

INFLUENCE OF ROOT ENVIRONMENT HUMIDITY ON THE GENERATION OF POTENTIAL DIFFERENCE IN A PLANT BIOELECTROCHEMICAL SYSTEM

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Abstract: *The dynamics of potential difference formation in bioelectrochemical systems with different root environment humidity levels from 13% to 60% was studied when growing bok choy cabbage. The highest voltage values reached 320 mV, specific power 0.01 mW/m² and were typical for samples with higher humidity. A weak correlation ($r=0.3$) between the root environment humidity indicators and the generated potential difference was obtained. It was suggested that, along with the properties of the root environment, the state of plants and the intensity of metabolic processes also play a significant role in voltage formation.*

Keywords: *bioelectrogenesis, bok choy, green energy, monitoring, root system.*

INTRODUCTION

Bioelectrogenic processes occurring in the root environment of plants, associated with the generation of potential differences during oxidation-reduction reactions and ion diffusion accompanying the development of the root system, are the basis for the creation of alternative devices for obtaining renewable, environmentally friendly, resource-saving energy – bioelectrochemical systems (BES) [1-3]. Electricity generation using biotechnological devices can be combined with production processes, one of which is the production of plant products. The properties of the root environment play a significant role in the formation of the electrogenic parameters of BES. Thus, it has been shown that when growing plants using peat, the average potential difference formed in the root environment of lettuce plants was about 300 mV [4], and when cultivating using the panoponics method, about 200 mV [5]. A change in the potential difference depending on the soil depth has been determined [6]. It has been suggested that the flow of water introduced into the system daily triggers a number of physical and chemical reactions on the electrodes – diffusion, oxidation-reduction processes, the intensity of which decreases as the liquid moves deeper into the soil.

Thus, the humidity of the root environment is one of the key parameters affecting the energy characteristics of the BES. The method of non-invasive measurement of bioelectric potentials in the soil-plant system, based on a new

method of providing surface contact between the root system and the electrodes, was used to study the responses of the BES to water deficiency stress and watering [7]. It has been shown that watering the plant from above causes a jump in biopotential at a level of 20-150 mV depending on the duration of the plant's exposure to water, while the influx of water from below leads to a smooth change in the bioelectric potential with an output at a level corresponding to the new physiological state of the plant. The aim of this work was to study the influence of humidity parameters of the root environment on the formation of electrical properties of bioelectrochemical systems when growing plants in them.

MATERIALS AND METHODS

The phyto-test object was pak choi (*Brassica rapa* L.), an early maturing plant rich in fiber and vitamin C.

The bioelectrochemical system was a 440 cm³ plant growing container. Electrical characteristics were measured by placing 8*8 cm biocompatible electrode systems in the root environment, which ensured surface electrical contact with the roots and root zone. The lower electrode was located at a distance of 3 cm from the bottom of the container, the upper electrode was placed at a distance of 3 cm from the lower electrode (Fig. 1a). In this experiment, a BES configuration with an upper electrode made of stainless steel and a lower electrode made of graphite felt was used.

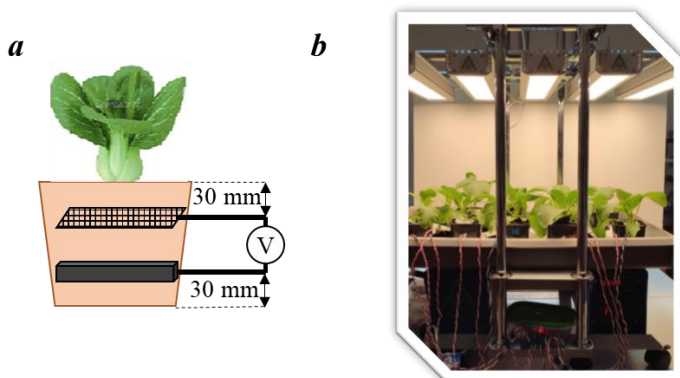


Figure 1. a – schematic representation of BES based on pak choi cabbage, b – vegetation-irradiation installation Ecofil.

The experiments were conducted in the controlled conditions of the agrobiological testing ground of the FGBNU AFI using the Ecofil vegetative-irradiation installation (Fig. 1b). The light source was AFI-3000 – LED lamps with a color temperature of 3000 K with a spectral composition in the visible region close to natural light, with a photosynthetic photon flux density PPFD of 320±20

$\mu\text{mol m}^{-2} \text{s}^{-1}$. The duration of the light period was 14 hours per day. The root environment was Agrobalt S peat soil (Pindstrup LLC, Russia) based on low-decomposition high-moor peat containing at least: N - 150 mg/l, P₂O₅ - 150 mg/l, K₂O - 250 mg/l, Mg - 30 mg/l, Ca - 120 mg/l. Watering was carried out with Knop solution.

