Journal of Integrative Agriculture 2017, 16(1): 97–105

Available online at www.sciencedirect.com

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RESEARCH ARTICLE

Effects of light intensity on leaf microstructure and growth of rape seedlings cultivated under a combination of red and blue LEDs

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Abstract

The aim of this study was to evaluate the growth of rape (*Brassica napus* L.) seedlings under different light intensities to select appropriate conditions for cultivation in an indoor system. Seedlings were grown under different light intensities of red and blue light provided by light-emitting diodes (LEDs) and their self-adjustment ability and changes in leaf microstructure were evaluated. Light was supplied by red LEDs with peak wavelengths of 630 (R_1) and 660 nm (R_2) and by blue LEDs (B) with a peak wavelength of 445 nm (the light intensity ratio of R_1:R_2:B was 3:3:2), at intensities of 400 (R_1R_2B400), 300 (R_1R_2B300), and 200 μmol m^{-2} s^{-1} (R_1R_2B200). Natural solar light served as the control (C). Plant height, stem diameter, root length, leaf area, and dry weight of rape seedlings gradually increased with increasing light intensity. The seedlings in the R_1R_2B400 treatment grew more vigorously, while those in the R_1R_2B200 treatment were weaker. The photosynthetic pigment contents did not differ significantly between the R_1R_2B400 treatment and C, but were significantly lower in the R_1R_2B300 and R_1R_2B200 treatments. The highest intercellular CO_2 concentration, stomatal conductance, and transpiration rate were in the R_1R_2B300 treatment. The highest photosynthetic rate was in the R_1R_2B400 treatment, and was related to more compact leaves, thicker and tidier palisade and spongy tissues, and well-developed chloroplasts. In contrast, the seedlings in the R_1R_2B200 treatment had disordered mesophyll cells, round chloroplasts, and fractured and fuzzy grana lamellae, all of which inhibited plant growth. In conclusion, the seedlings in the R_1R_2B400 treatment had well-developed leaves, which favored photosynthesis. Compared with the light intensities below 300 μmol m^{-2} s^{-1}, the light intensity of 400 μmol m^{-2} s^{-1} provided by a combination of red and blue LEDs was beneficial for cultivating strong and healthy rape seedlings in an artificial system.

Keywords: light intensity, rape seedlings, mesophyll cell, chloroplast, stomata, photosynthetic characteristics

1. Introduction

Rape (*Brassica napus* L.) is an important oil crop, but growing this crop on an industrial scale may affect food security in China (Wang and Feng 2013). Whereas plants cultivated in the natural environment can be exposed to unfavorable growth conditions, controllable artificial facilities can provide optimal conditions for cultivating plants, including rape. This is especially useful for breeding programs because it can accelerate the breeding process. In the future, knowledge

Received 1 March, 2016 Accepted 27 April, 2016
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doi: 10.1016/S2095-3119(16)61393-X

of appropriate artificial cultivation conditions will be important for more applications, for example, space planting. To optimize plant growth in artificial facilities, it is important to establish suitable environmental conditions, expecially light intensity. Plants grown under low light have frequently been shown to be more susceptible to photoinhibition than those plants grown under high light intensity. Generally, the increases in net photosynthesis rate (P_n) correlates with increases in light intensity. However, over-strong light also resulted in decreases of P_n. Therefore, determining which light intensity conditions are optimal for the cultivation of plants, including rape seedlings in artificial facilities is an important research goal.

Leaves are the main organ of photosynthesis and transpiration. The level of development of stomata, mesophyll cells, and chloroplasts directly affects photosynthesis and transpiration, which affect plant growth (Li 2006). Leaf morphology shows plasticity, and the photosynthetic characteristics and structure of leaves differ markedly under different light intensities. In previous studies, weak light conditions resulted in a decrease in P_n of eggplant (Yu *et al.* 2004) and reduced dry weight of wheat (Chen 2012). Long-term weak-light conditions resulted in thinner leaves with a smaller leaf area in potato (Qin *et al.* 2014), and a decrease in the specific leaf area of *Datura* (Mao *et al.* 2012). High-light intensity is also not conducive to plant growth; high-light can lead to wilted leaves, reduced leaf area and chlorophyll content and photosynthetic efficiency (Shirke and Pathre 2003). Additionally, high-light intensity can destroy the photosynthetic system, and cause serious oxidative damage to leaf tissues (Farquhar and Sharkey 1982).

