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Characteristics of Plant Bioelectric Potential and Purification Function under LED Light

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Abstract—**Recently, plant factory has been establishing and takes off in world wide countries. In the plant factory, the growing environment can be controlled and the crop can also be controlled. The products are growing in an enclosed environment, therefore agricultural chemicals has no use. Secure and safe food producing system can be constructed. However, efficient production formula for the plant (for example vegetable) is not defined well. It is an effective way to control the growing environmental factors using physiology information which are directly obtained from the vegetable. Light plays a key role in plant growth. There is a difference in the amount of production due to light frequency. In this study, plant bioelectric potential is examined under light emitting diode (LED) which is used in plant factory. In future, plant physiological function and environmental response can be understood by directly monitoring the bioelectric potential. The relationship between the potential and air purification capability was examined as an environmental response. As for the result, it became obvious that blue and red lights had highly influence. The lights make great contribution to photosynthesis. The characteristic agrees with effective wavelength of photosynthesis.**

Keywords; plant factory; sensor; bioelectric potential; air purification; LED

I. INTRODUCTION

Recently, awareness for food safety and environmental issues due to climate change is increasing. The plant factory is effective in the issues and food self-sufficiency. The pick-time and the production of the food (for example vegetable, rice and fruits) can be controlled artificially by controlling the growing environment, for example light, temperature and amount of carbon dioxide. Agricultural chemical is unnecessary in a fully-closed factory. Secure and safe production is also possible in the factory. However, high efficiency-production method is not still established and the growing control for environmental factors is based on the experience of researcher and practical farmer. Meanwhile, plant (vegetation) transmits various kinds of information with their growing and environmental variation. One of them is bioelectric potential and it is very complex. The plant-potential characteri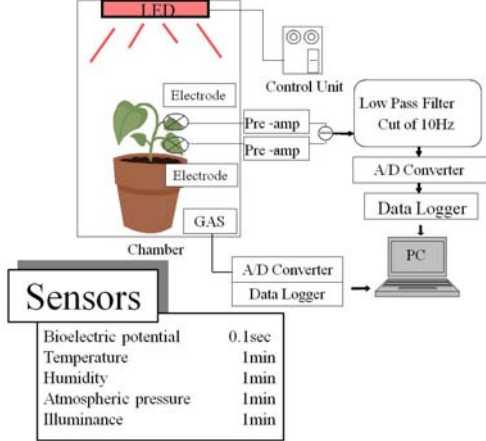stic includes the physiological and environmental information and the growing factors can be controlled using the characteristic. It will make important contributions for the growing and ingathering control. Light (frequency and intensity) plays important roles for the growing of leafy and fruit vegetables. Growing part of plant and the picking season can be controlled by light frequency and intensity in detail. Namely, production control of the vegetation becomes possible. The control which is adjusted for social situation (consumer needs and food self-sufficiency) is possible. The study aims to construct the production control system for improving food self-sufficiency ratio. The system should give due consideration to the nature social environments. Plant bioelectric potential is a kind of internally-occurred electric signal depending on the environmental factors. The potential changes due to variety of factors, namely light, temperature, humidity and atmospheric pressure. If the relationship among the potential characteristic, environmental factors and plant growth can become obvious, the growth could be controlled using the self-generating potential. The relationship between the potential and light frequency is investigated as a preliminary step in this study. And purification capability for an airborne chemical (ethyl alcohol) under LED is also investigated. Plant can intake the chemical as nutrition. The capability is depend on environmental factors, especially light frequency.

II. EXPEROMENT

A pothos (*Epipremnum aureum*) was adopted as the plant in this study. The plant is familiar to humans and it is easy to control to grow in this plant. The pothos is suitable for experiment because environmental factor to grow easily. It was kept in a pot with an internal diameter of 10 cm and a height of 14 cm. the plant height from the bottom of the pot was about 55 cm. The plant was installed in an experimental chamber (Inner volume: $575 \times 510 \times 1000mm$: $300litters$) and the experiment was carried out about characteristics of plant bioelectric potential and purification function under LED Light. The photograph of experimental and diagram of the system is shown in Fig.1. The experimental system was

(a) Photograph of experimental system.

