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Radish Sprout Growth Dependency on LED Color in Plant Factory Experiment

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***Abstract*—**Recent rapid progress in ICT (Information and Communication Technology) has advanced the penetration of sensor networks (SNs) and their attractive applications. Agriculture is one of the fields well able to benefit from ICT. Plant factories control several parameters related to plant growth in closed areas such as air temperature, humidity, water, culture medium concentration, and artificial lighting by using computers and AI (Artificial Intelligence) is being researched in order to obtain stable and safe production of vegetables and medicinal plants all year anywhere, and attain self-sufficiency in food. By providing isolation from the natural environment, a plant factory can achieve higher productivity and safe products. However, the biggest issue with plant factories is the return on investment. Profits are tenuous because of the large initial investments and running costs, i.e. electric power, incurred. At present, LED (Light Emitting Diode) lights are being adopted because they are more energy-efficient and encourage photosynthesis better than the fluorescent lamps used in the past. However, further cost reduction is essential. This paper introduces experiments that reveal which color of LED lighting best enhances the growth of cultured radish sprouts. Radish sprouts were cultivated in the experimental environment formed by a hydroponics kit with three cultivation shelves (28 samples per shelf) each with an artificial lighting rack. Seven LED arrays of different color (white, blue, yellow green, green, yellow, orange, and red) were compared with a fluorescent lamp as the control. Lighting duration was set to 12 hours a day. Normal water with no fertilizer was circulated. Seven days after germination, the length, weight and area of leaf of each sample were measured. Electrical power consumption for all lighting arrangements was also measured. Results and discussions: As to average sample length, no clear difference was observed in terms of color. As regards weight, orange LED was less effective and the difference was significant ($p < 0.05$). As to leaf area, blue, yellow and orange LEDs were significantly less effective. However, all LEDs offered higher productivity per W consumed than the fluorescent lamp. Of the LEDs, the blue LED array attained the best results in terms of length, weight and area of leaf per W consumed. Conclusion and future works: An experiment on radish sprout cultivation under 7 different color LED arrays showed no clear difference in terms of sample size. However, if electrical power consumption is considered, LEDs offered about twice the growth rate of the fluorescent lamp. Among them, blue LEDs showed the best performance. Further cost reduction e.g. low power lighting remains a big issue for actual system deployment. An automatic plant monitoring system with sensors is another study target.

***Keywords*—**Electric power consumption, LED color, LED lighting, plant factory.

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I. Introduction

PLANT factories, which control several parameters related with plant growth in a closed area/a greenhouse such as air temperature, humidity, culture medium concentration, and artificial lighting by using sensors have drawn attention in order to obtain the stable production of vegetables and medical plants all year, and increase self-sufficiency in food. The factory is now a frequent sight in air/soil polluted areas, severe weather areas thought unsuitable for plant growth, and even in the Antarctic explorer base. By providing isolation from the natural environment, a plant factory can achieve safer and higher productivity. However, the biggest issue with plant factories is the return on investment. Profits are tenuous because of the large initial investments needed. A report on the cost per 100 square meter (hydroponics vs. green house) stated that the hydroponics had 17 times larger initial CAPEX (Capital Expenditure) (3.1 M$ vs. 180 K$) and 47 times larger OPEX (Operating Expenditure) (186 K$ vs. 4 K$) than greenhouse due to utility fees [1]. It is also known several large plant factories went bankrupt in Japan [2]. There are two major goals in designing efficient plant factories: - lower costs by energy, efficient lighting and air conditioning, and higher plant yields by controlling the radiation and the culture medium [3]. Current plant factories mainly focus on light control. LED lights are being used because of their efficient energy consumption and color variation that encourages photosynthesis better than the fluorescent lamps [3], [4]. The previous paper by the authors clarified the basic experimental setup and plant growth evaluation method [5].

This paper presents experiments that reveal which color of LED lighting best enhances the growth of cultured radish sprouts. The relationship between plant growth and power consumption is measured and discussed.

This paper is structured as follows; in Section II, the experimental setup and materials are given. In Section III, experimental results are discussed, and a conclusion and future works are given in Section IV.

