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EFFECTS OF LIGHT QUALITY FROM DIFFERENT LED LIGHT SOURCES ON THE GROWTH OF FOUR LEAF LETTUCE CULTIVARS

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Abstract. *In recent years, light-emitting diodes (LEDs) have come to be used at cultivation sites instead of high-pressure sodium, halogen, and fluorescent lamps. To ascertain the effects of irradiation by LEDs of six kinds in a growth chamber, this study examined the growth and morphology of four leaf lettuce (Lactuca sativa L.) cultivars: 'Red wave', 'Fancy red', 'Green wave' and 'Fancy green'. The lighting was effective to increase fresh weight and dry weight under white LED light with or without red LED for 'Red wave'. However, the other cultivars did not share this characteristic with 'Red wave'. Especially, 'Fancy red' under white LED exhibited lower fresh weight, leaf weight, root weight, and dry weight compared with less than white with added red LED, but the results were similar to those obtained with red LED. These results suggest that it might be useful to grow plants under white LED light, instead of red LED light, depending on the cultivar.*

Keywords: Difference of wavelengths, Four cultivars, Growth analysis, Light quality

1. **Introduction.** Light is one of the most important factors affecting plant growth. Light sources are generally applied for plant cultivation and to increasing photosynthetic photon flux levels. In recent years, light-emitting diodes (LEDs) have been adopted for use at cultivation sites instead of high-pressure sodium, halogen, and fluorescent lamps because LEDs have adequate spectral composition, about four times longer life, and more specific wavelength than other lamps. It is possible for LEDs to irradiate a specific single wavelength to change the time of germination and flowering desired by producers [1-3]. Spectral light changes evoke different morphogenetic and photosynthetic responses that can vary among plant species. Such photo responses are of practical importance in recent plant cultivation technologies because the feasibility of tailoring illumination spectra purposefully enables a grower to control plant growth, development, and nutritional quality [4]. Therefore, LED light sources have already been adopted for use in facility agriculture and have become the most promoted artificial electronic light for plant cultivation in controlled environments such as plant factories [5]. Additionally, LED light sources have been regarded as the most suitable light to study light quality effects on plant growth and development [6].

Some studies have reported plant growth in relation to the spectral distribution of LEDs, especially for leafy vegetables. Actually, light from red and/or blue LEDs is known to increase plant biomass: it closely matches the peak absorbance of chlorophyll in lettuce (*Lactuca sativa* L.) and spinach (*Spinacia oleracea* L.) [7,8]. Lettuce is not only grown in greenhouses but also in closed growth chambers, as a closed plant factory

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just for lettuce cultivars of few kinds. It is among the most popular leafy vegetables cultivated in controlled environments. This study investigated differences of plant growth and morphologies under light irradiation by LEDs: red, blue, mixed red and blue, green, white and white with added red. In addition, white and white with added red LEDs tested in this experiment are used in some plant factories. Most papers for lettuce cultivated under LED were only for one cultivar [4,6,9,10], but the plants were four leaf lettuce cultivars grown in a growth cabinet to maintain the same environment for temperature, humidity, concentration of CO_2, and nutrient solution in this paper. Dry and fresh masses of plants were compared to four leaf lettuce cultivars grown under six kinds of LEDs.

2. **Materials and Methods.**

Seeds for 'Red wave (Sakata Seed Corp., Japan)', 'Fancy red (Nakahara Seed Co. Ltd., Japan)', 'Green wave (Takii Seed Co. Ltd., Japan)', and 'Leaf lettuce green (Nakahara Seed Co. Ltd., Japan)' were sown on urethane cubes (M Hydroponic Research Co. Ltd., Japan) with distilled water and were then germinated in a growth chamber (TGE-5-2L; Espec Corp., Japan) at 25°C, at 70% relative humidity, 600 ppm CO_2, for 16 hr under continuous illumination at 100 μmol/m^2/s^1 cool white fluorescent lamps (FHF32EX-D-HX-S; NEC Corp., Japan) for 1 week. Subsequently, the germinated seeds were transferred onto nutrient solution to grow for one more week.

