Effects of Ferrous Sulfate Seed Soaking with Different LED Light Quality on the Nutritional Quality and Growth of Pea Shoot

Wang Fang1,#, Peng Honggui1,2,#, Yuan Xinrui1, Zhu Min3, Yang Qichang1, Lin Zhitong1,*, Liao Qiuhong1,*

1Institute of Urban Agriculture, Chinese Academy of Agricultural Sciences, Chengdu 610213, China
2College of Horticulture and Landscape Architecture, Southwest University, Chongqing 400712, China
3Zhuhai (Hengqin) Food Safety Institute, Zhuhai 519000, China
#These authors contributed equally to this work.
*Corresponding author: liaoqiuhong@caas.cn

Received December 12, 2021; Revised January 17, 2022; Accepted January 25, 2022

Abstract In this study, to explore the suitable cultivation method of pea shoot in the plant factory, the effects of ferrous sulfate seed soaking with different LED light quality on nutrient and growth were studied. Pea seeds were soaked in ferrous sulfate (80mg/L) and then cultivated under six different light quality combinations, including #1: 38% white light + 30% red light + 30% blue light + 2% far-red light; #2: 50% white light +50% blue light; #3: 50% white light +50% red light; #4: 40% white light +30% red light +30% blue light; #5: 100% white light; #6: 39% white light +30% red light +30% blue light +1% ultraviolet light. The results showed that the nutrient of VC, active iron, and the growth parameters of stem diameter, branch number, and yield were not significantly affected by ferrous sulfate seed soaking, but by the LED light quality. After the seeds were routinely soaked in water, the supplement of ultraviolet light to the combination of white light and red-blue light was beneficial to the accumulation of VC content in pea shoot, while the increase of red light ratio significantly reduced the VC content. Blue light or white light seemed to increase the active iron content of pea shoot, but no obvious rule was found. The addition of a small amount of far-red light to the combination of white light and red-blue light significantly promoted the growth of the pea shoot, resulting in the largest stem diameter, branch number, and the highest yield. The results of this study provided important references to produce high-quality pea shoots in plant factories.

Keywords: pea shoot, plant factory, seed soaking, light quality

Cite This Article: Wang Fang, Peng Honggui, Yuan Xinrui, Zhu Min, Yang Qichang, Lin Zhitong, and Liao Qiuhong, “Effects of Ferrous Sulfate Seed Soaking with Different LED Light Quality on the Nutritional Quality and Growth of Pea Shoot.” Journal of Food and Nutrition Research, vol. 10, no. 2 (2022): 144-150. doi: 10.12691/jfnr-10-2-7.

1. Introduction

Pea shoot is the vine tip of pea (Pisum sativum L), which riches in vitamin A, vitamin C, mineral element, dietary fiber, and other nutrient and functional components, endowing pea shoot anti-oxidation, prevention of cardiovascular disease, and liver cleansing, as well as a variety of therapeutic effects (improving eyesight, reducing swelling, and hydrating). Pea shoot is a seasonal and regional specialties vegetable, which mainly grows in the southwest of China. Due to the rich nutrition and delicious taste, pea shoot is largely popular with people. Under field conditions, the time between November to January of the following year is the peak season for the market supply and demand. Greenhouse cultivation can advance or delay the market for half a month to a month, but it still cannot meet the market demand. Therefore, realizing the annual production of pea shoots can significantly enrich the vegetable supply, satisfy the dietary desires of consumers, and have excellent market potential.