Only under an appropriate light intensity can plants fully self-regulate to achieve the best state to absorb and transform light energy. In tomato seedlings, the light saturation point (LSP) was much lower under artificial light provided by light-emitting diodes (LEDs) than under solar light, where the LSP was about 500 μmol $m^{-2} s^{-1}$ (Liu *et al.* 2010). In lettuce, 100 μmol $m^{-2} s^{-1}$ light provided by blue and red LEDs was optimal for growth (Wang *et al.* 2011). The best light intensity to cultivate non-heading Chinese cabbage in a plant factory was 200 μmol $m^{-2} s^{-1}$ (Lu *et al.* 2015). Tomato plants grew well under a light intensity of 300 μmol $m^{-2} s^{-1}$ provided by blue and red LEDs, and these light sources resulted in lower energy consumption than other light sources (Fan *et al.* 2013). The results of these studies illustrate that plants have different light intensity requirements under artificial lights than under natural light.

In previous studies on rape, 40 μmol $m^{-2} s^{-1}$ red light was more advantageous than white light for seedling growth (Du *et al.* 2002), and compound light (35 μmol $m^{-2} s^{-1}$, with a ratio of three red to one blue LEDs) was better than monochromatic light (Chen *et al.* 2013). The LSP of rape under natural light was reported to be approximately 600 μmol $m^{-2} s^{-1}$ (Li and Zhang 1997). However, Leng *et al.* (2002) found that the LSP of rape was about 20–30 Klux, which is equivalent to 360 μmol $m^{-2} s^{-1}$ (1 Klux=18 μmol $m^{-2} s^{-1}$). Plantlets required a lower light intensity than seedlings did (Li *et al.* 2012). Clearly, the light intensity used by Chen *et al.* (2013) is too low to cultivate strong rape seedlings. In fact, there have been no reports to date on a suitable light intensity of LED lights for cultivating rape seedlings. In addition, photosynthetically active radiation and light conversion efficiency differ between solar and artificial light, and therefore the optimal light intensity of artificial light cannot be predicted from the optimal intensity of solar light. Photosynthetic pigments mainly absorb light in the red and blue regions of the spectrum (Pan 2000). Previous studies have shown that red and blue composite light significantly improve the photosynthetic rate and promote plant growth (Chang *et al.* 2010; Wang *et al.* 2011; Chen *et al.* 2013). Rape and non-heading Chinese cabbage both belong to the Cruciferae, and Chinese cabbage was reported to grow vigorously under composite lights at a ratio of three red to one blue. The addition of red light at 630 nm can increase the spectral width, which was shown to benefit rice seedling growth (Liu *et al.* 2015). In our previous research, we found that rape seedlings grew well under a combination of red LEDs with peak wavelengths of 630 and 660 nm and blue LEDs (B) with a peak wavelength of 445 nm (unpublished).

In this study, we evaluated the leaf development of rape seedlings grown under water-cooled LED lamps as described in our previous study (Liu *et al.* 2015), with natural light as the control. We investigated the effects of different light intensities on the leaf microstructure and growth of rape seedling grown under a combination of red and blue LEDs. We measured photosynthetic pigment contents and observed the structure and arrangement of mesophyll cells, chloroplasts, and stomata. Based on our results, we speculated about the self-adjustment ability and regulation mechanisms related to leaf microstructure of rape seedlings under different light intensities. These results allowed us to define a suitable light intensity to cultivate rape seedlings in an indoor system.

2. Materials and methods

2.1. Plant materials and growth condition

This experiment was conducted at the Nanjing Agricultural University, China in 2015. Seeds of rape (*Brassica napus* L.), provided by the oil crop research group of Nanjing Agricultural University, were soaked in distilled water at 30°C for 24 h, and then germinated in an incubator at 28°C. The seeds were cultivated in growth medium under natural light