Groups of eight plantlets in a urethane cube were transferred to other containers ($293 \times 211 \times 106$ mm) with 6 liters of commercial nutrient solution (A treatment: OAT Agrio Co. Ltd., Japan) to observe growth under LEDs of six kinds: red (660 maximum wavelength, nm; Union Electronics Industrial Co. Ltd., Japan), blue (450 nm maximum wavelength; Union Electronics Industrial Co. Ltd.), green (525 nm maximum wavelength; Union Electronics Industrial Co. Ltd.), mixed red and blue (450 and 660 nm maximum wavelength; Union Electronics Industrial Co. Ltd.), white (Union Electronics Industrial Co. Ltd.) and white with added red (Union Electronics Industrial Co. Ltd.) for 3 weeks. Figure 1 shows the wavelengths for all LEDs. During cultivation, their roots were given sufficient air by air pumping (Kotobuki Kougei Co. Ltd., Japan) to avoid root rot. Then all solutions were exchanged for new ones, adjusted to 1.2 dSm^{-1} for EC (electric conductivity) value, once a week. All LED treatments had intensity of 100 μmol/m^2/s^1.

After 3 weeks, all plants were harvested. We measured their fresh weight (g; FW), leaf weight (g; LW), stem weight (g; SW), root weight (g; RW), length of maximum leaf (cm; ML), length of main stem (cm; MS), number of leaves, SPAD value (SPAD-502; Konica Minolta Holdings, Inc., Japan) and dry weight (g; DW) after they were put in a dryer at 70°C for more than 3 days.

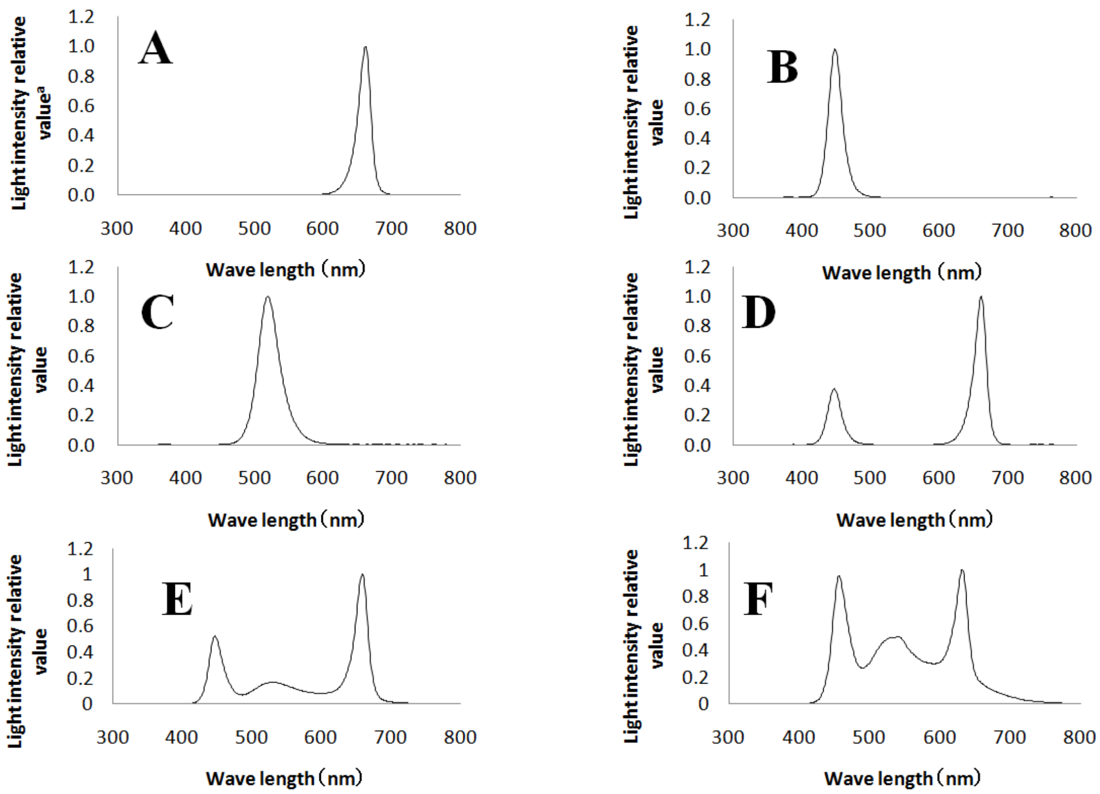
Data were analyzed using principal component analysis (Mulcel; OMS Publishing Inc., Japan).

