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Note

Effects of Sources and Quality of LED Light on Response of *Lycium chinense* of Photosynthetic Rate, Transpiration Rate, and Water Use Efficiency in the Smart Farm

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Abstract Smart farm is a breakthrough technology that can maximize crop productivity and economy through efficient utilization of space regardless of external environmental factors. This study was conducted to investigate the optimal growth and physiological conditions of Chinese matrimony vine (*Lycium chinense*) with LED light sources in a smart farm. The light source was composed of red + blue and red + blue + white mixed light using a LED system. In the red + blue mixed light, red and blue colored LEDs were mixed at ratios of 1 : 1, 2 : 1, 5 : 1, and 10 : 1, with duty ratios varied to 100%, 99%, and 97%. The experimental results showed that the photosynthetic rate according to the types of light sources did not show statistically significant differences. Meanwhile, the photosynthetic rate according to the mixed ratio of the red and the blue light was highest with the red light and blue LED ratio of 1 : 1 while the water use efficiency was highest with the red and blue LED ratio of 2 : 1. The photosynthetic rate according to duty ratio was highest with the duty ratio of 99% under the mixed light condition of red + blue + white whereas the water use efficiency was highest with the duty ratio of 97% under the mixed light of red + blue LED. The results indicate that the light source and light quality for the optimal growth of *Lycium chinense* in the smart farm using the LED system are the mixed light of red + blue (1 : 1) and the duty ratio of 97%.

Key words: mixed light, duty ratio, physiology, shrub

INTRODUCTION

Due to frequently occurring abnormal weather, various weather changes occur involving localized heavy rain, drought, and heavy snowfall; as a result, damages to human food production are increasing. The Ministry of Environment predicted that the global temperature would rise

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above 1 to 3°C, reducing the potential for food production. In France and Italy, fruit and grain yields are decreased by 25～30% compared with the year 2002 (Cias *et al*., 2005). In Korea, cultivation areas for apple, as well as highland crops, are remarkably reduced due to temperature rise, alarming a risk for its stable supply. It is also reported that productivity and quality of the paddy are impaired due to shortened growth period and early ripening (Shim *et al*., 2008a), while warm winters cause wintering insects to increase, so harmful effect caused by insects on food production is expected (Shim *et al*., 2008b). Such changes led to the establishment of smart farm that can produce crops through effective utilization of space regardless of external environmental factors.

Smart farm are computer-integrated systems (Hashimoto, 1991) that artificially control environmental factors such as light, temperature and humidity, CO_2 concentration, and nutrient solution through computers mainly for vegetables and seedlings inside the facilities. This type of protective cultivation under facilities can produce crops through automation regardless of seasons or locations, with the same crops produced in a planned manner (Despomimer and Ellingesen, 2008). Smart farm can be broadly categorized into two types. One is a smart farm using sunlight based on the sunlight to cultivate plants and to improve light conditions using artificial supplementary lights when sunlight is insufficient. These smart farms are facilities that are not completely disconnected from the external environment and cannot control the environmental factors perfectly, causing heavy use of pesticides due to the occurrence of pests (Son, 1997). Meanwhile, a fully controlled type of smart farm completely disconnects the external environment whereas hydroponics is carried out under artificial lights. This fully controlled type of smart farm aims for the automatic production of crops, which results to less use of pesticides by less occurrence of pests (Lee, 2010).

