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# Spindly growth of watercress observed under the monochromatic light of a red light-emitting diode improved with slight changes in light quality using white light-emitting diode

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## Abstract

The suppression effect of white light-emitting diode (LED) on spindly growth observed under monochromatic light of the red LED in watercress (*Nasturtium officinale* R. Br.) was investigated for production in plant factories. Watercress was cultured in a growth chamber under total photosynthetic photon flux density (PPFD) of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ using three differential treatments; the ratio of red LED to white LED based on PPFD was 100:0 (R100W0), 90:10 (R90W10), and 75:25 (R75W25). Watercress was harvested 33 days after sowing. The longest internode length was observed with R100W0. Watercress in R100W0 were observed with the lowest value for node number, maximum leaf length, shoot fresh weight, shoot dry weight, dry matter rate, and SPAD. R90W10 recorded higher values for maximum leaf length, shoot fresh weight, shoot dry weight, dry matter rate, and SPAD than R100W0. In watercress cultivation, replacing 10% of the red LED with a white LED proved effective in inducing morphological changes and enhancing dry matter production.

**Key words:** Artificial light, leafy vegetable, *Nasturtium officinale* R. Br., photomorphogenesis, plant factory, protected horticulture

## Introduction

Watercress (*Nasturtium officinale* R. Br.) is a leafy vegetable rich in minerals and vitamins (Shear, 1968). It is a perennial herbaceous plant widely reported in several parts of Europe, China, New Zealand, and North America, both as a wild-growing species and a cultivated crop (Palaniswamy and McAvoy, 2001). Akagi *et al.* (1991) cite watercress as a cultivated item in the plant factory. Kratky (2015) has published a watercress cultivation manual by non-circulating hydroponic methods. Calori *et al.* (2015) studied the effect of electric conductivity (EC) and space between plants on watercress growth in NFT hydroponic system. Therefore, this vegetable is grown in open fields, plant factories, and protected horticulture.

Effects of supplemental light before harvest on growth and isothiocyanate of watercress were studied (Palani Swamy *et al.* 1997). Engelen-Eigles *et al.* (2006) studied the effect of photoperiod and light quality on growth and gluconasturtiin of watercress. Thus, the effects of artificial light on the growth and composition of watercress have been studied. Agriculture uses various artificial lights such as fluorescent lamps, high-pressure sodium lamps, and metal halide lamps (Hamamoto and Yamazaki, 2013). The light-emitting diode (LED) have replaced existing artificial light sources. For example, it was investigated whether LEDs could be replaced with metal halide lamps as supplemental light sources in lettuce cultivation in greenhouses under seasonal low light conditions (Bumgarner and Buck, 2016). LED has attracted attention since the late 1980s and is used today in research and plant production because of the pronounced peak and narrow bandwidth wavelength emissions (Goto, 2003). LEDs used mainly for plant factories are red and blue, which are more effective for plant photosynthesis and morphogenesis. Cultivation of watercress using LEDs in a closed system has been studied (Choi *et al.,* 2018; Mizushima, 2020; Lam *et al.,* 2021). Previous reports observed the watercress's spindly growth under the red LED's monochromatic light (Choi *et al.,* 2018; Mizushima, 2020). Combining with blue LED improved this phenomenon (Choi *et al.,* 2018).

White LED is becoming more important as an artificial light sources in plant factories. White LED replaces blue LEDs as the light source in plant factories because white LED contains blue light length and are versatile. For example, lettuce (Mori *et al.,* 2002), turnip (Tanemura *et al.,* 2014), and strawberry (Maeda and Ito, 2020) are grown using white LEDs. Watercress could achieve optimal growth under specific light conditions, wherein the ratio of red to white LEDs was 50:50, based on the photosynthetic photon flux density (PPFD) (Mizushima, 2020). However, the proportion to mix white LED is unknown to suppress the spindly growth generated by the monochromatic light of the red LED in watercress. Therefore, this study investigated the watercress growth under a mixture of white LED based on a red LED.

## Materials and methods

**Plant culture:** Watercress ('watercress'; Takii & Co., Ltd, Kyoto, Japan) was cultured from 22 November to 25 December 2018 in a closed cultivation room of Wakasa-higashi High School. Cells (Volume; 50 mL) of connected pots were filled with vermiculite before sowing the watercress seeds. Watercress seeds were sown as five seeds per cell, and plants were thinned to one plant per cell eight days after sowing. Following sowing, connected pots were placed on plastic trays in the growth chamber (Preset temperature:

22°C). The nutrient solution (SA-prescription; OAT Agrio Co., Ltd, Tokyo, Japan) was made in 0.5 units and fertilized to the plants at 8, 15, and 22 days after sowing.

**Light treatment:** An LED unit (Valore Corp., Kyoto, Japan) with alternating red and white LED chips, which were independently adjustable, was used as the light source for cultivation. The red and white LED's peak wavelengths were 655 nm and 455 nm, respectively (Fig. 1). watercress was grown under a 12 h photoperiod and a total PPFD of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on the surface of the soil using three differential treatments. Based on PPFD, the ratio of red LED to white LED, the treatments were R100W0 (100:0), R90W10 (90:10), and R75W25 (75:25) (Fig. 2).

