

# Individual Differences in Pothos Bioelectric Potential in a Living Space

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Plants respond to various environmental factors. Bioelectric potential is used to examine such responses. The bioelectric potential of pothos pots in response to light intensity, atmospheric temperature and air volume have been examined. From our results, it is clear that the potential changes with environmental factors. In this study, two pothos pots were set up in a living space, and the bioelectric potentials of the pots were examined to investigate whether there are any marked individual differences between the two. If there is a noticeable difference, the effective application of the bioelectric potential becomes relatively limited. We found a correlation coefficient of 0.7 between the potentials of the two plants under darkness and the operation of an air conditioner. A proposed summarized value was adopted to analyze the bioelectric potential. Individual differences were identified to some degree, but the characteristics closely resembled each other. The coefficient between the summarized potentials exceeded 0.85 as time progressed. It is considered that plants can function as sensors of environmental factors.

## 1. Introduction

Plants exhibit circadian fluctuations arising from bioelectric potential under the influence of an electrodynamic field.<sup>(1)</sup> The potential has not, however, been characterized in detail. It is considered that plants can generally sense their living environment and carries out physiological activity. Plants are also important for humans as source of food, energy, and medicine. They can adopt to various environmental

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changes and sense the weather, for example, by determining atmospheric pressure and light intensity.<sup>(2)</sup> Plants can be adopted as environmental sensors by applying this capacity for sensing environmental changes.<sup>(3)</sup> This could have practical applications to increase the yield in plant factories and greenhouse-based farms. A meaningful contribution to the agricultural management field is expected from understanding the capacity of plants to sense environmental factors using bioelectric potential.<sup>(4)</sup> The interface that the capability of plant's environmental conditions in an understandable manner has been studied.<sup>(5)</sup> However, the environment could not be understood from the information from only one plant if there are considerable differences between plant bioelectric potentials among plants of the same species. Therefore, it is necessary to examine the differences between individual plants.

In this study, individual differences were examined under a living space. There are no weather changes, only comfortable conditions in an indoor environment. A household environment was adopted in this investigation. How the bioelectric potential of plants changes according to environmental factors and whether there are individual differences between plants were examined.<sup>(6,7)</sup>

## **2. Experimental Procedure**

The experiment was carried out in a living room of a typical house.<sup>(3)</sup> Two pothos pots were used. The heights were about 100 cm from the bottom of each pot. The heights of each pot were 23.5 cm and the diameters were 23 cm. Two electrodes were attached to two adjacent leaves. The leaf height was about 75–80 cm from the pot bottom. The electrodes were composed of aluminum and of the clip type. The bioelectric potential was measured using the electrodes. The earth was the pot soil. A difference in potential was input into a portable computer through an A-D converter (KEYENCE Co., NR-350) and an op-amp (KEYENCE Co., OP-3009). The original potential of the plants was on the order of millivolts. The sampling interval for the potential was 0.1 s. Illuminance (T&D Co., PHR-51), room temperature, humidity, atmospheric pressure (T&D Co., TR-73U), and wind velocity (KANOMAX Inc., CLIMOMASTER MODEL6542) were also measured. The measurement interval was 10 min, except for wind velocity. The interval for wind velocity was 1 min. A schematic diagram of the system is shown in Fig. 1 and a photograph of the plants is shown in Fig. 2. A means of reducing noise was adopted, in which the equipment used was kept as far away from other home electrical appliances as possible. The experiment was carried out for three days and five days after watering. The data for the five days were collected, but only data for three days were analyzed, namely, those from the fifth day to the seventh day. Since it takes more than one day for a plant to acclimatize to a new environment.<sup>(8)</sup> The experimental system was set on a table located in a corner of the experimental room 30 cm from the floor.