The light sources used in the smart farm include incandescent lamps, sodium metal lamps, fluorescent lamps, and LEDs for the cultivation of the plants. High-voltage sodium lamps generate a considerable amount of heat and the distance from plants should be sufficiently maintained, by which these lamps cannot be used in the multi-layer smart farms that are mainly installed in a narrow space. In addition, high-voltage sodium lamps and metal halide lamps consume high power; blue light and red light, which are effective for the photomorphogenesis reaction of plants, are insufficient and the light utilization efficiency by plants is low. Unlike these artificial lights, LEDs have several merits which require when plants are cultivated in the smart farm. Firstly, natural light contains various light sources, but LED is a single-colored light, which can cultivate plants by selecting wavelength that is effective for the tracheal development or photosynthesis. Secondly, LEDs emit far less heat compared to the high voltage discharge types of lamps such as high-voltage sodium lamps or metal halides lamps, giving benefits of lesser heat-induced damages for the plants throughout the cultivation period (Lee, 2010). Thirdly, mercury is not used in the LED, which makes the LED environment-friendly, economical due to its long life of 10,000～50,000 hours, and power-efficient (Hwang *et al*., 2004; Yoon, 2012). Fourthly, since sunlight contains various light wavelengths, it is difficult to identify specific optical wavelength conditions that have optimal growth physiological effects of the target plants (Lee, 2010), but LED light sources can selectively supply specific light that can affect plant growth and physiological responses. These LED lights with several merits are being used in the field of photobiology including photosynthesis, chlorophyll, and photomorphogenesis (Robin *et al*., 1994; Tripathy and Brown, 1995; Tanaka *et al*., 2009; Lee, 2010).

Currently, the growth and eco-physiological researches for the vegetables including leafy vegetables according to the lighting environment conditions are progressing (Cho *et al*., 1998; Park and Lee, 1999). However, the data for the tree plants are lacking. Therefore, this study was conducted to investigate the growth and eco-physiological changes for the medicinal plant *Lycium chinense* according to the mixed ratio of red and blue LED light sources and the duty ratio.

MATERIALS AND METHODS

1. Target plant

The target plant, *Lycium chinense*, is a woody plant belonging to the family *Solanaceae*. Its size is about one meter and it is widely being used for medicinal, ornamental, and greening purposes. Fruits of *Lycium chinense* are sweet and non-toxic longevity food that brightens the eyes. Recently, there have been several researches published for the extracts of *Lycium chinense*. Hwang *et al*. (2009) reported that the extracts from the fruits of *Lycium chinense* were an excellent aid for dropping blood sugar level and are effective for the prevention and treatment of diabetes. Yoon *et al*. (2000) reported that extracts of *Lycium chinense* were effective in detoxifying alcohols. In addition, several researches are

Table 1. Nine light treatments with LED source, LED ratio (mixed ratio of red (R), blue (B), and white (W) LED element), light intensity, and duty ratio.

Gradients	LED source	LED ratio	Light intensity ($umol^{-1}$ m^{-2})	Duty ratio (%)
T1	R+B	1 : 1	256.1±13.5	100
T2	R+B	1 : 1	196.5±17.6	99
T3	R+B	1 : 1	196.3±18.2	97
T4	R+B	2 : 1	203.5±44.8	100
T5	R+B	5 : 1	186.0±40.9	100
T6	R+B	10 : 1	167.0±41.7	100
T7	R+B+W	1 : 1 : 1	248.0±23.9	100
T8	R+B+W	1 : 1 : 1	220.4±38.7	99
T9	R+B+W	1 : 1 : 1	203.9±28.6	97

being conducted in foreign countries including the study for the prevention of aging with the extract of *Lycium chinense* (Chang and So, 2008).

2. Lighting conditions in the smart farm

The lighting treatment conditions applied in the smart farm are shown in Table 1. The types of lighting were constructed as red+blue mixed light, as well as red+blue+white mixed light, using the LED grow system (Parus Co. 2010).

Red light (R) and blue light (R) are the light sources mainly used by plants for photosynthesis. Red light plays an important role in the photosynthetic rate, tracheal formation, and accumulation of starch, while blue light is essential for chlorophyll formation and the development of stomatal conductance (Cosgrove, 1981; Akoyunoglou and Anni, 1984; Saebo *et al*., 1995).

The size of smart farm were 120 cm in width, 52 cm in length and 50 cm in height. It has 4 lines of LED lighting, and it consist of 18 elements in one line of LED lighting. The size of LED element is the same as 1cm and power consumption is 160watt. In this study, the mixed ratios of the red and blue LED light were set as 1 : 1, 2 : 1, 5 : 1, and 10 : 1 using the LED element. The optimal spectrum of each light source reached its peak when the wavelengths of the light were measured at 630~660 nm with R, 440 nm with. White LED light was used that its wavelength is 450~540 nm.