**Evaluation of plant growth and data analysis:** At harvest (33 days after sowing), nine plants were examined from each treatment group and the following parameters were recorded: stem length, node number, internode length, maximum leaf length, shoot fresh weight, shoot dry weight, dry matter rate, and SPAD value. The internode length was calculated by dividing stem length by node number. The maximum leaf length was measured as the longest leaf (leaf blade and petiole) in individual plants. The shoot fresh weight was measured immediately after cutting the stem. The shoot dry weight was taken after drying the samples in an electric oven for 48 h at 80°C. The dry matter rate was calculated based on the data of shoot fresh weight and shoot dry weight. SPAD-502 Plus (Konica Minolta, Inc., Tokyo, Japan) was used to measure the SPAD value. All data were analyzed using Tukey's multiple comparison test.

## Results and discussion

The stem length was not significantly different between the three treatments (Table 1). The node number increased as the ratio of white light increased. The internode lengths of R90W10 and R75W25 were shorter than that of R100W0. When the ratio of white light was 25% or more, the internode length became shorter than that under the monochromatic red light (Mizushima, 2020). In this study, internode elongation was suppressed even when the proportion of white LED was 10%. Therefore, fewer value than those reported in previous studies (Mizushima, 2020) caused the suppression of internode elongation by a white LED. The maximum leaf length, shoot fresh weight, shoot dry weight, dry matter rate, and SPAD value of R90W10 and R75W25 were higher than R100W0 (Table 1). R100W0, R90W10, and R75W25 SPAD values were 16.6, 35.4, and 37.1, respectively. The chlorophyll content was normal in the R90W10 and R75W25. Because SPAD value of watercress cultivated in a floating system was 36.4 at harvest (Logegaray *et al.,* 2016). However, the watercress of R100W0 had decreased chlorophyll content and displayed spindly growth (Fig. 3).

The growth characteristics were improved by replacing red light with white light by 10 and 25%. The ratio of blue light range (400–499 nm) of R90W10 and R75W25 were 0.9 and 3.8%, respectively (Table 2). In a previous study in lettuce, stem length decreased with 5% blue LED added to the red LED, compared with monochromatic red light (Saito *et al.,* 2012). In a study on peppers, light conditions influenced leaf characteristics. The addition of blue light by 1% improved the chloroplast number per palisade in the mesophyll cells, the thickness of the palisade, and the spongy mesophyll tissues when compared with the monochromatic light of red LED (Schuerger *et al.,* 1997). These results suggested that slight changes in light quality will influence the morphological characteristics and growth of the watercress.

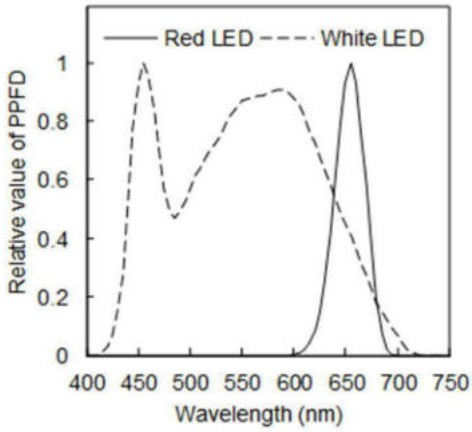


Fig. 1. Spectral characteristics of the red LED, and white LED used in the study.

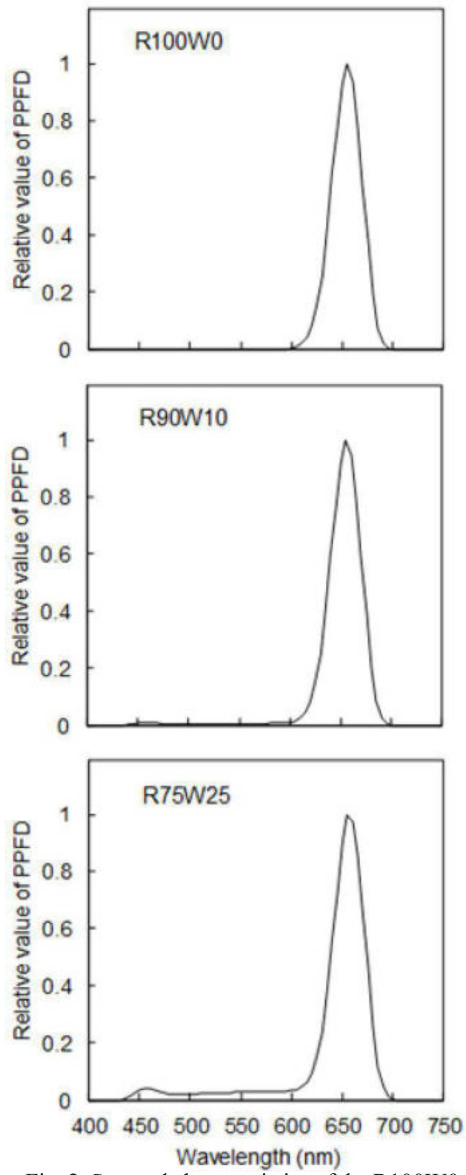


Fig. 2. Spectral characteristics of the R100W0, R90W10, and R75W25.