II. Experimental Setup and Materials

A. Experimental Setup

A commercially available hydroponic kit (APN Ltd. [6]) is used for the experiment. The kit has three cultivation shelves each with an artificial lighting rack. Therefore, growth rates on different shelves each with different color can be compared. Table I summarizes the features of LED lights used. Seven different LED lights; white (W), Blue (B), Yellow Green (YG), Green (G), Yellow (Y), Orange (O), and Red (R) and one fluorescent lamp as the control are used. Typical wavelength and the number of chips are also indicated in the table.

TABLE I
FEATURES OF LED LIGHT USED

Color	Typical Wavelength (nm)	# of Chips	Chip Type
White (W)	RGB (463/528/625)	20	LTRB R8SF*
Blue (B)	450 - 475	20	LB G6SP-V2BB-35-1*
Yellow green (YG)	560	20	LP E675-P1Q2-25*
Green (G)	520	20	LT E6SG-AABB-35*
Yellow (Y)	595	20	LY E67F-AABA-35-1*
Orange (O)	610 - 650	20	LO T67F-V1AB-24*
Red (R)	630	20	

*OSRAM Opto Semiconductors [7].

Fig. 1 Hydroponic kit used in the experiment; the fluorescent lamp (top) and two LED lights (middle and bottom) illuminate separate shelves

Fig. 1 shows the hydroponic kit used in the experiment; the fluorescent lamp for the control and two LED lights illuminate different shelves.

Fig. 2 shows cultivation shelf configuration. After several trials, the optimum spacing between plants was set to 2 cm, so that a total of 28 samples could be grown simultaneously on each shelf (indicated by green circles in Fig. 2).

Lighting duration, 12 hours a day, was controlled by the timer. Normal water with no fertilizer was circulated.

B. Experimental Procedures

Experimental procedures are as follows;
Step1. Selection of seed/sample,
Step2. Germination for 3 days,
Step3. Plant and growth for another 4 days on the kit
Step4. Harvesting and measurement of samples.

This procedure is then repeated with other LED colors as the kit used is able to be illuminated by two LED colors, plus one fluorescent lamp, simultaneously.

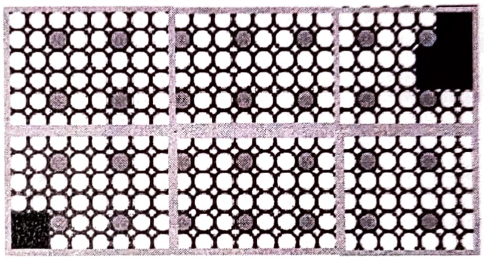


Fig. 2 Cultivation shelf configuration (plan view), green shows the position of plant (28 in total)

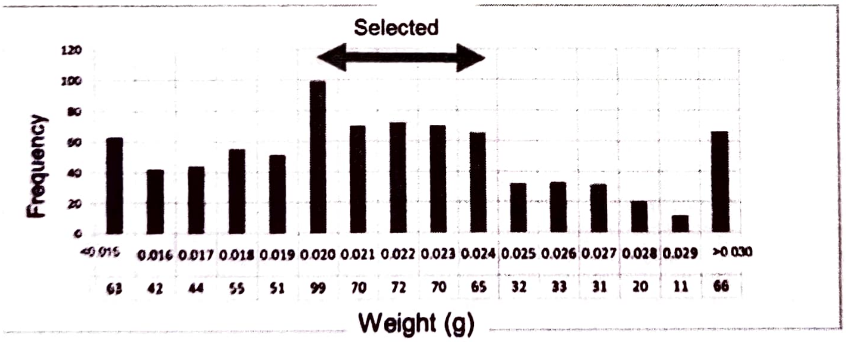


Fig. 3 Weight distribution of seeds in a package; Among them, weighing between 0.020 to 0.024 g were selected

C. Sample

Radish sprouts were selected in the experiment as they have many advantages such as; higher growth rate, maturing in about 7 days from germination, suitability for hydroponics, currently being grown in plant factories, and small size. Commercially available seeds in a package have a variety of weight as indicated in Fig. 3. Therefore, in the experiment, seeds weighing between 0.020 to 0.024 g were selected for germination to eliminate weight dependency effects from plant growth.