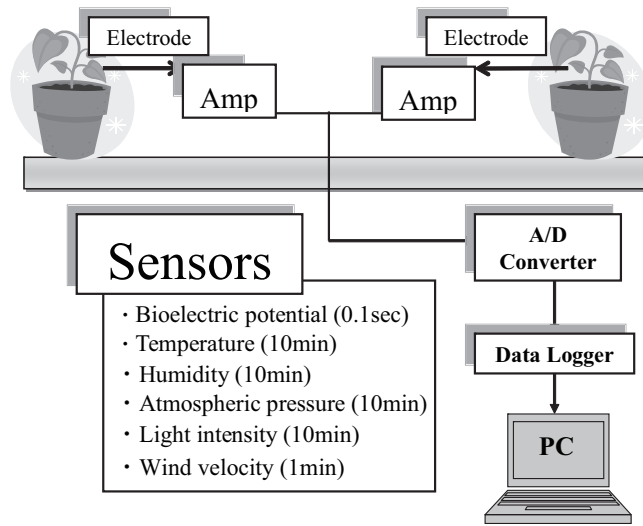


Fig. 1. Schematic diagram of the experimental system.



Fig. 2. Photograph of the plants.

### 3. Results

#### 3.1 Bioelectric potential and the summation value

It is known that the bioelectric potential of plants changes according to environmental factors, for example the moisture content in the pot soil.<sup>(2,3,5-8)</sup> The bioelectric potential changed rapidly. It was difficult to derive the features of the plant condition from the bioelectric potential. Therefore, the summation of the input data for a period was adopted as the representative value, which was analyzed for deriving the features of plant. Namely, the summation value for 1 h ( $v_{h1}$ ) was used as indicated in eq. (1), where  $s_i$  means the bioelectric potential input every 0.1 s. The absolute values of  $s_i$  are summed. Other values are also used, for example  $v_{m1}$  for 1 min and  $v_{s1}$  for 1 s. In this study, the relationship between  $v_{h1}$  and environmental factors was mainly examined because the factors changed moderately.

$$v_{h1} = \sum |s_i| \quad (1)$$

The original data obtained for the bioelectric potential are shown in Fig. 3. They represent the characteristics of the plants three days after setting them, when the plants have adapted to the environment. There are 600 plots in the figure. These were obtained for 1 min at midnight. The bioelectric potentials do not appear to fluctuate regularly. The two bioelectric potentials for the plants are denoted ch1 and ch2 in the figures. The bioelectric potentials ( $v_{h1}$ ) of ch1 and ch2 for three days are indicated in Fig. 4. The data are standardized in the figure and  $s-v_{h1}$  is adopted as a symbol. The variations for ch1 and ch2 can be compared on the same scale.  $s-v_{h1}$  can be introduced using average  $v_{h1}$  ( $ave-v_{h1}$ ) and standard deviation ( $\sigma$ ), namely, the equation is as follows:

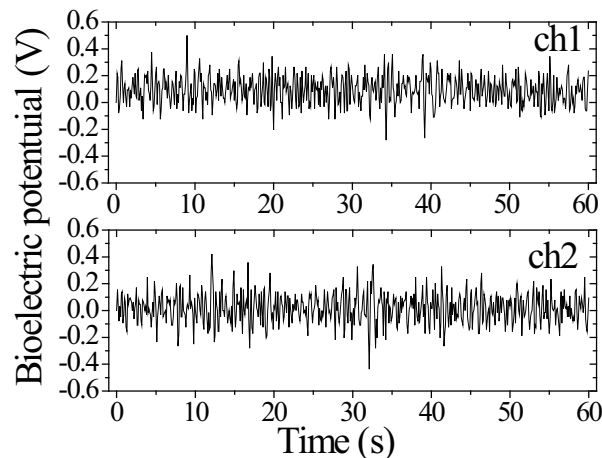


Fig. 3. Bioelectric potentials of two pothos pots for 1 min (600 data).