The duty ratio is a term used in a pulse having a cycle and refers to a ratio of a time during which a current flow over time and does not flow against time. That is, it is a ratio of time when the pulse is turned on during one cycle (Jao and Fang, 2004). Therefore, LED in the smart farm has a potential to save power by controlling duty ratio. Based on the theory, duty ratios in this study were adjusted to 97%, 99%, and 100% under the red+blue mixed light, as well as red+blue+white mixed light conditions.

3. Plant growth and measurement

The experimental plants were grafted with plants (length 15 cm and diameter 1.3 cm) grown for one year in the field from the *Lycium chinense* Experimental Station, Cheongyang, Chungcheongnam-do in Oct. 2011 and transplanted in the plant pots (height 20 cm and diameter 25 cm) filled with bed soil (horticultural bed soil with mineral supplements, Han Aruem Co.) for three plants per pot. One plant pot was allotted per light treatment. The fertilizer (GoldSoil, KGChemical Co.) which consists of 70% organics, 4.3% nitrogen, 1.7% phosphoric acid, 1% potassium, was diluted in water by 3% and supplied every 7 days as a soil nutrient. The plants were grown from Oct. 2011 to June 2012. Water was supplied every 2 to 3 days during the experiment period. The average photosynthetic photon flux density of each smart farm chamber was 150.59±27.29 $\mu molm^{-2}$ s^{-1}. Temperature was set at 19.42±5.10°C on average and adjusted using a cold and hot-air circulator (SS-2000, Zero engineering Co, Korea). Humidity was kept at an average of 71.81±9.22% using a humidifier (Fox-1H, Parus Co, Korea). The CO_2 concentration within the smart farm was at 401.59±86.87 ppm during cultivation. Above-mentioned data were collected in computer and were measured every 10 minutes using LCSEMS (PARUS Co., Korea). Photoperiod was set at 16 hours out of 24 hours.

Physiological response was measured using a leaf which is the end of shoot of each individual in each lighting treatment in June 2012. To investigate the physiological response of *Lycium chinense* photosynthetic rate, transpiration rate, and water use efficiency were measured. Photosynthetic rate and transpiration rate were measured by Photosynthesis measuring apparatus (Lci Ultra compact Photosynthesis System, ADC Co.). Water use efficiency was calculated from dividing the photosynthetic rate by the transpiration rate.

4. Statistical analysis

A statistical analysis was carried out to investigate the differences in responses for the photosynthetic rates, transpiration rate, and water use efficiency of the *Lycium chinense* according to each lighting treatment. The normality test results for the data did not exhibit a normal distribution.

Therefore, non-parametric statistical analysis Mann-Whitney U test and Kruskal-Wallis ANOVA were used. The significance of difference in the light environment was analyzed by post hoc analysis at the 5% least significant difference level. STATISTICA 8 (Statsoft, Inc., Tulsa, OK, USA) was used for statistical analysis.

RESULTS AND DISCUSSION

1. Reponses to mixed lights

The eco-physiological responses of the *Lycium chinense* under the red + blue mixed light and red + blue + white mixed light conditions are as follows. The photosynthetic rate and water use efficiency did not differ with all the treated lighting conditions, but the photosynthetic rate and water use efficiency were high under the red + blue + white mixed light condition while the transpiration rate was high under the red + blue mixed light condition (Fig. 1). The water use efficiency was high under the red + blue + white mixed light condition because the transpiration rate which indicates the amount of evaporated water is low, making water use efficiency display relatively high.

In the similar preceding research with the other plant species, Goins *et al.* (1997) published that when the wheats were irradiated with the blue light along with the red light (red + blue mixed light), the photosynthetic rate was increased. Furthermore, in the research conducted by Okamoto *et al.* (1996), the photosynthetic rates per leaf area were high under the red and blue mixed light regardless of rice varieties.