The plant factory is an efficient agricultural system that realizes the annual continuous production of crops through high-precision environmental control. The artificial environmental control systems include light, temperature, humidity, CO₂ concentration, wind speed, making plant factories free or less restricted by natural climate and geographical conditions, as well as benefits to crop growth and development [1]. Utilizing the advantages of plant factories can effectively make up the production limitations of pea shoot, realize the annual continuous production and meet the market demand. Light is the most important environmental factor that affects the growth and development of crops in plant factories, and its suitability directly related to the crop yield and quality. Therefore, the regulation of the artificial light environment is the
keyway in crop production. Due to the outstanding advantages, such as high light efficiency, low heat radiation, single light quality, rich wavelengths, and convenient spectral regulation, LED is widely used as an ideal artificial light source for crop production in plant factories [2,3,4,5,6]. Different wavelengths of light play various important roles in plant photosynthesis, morphogenesis, metabolic regulation, and quality formation [7,8,9,10]. Numerous studies have shown that red light can significantly increase plant height, stem thickness, leaf area, β-carotene content, and antioxidiant enzyme activity. Blue light plays an indispensable role in chloroplast development and stomatal opening. Greenlight can improve plant height and stem thickness [11,12]. Ultraviolet light can increase the vitamin C and anthocyanin content of plants [13,14,15,16]. Besides, different crops have different requirements for light quality [17,18,19]. When the ratio of red to blue light is 4:1, the fresh weight and dry weight of red leaf and purple lettuce are the largest; the ratio of red to blue is 1:1, promoting the growth of cherry radish seedlings above ground [20,21]. Therefore, exploring suitable light quality ratios according to the growth and development characteristics of different crops is beneficial to improve the efficiency of light energy of crops and promote high yield.

Soaking seed is the most commonly used technique in seed germination. It was found that soaking seed with exogenous zinc, iron, iodine, and selenium was not only beneficial to the accumulation of corresponding micro-nutrients in sprouts, but also to the improvement of biomass and nutritional quality without affecting seed germination and sprout growth [22,23]. To explore the cultivation method in plant factory, we creatively combined the pre-germination of pea seeds with growing light and proved that ferrous sulfate seed soaking combined with different light qualities affected the nutritional quality (The effects of ascorbic acid, active iron, and growth) (stem diameter, number of branches and yield), thereby providing theoretical support for the annual continuous production of pea shoot in LED plant factory.

**2. Materials and Methods**

**2.1. Materials**

The experiment was carried out in the plant factory of the Institute of Urban Agriculture, Chinese Academy of Agricultural Sciences, from September 2019 to January 2020. The material is a special pea variety “Feicui” in the southwest of China. We soaked the pea seeds in hot water at 50°C for 10 minutes to break the dormancy. The seeds were divided into two parts and then soaked with clear water or 80 mg/L ferrous sulfates (FeSO₄·7H₂O) solution for 24 hours until the seed coats broke. Finally, the seeds were sown on a drenched sponge block.

After a day of dark treatment, the seedlings were grown under a white LED light with a light intensity of 150 μmol·m⁻²·s⁻¹. When the seedlings grew to about 5 cm, the seedlings were selected and transplanted on six double-layer artificial light plant cultivation racks with different light treatments (three independent repetitions of each layer). The detailed cultivation experiment design was shown in Figure 1. In this study, the AB fertilizer (leaf vegetables) from Shanghai Yongtong Co., Ltd. was used. The EC value of fertilizer was adjusted to 1.2 mS/cm and the PH value was adjusted to 6.0. The indoor temperature was 20 ± 1°C, the humidity was 70%. Atmospheric CO₂ concentration was also used in this study.

**2.2. Light Environment**

The light source was LED lamp board provided by Guangdong Chenghui Co., Ltd. Each lamp board includes five light qualities, namely white light (continuous spectrum), red light (640 nm), blue light (460 nm), far-red light (740 nm) and ultraviolet light (380 nm). In this study, six light quality combinations were set up to explore the effects of different light quality on the growth and quality of pea shoot, which were light treatment # 1: 38% white light + 30% red light + 30% blue light + 2% far-red light; treatment #2: 50% white + 50% Blue; treatment #3: 50% white +50% red; treatment #4: 40% white + 30% red + 30% blue; treatment # 5: 100% white light; treatment # 6: 39 % white light + 30% red light + 30% blue light +1% ultraviolet light. The detailed of light quality combinations is shown in Table 1. The total light intensity is 100 μmol·m⁻²·s⁻¹, and the photoperiod is 16 hours per day.