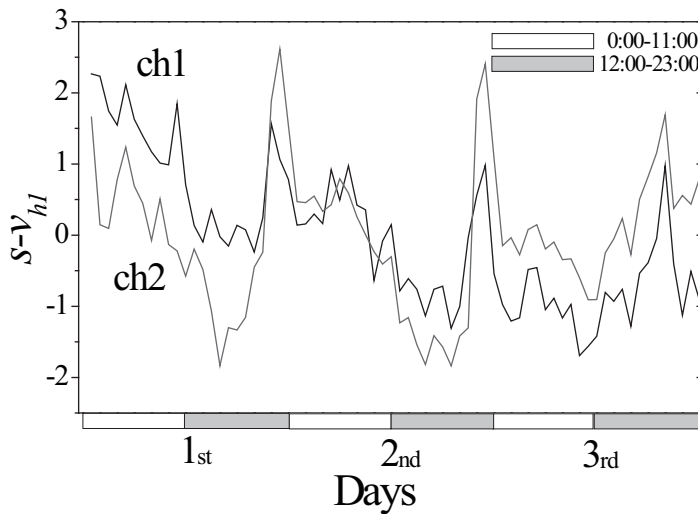


Fig. 4. Summation of two bioelectric potentials for three days.

$$s-v_{h1} = (v_{h1} - ave-v_{h1}) / \sigma. \quad (2)$$

The two characteristics are similar to each other.

The characteristic of  $s_i$  changes unusually or the fluctuation width becomes larger when a plant is installed under different conditions. The data after three days from the start of the experiment were adopted for analysis to avoid irregular characteristics. The average  $v_{h1}$  ( $ave-v_{h1}$ ) values for each day are shown in Fig. 5.  $ave-v_{h1}$  is the average of 24 points each day. The vertical axis represents an arbitrary unit in the figure.  $s-v_{h1}$  of ch1 is larger than that of ch2 as a whole. It is 22% greater than that of ch1. The third-day value of ch2 decreases by about 25% compared with the first-day value, but their characteristics ( $ave-v_{h1}$ ) are almost the same.

### 3.2 Correlation coefficient of daily fluctuation of $v_{h1}$

Individual differences (variability) in bioelectric potentials between two plants were examined in this study, that is, it was examined whether or not their response characteristics are the same. The similarity was investigated daily using the trajectory pattern for the  $v_{h1}$  of ch1 and ch2. Other methods can be considered instead of the trajectory pattern. The result is indicated in Fig. 6. The result in Fig. 6(a) corresponds to the bioelectric potential on the first day, that in Fig. 6(b) corresponds to that on the second day, and that in Fig. 6(c) corresponds to that on the third day. The horizontal axis represents the  $v_{h1}$  of ch1 and the vertical axis represents that of ch2. The correlation coefficient  $\gamma$  is about 0.65 for the first day,  $\gamma = 0.82$  for the second day, and  $\gamma = 0.86$  for the third day. The coefficient increases over time, and the two outputs (ch1 and ch2) resemble each other. The plot in Fig. 6(c) is almost rectilinear and the coefficient is very high.

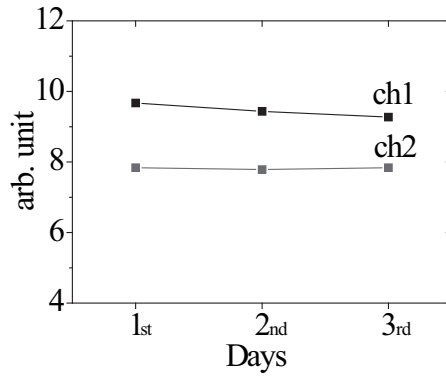


Fig. 5. Average characteristics  $ave-v_{hl}$  of ch1 and ch2.