2. Effects of mixed ratio of red light and blue light

The eco-physiological responses of *Lycium chinense* according to the mixed ratio of the red (R) and blue (B) are as follows. The photosynthetic rate and the transpiration rate were highest with the R and B ratio of 1 : 1, while these values were lowest under the ratio of 10 : 1 (Fig. 2). The water use efficiency was highest with the R and B ratio of 2 : 1, but it was lowest with the R and B ratio of 10 : 1. These results indicate that the eco-physiological response of *Lycium chinense* became lowered as the ratio of the red light was increased.

The obtained experimental results were similar with the decreased physiological responses in the *Boehmeria nivea*

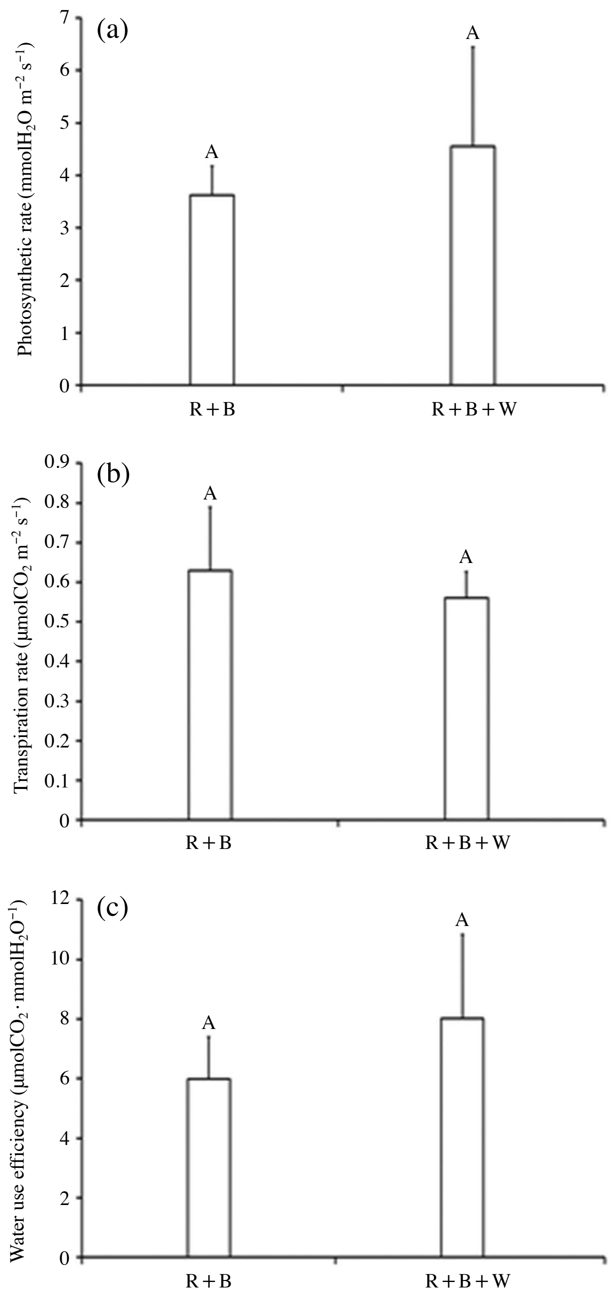

Fig. 1. Photosynthetic rate (a), transpiration rate (b), and water use efficiency (c) of *Lycium chinense* under the different LED light quality treatments (R + B means red + blue, R + B + W means red + blue + white). The different letters on the bars refer to significant differences between lighting treatments ($p < 0.05$). Vertical lines on the bars mean standard deviation.

when the ratio of the red light was high in the red and blue light ratio (Lee, 2013). It is because in general, plants can have high stomatal conductance by the blue light (Sharkey and Raschke, 1981), and as the stomatal conductance is

