Effects of LED Light and Temperature on Lettuce Growth

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Abstract This study examines the effects of light-emitting diode (LED) light and temperature on lettuce growth. For plant growth, we used an LED bar composed of red, white and blue LEDs (4:1:2). Six types of cultivation equipment were used to measure the temperature. To compare their effects, the heights of the lettuces and the water temperatures were measured. The results demonstrated that the lettuce growth was optimal at 25ºC.

Keywords LED · Lettuce · Temperature

1 Introduction

1.1 Summary

Recently, plant factories that use light-emitting diodes (LEDs) have been attracting a great deal of attention. One reason for this is that, as the cultivated area of a single crop increases, disease outbreaks and insect pests for which these plants are hosts also increase. Accordingly, pesticides to prevent diseases and insect pests have been developed and sprayed, but these crop dustings kill not only the disease and insect pests but also other beneficial insects or microorganisms that form food chains, ultimately culminating in a hugely destructive environmental problem. Furthermore, recurrent and abnormal climate problems, such as global warming and frequent rainfalls, have serious impacts on agriculture. Studies on plant factories have begun in an effort to solve these problems. Plant factories are advantageous because they can produce crops regardless of season or location (e.g., at the South Pole) by artificially controlling the environmental conditions inside the facilities, such as the light, temperature, humidity, carbon dioxide concentration, and culture medium.

1.2 Lighting in the plant factory

At first, incandescent light was used as the light source in the plant factory; it has subsequently been replaced by LEDs, based on the results of continuous studies that have reported that LEDs emit the optimum wavelengths for plants, generate less heat, and have a long lifespan. To date, fluorescent light has mainly been used for plant cultivation using artificial light (Kim 2009, 2010).

In general, the known photoconversion efficiencies for incandescent and fluorescent light are 8% and 20%, respectively. However, the LED efficiency is 25-30%; additionally, LEDs emit much more light and less heat than fluorescent light. Thus, LED light sources can be installed closer to plants. The intensity of the light is inversely proportional to the square of the distance from the light source. Consequently, as fluorescent light must be installed some distance away from plants because it generates a large amount of heat, the intensity is inevitably weaker (Park 2010). This

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light loss problem is crucial when addressing plant cultivation using artificial light.

LED light can easily be used for plant cultivation, as its wavelength is narrower and monochromatic. Furthermore, it is possible to choose a certain wavelength of monochromatic light that only emits the wavelength that is necessary for plant photosynthesis. During plant cultivation, it is possible to effectively cultivate plants using two main ranges of wavelengths, red (660 nm) and blue (450 nm), which are effective for photosynthesis (Lee 2010).

Light consists of many colors, and each color of light plays a different role. Blue and ultraviolet rays react chemically, whereas red and infrared rays generate heat. Plants appear green because they reflect most green light; therefore, green light is ultimately not particularly helpful for plant growth. Hence, even when plants are provided with complete sunlight or fluorescent light, they only select and absorb the colors that are needed for photosynthesis. Thus, with LED lights, selecting and combining the colors of light that plants require is simple and lessens the unnecessary loss of light. Additionally, using LED lights miniaturizes the lighting product, such that it can be used in a relatively small space. LED lights are also economical because they consume less electricity and generate less heat, and their lifespan is semi-permanent (Park 2010).

When LEDs are used as the light source for plant cultivation, certain functions (such as promoting photosynthesis, controlling flowering, enhancing coloring, increasing the content of sugar and saponin, and controlling mold outbreaks) can be regulated using certain monochromatic lights. Plants fixate carbon dioxide and synthesize carbohydrates using light, and the amount of synthesized carbohydrates is determined by the quantity of the light. The quantity of the light that is related to plant photosynthesis is not expressed in lux or lumens, which are the commonly used units of illumination in lighting; instead, it is expressed in units such as the photosynthetic photon flux density (PPFD) or photosynthetic active radiation (Lee 2010).

1.3 The purpose of this study

This aim of this study was to find the optimum range of conditions for controlling the environment inside a plant factory. First, an experiment was conducted to analyze the changes in the temperature environment. Control groups of plants with different temperature environments were used in the experiment. The dependence of the plant growth velocity on the temperature change was analyzed. By adjusting the plant growth velocity via alterations in the temperature inside the plant factory facilities based on the optimum conditions, applications for more efficient management become possible.