**2.3. Measurement Method**

One week after transplantation (seedlings grew to about 20 cm), the tender shoots were harvested. Generally, the tender shoots with one to two immature leaves are picked at the tip, and then the tender shoots of branches are harvested at the same time every week, with a total of six stubble. The pea shoots from the second to the fifth stubble were weighed and tested for quality indexes. The VC content was determined by fluorescence spectrophotometry (GB 5009.86-2016), and the content of active iron was determined by flame atomic absorption spectrometry (GB 5009.90-2016). Five pea plants were randomly selected in each independent replicate after the six stubble harvested. The stem diameter of each branch was measured with vernier calipers and the number of branches was recorded. The total weight of tender shoots harvested in six stubble was the yield of pea shoot.

![Figure 1. Experimental design](image-url)
Table 1. The ratio of light quality in different light treatments

| Treatment | White (μmol·m⁻²·s⁻¹) | Red light (640 nm) | Far-red light (740 nm) | Blue light (460 nm) | Ultraviolet light (380 nm) | Total light intensity (μmol·m⁻²·s⁻¹) |
|-----------|------------------------|-------------------|-----------------------|---------------------|--------------------------|----------------------------------|
| #1        | 38                     | 30                | 2                     | 30                  | 100                      | 100                              |
| #2        | 50                     | 50                | 50                    | 30                  | 100                      | 100                              |
| #3        | 50                     | 50                | 50                    | 30                  | 100                      | 100                              |
| #4        | 40                     | 30                | 30                    | 100                 |                          | 100                              |
| #5        | 100                    |                   |                       |                     |                          | 100                              |
| #6        | 39                     | 30                | 30                    | 1                   | 100                      | 100                              |

2.4. Data Analysis

SPSS 24.0 was used for statistical analysis. One-way analysis of variance (ANOVA) was used for statistical analysis of data with different light treatments, and the Duncan test was used for multiple comparisons of significant differences (P<0.05).

3. Results and Analysis

3.1. VC Content of Pea Shoot

There were significant differences (p<0.05) in the VC content of pea shoot with different seed soaking methods, light treatments, and growth periods (Figure 2). In the second stubble, the VC content of the pea shoot was 319 mg/kg after soaking in ferrous sulfate combined with light treatment #2 (50% white light + 50% blue light); in the fifth stubble, the highest VC content (967 mg/kg) was detected after water soaking combined with light treatment #6 (39% white light + 30% red light + 30% blue light + 1% ultraviolet light). Overall, the VC content of pea shoot increased with the planting time. Especially, the VC content of pea shoot under light treatment #1 (38% white light + 30% red light + 30% blue light + 2% far-red light) after soaking seed in ferrous sulfate was the highest (except for the fourth stubble), and the VC content under light treatment #6 after soaking in water was significantly higher than other light treatments. In addition, under the artificial light cultivation, the VC content of pea shoot after seed soaking in ferrous sulfate was not significantly higher than that in water.

3.2. Active Iron Content of Pea Shoot

It could be seen from Figure 3 that there were significant differences (p<0.05) in active iron content of pea shoot with different harvest periods and seed soaking methods under six-light treatments. Among them, the lowest active iron content of pea shoot in the fifth stubble under the light treatment #1 (38% white light + 30% red light + 30% blue light + 2% far-red light) after soaking seed with ferrous sulfate was 11.5 mg/kg. The fourth stubble had the highest active iron content (28.4 mg/kg) of pea shoot under light treatment #5 (100% white light) after soaking the seed in water. Light treatment #2 (50% white light + 50% blue light) and #5 generally had higher active iron content in pea shoot under two seed soaking methods. However, there was no apparent regular relationship between the active iron content and light treatment. As the pea plants grow, the active iron content under the light treatment #2 and #3 (50% white light + 50% red light) after soaking the seed with ferrous sulfate decreased. Besides, the active iron content under the light treatment #1 and #3 after soaking seed with water decreased, and no obvious regular in other light treatments. In addition, the active iron content of pea shoots did not increase significantly after soaking seed with ferrous sulfate.