Table 1. Effects of red LED to white LED ratio on watercress growth at harvest (33 days after sowing)

| Parameter | Red to white ratio | | |
|---|---|---|---|
| | R100W0 | R90W10 | R75W25 |
| Stem length (cm) | 12.7 a [z] | 11.0 a | 13.6 a |
| Node number | 6.3 c | 8.2 b | 10.8 a |
| Internode length (cm) | 2.0 a | 1.3 b | 1.3 b |
| Maximum leaf length (cm) | 2.2 c | 4.6 b | 7.2 a |
| Shoot fresh weight (g $Plant^{-1}$) | 0.12 c | 0.57 b | 1.57 a |
| Shoot dry weight (g $Plant^{-1}$) | 0.006 c | 0.033 b | 0.090 a |
| Dry matter rate (%) | 4.6 b | 6.0 a | 5.8 a |
| SPAD value | 16.6 b | 35.4 a | 37.1 a |

[z] Means with different letters indicate a significant difference at the 5% level by Tukey's multiple comparison test in each row.

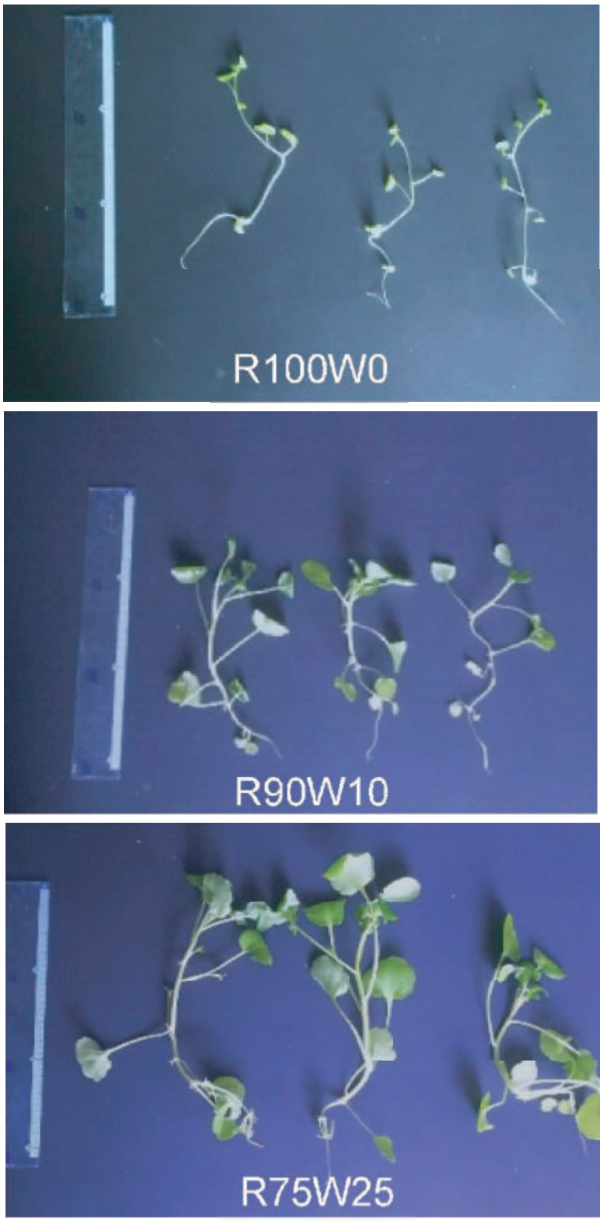


Fig. 3. The appearance of watercress at harvest (33 days after sowing).

Table 2. Wavelength characteristics of the R100W0, R90W10 and R75W25

| Wavelength (nm) | Relative value of based on PPFD | | |
|---|---|---|---|
| | R100W0 | R90W10 | R75W25 |
| 400–499 | 0.000 | 0.009 | 0.038 |
| 500–599 | 0.000 | 0.014 | 0.063 |
| 600–699 | 1.000 | 0.977 | 0.899 |

The red LED's lettuce growth with monochromatic light was similar to its growth under fluorescent lamps (Bula *et al.,* 1991). On the other hand, watercress cultivation required mixed light because its growth was poor with only the monochromatic light of the red LED. The maximum leaf length, shoot fresh weight, and shoot dry weight increased as the ratio of white light increased (Table 1). The dry matter rate and SPAD values of R90W10 and R75W75 were higher than that of R100W0. The best growth characteristics were recorded under R75W25.

Replacing the red LED with a white LED by 10 and 25% was more effective for morphological changes and dry matter production in watercress cultivation. However, the watercress growth characteristics of R75W25 were inferior to R50W50 (Mizushima, 2020).

In summary, watercress growth, internode elongation, and other parameters improved when 10 and 25% red LEDs were replaced with white LEDs. White light improved chlorophyll and plant growth, especially R75W25. This study emphasizes the importance of proper red-to-white LED light ratio for watercress cultivation.

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