(b) Schematic diagram of the system.
Figure 1. Experimental system.

composed with environmental sensor, LED panel (CCS: ISL-150×150), LED units (CCS: ISC-201-2), bioelectric code, A-D converter, and portable computer. There were four types of LED panel, namely, Blue, Green, Red, and White. Bioelectrical sensor, tin oxide gas sensor (Figaro: TGS#800, Oska) for sensing air purification , temperature・humidity・atmospheric pressure (T&D: TR-73U, Nagano), illuminance (T&D: PHR-51, Nagano) were adopted. And the chamber was set up to protect from light outside. The bioelectric potential's sampling interval is 0.1 s and the others are 1 m. Two electrodes (material: aluminum) are attached to two leaves of plant, which are near the surface of the pot soil and are adjacent. The difference of potential among the electrodes is amplified 100-fold because the original potential of the plant is the order of millivolts. And the signal inputs into a portable computer through an A-D converter and data logger (KEYENCE: NR-350, Osaka). The ground is connected to the soil of pots in this system. A measured characteristic of original data for 1m (600 data) is indicated in Fig.2. The bioelectric potential changes rapidly. It is difficult to derive from relevant to environmental factors. In this study, summation values of the absolute in original data (v_{h1}) were adopted. The equation is shown in Eq. (1).

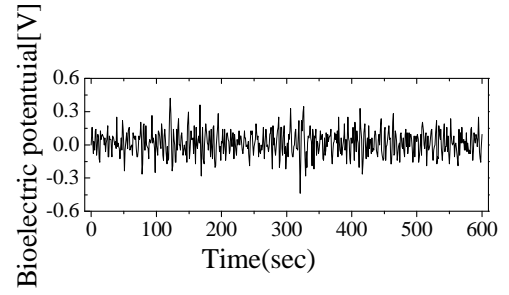$$v_{h1} = \sum_{i=1}^{n} |S_i| \qquad (1)$$

Figure 2. Original characteristic of bioelectric potential for pothos.

A S_i means that the sampled bioelectric potential input every 0.1 s. The study used summation per 1 h, namely, i = 36,000. This summation can observe a trend in the bioelectrical potential responses to environmental factors. In this study, two types of experiment were examined.

1) Characteristics for bioelectric potential under LED

2) Characteristics for purification function under LED

This experience was set at the same time each from 15:00 to 09:00, and measured bioelectric potential to observe relation to environmental factors. Each measurement item was examined in the same condition more three times. In experiment of air purification, Ethyl alcohol was used as a sample of pollution material. The purification experiment was set up as 8ppm in the chamber and the characteristics for decrease in concentration by purification capability of plants were measured. The chemical (Ethyl alcohol) was injected into the chamber using a micro syringe after setting the plant 3h (Offset level). And the purification characteristics were developed [7]. If the plants would largely have a purification capability and be used as food, this study could lead to a high added value. In the feature, these added-value vegetables would be made in plant factory and home garden. It could contribute to more human society. Also it will be considered that a amount of production increases. It is thought that our findings contribute to growth environment and control of production in plant factory.

III.   EXPERIMENTAL RESULT

A. Characteristics for Bioelectric Potential under LED

 i).   Radiation bioelectric potential under lights

LED panels can shed light on the plant with four types of light, namely, Blue, Green, Red, and White. By photosynthesis, all plants including fruit vegetable and leaf vegetable grow with various parts formed. It is expected that the circadian rhythm of plants is disturbed by difference time and fluctuation and times are slightly different about physiological effect. Day length time is also largely related to photosynthesis rate. It is considered that time dilation differs due to frequency of irradiating light. In this study, first, a bioelectric potential under dark as control was measured in a row. And then those under LED lights were measured. Measured characteristic under red light and dark is shown in Fig.3. This figure shows similar
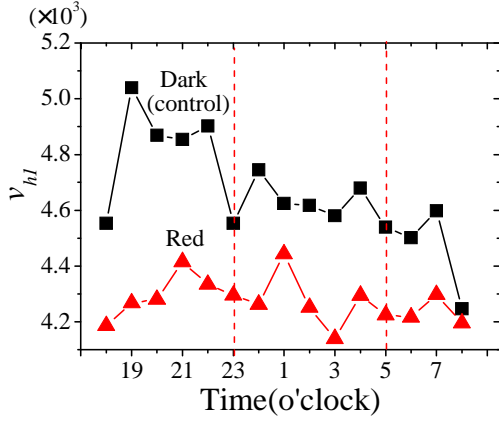
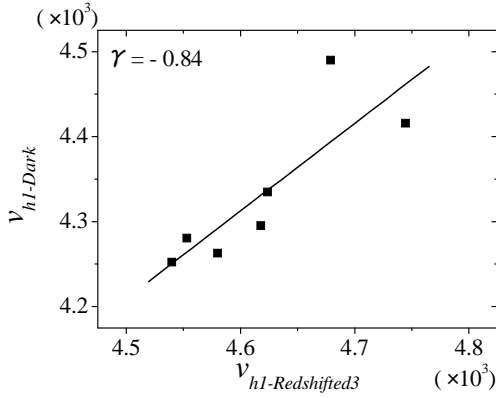Figure 3. Bioelectric characteristic (v_{h1}) in Red LED and under darkness.