Figure 2. Effect of different seed soaking and light qualities on the vitamin C content of pea shoot
3.3. Stem Diameter of Pea Shoot

Significant differences (p<0.05) in stem diameter of pea plants under different light treatments were detected (Figure 4). The stem diameter of pea plants in light treatment #1 (38% white light + 30% red light + 30% blue light + 2% far-red light) after soaking seed with ferrous sulfate was the largest (2.03 mm), followed by light treatment #3 (50% white light+ 50% red light; 1.99 mm), and light treatment #4 (40% white light + 30% red light + 30% blue light; 1.83 mm). After soaking the seed in water, the maximum stem diameter of pea plants was detected under light treatment #1 (2.01 mm), and the minimum stem diameter was observed under light treatment #2 (50% white light + 50% blue light; 1.75 mm) and #5 (100% white light; 1.78 mm), respectively. In addition, compared with soaking the seed in water, the effect of soaking the seed with ferrous sulfate on stem diameter was not significant.

3.4. The Branch Number of Pea Shoot

As we could see in Figure 5, the branch number of pea shoot under the light treatment #1 (38% white light + 30% red light + 30% blue light + 2% far-red light) and #4 (40% white light + 30% red light + 30% blue light) after soaking seed with ferrous sulfate was 11, while other light treatments were 10. Hence, no significant difference (p>0.05) was detected with the branch number under different light treatments after soaking seed with ferrous sulfate. However, we found that there was a significant difference (P<0.05) in branch number under different light treatments after soaking the seed in water. Especially, light treatment #1 had the highest branch number at 11 pea plants. Light treatment #3 (50% white light + 50% red light) and #6 (39% white light + 30% red light + 30% blue light + 1% ultraviolet light) had the least branch number, which was 7. The branch number of pea seed soaked in ferrous sulfate was generally higher than that soaked in water (except for light treatment #1).
3.5. The Yield of Pea Shoot

Similarly, there was a significant difference (p<0.05) in the yield of pea shoot after soaking seed with ferrous sulfate and water under different light treatments (Figure 6). The yield of pea shoot under light treatment #6 (39% white light + 30% red light + 30% blue light + 1% ultraviolet light; 191 g) and #1 (38% white light + 30% red light + 30% blue light + 2% far infrared light; 182 g) was the highest by summarizing six stubble. Light treatment #2 (50% white light + 50% blue light) and #5 (100% white light) had the lowest yields of 152 g and 155 g, respectively. The yield of pea shoot after soaking the seed in water was similar to that in ferrous sulfate.

The highest yield of pea shoot was 196 g under light treatment #1, followed by light treatment #6 with 169 g, and the lowest yield was 121 g and 141 g under light treatment #2 and #5, respectively. In addition, the yield of pea shoot after soaking seed with ferrous sulfate was not significantly higher than soaking with water.

4. Discussion

Pea shoots riches in nutrients, such as vitamins and minerals, and has high edible value. The use of plant factories to produce pea shoots has a short growth period and high yield. It can realize annual continuous production without fertilization and spraying, which is safe and hygienic. Light, nutrition, temperature, and humidity are important factors that affect the growth and quality of pea shoot. Among these, light is the most essential factor for the plant energy source. This study plans to use ferrous sulfate to soak seed before germination, thereby changing the nutrient of the seeds and exploring the suitable cultivation mode to improve the quality and yield of pea shoot in combination with different light quality.