2 The plant factory

2.1 Definition and significance of the plant factory

The term "plant factory" ("vegetable factory" in English) is mainly used in Japan. It is also called a “vegetable factory” because the main cultivated crops are vegetables. Masamoto Takatsuji, who is the chairman of the Committee of Agricultural, Commercial, and Industrial Experts on Plant Factories and is known as the godfather of the study of plant factories in Japan, defined a plant factory as “a system that continuously and automatically produces crops, mainly vegetables or seedlings, without being limited by the season or place, and by artificially controlling the environmental conditions, such as the light, temperature, humidity, carbon dioxide concentration, and culture medium, inside the facilities.” These systems can be regarded as the factory production of vegetable crops. The core of the definition of the concept of a plant factory is the factory production method. Two elements, the quantification of production and mass production, are the characteristics of factory production; thus, emphasis is placed on realizing the quantification and promotion of growth. The growth rate of salad vegetables is known to be 5-6 times faster in plant factories than in outdoor cultivation. The production method of plant factories is different than that of outdoor cultivation. The characteristics of plant factories render the notion of facilities agriculture possible; it is not strongly, if at all, affected by natural conditions, such as the climate or geography. It is also possible to generate stable, year-round agricultural production, regardless of the changes in the seasons, using controlled facilities and scientific devices. Further, it is possible to ease price changes in the market and predict agricultural incomes via the production of uniform, standardized, and high-quality agricultural products (Kim 2010).

2.2 History of the plant factory

In 1957, the Christensen farm in Denmark was equipped with a mass production system for cress. It moved crops across flat-surface facilities using a conveyor belt system for pollution-free cress production and was equipped with a sowing room, a germination room, a nurturing room, and a shipment room. Afterwards, high-pressure sodium lamps with high-pressure gas were used as light sources that supplemented sunlight. This was the first inception of the plant factory. Such plant factories have spread to the Netherlands, Belgium, and Austria.

The cultivation methods for lettuces and tomatoes using the three-dimensional vertical movement system began in Ruther, Austria, in the early 1960s. Next, in the 1970s in the United States, General Electric, General Mills, and General Foods successively developed fully controlled plant factory production systems. However, these systems were terminated due to a lack of profitability. Later, in the 1980s, Agrisystems and Agronotic commercialized large-scale, automated, and partially controlled plant factory production systems. In Korea, studies of roses and green vegetables, including lettuce, have been conducted at the Rural Development Administration, the University of Seoul, Seoul National University, and Chonbuk National University since 1990. Additionally, studies on work process automation and closed seedling production have been conducted by Seoul National University and Chonbuk National University, respectively, since 2000. Then, in July 2009, the Korean government selected and supported “Challenges for Developing the Core Components of IT-LED-Based Plant Factories” as the New Growth Engine SMART Project and supported private efforts toward plant factory research and development at the government level. The Jeonju Biomaterials Institute began to actually manage plant factories, starting on a 60-m^2 scale and ultimately testing a 100-m^2 facility. Various simulations for measures to reduce the initial investments and operating costs have since been and are currently being attempted in the first 220-m^2 basement, proceeding at the same time as the review of the cultivation methods of various crops. In addition, facilities to conduct the adaptation testing of a fully closed, 400-m^2 plant factory are under construction at the Jeollabuk-do LED Convergence Support Center (Iksan Campus, Chonbuk National University). The Korean electronic goods that have commercialized this endeavor are dominating the global market. As a leader in LED technology, Korea is also attracting attention for a plant factory that utilizes LED technology and is conducting tests on the overall light conditions (Doo 2010).

In September 2009, the Rural Development Administration developed a “closed seedling culture system,” a container field of plants at the Antarctic King Sejong Station, which has enabled the production and consumption of vegetables even under intensely cold weather conditions. The Rural Development Administration is also planning to begin construction of a plant factory in 2011 for research purposes. Lately, local governments, such as Namyangju, Bucheon, Incheon, and Iksan, have announced plans to construct plant factories as buildings. Companies are also continuing efforts to commercialize plant factories. Internationally, Japan currently has approximately 50 plant factories and is planning to expand to about 150 factories by 2015. Furthermore, the United States and several European countries are reviewing establishing plant factories as skyscrapers (Park 2009).