Figure 4. Scattering Diagram (v_{h1Dark}-$v_{h1Redshifted3}$) for the shifted characteristic for 3 hours in red light and the control characteristic.

Figure 5. Illuminated light frequency and the maximum correlative relationship.

trends. In these characteristics, the characteristic under the LED lights are given by the 1 h than one in darkness and the correlation coefficient γ between shifted characteristic and control is introduced. The scatter graph is indicated in Fig.4. It was recognized that the γ has a maximum value between control v_{h1Dark} and $v_{h1Redshifted3}$ at the shifted period of 3h under red light. The characteristic has time lag for 3 h. Equally, characteristics under Blue and Green lights and these results are shown in Fig.5. A horizontal axis means wave length, and a vertical axis means maximum correlation coefficient to v_{h1LED}. The experimental results denoted the tendency of disturbing a circadian rhythm in plants. In fact, a wave length is longer light, a control characteristic more significantly delay, according to Fig.5.

  ii). Relation in between bioelectric potential and light frequency

The fluctuation of bioelectric potential was examined by light frequency. Histograms of these bioelectric potential for control (Dark), Blue, Green, and Red was examined. By comparison, the average of control (v_{h1Dark}) is the highest among that of v_{h1LED}. It is thought that the plants have effect to substantial stress under dark. This characteristic was indicated in Fig.6 (a). A lot of data in dark was measured for comparison. The average of the bioelectric potential (Ave) is
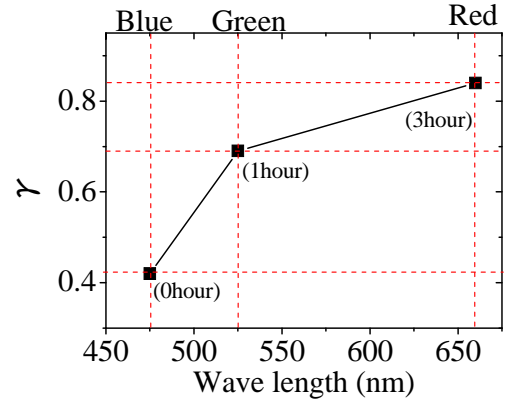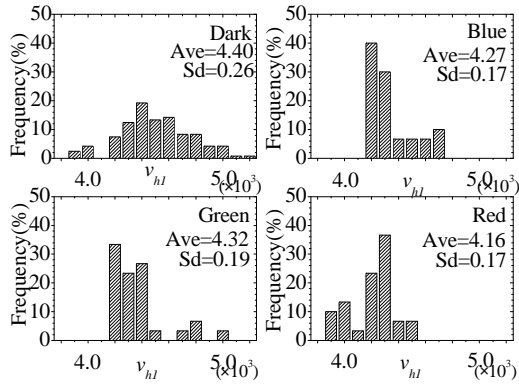
the most largely value under Green light and followed by one under Blue light. And one under Red light means the smallest. It is not clear yet that the large or small bioelectric potential stress associate with plant's stress. By investigating these functions, it is thought that the relationship between the bioelectric potential and the stress become clear. In general, the sunlight includes various kinds of frequency light. In this experiment, the panel of White light is close to the sunlight. The data under white, Blue, Green, and Red light are marshaled and these histograms are shown in Fig.6 (b). The average (Ave, unit: 10^3[V]) of 4.27 under White light and the ones of 4.25 among Blue, Green, and Res light is derived. This result becomes pretty much the same. In the Fig6 (a), the control (Dark) was considered as a standard of comparison. The averages of the bioelectric potential ($difv_{h1}$) were derived and plotted as Fig.7. The $difv_{h1}$ is indicated in Eq. (2). As is clear from the figure, difference value is higher under red light and bioelectric potential becomes small as compared with that under dark. The red light also the most important contributes to the photonic synthesis It is said that the photonic synthesis is the most effective to the photosynthesis rate in the case of rate ten to one between red light and blue light [8, 9]. Namely, as indicated in Fig.6 (a), the bioelectric potential becomes high under dark and green light.