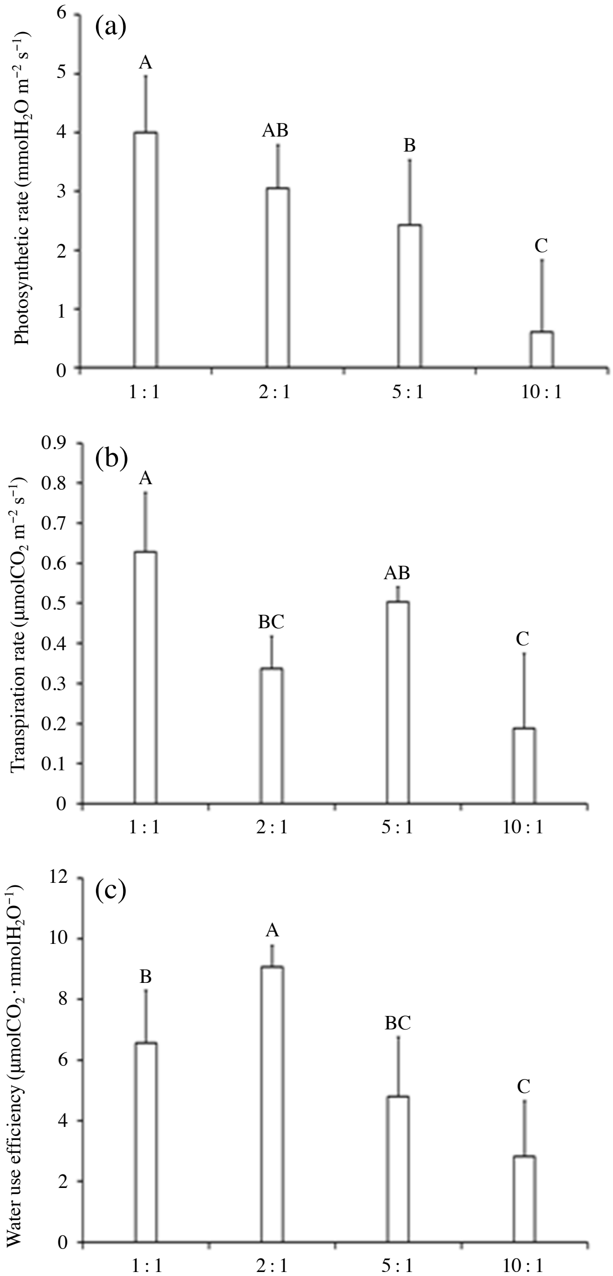

Fig. 2. Photosynthetic rate (a), transpiration rate (b), and water use efficiency (c) of *Lycium chinense* under mixed ratio of red and blue (1 : 1, 2 : 1, 5 : 1, and 10 : 1) LED element. The different letters on the bars refer to significant differences between lighting treatments ($p<0.05$). Vertical lines on the bars mean standard deviation.

