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Methodology and Results of Studying the Electrophysical Properties of Plants

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Annotation. This article discusses methods for studying the electrophysical properties of plants, the importance of bioelectric parameters in determining their physiological state, and experimental results. As a result of the research, it was proven that changes in the capacitance and resistance of plant cell membranes are an important indicator in determining their response to external factors.
Keywords: electrophysiology, membrane potential, plant, bioelectric properties, UV-C radiation, capacitance, resistance.

I. Introduction. The study of the electrophysical properties of plants is of great importance in understanding the electrical activity of biological systems. Bioelectrical phenomena occurring in plant cells, such as membrane potential, ionic currents, and slow electrical signals, are important indicators of their physiological responses to the external environment [1-2]. The analysis of these phenomena serves as an invaluable tool for determining how plants respond to various environmental stress factors (water shortage, salinity, temperature changes, etc.). In recent years, scientific interest in the field of plant electrophysiology has been growing, as this area serves as a solid scientific basis for research of practical importance in agriculture, along with fundamental biological knowledge. [108; 45-68-b.]. In particular, based on bioelectrical indicators, the level of stress resistance of plants can be assessed and the effectiveness of selection and agrotechnical measures can be determined. In this research work, experimental methods aimed at studying the electrophysical properties of plants were developed and practical tests were carried out. During the experiments, modern equipment was used to detect, measure and analyze electrical signals generated in plant tissues. The experiments were conducted under specified agroecological conditions, under control, which ensured the reliability of the results obtained [3].

Plants have the ability to adapt to the external environment through the distribution of electric current and changes in electric potentials within their living tissues. Their electrophysical state is mainly related to the degree of polarization of the cell membrane, the movement of ions (K^+, Na^+, Ca^{2+}, Cl^-) and osmotic pressure. The membrane potential (Vm) formed in the cell membrane is around 70–120 mV, which plays an important role in the transmission of signals by plants. The following formulas are mainly used for electrophysiological measurements. These properties differ in different plants. For example, the electrical response strength in leaves, branches and roots changes. Also, external factors - temperature, humidity, light - have a significant effect on the electrophysiological activity of plants [4]. The membrane potential (Vm) is formed by the ion distribution between the internal and external environment of plant cells. This potential can be expressed using the Nernst equation:

Nernst equation:

$$E_k = \frac{RT}{zF} \ln(\frac{[K^+]}{[K^+]} \quad (1)$$

Here:

E_k – Nernst potential for potassium ions (mV)

R – gas constant (8.314 J/mol·K)

T – temperature (Kelvin)

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z – ionic charge (K^+ uchun z = +1)
F – Faraday's constant (96485 C/mol)
[K^+] – concentration of potassium ions in the external and internal environment (mol/L)
ln - This is the natural logarithm, that is, the logarithm to the base e. $\ln(x)=\log_e(x)$
Here :
e — Euler's number is approximately equal to 2.71828..
For example:
ln(1)=0 (because e0=1e^0 = 1e0=1)
ln(e)=1
Natural logarithms are widely used in physics, chemistry, biology, and especially electrophysics, for example in the Nernst equation..
UV-C Radiation increases the ion permeability of plant cell membranes, which is expressed by the following formula:

$$R_m = \frac{U}{I} \tag{2}$$

Here:
U — voltage
I — current strength
Effect on electrophysical properties: UV-C radiation increases the ionic permeability of cell membranes. Photons stimulate the movement of electrons on the surface of the plasmalemma, and as a result, changes in membrane resistance Rm, capacitance Cm, and electropotential are observed. [5]. Biological membranes (especially the plasma membrane of plant cells) behave like thin films with dielectric properties. This membrane acts as a capacitor, that is, it has an electrical capacity between two charged layers (inner and outer), i.e.

$$C_m = \varepsilon\varepsilon_0\left(\frac{A}{d}\right) \tag{3}$$

Here:
C_m- membrane capacity (Farad),
ε- dielectric constant for the membrane material (typically between 2–10),
$\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m — vacuum dielectric constant,
A- membrane surface (m²),
d- membrane thickness (m).
The essence of this formula is that the membrane capacitance directly affects the distribution of ions inside the cell. The speed of propagation of electrical signals and the change in potential depend on the membrane capacitance. When plants are exposed to UV-C radiation, changes occur in the membrane structure, which leads to a change in the capacitance value, which is important for studying the mechanisms of biophysical responses. [6]. The graph below shows the dependence of membrane capacitance on surface area.