2.3 Plant factories and lettuce

Plant factories have dramatically changed by shifting from lettuce production (at the early stages) to herb production systems, which have a high added value later in production. Countries managing such plant factories include the United Kingdom, the Netherlands, Germany, Denmark, Poland, Portugal, Russia, and Sweden. In most of Europe, with the Netherlands at its center, there is a tendency towards partially controlled plant factory production systems, which add artificial light to a large-scale glass greenhouse. In the case of lettuce, approximately 200 g of lettuce can be harvested 16 days after transplantation in the summer and after 23 days in the winter; the sales price is approximately twice the production cost (Lee 2010). Lettuce is the representative crop in terms of the early-stage management of plant factories because it is easier to establish the environment for lettuce to grow and develop compared to other crops; additionally, lettuce has a fast harvest time. Table 1 shows the properties of lettuce as a crop.

Table 1 The crop properties of lettuce

Temperature adaptability	Optimum germination temperature	15-20ºC
	Minimum germination Temperature	4ºC
	Dormancy temperature	25ºC
	Growth disorder temperature	24-26ºC
Sunlight adaptability	Compensation point	1500 lux
	Light saturation point	25 klux
Soil adaptability	The root system spreads up to 1 m in diameter and 1.2-1.5 m in length.	
	The moisture demand is large in the late stages of growth.	

3 Methods

3.1 Experimental setup

The location of the experiment was an indoor space unaffected by the outside temperature and equipped with heating and cooling systems. The indoor temperature was maintained at 22ºC. Various installation heights for the cultivation tables were used in the experiment; the temperatures were low for the lower-level cultivation tables and high for the upper-level cultivation tables. The cultivation table had a length of 152 cm, a depth of 660 cm, and a height of 2000 cm (Figure 1).

Fig. 1 A photograph of the experimental location

3.2 Experimental conditions

The measurement period of the experiment was 36 days, starting on March 22, 2011. The lettuces, which were germinated under identical conditions, were transplanted as seedlings using an LED plant cultivation device. The standard for transplantation was a length of 4 cm for the lettuce seedling leaf, and 20 seedlings were transplanted onto each cultivation table. Furthermore, five types of control groups under identical conditions were procured for the experiment. The LED bar used in the experiment contained a 1-W LED. Figure 2 shows the spectrum of the LED bar.

Fig. 2 An analysis of the spectrum of the LED bar (left, 0.2 W; right, 1 W)