Monitoring of changes in the potential difference in the BES was carried out every 15 minutes using the Arduino Mega hardware platform built on the ATmega2560 microcontroller [10].

Ten BES variants were studied, differing in the level of humidity of the root environment from 13% to 60%, which was provided by daily automatic watering with Knop's solution in different volumes. The humidity indicators of the root environment were obtained by measuring in five places of the BES with subsequent averaging using a capacitive sensor.

RESULTS AND DISCUSSIONS

The average humidity value in the root environment was: BES-1 – 10.9 relative units, BES-2 – 18.3 relative units, BES-3 – 10.8 relative units, BES-4 – 10.9 relative units, BES-5 – 22.1 relative units, BES-6 – 13.8 relative units, BES-7 – 16.8 relative units, BES-8 – 16.7 relative units, BES-9 – 8.7 relative units, BES-10 – 21.5 relative units.

Fig. 2 shows the dynamics of changes in the potential difference when growing pak choi plants in a BES with variable humidity values of the root environment. The average voltage value in plant systems was: BES-1 – 312 ± 36 mV, BES-2 – 314 ± 48 , BES-3 – 310 ± 34 mV, BES-4 – 298 ± 27 mV, BES-5 – 282 ± 32 mV, BES-6 – 286 ± 27 mV, BES-7 – 310 ± 37 mV, BES-8 – 327 ± 30 mV, BES-9 – 264 ± 27 mV, BES-10 – 317 ± 52 mV.

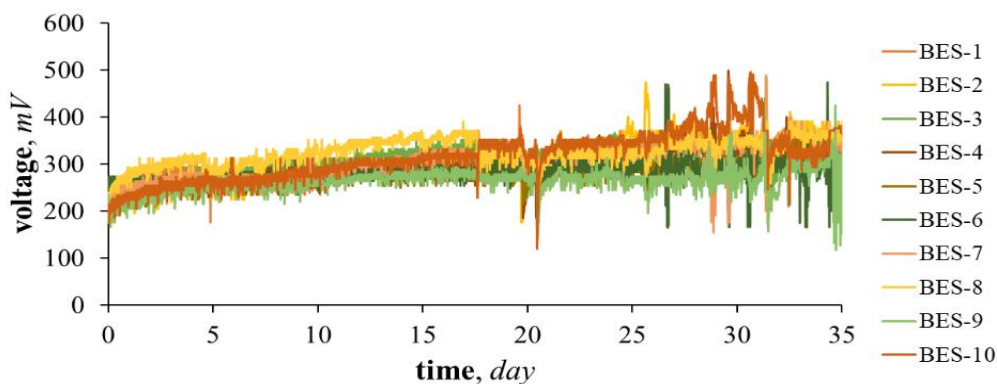


Figure 2. Changes in the potential difference in the BES during the growing season of pak choi at different humidity levels of the root environment.

BES-8 and BES-10 with the highest humidity were characterized by the

highest voltage generation. However, for the BES-5 sample with comparable humidity indicators, the potential difference was smaller. A weak correlation ($r=0.3$) was obtained between the humidity indicators of the root-inhabited environment and the generated potential difference (Fig. 3). It is likely that, along with the properties of the root environment, the state of the plants and the intensity of metabolic processes also play a significant role in the formation of voltage.

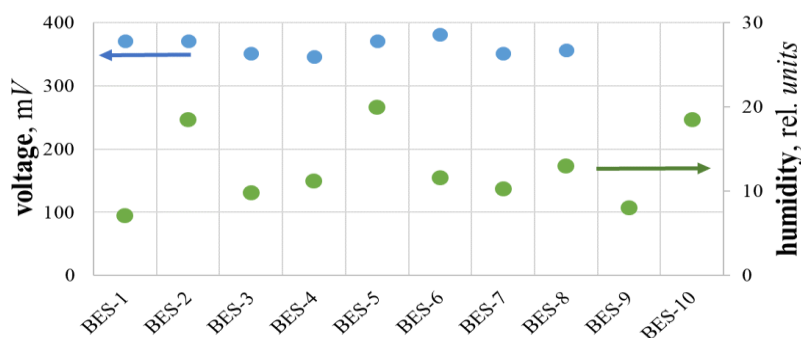


Figure 3. Comparison of the humidity indicators of the root environment and the generated potential difference when growing pak choi in a BES on the 36th day.