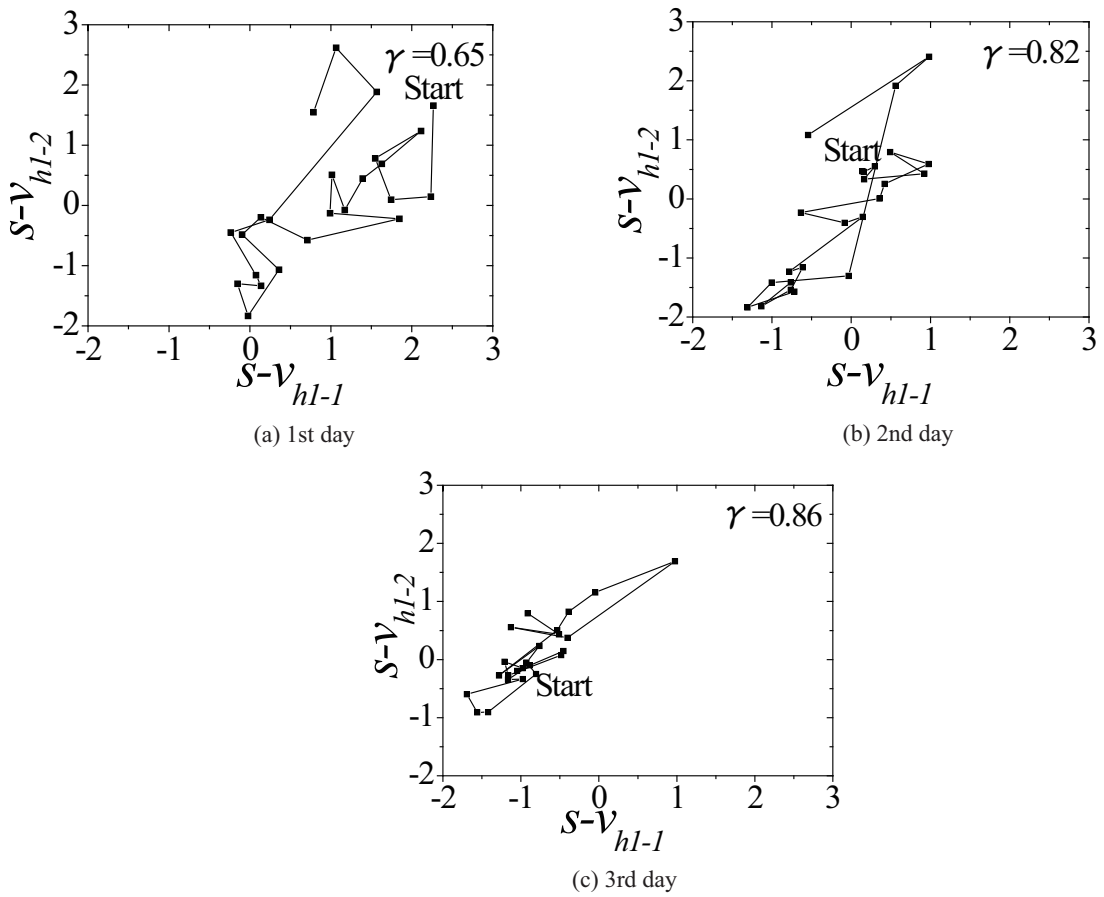


Fig. 6. Locus tracing of  $v_{hl}$  for ch1 and ch2 for three days. The correlation coefficient  $\gamma$  is also indicated in each figure.

### 3.3 $v_{hl}$ characteristic for environmental factors

The bioelectric potential changes with environmental factors, namely temperature, humidity, atmospheric pressure, wind velocity, and illuminance, were also investigated. Temperature, humidity, and atmospheric pressure are factors that determine weather conditions. The changes in bioelectric potentials with these factors for three days are shown in Fig. 7. The experiment was carried out in an indoor environment. Therefore, the temperature was in the range of 25–30°C and the humidity was in the range of 60–82% RH. The atmospheric pressure was in the range of 992–1002 hPa. The change in wind velocity is illustrated in Fig. 8. The velocity was measured every minute and the unit was m/s. An air conditioner was sometimes used in the experimental room and a relatively low wind speed was measured in the room. The air conditioner was used in the late afternoon. The illuminance characteristic is shown in Fig. 9. The fluorescent light was switched on in the evening and the illuminance was in the range of 80–100 lx. The illuminance sometimes increased owing to sunlight during the daytime but was insufficient for the plants to photosynthesize significantly. The illuminance sensor was set at a height of 30 cm from the floor, at the same level as the plant pot bottom. The illuminance was about 500 lx immediately below the fluorescent light. This was due to the switching off and extinction of the fluorescent light.