VC is one of the important indicators of vegetable nutritional quality. This study showed that the VC content of pea shoot did not increase significantly after soaking with ferrous sulfate compared with water soaking. However, the light has a more significant impact on it during the growth of the pea shoot. After the water soaking treatment, the VC content of pea shoots in light treatment #6 (39% white light + 30% red light + 30% blue light + 1% ultraviolet light) was significantly higher than other light treatments in different harvest periods. Compared with treatment #4 (40% white light + 30% red light + 30% blue light), only 1% of the white light component of treatment #4 was replaced by ultraviolet light, thereby significantly increasing VC content. This study indicated that ultraviolet light can significantly
increase the VC content of sprouts [15,16]. Light treatment #3 (50% white light + 50% red light) has the highest proportion of red light. Under this treatment, the content of VC is generally lower, which is consistent with the conclusion that red light can reduce the VC content of plant seedlings [24]. Besides, some studies showed that light quality has a regulatory effect on the activity of GLDH, the key enzyme in VC biosynthesis. Blue, white and ultraviolet light can significantly increase GLDH activity, and ultraviolet light has the most significant increase effect on GLDH activity and VC synthesis [25,26]. Therefore, in this study, light treatment #6 can significantly increase the VC content of pea shoot after supplementing ultraviolet light. While, the content of VC was not significantly increased by light treatment #6 containing ultraviolet light after soaking the seeds with ferrous sulfate, which may be due to the change of the nutrient environment for seed germination, resulting in the change of pea shoot response to light.

Iron is an essential nutrient element for the human body to maintain normal physiological functions, and vegetables are one of the important sources of active iron. This study shows that different light qualities have significant various effects on the active iron content of pea shoot. Light treatments #2 (50% white light + 50% blue light) and #5 (100% white light) have higher active iron content. There is an iron homeostasis regulation system in plants. Light intensity affects the absorption of active iron by phytoplankton. Chen et al. (2021) [27] showed that red and blue light could enhance the absorption capacity of Na, Fe, Mn, Cu, and other elements in roots of hydroponic lettuce, but the response of plant iron absorption regulation system to different light qualities is rarely reported. In this study, different light quality significantly affected the active iron content of pea shoots, but the law of its influence is still unclear and needs further study. In addition, some research results showed that the active iron content of pea shoots after seed soaking with 80 mg/L ferrous sulfates was much higher than water soaking. However, this study did not obtain a consistent conclusion, which may be due to the effect of light quality on the active iron content being greater than that of soaking seed with ferrous sulfate under artificial light cultivation conditions.

The stem diameter of the pea shoot is directly related to the yield and is usually used to evaluate the sensory quality of the pea shoot. In this study, after soaking seed with ferrous sulfate or water, light treatment #1 (38% white light + 30% red light + 30% blue light + 2% far-red light) had a significantly larger stem diameter than other light treatments, followed by light treatment #3 (50% white light + 50% red light), and light treatment #2 (50% white light + 50% blue light) has the smallest stem diameter. Compared with light treatment #4 (40% white light + 30% red light + 30% blue light), 2% of white light was replaced by far-red light in light treatment #1, and the proportion of red light was increased in treatment #3. The smallest stem diameter in treatment #2 resulted in an increased proportion of blue light. Many studies have found that far-red light can significantly increase the diameter of tomato stems and promote the growth of seedlings by increasing leaf expansion and whole-plant net assimilation [28,29]. Besides, blue light is not conducive to the formation of cellulose, which tends to cause short plants and reduced stem diameters. Our study also showed that red and far-red light promoted stem diameter during pea shoot growth, while blue light did the opposite.

The number of branches is a crucial factor that affects plant architecture, biomass, and yield. Since pea shoot is harvested at the tender shoot of branches, the maximum number of branches determines yield. Our study showed that the number of pea shoot branches varied with different light treatments. Light treatment #1 (38% white light + 50% red light + 30% blue light + 2% far-red light) showed the maximum number of pea shoot branches. Different light qualities have different effects on plant bud induction. Some research showed that far-red light could increase the number of sprouts branches. Ji et al. (2020) [30] obtain the same conclusion with tomato and lettuce seedlings, believing that far-red light can promote the accumulation of carbohydrates, thus playing a key role in plant morphogenesis. This study also shows that far-red light is beneficial to promote pea shoot branching.

In terms of output, light treatment #1 (38% white light + 50% red light + 30% blue light + 2% far-red light) and light treatment #6 (39% white light + 30% red light + 30% blue light + 1% ultraviolet) had the highest pea shoot yield than other light treatments. Numerous studies have shown that red and blue light is the most basic spectra for plant growth, and far-red light is essential for morphology. Blue-violet light is not only good for plant seedlings but also promotes biomass accumulation. Red light and far-red light can promote the accumulation of soybean sprouts biomass. Our study also found that the yield of white light with red light, blue light, or red-blue light separately is lower than that of white light with red-blue light and far-red light or ultraviolet light at the same time, indicating that the plant growth is not only the result of a single light but more a suitable combination of a variety of large and small light qualities.