Polarization curves were measured for the studied BES with different humidity levels, taken on the 36th day of pak choi vegetation. For BES-10 with the highest humidity, the maximum power generation of 0.01 mW was observed, the lowest indicator – 0.005 mW was characteristic of BES-6 with one of the lowest values of root environment humidity. The obtained morphometric characteristics of pak choi cabbage samples grown with different root environment humidity are presented in Table 1. It is evident that the plants have a strong spread in physiological indicators. The largest mass of the above-ground part and leaf area were characteristic of the BES-1 and BES-4 variants, and the lowest indicators for BES-10, which was inversely proportional to the formed average root environment humidity for these variants.

Table 3. Morphometric characteristics of BES with different humidity levels.

BES options	BES 1	BES 2	BES 3	BES 4	BES 5	BES 6	BES 7	BES 8	BES 9	BES 10
Height, cm	14±1	15±2	15±1	19±2	10±1	9±2	10±1	15±1	10±1	11±1
Diameter, cm	27±2	24±3	23±1	30±3	20±3	8±2	21±2	12±1	13±1	12±1
Weight, g	185±14	69±8	95±4	200±20	64±9	61±11	118±13	114±7	90±6	46±55
Leaf area, cm ²	156±12	130±15	110±5	195±20	64±9	56±11	100±11	99±6	63±4	60±6

Thus, the role of the humidity of the root environment in the formation of the potential difference in the BES during the development of pak choi plants was established - the highest voltage values were characteristic of samples with higher

humidity, the specific power reached 0.01 mW/m².

CONCLUSIONS

The possibility of using bioelectrogenesis in the root environment-plants system as a new green source of electric power has great potential for use, first of all, in agriculture to provide power to low-power devices for monitoring the state of the environment and plants, as well as partial power supply of devices for supporting the life of plants in artificial agroecosystems, which is especially important in areas remote from power grids.

REFERENCES

1. NITISORAVUT, Rachnarin, REGMI, Roshan Plant microbial fuel cells: A promising biosystems engineering. In: *Renewable and Sustainable Energy Reviews*. 2017, vol. 76, pp. 81-89. ISSN: 1364-0321
2. KABUTEY, Felix Tetteh, ZHAO, Qingliang, WEI, Liangliang, DING, Jing, ANTWI, Philip, QUASHIE, Frank Koblah, WANG, Weiye. An overview of plant microbial fuel cells (PMFCs): Configurations and applications. In: *Renewable and Sustainable Energy Reviews*. 2019, vol. 110, pp. 402-414. ISSN: 1364-0321
3. KULESHOVA, Tatiana, GALUSHKO, Alexander, PANOVA, Gayane, VOLKOVA, Elena, APOLLON, Wilgince., SHUANG, Chendong, SEVDA, Surajbhan. Bioelectrochemical systems based on the electroactivity of plants and microorganisms in the root environment (review). In: *Sel'skokhozyaistvennaya Biologiya (Agricultural Biology)*. 2022, vol. 57, nr 3, pp. 425-440. ISSN: 0131-6397
4. KULESHOVA, Tatiana, EZERINA, Elizabeth, VERTEBNY, Vitaly, KHOMYAKOV, Yuri, SINYAVINA, Nadezhda, PANOVA, Gayane. Bioeletrogenesis in the root environment of leaf, fruit and root vegetable crop). In: *Sel'skokhozyaistvennaya Biologiya [Agricultural Biology]*. 2024, vol. 59, nr. 5, pp. 893-909. ISSN: 0131-6397
5. KULESHOVA, Tatiana, PANOVA, Gayane, GALL, Nikolay, GALUSHKO, Alexander. Concentration cell based on electrogenic processes in the root environment. In: *Technical Physics Letters*. 2022, vol. 48, nr. 4, pp. 66-69. ISSN: 0320-0116
6. KULESHOVA, Tatiana, BLOHIN, Yuri, GALL, Nikolay, PANOVA, Gayane. Izuchenie gradienta bioelektricheskogo potenciala v korneobitaemoj srede. In: *Genetica, fiziologia și ameliorarea plantelor*, October 4-5, 2021, Chisinau, Republic of Moldova, pp. 38-41. ISBN: 978-9975-56-912-5
7. KULESHOVA, Tatiana, GALL, Nikolay. Dynamics of Bioelectric Potential in the Root Zone of Plants during Irrigation. In: *Eurasian Soil Science*. 2021, vol. 54, nr. 3, pp. 381-388. ISSN: 0032-180X