3. **Results and Discussion.**

Fluorescent lamps have been replaced by LEDs to boost flower bud formation. Particularly, red LEDs support better photosynthesis and blue LEDs support flower bud formation and phototropism at cultivation sites [2,11]. Therefore, which light quality can increase FW and DW is important for the plants that we are cultivating.

Plants showed distinct growth response to different light quality treatments. As the first components found by the principal component analysis, FW, LW, RW, ML, LN, DW, MS, and SW were found to have positive factor loadings; only SPAD was negative. As the second components, FW, LW, RW, SPAD and DW were positive; the others were negative. The respective contributions of the first and second components were 46.50% and 26.14%. Consequently, these results were useful and were then analyzed using principal component analysis (Table 1).

All cultivars aside from 'Red wave' showed an increasing tendency for FW, LW, RW, ML, LN, DW, MS, and SW under red LEDs (Figure 2). For all cultivars grown under blue



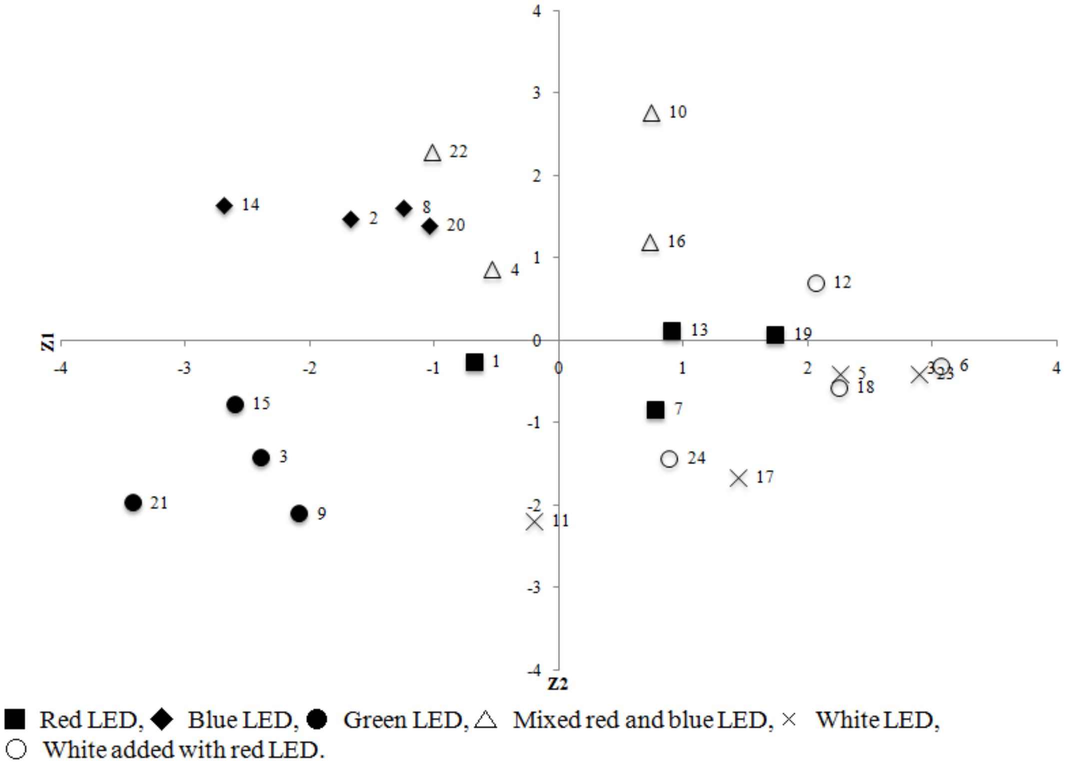
a: It was indicated relative value with the maximum peak taken as 1 against the measured light intensity