Examining the bioelectric potential of plants under light and dark conditions is important. In this experiment, the plants could not photosynthesize fully under the illuminance. Namely, this experiment was carried out to examine the bioelectric potential when the plant was affected by fluorescent light. First, the correlation between the bioelectric potentials  $v_{hl}$  of the two potted plants (ch1 and ch2) in darkness was derived. This is indicated in Fig. 10. The coefficient is 0.7 and the bioelectric potentials

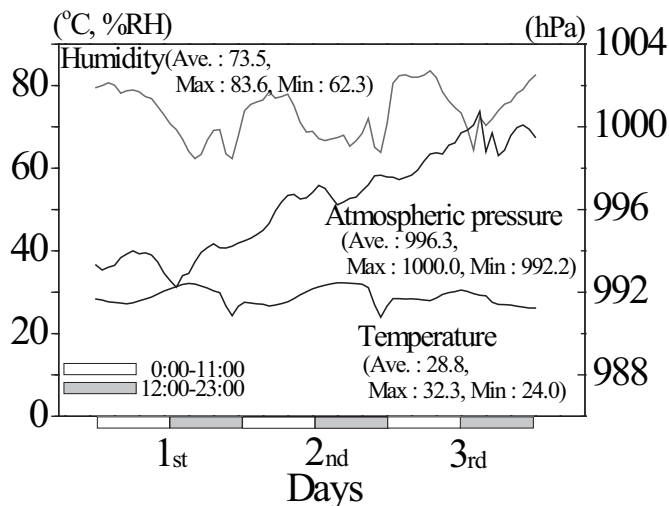


Fig. 7. Humidities, temperatures, and atmospheric pressures for three experimental days.

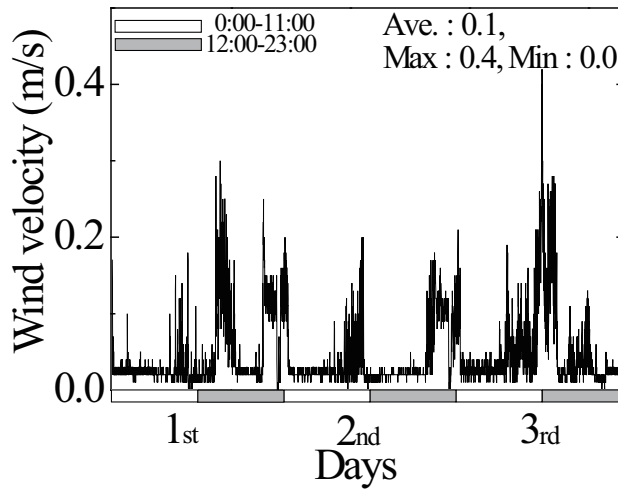


Fig. 8. Air volume characteristic for the three days.

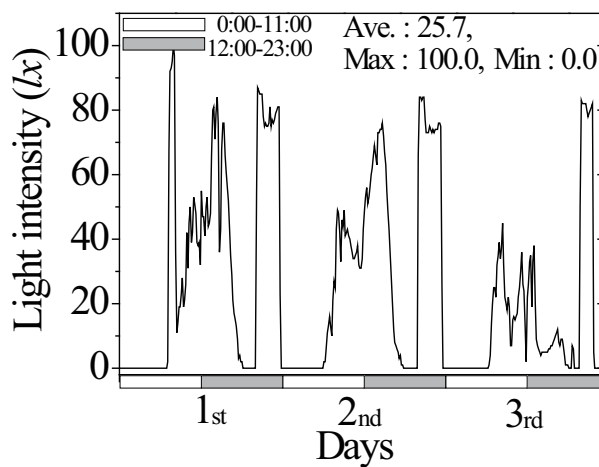


Fig. 9. Light intensity characteristic for the three days.