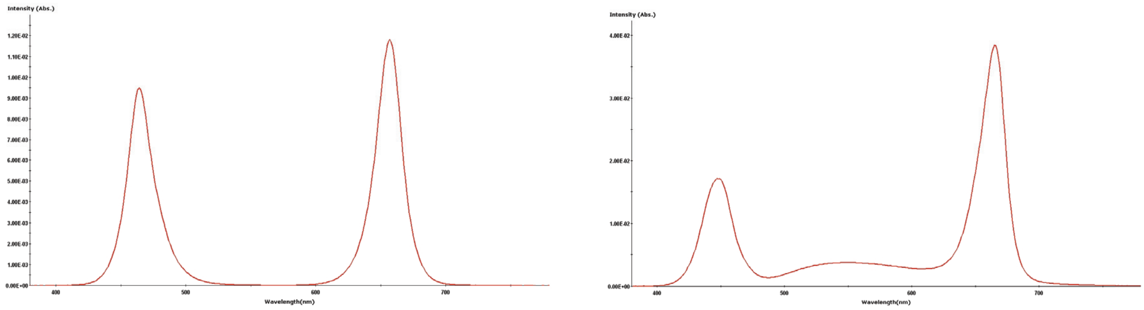
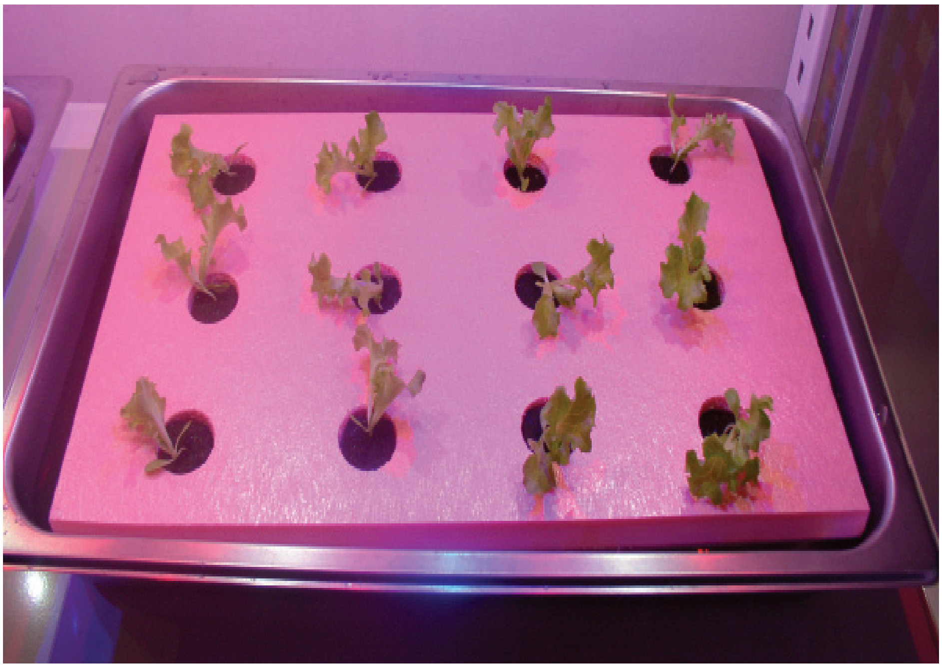


Fig. 3 A photograph of the seedlings after transplantation



This study arranged a total of six types of test groups (A to F) and measured the average heights of the lettuces on each cultivation table. The differences among the water temperatures of each of the lettuce cultivation tables were also determined. Figure 3 shows the seedlings used in the experiment. All of the test group conditions, except for the water temperature, were identical. The experimental conditions were as follows:

A measuring period of 36 days; a 4-cm seedling leaf length at the time of transplant; an average indoor temperature of 22ºC; an average humidity of 50%; a 20-cm distance between the LED and the lettuce; and a red : blue : white wavelength ratio of 4:1:2

3.3 Experiment

The various water temperatures of the test groups (1st floor – 6th floor) were maintained by managing the cultivation tables by level. The water on the first-level cultivation table had an average temperature of 17ºC, and the temperature increased at progressively higher levels. The water temperatures of the cultivation tables were measured regularly (twice per day, at 10 am and 5 pm), and the information was entered in a daily log. Figure 4 and Table 2 show the changes in the cultivation table temperatures over the 36 days. The average cultivation table temperatures were 18-23ºC.