Figure 1. Wavelength distribution characteristics of various LED light sources used for this experiment, A: red LED, B: blue LED, C: green LED, D: mixed red and blue LED, E: white LED, F: white with added red LED

Table 1. Eigen value, contribution and factor loading of the 1st, 2nd and 3rd principal components

Characteristics	Component No.		
	1	2	3
Fresh weight (g)	0.921	0.287	−0.080
Leaf weight (g)	0.870	0.172	−0.030
Root weight (g)	0.548	0.572	0.474
Maximum leaf length (cm)	0.792	−0.336	0.228
No. of leaves	0.606	−0.162	−0.654
SPAD value	−0.138	0.851	0.118
Dry weight (g)	0.842	0.333	0.003
Lengh of main stem (cm)	0.118	−0.770	0.470
Stem weight (g)	0.738	−0.589	0.020
Eigen value	3.639	2.046	0.824
Contribution	46.50%	26.14%	10.53%
Cumulative contribution	46.50%	72.64%	83.17%

or green LEDs, the main stem length had characteristics without elongation compared to other LEDs. Green LEDs showed no increase for any measured trait except the SPAD value. ‘Red wave’ and ‘Fancy green’ grown under mixed red and blue LEDs showed a decreasing tendency for FW, LW, RW, ML, LN, DW, MS, and SW, but ‘Fancy red’ and ‘Green wave’ showed the opposite tendency. On the other side, all cultivars under white



* Number indicates the cultivars that 'Red wave' is 1-6, 'Fancy red' is 7-12, 'Green wave' is 13-18 and 'Fancy green' is 19-24.

FIGURE 2. Scatter diagram in Z1-Z2 plane nine characteristics in lettuce arranged by the principal component analysis

with or without red LEDs showed an increasing tendency for FW, LW, RW, ML, LN, DW, MS, and SW compared to another LEDs. Especially, 'Red wave' grown under red LED was no increase for FW and DW compared to under white with or without red LEDs, so it might be better to grow under white with or without red LEDs. These results suggest that it might be useful to grow plants under white LEDs, instead of red LEDs, depending on the cultivar.

However, it is important that main stems are shorter for leaf vegetables including leafy lettuce because longer stems decrease the product quality, taste, and appearance. When it focused on ML, it seemed that it was the best condition under red and blue LEDs, and blue LEDs for all cultivars (Figure 2). Reportedly, stem elongation of *Pelargonium* was inhibited *in vitro* by blue light [12,13]. Consequently, the effects of stem elongation are known to differ among plant species and cultivars, as shown also by our results. Furthermore, the blue light strength might affect stem elongation. It might be necessary to investigate the putative relation of stem elongation to the strength of blue light for leafy lettuce, depending on the cultivar.

Leaf lettuce is grown in controlled environments like those in a plant factory under red and/or blue LEDs. However, they are more expensive and less accessible than white LEDs that someone might buy easily and use in the home. If it is possible to grow plants using white LEDs used in the home, then it might be less costly to buy and change new LEDs rather than red LEDs. Results of our research demonstrate that irradiation by white with and without red LEDs can significantly increase FW and DW for 'Red wave'. Even for 'Green wave' and 'Fancy green', they can provide almost equal amounts of FW and DW as irradiation by red and/or blue LEDs. For 'Fancy red', white LEDs produce similar amounts of FW and DW to those produced using mixed red and blue LEDs.