$$difv_{h1} = ave\ (v_{h1\text{-}control}) - ave\ (v_{h1})\qquad(2)$$
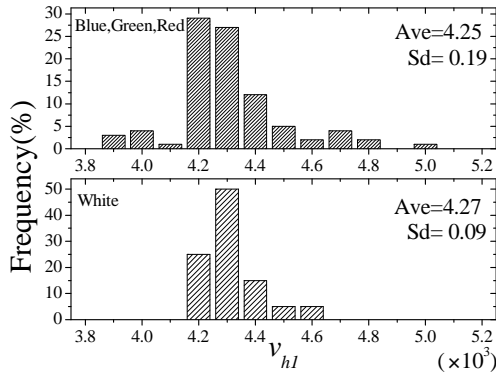
B. Characteristics for Purification Function under LED

  i). Relation between purification function P_a and light frequency

A foliage plants as photos process a capability to absorb air-polluting substance and break down it in physiological tissue [10]. Especially, in indoor environment, the plants have a capability to purify Volatile organic compound (VOCs: Volatile Organic Compound), which is a causative substance for sick-building syndrome [10]. And it is common knowledge that the plants fix carbon dioxide from the atmosphere as factor contributing to global warming. Light frequency causes these functions to ability difference. The irradiated plants are affected a differences in these functions per frequency.

(a) Histograms of v_{h1} for Dark, Blue, Green and Red.

(b) Histograms for three lights and white.

Figure 6. Histograms of v_{h1} for each LED panel.

Figure 7. Relationship of light frequency and $difv_{h1}$.

Figure 8. Conceptual diagram for air purification capability P_a of plant.

function (P_a) was detected with the use of these values. So, the P_a is indicated as Eq. (3). A schematic diagram is shown n Fig.8. In this study, ethyl alcohol was adopted as the pollution substance.

$$P_a = h / t_w \times 100 \qquad (3)$$

An effect to purification capability of the plant by light frequency was examined. Under four types of frequency, these P_a values were indicated in Fig.9. From this figure, white light including any wave length means the most effective and the average of P_a is 15.8. While on the other hand, the capability under Dark means the lowest value and the average of P_a is 9.9. It is considered that the purification capability would be lower due to the photosynthesis. That is, it is thought that the carbon constituent in the pollution substance decreases at the same time various kinds of functions of the plants also decreases. The values of P_a under Red, Blue lights are higher following the one under White. The value of P_a under Green light was indicated the lowest among three of monochromatic light. The P_a under Blue, Green, and Red was located during Dark and White. This result in purification capability agreed with the effectual wave length to the photosynthesis [11, 12]. The characteristic graph shown in Fig.7 is remarkably similar to that Fig.9. That is, a characteristic of V configuration was indicated. Scatter diagram of the relationship between Fig.7 and Fig.9 was shown in Fig.10. The more effectual wave length for photosynthesis becomes higher purification

Additionally, it is thought that the plants is consume air-pollutant substances as nitroxide and sulfur oxide. For this reason, the plants growth rate is high in area where car-exhaust pollution partway becomes advanced. It remains possible that these functions can be ready applied to plant factories. At all, the plants are food and system of environmental purification. In this study, a relationship between a characteristic air-purification and wavelength was examined. After subjective plant was placed in the experimental chamber, a pollutant was injected into the chamber using microsyringe and a change in concentration was investigated. The pollutant concentration was estimated by an output from tin gas sensor. Change in concentration was used as the baseline, namely, it means offset level before injecting the pollutant into the chamber. The pollutant disperse into the chamber and a sensor detected the increase in the concentration of the pollutant in the chamber when the chemical when the pollutant was injected. Then the sensor output [V] increases in response to the concentration. After the sensor output reached a peak-level (maximum concentration), it gradually became lower because the polluting chemical was purified by capability of the plant. Eventually, the concentration drop to a lower value by offset level at the time of injection. Then, the h [V] means peak-value from the offset level and the t_w means the half-value width, namely, the time in which the h becomes half value. The purification
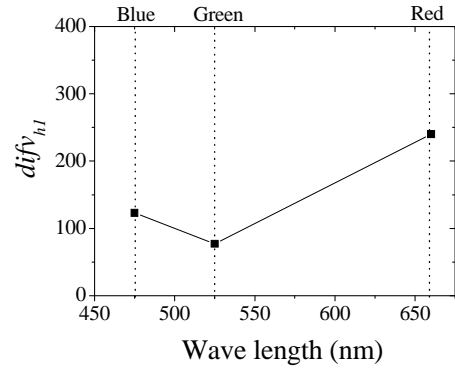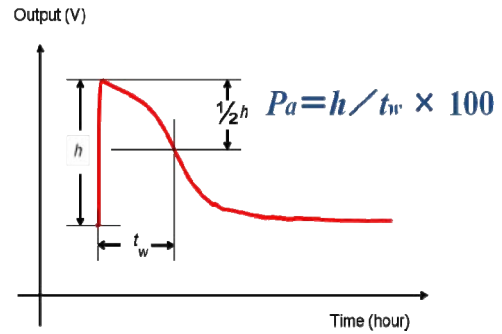
Figure 9. P_a as a function of illuminating light.