D. Measurement for Comparison

Length of the stem, weight and leaf area of each sample were measured for growth comparison. Some details are;

- Length of the stem: Each length from the bottom root to the top of leaf is measured by a ruler,
- Weight: Each weight was measured by the Electric weighing scale, FX-120i; A&D Co. Ltd., with accuracy of

1 mg, and

- **Leaf area:** After taking photo of each leaf spread on a sheet, its area was measured by the free software "lenaraf220b" (its accuracy was confirmed to be better than +/- 3%). Fig. 4 shows a snapshot of PC screen for measuring a leaf area by the free software "lenaraf220b".

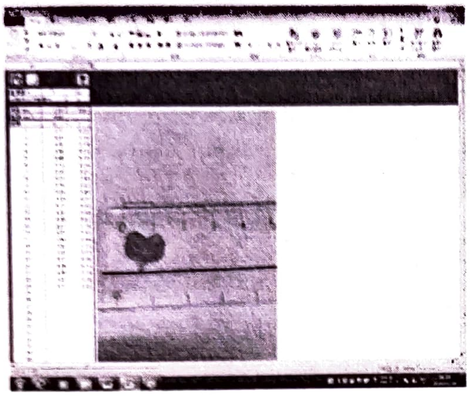
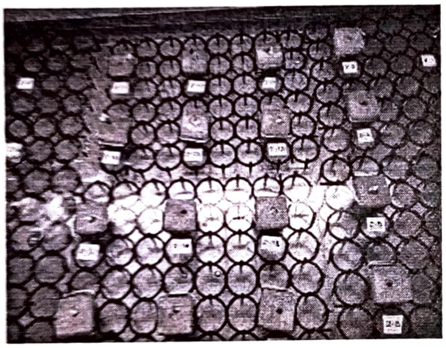


Fig. 4 Snapshot of measurement of a leaf area by the free software "lenaraf220b"



(a)

(b)

Fig. 5 (a) Photo of a shelf on the first day just starting of cultivation, and (b) 3 days after with the green LED

III. Experimental Results and Discussions

Fig. 5 (a) shows a photo of a shelf on the first day just starting of cultivation. Fig. 5 (b) also shows a photo of that on 3 days after with the green LED where radish sprouts grew. Almost similar results were also obtained with all LED colors and FL. Experimental results are shown in Figs. 6-8.

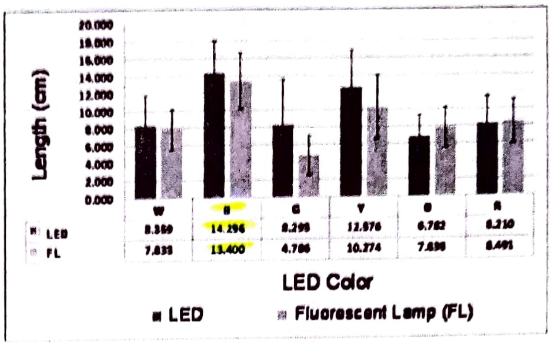


Fig. 6 Measured average length of samples and its deviation for 6 LED lights and the fluorescent lamp

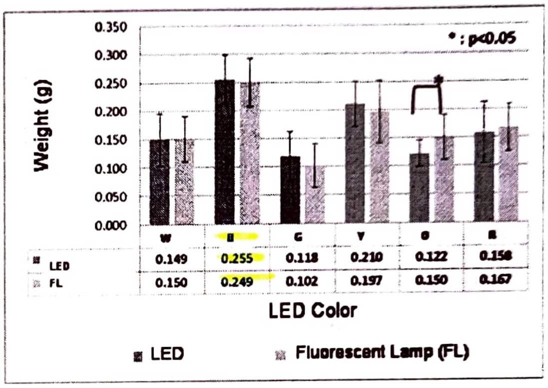


Fig. 7 Measured average weight of samples and its deviation for 6 LED lights and the fluorescent lamp