It might be necessary to investigate and compare plant growth results obtained under monochromatic LEDs such as red, blue and green, and white LEDs for more cultivars of leaf lettuce because differences between plant growth and optimal light quality differ among leaf lettuce cultivars. Furthermore, it might be important to find a suitable white LED for each cultivar because light quality and wavelengths of white LEDs differ among lights produced by different companies.

4. **Conclusion.** The four leaf lettuces, ‘Red wave’, ‘Fancy red’, ‘Green wave’ and ‘Fancy green’, cultivars used in this experiment were produced the similar or higher FW and DW under white with and/or without red LEDs compared to under red, blue, green, and mixed red and blue LEDs. It should avoid elongating the main stem because commercial value would decrease for leafy vegetables. However, main stem for all cultivars seemed to elongate under white with and/or without red LEDs, and it might be the most important to find a suitable wavelength for each cultivar.

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REFERENCES

[1] T. Clack, S. Mathews and R. A Sharrock, The phytochrome apoprotein family in Arabidopsis in encoded by five genes: The sequences and expression of *PHYD* and *PHYE*, *Plant Mol. Biol.*, vol.25, pp.413-427, 1994.
[2] C. Lin, Plant blue-light receptors, *Trends Plant Sci.*, vol.5, pp.337-342, 2000.
[3] H. Smith, Physiological and ecological function within the phytochrome family, *Annu. Rev. Plant Physiol. Plant Mol. Biol.*, vol.46, pp.289-315, 1995.
[4] K.-L. Lin, M.-Y. Huang, W.-D. Huang, M.-H. Hsu, Z.-W. Yang and C.-M. Yang, The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (*Lactuca sativa* L. var. *capitata*), *Scientia Horticulturae*, vol.150, pp.86-91, 2013.
[5] R. C. Morrow, LED lighting in horticulture, *Hort Science*, vol.43, pp.1947-1950, 2008.
[6] H. Liu, Y. Fu, D. Hu, J. Yu and H. Liu, Effect of green, yellow and purple radiation on biomass, photosynthesis, morphology and soluble sugar content of leafy lettuce via spectral wavebands “knock out”, *Scientia Horticulturae*, vol.236, pp.10-17, 2018.
[7] S. E. Balegh and O. Biddulph, The photosynthetic action spectrum of the bean plant, *Plant Physiol.*, vol.46, pp.1-5, 1970.
[8] M. S. McDonald, Photobiology of higher plants, *Nature*, pp.199-239, 2003.
[9] T. Oshima, K. Ohashi-Kaneko, E. Ono and H. Watanabe, Determination of optimum red and blue lighting conditions for production of red-leaf lettuce cultured under LEDs, *J. SHITA*, vol.27, pp.24-32, 2015.
[10] T. Jishi, K. Kimura, R. Matsuda and K. Fujiwara, Effects of temporally shifted irradiation of blue and red LED light on cos lettuce growth and morphology, *Scientia Horticulturae*, vol.198, pp.227-232, 2016.
[11] S. E. Balegh and O. Biddulph, The photosynthetic action spectrum of the bean plant, *Plant Physiol.*, vol.46, pp.1-5, 1970.
[12] M. Appelgren, Effects of light quality on stem elongation of *Pelargoniun in vitro*, *Scientia Horticulturae*, vol.45, pp.345-351, 1991.
[13] N. Fukuda, M. Kobayashi, M. Ubukawa, K. Takayanagi and S. Sase, Effects of light quality, intensity and duration from different artificial light sources on the growth of Petunia (*Petunia* × *hybrida* Vilm.), *J. Japan. Soc. Hort. Sci.*, vol.71, pp.509-516, 2002.