have a high correlation. It is considered that this is because the experiment was carried out in darkness. The condition has fewer variable factors than that conducted under light. A similar plot for light conditions is shown in Fig. 11. The coefficient is 0.5. In the figure, a correlation can be observed to some degree but it is lower than that in Fig. 10. Under fluorescent light, it is considered that human behavior, for example, entering



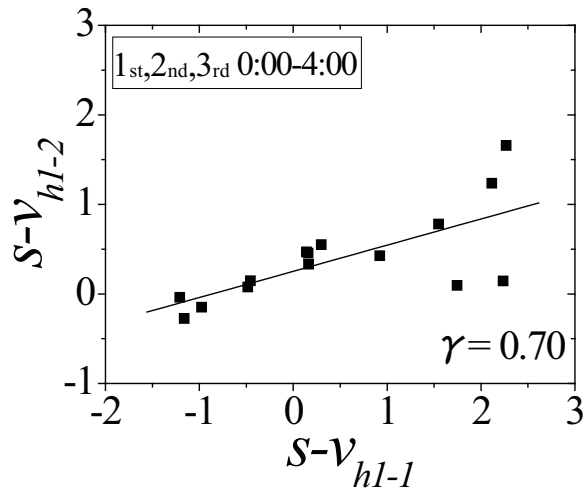


Fig. 10. Relationship between  $v_{hl}$  of ch1 and that of ch2 in darkness.

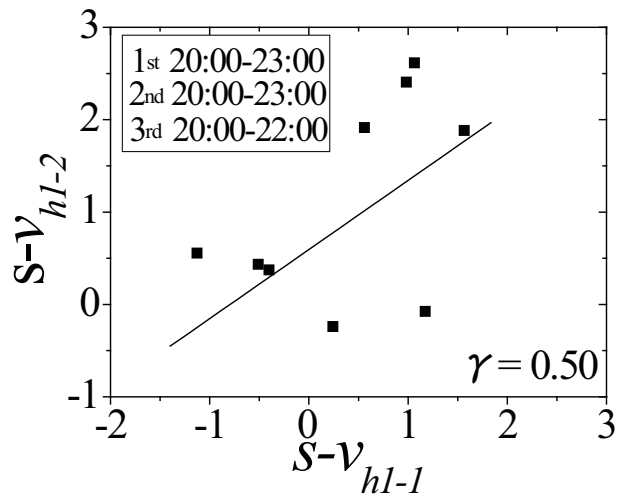


Fig. 11. Relationship between  $v_{hl}$  of ch1 and that of ch2 under fluorescent light.

a room, leaving a room or staying, affects the bioelectric potential and causes the coefficient to decrease.

The correlation coefficient was also investigated when the air conditioner was switched on. In this experiment, the air conditioner was used only at night time so the operating period was relatively short and only six data values were obtained. The result

is shown in Fig. 12 using a scatter diagram. The correlation coefficient is 0.69, which is greater than that in Fig. 11. The optimum temperature growth range of pothos plants is 20–30°C (minimum temperature is 10°C). The optimum growth temperature is 26°C. The temperature drops by 2–3°C and approaches the optimum growth temperature using the air conditioner, and the individual differences between the plants become smaller.

### 3.4 Evaluation of individual differences

The fluctuations in bioelectric potential  $v_{h1}$  for the two pothos pots are shown in Fig. 4. It is necessary to express the individual differences numerically. The difference can be understood concretely when it is expressed numerically and the variation in time can also be expressed. It is considered that the bioelectric potential can be used to obtain data from green plants. This type of data collection from plants using bioelectric potential has been studied over the last three decades.<sup>(2,9)</sup> The differences between ch1 and ch2 at each hour were obtained, and the summation of absolute values ( $v_{h1-1} - v_{h1-2}$ ) for each day was determined. The arbitrary unit was adopted to evaluate the individual differences. The result is shown in Fig. 13. The vertical axis represents individual difference and the horizontal axis represents elapsed days. The difference decreases gradually as the days pass. It decreases by about 20% on the third day compared with the value on the first day. It is considered that the difference decreases gradually through adaptation to the environment. The bioelectric potentials of the plants closely resemble each other owing to the adaptation to the environmental. From the way by which individual differences were reduced among the two subjects, it is considered that the plant bioelectric potential could be used as sensor information from one plant.

