the same column.

The light transmittance, reflection, and absorptance of hydroponic pakchoi leaves under different LED light quality showed similar trends that most red, blue, and ultraviolet light was absorbed, part of green light, and nearly all of the far-red light was transmitted and reflected (Figure 4). The absorptance spectrum of hydroponic pakchoi leaves was consistent with previous studies[36,37] and mainly influenced by photosynthetic pigments absorbing light with varied efficiency at different wavelengths.[21]

Pakchoi leaves under L4.0 treatment showed higher transmittance of green and red light. Meanwhile, the leaves under L2.7 treatment showed higher reflectance in the same range as a result of its high content of chlorophyll. The calculation results showed that the absorptance of lower R:B (L0.9 and L1.8) treatments kept more than 70% when the wavelength light was between 500 nm and 680 nm. The minimal absorptance of pakchoi leaves under L2.7 and L4.0 treatments was at around 64% in the same range.

The largest absorptance gap among different treatments was observed in the interval of 530-570 nm. Besides, the pakchoi leaves under L0.9 and L1.8 treatments absorbed more light in these wavelengths, which could result in higher biomass of plant, and the growth of pakchoi under L0.9 was enhanced. The blue light could contribute to anthocyanin accumulated in the leaves.[28] and hydroponic pakchoi leaves under L0.9 and L1.8 treatments showed high absorption of green light which might related to the high content of anthocyanin.[21,39]

3.4 Energy use efficiency of hydroponic pakchoi

LUE, PY, and EY of hydroponic pakchoi were significantly higher in L0.9 treatment, which reached 0.058, 12.52 g/mol, and 75.09 g/kW·h, respectively, and there was no significant difference between L1.8, L2.7, and L4.0. The PY in L0.9 treatment were 38.6%, 47.0%, and 45.4% more than those in L1.8, L2.7, and L4.0, respectively. Nevertheless, the effects of light...
Yan et al. [20-21] observed LUE and EUE of lettuce would increase the types of LED fixtures that influenced EUE and EY strongly. The photoelectric conversion coefficient was quite different in terms of photoelectric conversion coefficient based on yield, while LUE depends also on the absorption and utilization quality on EUE of pakchoi had no significant difference. The photon efficacy of LED fixtures used for L0.9 treatment was lower than other treatments, which led to more LED fixtures fixed. Therefore, the total energy consumption for lighting of L0.9 treatment was higher than others, which also led to higher LUE.

### Table 4  Energy use efficiency of hydroponic pakchoi grown under LED lighting environment at light intensity of 250 μmol/(m²·s) provided by white LEDs with R:B ratios of 0.9 and 1.8, white plus red LEDs with R:B ratios of 2.7 and 4.0, respectively

<table>
<thead>
<tr>
<th>Lighting treatment</th>
<th>Light energy use efficiency</th>
<th>Electrical energy use efficiency</th>
<th>Photon yield/g mol⁻¹</th>
<th>Energy yield/g kWh⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0.9</td>
<td>0.058±0.008³</td>
<td>0.0199±0.0029⁴</td>
<td>12.52±0.34³</td>
<td>75.09±2.04³</td>
</tr>
<tr>
<td>L1.8</td>
<td>0.045±0.007³</td>
<td>0.0167±0.0024⁴</td>
<td>7.69±1.14³</td>
<td>51.89±7.70³</td>
</tr>
<tr>
<td>L2.7</td>
<td>0.048±0.006³</td>
<td>0.0196±0.0024⁴</td>
<td>6.64±0.86³</td>
<td>50.45±6.53³</td>
</tr>
<tr>
<td>L4.0</td>
<td>0.043±0.005³</td>
<td>0.0169±0.0024⁴</td>
<td>6.84±1.18³</td>
<td>51.93±8.98³</td>
</tr>
</tbody>
</table>

Note: Different letters in the same column indicate significant differences (p<0.05), NS represent no significant difference in the same column.

### 4 Conclusions

Suitable R:B ratio could promote the growth of hydroponic pakchoi and improve energy use efficiency. The white LED with R:B ratio of 0.9 could achieve much higher biomass of pakchoi than R:B ratios of 1.8, 2.7, and 4.0. L0.9 could promote the expansion of leaves and photosynthesis. Lower R:B ratios at 0.9 and 1.8 could help increase the light absorption capacity of pakchoi leaves. The LUE, PY, and EY were much higher in L0.9 than those in other treatments. Considering the yield and quality of hydroponic pakchoi and energy use efficiency, it is suggested that full spectrum LED with R:B ratio of 0.9 could be selected to provide a proper lighting condition for hydroponic pakchoi production.

### Acknowledgements

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Note: Different letters in the same column indicate significant differences (p<0.05), NS represent no significant difference in the same column.

### 4 Conclusions

Suitable R:B ratio could promote the growth of hydroponic pakchoi and improve energy use efficiency. The white LED with R:B ratio of 0.9 could achieve much higher biomass of pakchoi than R:B ratios of 1.8, 2.7, and 4.0. L0.9 could promote the expansion of leaves and photosynthesis. Lower R:B ratios at 0.9 and 1.8 could help increase the light absorption capacity of pakchoi leaves. The LUE, PY, and EY were much higher in L0.9 than those in other treatments. Considering the yield and quality of hydroponic pakchoi and energy use efficiency, it is suggested that full spectrum LED with R:B ratio of 0.9 could be selected to provide a proper lighting condition for hydroponic pakchoi production.

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