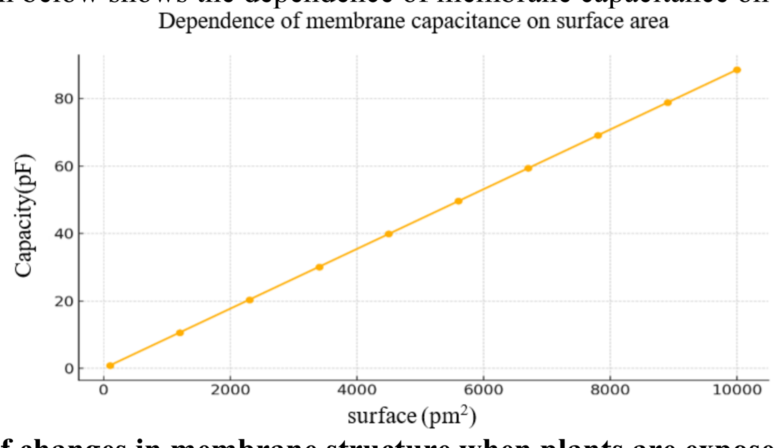

Figure 1.. Diagram of changes in membrane structure when plants are exposed to UV-C radiation.
One of the most important indicators in measuring the electrophysical properties of plant tissues is electrical resistance and dielectric permittivity. The main factors affecting these parameters are the structural state of the cell membrane, the concentration of ions in the cytoplasm, and external physical influences, including

ultraviolet radiation. These processes can be expressed by the following formulas. The formula for expressing electrical resistance in plant tissues, based on Ohm's law, has several dependencies, which are:

1. Electrical resistance:

$$R = \rho \frac{L}{A} \tag{4}$$

Here:
R- total electrical resistance of a body (Om),
ρ - specific resistance of a material (Om·m),
L - length in the measurement direction (m),
A - cross-sectional surface area (m^2).
This formula determines the electrical resistance of plant tissues depending on their internal structure, i.e. cell walls, water content, and other physiological factors. The electrical resistance of plant tissues provides information about their vital state. For example, the resistance of healthy tissues and damaged tissues differs significantly [7-8].

2. Complex resistance:

$$Z(\omega) = \frac{R+1}{j\omega C} \tag{5}$$

Here:
Z(ω)- complex impedance (Om),
R- membrane resistance, (Om),
C- membrane capacity (Farad),
ω =2πf- angular frequency,
j — imaginary unit ($j=\sqrt{-1}$)

3. Dielectric permittivity (ε)

$$C = \varepsilon_0 \varepsilon_r \cdot \frac{A}{d} \tag{6}$$

Here:
C- capacitor capacity (Farad),
$\boldsymbol{\varepsilon_0}$- dielectric constant of vacuum (8.854×10^{-12} F/m),-
ε'- energy storage device,
$\boldsymbol{\varepsilon_r}$ – energy-dissipating part.
A- plate surface (m^2),
d- distance between plates (m).
This formula can be used to estimate the dielectric properties of fluids or membranes between plant cells. Dielectric conductivity is strongly influenced by temperature, fluid volume, ionic composition within the cell, and other factors [9].
Dielectric loss tangent

$$\sigma = \frac{1}{p} \tag{7}$$

This coefficient shows how plant tissue absorbs electromagnetic waves. [10].

II. Methodology. The importance of studying the electrophysical properties of plants.

The study of the electrophysical properties of plants is important for assessing their physiological state, determining how they respond to external environmental factors, and increasing the effectiveness of agrotechnical measures. Plant cells have a complex biological structure, which maintain their internal balance through sensitivity to electric fields. In particular, the electrostatic properties of the cell membrane (for example, dielectric constant, capacitance, resistance, and conductivity) directly reflect whether the plant is healthy or stressed. Electrophysical indicators allow for a precise and rapid assessment of the degree of dehydration of plants, photosynthetic activity, nutrient cycling, pest or disease damage, and the effects of ultraviolet, infrared, or other physical factors. This method is also one of the modern approaches that allows for non-invasive (i.e., without damaging the plant) analysis, and is widely used in agriculture to control yield,

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combat insect pests, optimize fertilization regimes, and monitor the effects of biologically active substances on plants. Since changes in the electrical parameters of plant tissues can be monitored in real time, this method is also of great importance in ecological monitoring, breeding work, and assessing soil-water balance [11-12].