In summary, under artificial light cultivation in plant factories, soaking seed with ferrous sulfate has no significant effect on the nutrition and yield of pea shoots. Light quality is an essential factor affecting the nutritional quality and growth of pea shoots. Supplementing ultraviolet light (1%) to the white, red-blue light formula can significantly increase the VC content of pea shoot in each harvest period. The content of active iron in pea shoot increased when the proportion of blue light was increased or continuous white light was used, though no obvious rule was found. Supplementing far-red light (2%) to the combination of white light and red-blue light can effectively promote the growth of stem diameter, increase the number of branches, and significantly increase the yield of pea shoot. Therefore, according to the harvest purpose, pea shoots cultivated in plant factories can be selected with different light quality components. However, to realize the annual continuous cultivation of pea shoots in plant factories, further experiments are needed to optimize the light quality ratio and light intensity to obtain the optimal light formula for pea shoots produced in plant factories.

Competing Interests

The authors declare no financial or commercial conflict of interest.
Funding

This work is supported by the Central Public-interest Scientific Institution Basal Research Fund (No. Y2021XK04), the innovation project team of 34-IUA-01 and 34-IUA-03.

References

[1] Zhang G, Shen S, Takagaki M, Kozai T, Yamori W. Supplemental Upward Lighting from Underneath to Obtain Higher Marketable Lettuce (Lactuca sativa) Leaf Fresh Weight by Retarding Senescence of Outer Leaves. Front Plant Sci. 2015; 6: 1110.

[2] Rahman MH, Azad MOK, Islam MJ, Rana MS, Li KH, Lim YS. Production of Potato (Solanum tuberosum L.) Seed Tuber under Artificial LED Light Irradiation in Plant Factory. Plants (Basel). 2021; 10(2): 297.

[3] Tewolde FT, Shima K, Maruo T, Takagaki M, Kozai T, Yamori W. Supplemental LED inter-lighting compensates for a shortage of light for plant growth and yield under the lack of sunshine. PLoS One. 2018; 13(11): e0206592.

[4] Tewolde FT, Lu N, Shima K, et al. Nighttime Supplemental LED Inter-lighting Improves Growth and Yield of Single-Truss Tomatoes by Enhancing Photosynthesis in Both Winter and Summer. Front Plant Sci. 2016; 7: 448.

[5] Zou T, Huang C, Wu P, Ge L, Xu Y. Optimization of Artificial Light for Spinach Growth in Plant Factory Based on Orthogonal Test. Plants (Basel). 2020; 9(4): 490.

[6] Wojciechowska R, Długoż-Grochowska O, Kolton A, Żupnik M. Effects of LED supplemental lighting on yield and some quality parameters of lamb’s lettuce grown in two winter cycles. Sci Hortic. 2015; 187: 80-86.

[7] Kitazaki K, Fukushima A, Nakabayashi R, et al. Metabolic Reprogramming in Leaf Lettuce Grown Under Different Light Quality and Intensity Conditions Using Narrow-Band LEDs. Sci Rep. 2018; 8(1): 7914.

[8] Zhou C, Zhang Y, Liu W, Zha L, Shao M, Li B. Light Quality Affected the Growth and Root Organic Carbon and Autoxidation Secretions of Hydroponic Lettuce. Plants (Basel). 2020; 9(11): 1542.

[9] Yeo HJ, Park CH, Park SY, Chung SO, Kim JK, Park SU. Metabolic Analysis of Root, Stem, and Leaf of Scutellaria baicalensis Plantlets Treated with Different LED Lights. Plants (Basel). 2021; 10(5): 940.