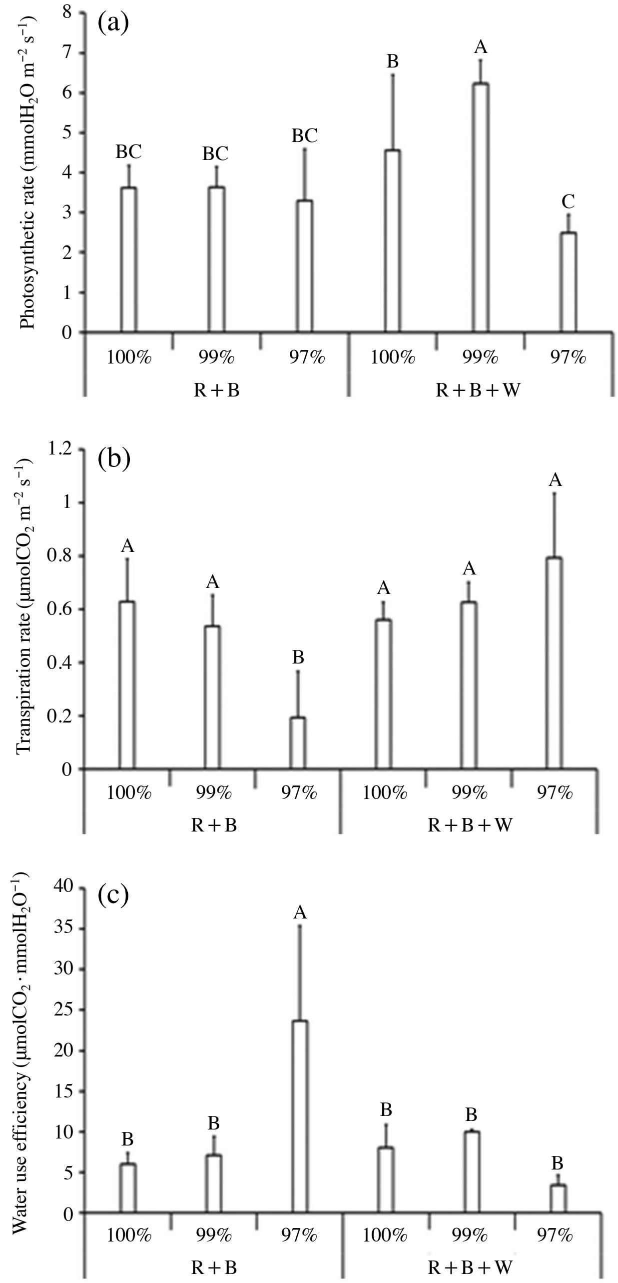

Fig. 3. Photosynthetic rate (a), water use efficiency (b), and stomatal conductance (c) of *Lycium chinense* are under the duty ratio (100%, 99%, and 97%) of mixed light with red + blue (R + B) and red + blue + white (R + B + W) LEDs. The different letters on the bars refer to significant differences between lighting treatments ($p<0.05$). Vertical lines on the bars mean standard deviation.

increased, the carbon fixation capacity and water use efficiency of the plans are increased (Park *et al.*, 2016). Therefore, it is judged that for the *Lycium chinense*, eco-physiological responses could be improved if it is cultivated under the condition of red and blue mixed light ratio of 1 : 1. On the contrary, the water use efficiency was highest when the plant was cultivated with the red and blue light ratio of 2 : 1, which means a low transpiration rate of the plant, drawing conclusion that the *Lycium chinense* can be also efficiently grown with a red and blue light ratio of 2 : 1 when cultivated in the soil having insufficient moisture.

3. Effects of duty ratio

The eco-physiological responses of *Lycium chinense* according to the duty ratio are as follows. The photosynthetic ratio was highest with the duty ratio of 99% under the mixed lighting condition with the red + blue + white. It was lowest with the duty ratio of 97% under the mixed lighting condition of the red + blue + white. Meanwhile, the transpiration rate was lowest with the duty ratio of 97% under the mixed lighting condition with the red + blue whereas the water use efficiency of the *Lycium chinense* was highest with the duty ratio of 97% opposite the transpiration rate. This high water use efficiency might be due to the low transpiration rate with the duty ratio of 97% under the mixed lighting condition of red + blue.

In the research by Kim *et al.* (2014) similar to this study about the growth responses of the six types of leafy vegetables towards the light sources and light quality inside the smart farm, cultivation with the duty ratio of 97% under the mixed light condition of red + blue + white could save energy and produce good quality crops. In addition, in the experiment by Hashimoto *et al.* (1987) wherein the duty ratio and CO_2 were controlled, the CO_2 net respiration with the duty ratio of 50% could be pulled up to the level with the duty ratio of 100% by controlling CO_2 concentration under the duty ratios of 100% and 50%. With the above experimental results and preceding research outcomes, it could be suggested that when the duty ratio is made as low during cultivating *Lycium chinense*, electric energy could be saved to improve excessive power input which is a drawback in the smart farm.

Author Contributions All authors conducted a study together during the study period. Seungyeon Lee wrote the manuscript. Younghan You participated in the design of the study and examined the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest The researcher claims no conflicts of interests.

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