III. Experimental results and discussion

The following sample Table 3.1 presents the results of an experiment conducted to determine the capacity of a plant membrane.

1- table

Sample	U (mV)	I (mA)	C (mF)
1	10	0.2	20
2	20	0.4	20
3	30	0.6	20
4	40	0.8	20
5	50	1.0	20

Research methods and experimental conditions: an apple tree was chosen as the object of research. Apple is one of the fruit trees widespread in Uzbekistan, of economic and agroecological importance. By studying its electrophysical properties, it is possible to determine the state of vegetative activity, the level of stress resistance. Healthy 5–6-year-old apple seedlings were selected for the experiment. Electrophysical measurements on apple tree samples were carried out in open field conditions, and the tests were carried out in March–May during the active period of the vegetation phase under constant control of temperature, light and soil moisture.

2-table.

Plant type	Latin name	Age (years)	Reason for choice
Apple tree	Malus domestica	5–6	Adapted to the local climate, bioactive

Parameter	Value	Note
Temperature	24–28 °C	Natural temperature range
Light	14 hours day / 10 hours night	Semi-natural light mode
Irrigation	Once a week	1 l each time
Soil moisture	60–70%	Wet soil

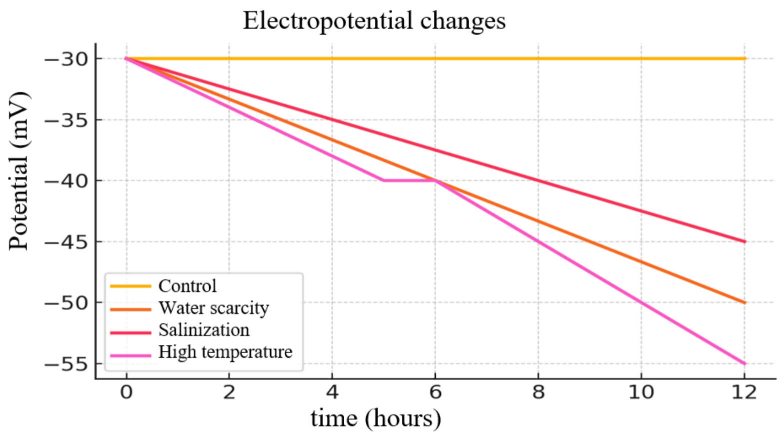

Figure 2. Time-dependent changes in electropotential under the influence of various stress factors in plants

This graph shows how the electropotential (membrane potential) of plants changes over time (hours) under the influence of various environmental stress factors. The vertical axis shows the electropotential values (millivolts, mV), and the horizontal axis shows time (hours). The graph shows four different conditions, (yellow line) plants grown under optimal conditions. The potential does not change much, which indicates the

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stability of the plant state, (orange line) the electropotential gradually changes to the negative side as a result of water shortage, which indicates a deterioration in the biophysical state of the cell membrane, (red line): the membrane potential becomes more negative even when the salt content in the soil increases, which indicates that the cell is under osmotic stress, (pink line) the potential becomes sharply negative as a result of heat stress, which is a sign of membrane instability and possible cell damage. The shift of electropotential to the negative side allows for rapid and effective detection of stress sensitivity and changes in the physiological state of plants. Therefore, electropotential measurements serve as an important diagnostic indicator in assessing plant health [13].

IV. Conclusion and future work

The research results show that the electrophysical responses of plants are closely interconnected with their morphological and biochemical states. UV-C radiation has a positive effect on the electrical properties of plant membranes by activating their defense mechanisms. This direction in plant electrophysiology opens new scientific and practical opportunities in the following areas:
Combating pests through the application of electric fields
Regulating plant metabolism by means of electrostimulation
Modeling ion exchange processes at the cellular level
Developing bioelectric diagnostic platforms for digital analysis of the plant's energetic state.
Furthermore, this approach holds great promise for the development of energy-efficient agrotechnologies based on electrophysical control, automation of crop productivity monitoring, and modeling of photophysiological responses.
The study of the electrophysical properties of plants is one of the pressing fields of modern biophysics. It is significant not only for a deeper understanding of plant physiological mechanisms but also for the development of environmentally safe and energy-efficient technologies in agriculture. In the conducted studies, bioelectric phenomena occurring in plant cells—such as membrane potential, ion currents, dielectric permeability, and electrical resistance—were investigated, and the dynamics of their variations under external factors, including ultraviolet (UV-C) radiation, were analyzed.

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