Figure 11. Scattering diagram for P_a and P_a'.
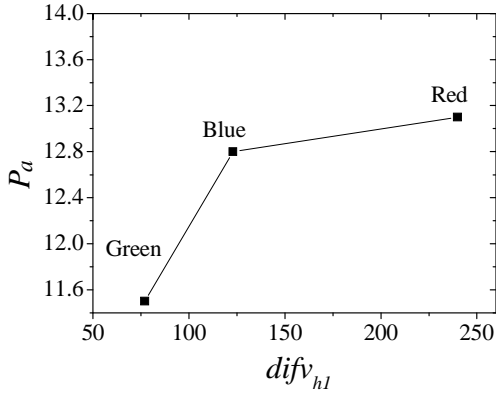

Figure 10. P_a as a function of $difv_{h1}$.

capability of the P_a. The difference in bioelectric potential of the $difv_{h1}$ becomes larger as the purification capability of the P_a becomes smaller. This result deeply relates to the photosynthesis function. Because the plant grows by photosynthesis, this growth relates to the purification capability, which is one of the plant functions. A characteristic of purification under Red light advance 14% compared to Green light.

ii). Derivation to P_a by multiple liner regression analysis

In the plant factories, it is necessary to control the growth, picking season, and yield amount of the plants. Factors of light, temperature, carbon dioxide, and nutrition (for example, carbon, air-pollutant, etc) effect the plant growth. It is also important to effect the plant growth by the three major nutrients as nitrogen, phosphorus, and potassium. By using this experimental result, a multiple regression equation was derived from the environmental factors as explanatory variable. Especially, a degree to affect P_a was introduced by statistical validation. A kind of LED lights, average of the temperature, humidity, and atmosphere were used as explanatory variable. The equation is indicated in Eq. (4).

$$y = 4.769\, W_{hite} + 2.960\, B_{lue} + 2.164\, R_{ed} + 0.783\, G_{reen} + 0.242\, T_{emp} - 0.022\, H_{umid} + 0.002\, A_{toms} + 4.446 \quad (4)$$

A value of the White is the largely compared to the coefficient about the explanatory variable. Next, the values of Blue and Red are large in a row. This three were tested by variable hypothesis test. White was dismissed as the level of 1% and Blue, Red was as one of 5%. Namely, these coefficients have largely effect to purification capability of the P_a. From this result, it is thought that the P_a required can be configured by controlling the environmental condition for example kinds of lights, temperature, humidity, and atmosphere. But, in this study the environmental conditions were not controlled and the coefficient to temperature was very small. After this, it is necessary to analysis with changing all environmental factors. Deriving from Eq. (4), Scatter diagram between measured value P_a and estimated value P_a' is shown in Fig.11. The correlation coefficient was the acceptable value of 0.89. By the category for types of the plant, it is easy to manage a production line deriving these equations. Also it is able to apply to production simulation as yield amount and picking season.

IV. RESULTS

In Japan, the environmental problem and the food problem are urgent issue. It is obvious that the plants assume important role to solve these problems. Meanwhile, it is necessary to reduce the effects on the environment in transportation as food mileage by local production for local consumption. From these social environments, the plant factories of energy saving type using solar panel are proposed and close to practical use. These factories are being controlled based on the practical farmer's hunch and experience. In the future, the maximum cost benefit performance will be achieved if these plants could be controlled by the information that the plants send by itself, for example the bioelectric potential. In this study, as the part of the basic data, the characteristic for the bioelectric potential and purification capability under LED were examined. As the results, it was obvious that the characteristics under Blue and Red lights, which are photosynthetically active wave length, became significantly high. Especially, the Red light's effect has a significant impact on the characteristics. The characteristic

for air purification was examined due to carry out as one element of a carbon fix in growing plants. As a consequence, it is thought that effects on light frequency are need to be utilized. For the future, the experiment as temperature, humidity, intermittent light will be examined and give a thorough report about establish a system of the full-control to the plant factories.

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