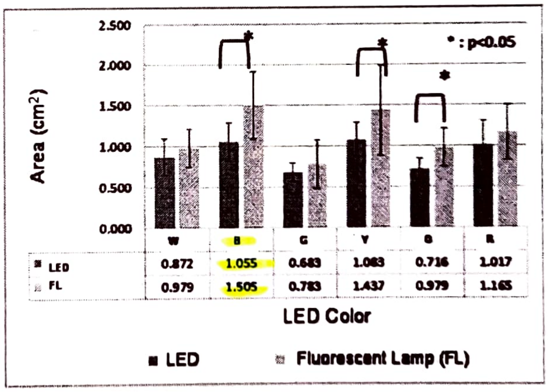


Fig. 8 Measured average leaf area of samples and its deviation for 6 LED lights and the fluorescent lamp

Fig. 6 shows measured average length of samples illuminated by the 6 LED lights and the fluorescent lamp as the control. Error bars in the figure represent the standard deviation (SD). These values were measured by the ruler. As seen, measured lengths differ from each other. However, it is noted that comparison of the length itself has no meaning as all experiments were not performed simultaneously. Therefore, relative values to those by fluorescent lamp (FL) have meaning for color comparison.

As for LEDs with color of W, B, G, and Y, lengths were longer than that for the FL. However, no clear difference was observed in terms of color.

Fig. 7 shows measured average weight of samples that were measured by the electric weighing scale. As for LEDs with color of W, B, G, and Y, values were heavier than that for the FL. Those for LED with O and R were lighter. Orange only had significant difference with $p < 0.05$.

Fig. 8 shows measured average leaf area measured by the software given in Fig. 4. Areas with all LEDs had smaller than that with the FL. Among them, B, Y, and O had significant difference with $p < 0.05$.

All results are summarized in Table II where values are normalized to those of the fluorescent lamp used as the control. Significance is also indicated by the asterisk. As to average sample length, LEDs with color of W, B, G, and Y, values showed longer than the FL. Especially, with G, the average value was about 1.7 times longer. However, no clear difference was observed in terms of color. As regards to weight, almost all were similar. However, orange LED was less effective and the difference was significant ($p < 0.05$). As to leaf area, all colors showed smaller values. Among them, blue, yellow and orange LEDs were significantly less effective.

TABLE II
MEASURED RESULTS (RELATIVE TO THOSE OF FLUORESCENT LAMP)

Color	Length	Weight	Area
White (W)	1.067	0.993	0.891
Blue (B)	1.067	1.023	0.701*
Green (G)	1.733	1.166	0.873
Yellow (Y)	1.224	1.069	0.754*
Orange (O)	0.866	0.812*	0.732*
Red (R)	0.967	0.947	0.873

*$p < 0.05$

TABLE III
MEASURED RESULTS (GROWTH PER W)

Color	Length	Weight	Area
White (W)	1.154	0.021	0.125
Blue (B)	6.663	0.123	0.570
Green (G)	1.690	0.022	0.111
Yellow (Y)	1.156	0.019	0.019
Orange (O)	0.856	0.015	0.015
Red (R)	0.890	0.017	0.105

Experimental results (growth per W) are summarized in Table III. Electric current and voltage applied to each LED was measured by DC ampere and voltage meters while lighting. Then, their values were used for calculating per W values with measured actual values listed in Table II. As seen, blue yields the highest of length, weight and area.

IV. CONCLUSION AND FUTURE WORK

This paper presented experiments that reveal which color of LED lighting best enhances the growth of cultured radish sprouts. The experiment on radish sprout cultivation under 7 different color LED arrays showed no clear difference in terms of sample size. However, if electrical power consumption is considered, LEDs offered about twice the growth rate of the fluorescent lamp. Among the LEDs, blue LEDs showed the best performance.

Future work includes using other samples such as leaf lettuce, and *Lactuca sativa*, to use mixed color light for much higher growth rate, and to use sensors in order to further optimize plant growth. Further cost reduction e.g. low power lighting remains a big issue for actual system deployment. An automatic plant monitoring system with sensors is another study target.

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