Soybean as an Environmental Biosensor: Action Potentials and Excitation Waves

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The processes of life have been found to generate electric fields in every organism that has been examined with suitable and sufficiently sensitive measuring techniques [1-6]. The electrochemical conduction of excitation over specialized structures must be regarded as one of the most universal properties of living organisms.

Action potentials in higher plants might be the information carriers in intercellular and intracellular communication in the presence of environment changes [1]. The irritability of plants developed during their evolution and improved in adaptation to changes in their environment. Plants are exposed to a diversity of continuously varying perturbations, including acid rain, air and soil pollution, attack by insects and pathogens, nutrient deficiencies and surpluses, drought, variations of temperature and illumination. The speed of propagation of the action potential does not depend on the location of the working electrode in the stem of the plant or in the leaves, or on the distance between the working and reference electrodes. Action potentials take an active part in the expedient character of response reactions of plants as a reply to external effects. These impulses transfer a signal about the changes of conditions in a conducting bundle of a plant from the root system to the point of growth and conversely. The response reactions of plant tissues and organs can be local or they can be transmitted from cell to cell over long distances via the plasmodesmata. Excitation, due to impulses generated by changes in environmental conditions, functions as a carrier of information in soybean. Action potentials are signals caused by the depolarization of cellular membrane potentials. Mechanical, physical or chemical external irritants act not only at the place of occurrence, but the excitation can be also transferred along the whole plant [3]. The speed of transfer depends on many factors, such as the intensity of the irritation, temperature, chemical treatment or mechanical wounding, and is also influenced by previous excitations. The excitation reaction goes in both directions, from the top of a stem to roots and conversely. The transfer of excitation has a complicated character, accompanied by an internal change in cells and tissues.

The most rapid methods of long distance communication between plant tissues and organs are bioelectrochemical or electrophysiological signals. The effectiveness of such long-distance communication is clear since plants can rapidly respond to external stimuli (e.g., changes in temperature or osmotic environment, plant pathogens, insects, illumination level, wounding, cutting, mechanical stimulation or water availability), and changes can be detected in distant parts of the plant soon after the injury. The cells of many biological organs generate an electric potential that may result in the flow of electric current. Electrical impulses may arise spontaneously or they may result from stimulation. Once initiated, they can propagate to adjacent excitable cells. The change in transmembrane potential creates a wave of depolarization, or action potential, that affects the adjoining, resting membrane. Thus, when the phloem is stimulated at any point, the action potential is propagated over the entire length of the cell membrane and along the phloem with a constant voltage. Once initiated, the action potential has a stereotyped form and an essentially fixed amplitude - an "all or none" response to a stimulus. The propagation of each impulse is followed by the absolute refractory period during which the fiber cannot transmit a second impulse. The high sensitivity of protoplasm and all cell organelles to any natural and chemical effects is the basis for excitability. The integral organism of a plant can be maintained and developed in a continuously varying environment only if all cells, tissues and organs function in concordance. Plants are continuously balancing with the external world. The co-ordination of internal processes and their balance with the environment are connected with the excitability of plant cells.

Carbonyl cyanide 4-trifluoromethoxyphenyl hydrazone (FCCP) induces ultra fast action potentials and decreases the variation potential in a soybean. The speed of the propagation of action potentials in a soybean induced by FCCP reaches up to 40 m/s. The duration of single action potentials after treatment by FCCP is 0.3 ms. Adding FCCP to soil reduces variation potential to zero.

The spatial distribution of protons around the soybean root was measured by using pH indicators. All experiments showed that proton concentration around the plant surface was higher than in the rest of the bulk solution. When proton distribution was measured with Universal Indicator, three zones were observed around the plant in FCCP and control culturing solutions: orange, yellow, and green, which correspond to pH values of 5, 6, and 7, respectively. Two zones were observed around soybean with Bromocresol Purple: purple and yellow, which corresponds to pH values of 7 and 5 respectively. The color intensity of the orange zone was slightly lighter around FCCP treated plants than around control plants. FCCP does not influence turgor pressure, H^+ efflux, or K^+/H^+ antiporter in the root of a soybean; however, it was found to reduce the rate of plant maturation. The mechanism by which FCCP decreases plant maturation most likely includes depolarization of the plasma membrane, retardation of photosynthetic water oxidation and respiratory electron transfer.

References.

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