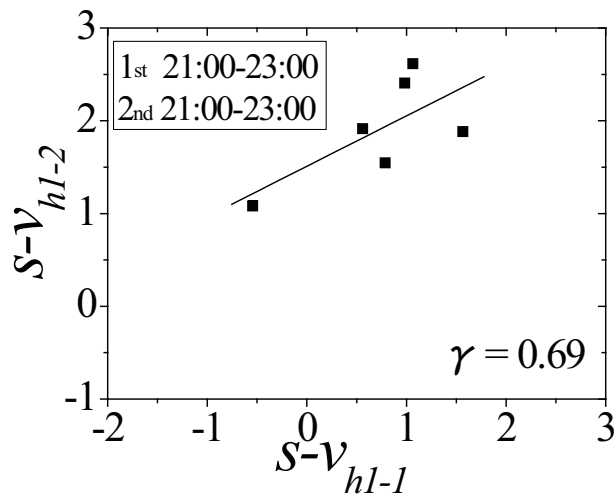


Fig. 12. Relationship between  $v_{h1}$  of ch1 and that of ch2 when using an air conditioner.

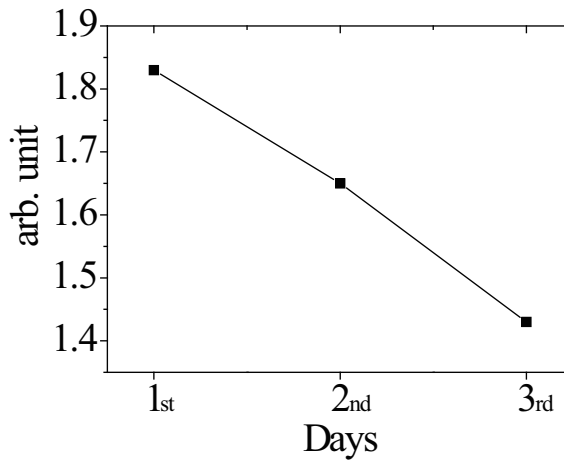


Fig. 13. Evaluation of individual variability of two pothos pot bioelectric potentials.

#### 4. Conclusions

In the future, it is possible that the use of plants as sensors will contribute to the improvement of food production. This may be a clue to solving food problems with increasing population. Thus, it is necessary to supply a comfortable environment for plants to predict plant conditions, and to utilize them. Plant specialists (for example, practical farmers) can determine plant conditions in one glance, but ordinary people cannot. The bioelectric potential can be used to obtain information from a plant. Many correlations between bioelectric potential and environmental factors have been studied. Whole individual differences have to be examined if there are large distinctions among plants of the same species. Therefore, the differences in bioelectric potential among plants were investigated in this study. The potential was affected by various environmental factors, but a complete understanding could be obtained gradually. This experiment was carried out in an indoor environment and the environmental factors were restricted. A high correlation coefficient for two sample plants (pothos pots) was determined and the experiment gave good results using a summation value and a standardized value, but there were individual differences to some degree. A correlation coefficient of 0.7 was obtained in darkness and under air-conditioner operation, which is a relatively high value.

In this investigation, it was determined whether there are large individual differences between two pothos plants. This study investigated surface potential in two pothos plants and will be extended in the future. The numerical value of the difference will be derived statistically under various types of environment and examined to have the same results under many circumstances, for instance, for a month. Briefly, our results are still those of an exploratory experiment, which utilized plants that can be adopted as environmental sensors. Moreover, it is considered that the use of the bioelectric potential

of plants common to humans would afford better understanding and enable control of plant conditions. This type of use has great significance in a plant factory's application possibility. Moreover, it is effective to apply the bioelectric potential of plants to the determination of a suitable growth environment.

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