[10] Li J, Wu T, Huang K, Liu Y, Liu M, Wang J. Effect of LED Spectrum on the Quality and Nitrogen Metabolism of Lettuce Under Recycled Hydroponics. Front Plant Sci. 2021; 12: 678197.

[11] Deng M, Qian H, Chen L, et al. Influence of pre-harvest red light irradiation on main phytochemicals and antioxidant activity of Chinese kale sprouts. Food Chem. 2017; 222: 1-5.

[12] Bian Z, Yang Q, Li T, Cheng R, Barnett Y, Lu C. Study of the beneficial effects of green light on lettuce growth under short-term continuous red and blue light-emitting diodes. Physiol Plant. 2018; 164(2): 226-234.

[13] Lee MJ, Son JE, Oh MM. Growth and phenolic compounds of Lactuca sativa L. grown in a closed-type plant production system with UV-A, -B or -C lamp. J Sci Food Agric. 2014; 94(2): 197-204.

[14] Park SY, Lee MY, Lee CH, Oh MM. Physiologic and Metabolic Changes in Crepídulastrum denticulatum According to Different Energy Levels of UV-B Radiation. Int J Mol Sci. 2020; 21(19): 7134.

[15] Li Y, Zheng Y, Zheng D, et al. Effects of Supplementary Blue and UV-A LED Lights on Morphology and Phytochemicals of Brassicaceae Baby-Leave. Molecules. 2020; 25(23): 5678.

[16] He R, Zhang Y, Song S, Su W, Hao Y, Liu H. UV-A and FR irradiation improves growth and nutritional properties of lettuce grown in an artificial light plant factory. Food Chem. 2021; 345: 128727.

[17] Goto N, Homma Y, Yusa M, et al. Effects of using LED supplemental lighting to improve photosynthesis on growth and yield of strawberry forcing culture. Acta Hortic. 2018; 1227: 563-570.

[18] Shengxin C, Chuaxia L, Xuyang Y, et al. Morphological, Photosynthetic, and Physiological Responses of Rapeseed Leaf to Different Combinations of Red and Blue Lights at the Rosette Stage. Front Plant Sci. 2016; 7: 1144.

[19] Pennisi G, Blasioli S, Cellini A, et al. Unraveling the Role of Red-Blue LED Lights on Resource Use Efficiency and Nutritional Properties of Indoor Grown Sweet Basil. Front Plant Sci. 2019; 10: 305.

[20] Chen XL, Yi YL, Wang LC, Guo WZ. Red and blue wavelengths affect the morphology, energy use efficiency and nutritional content of lettuce (Lactuca sativa L.). Sci Rep. 2021; 11(1): 8374.

[21] Yang B, Zhao X, Li X, et al. Comprehensive Analysis of Photosynthetic Characteristics and Quality Improvement of Purple Cabbage under Different Combinations of Monochromatic Light. Front Plant Sci. 2016; 7: 1788.

[22] Liu P, Li Q, Gao Y, et al. A New Perspective on the Effect of UV-B on l-Ascorbic Acid Metabolism in Cucumber Seedlings. J Agric Food Chem. 2019; 67(16): 4444-4452.

[23] Lu Y, Guo X. The Effect of Light in Vitamin C Metabolism Regulation and Accumulation in Mung Bean (Vigna radiata) Germination. Plant Foods Hum Nutr. 2020; 75(1): 24-29.

[24] Chen XL, Guo WZ, Xue XZ, et al. Effects of LED spectrum combinations on the absorption of mineral elements of hydroponic lettuce. Spectrosc Spect Anal. 2014; 34(5): 1394-1397.

[25] Kalaitzoglou P, van Ieperen W, Harbinson J, et al. Effects of Continuous or End-of-Day Far-Red Light on Tomato Plant Growth, Morphology, Light Absorption, and Fruit Production. Front Plant Sci. 2019; 10: 322.

[26] Zhang G, Shen S, Takagaki M, Kozai T, Yamori W. Supplemental LED inter-lighting compensates for a shortage of light for plant growth and yield under the lack of sunshine. PLoS One. 2018; 13(11): e0206592.

© The Author(s) 2022. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).