Fig. 4 The cultivation table temperatures

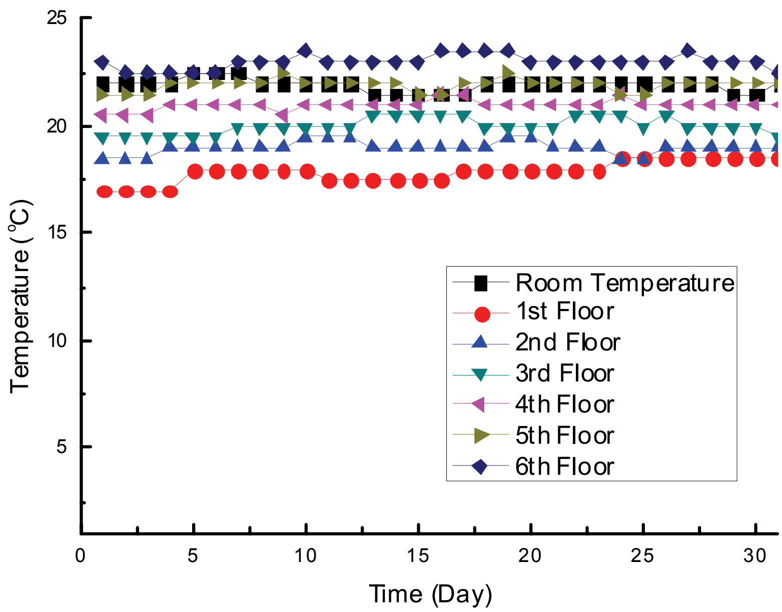


Table 2 The average measured water temperatures of the cultivation tables

Cultivation group	1st floor	2nd floor	3rd floor	4th floor	5th floor	6th floor
Water temperature	18ºC	19ºC	20ºC	21ºC	22ºC	23ºC

The experiment was conducted for 36 days under the conditions described above. The leaf lengths were measured once daily, and the average leaf lengths of 15 seedlings from each cultivation table were measured and recorded in the growth log. Figure 5 and Table 3 show the lengths of the lettuce leaves.

Fig. 5 The lettuce leaf length measurement data

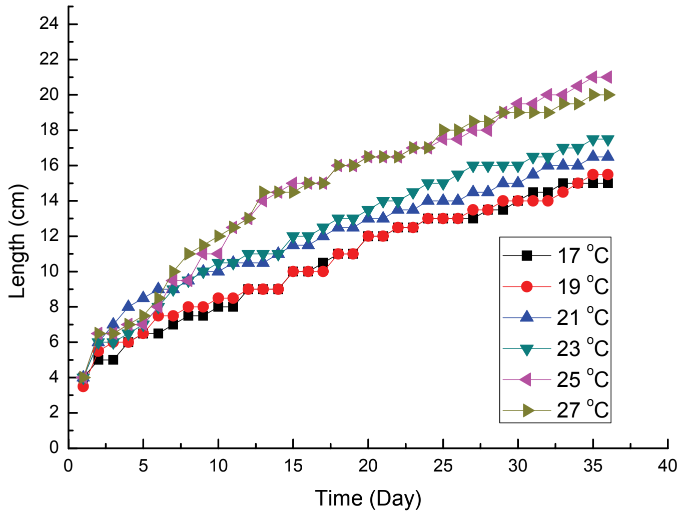


Table 3. The lettuce leaf lengths at the time of harvest

Water temperature	17ºC	19ºC	21ºC	23ºC	25ºC	27ºC
Lettuce leaf length	15 cm	15.5 cm	16.5 cm	17.5 cm	21 cm	20 cm

4 Results and discussion

The control group was placed onto the cultivation tables to measure the effects of differences in the water temperature on the lengths of the lettuce leaves. Growth was observed over 36 days, with all of the conditions (except for the water temperature) kept identical. The results revealed that the lettuce on cultivation table E (average water temperature, 25ºC) had the longest leaves. It was also observed that the growth velocity was considerably lower when the temperature was less than 21ºC than when the temperature was greater than 25ºC.

Plants that are grown with hydroponics are sensitive to changes in the water temperature. To adequately account for this, large amounts of accurate data and supporting materials are necessary. A high temperature does not necessarily aid the growth of lettuce, and the efficient management of plant factories may be possible when the environment of the cultivation room is constructed based on the most favorable temperatures for each crop.

5 Conclusions

This paper analyzed the effects of various water temperatures on the growth of lettuce on cultivation tables built with LED bars with a combination of 1-W red and blue lights. The results of this experiment indicate that the growth rate reached its maximum at 25ºC and declined at warmer and cooler temperatures.

We predict that maintaining the optimum temperature conditions in a plant factory (as determined by this study) will increase plant crop yields. Analyzing the temperature conditions at the location where the cultivation device is installed is desirable. Managing the temperature of the cultivated nutrient solution is especially desirable. Air circulation is also important, as the temperatures of the upper and lower levels of a plant factory are clearly different. Constructing a temperature management program that sets the optimum temperature by regularly monitoring the temperature of the nutrient solution is recommended.

This paper only reports the analysis of lettuce; in future studies, we intend to analyze the growth and development conditions of other vegetable plants, such that this concept can contribute to the formation of optimized plant factory systems.

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