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Plants Talk To One Other

Prof. Stanisław Karpiński discusses groundbreaking research into how plants communicate, remember stress, and process information.

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How do plants communicate?

STANISŁAW KARPIŃSKI: What people commonly "know" about plants is that they are alive, but they don't feel anything, so they don't react when when you injure them, for example. However, our research shows that at the cellular and intercellular (systemic) levels, plants are complicated, like animals. Plant cells communicate using electrical and chemical signals, just like animals do. Compared to animals, plants have fewer tissues, but their cells are more complex. In addition to the mitochondrial and nuclear genomes, plant cells also have the chloroplast genome, essential in the process of photosynthesis. Plants regulate their integrity by means of internal communication between cells, from the meristem in the stem to the meristem in the root. In large trees, cells can communicate over distances of tens or even hundreds of meters.

Plants have specialized bundle-sheath cells surrounding vascular bundles (known as leaf veins or leaf nerves), whose role is analogous to that of nerve cells, veins, and arteries. As a systemic network, electrical signals regulate the process of photosynthesis depending on light intensity, just as humans regulate breathing depending on the level of physical activity. For example, only a few percent of the surface of a tree's crown is exposed to direct sunlight. The leaves that receive sunlight must somehow inform those that are in shade about the temperature, the intensity of absorbed light, and so on, to help them in acclimation.

This is done using chemical (hormonal) and electrical signals, as well as reactive oxygen species (ROS). ROS are byproducts of oxygen metabolism, formed during respiration or photosynthesis. They are characterized, for example, by the presence of an unpaired electron or the reversal of electron spin in the oxygen molecule.

When we say that plants communicate at the cellular level, what does this mean exactly?

The transmission of signals and information carried by them occurs, for example, between chloroplasts and the cell nucleus and is mediated by what are called stromules (which resemble a tube within a tube). Cell communication is mediated by plasmodesmata, or channels that cross the walls of plants cells through special openings, like through a microscopic colander. In this way, ROS, electrical, or hormonal signals can be transmitted between organelles or from cell to cell. Electrical signaling in plants is a lot slower than, for example, in humans. In humans, electrochemical nerve signals propagate at a speed of about 2 meters per second. In such plants as the thale cress or the dandelion, they propagate at about 5 mm per second. There are exceptions, though: in the touch-me-not or in the Venus flytrap, the speed of electrochemical signals matches that seen in animals.

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That's from cell to cell, but do individual plants also "talk" to one other?

Exactly, having this knowledge about communication on the cellular level, we asked ourselves if such an internal electrochemical (systemic) signal can somehow emerge and get transmitted to another plant. It turns out that indeed it can, and this signal is very complicated. It is not simply a stimulus. Plants communicate very precise bits of information, ones that could be translated as "I've been attacked by a pest" or "I'm absorbing too much light." A plant in a dry area can inform a nearby plant that it has found water. When dandelions are in bloom in the spring and someone walks across a meadow and steps on them, the touching leaves of the neighboring dandelions will inform other flowers, "I've been injured, get ready for stress." They will do so by sending a specific electrical signal (with a specific amplitude and frequency). What's more, such a signal can be read and processed by another plant, which can use it to prepare for a specific stress situation (acclimation).

Do plants help one another out in this way only within the same species?

No, it is beyond doubt that plants do communicate between species. Why do they do so? For the time being, that's the million-dollar question. Should we talk about something akin to altruism among plants? It seems to be more about symbiosis and cooperation within the plant ecosystem, all of which are known in nature. Animals form communities and help one another. Plants do so, too: both within the same species and between many different species. The best examples include forests and meadows. In such ecosystems, nothing is a matter of coincidence: their participants interact with one another and are interdependent. But can plants deceive other plants to their own advantage? We know that there are clusters of plants that either tolerate or do not tolerate one another, and that plants can chemically repel each other, so such a thing is theoretically possible, but this topic has yet to be studied. Such mechanisms are an example of competition between species, which is well-known among animals as one of the mechanisms of natural selection.

How was this groundbreaking discovery made?

Fifteen years ago, a system of inter-root communication was discovered, but this communication needs an intermediary – the mycelium. Roots use the mycelium to inform one another via electrical signals about dangers, regions to be avoided for reasons related to toxic soil, and places with water or needed minerals. Roots are characterized by directed growth, which is why they are so extensive – they search for water, minerals, and organic compounds.

We have discovered that plants can also communicate without an intermediary on the surface (not in the soil), through leaves that are touching one another. This marks a completely new, unknown chapter not only in plant physiology, but also in the way we think about nature and the world around us. In the past, forming communities and communicating was believed to be the domain of animals. But plants can also communicate with one another: they can transmit a signal, process it, and generate responses. Such responses may vary in strength depending on the plant's acclimation to a specific type of stress.

How did we come up with this idea? It all started with studies looking at the transmission of ROS signals. Surface electrical signals transmitted by the plant's leaves are closely linked to the process of photosynthesis. In one of the numerous experiments we conducted, two rosettes of dandelions touched one another by the tips of just two individual leaves (which were connected by a drop of water). One of them was additionally connected to a touch-me-not via an electrical circuit (a cable). At one point, we touched a leaf of the first dandelion (not the one in contact with the second plant) with a heated wire. The leaf we burned transmitted the information, first systemically to another leaf of the same plant, which then transmitted it to a leaf of the second dandelion. But seconds after we had touched the first dandelion with the heated wire, the touch-me-not curled its leaves, which is how it reacts to being touched by an animal. The dandelion does not curl up its leaves, but the touch-me-not's reaction proves that the dandelion transmitted the information about the burn using electrical and ROS signaling. This means that the signal is universal across plant species. Prof. Ron Mittler, a friend of mine and a biologist from the University of Missouri in Columbia, had access to a modern system for imaging ROS signals in leaves. This imaging showed that ROS signals propagate more slowly than electrochemical signals. In an article in the journal *The Plant Cell*, we described experiments on several plant species and on a model organism – the thale cress. The idea was to demonstrate not only the existence of this signal and its physiological features, but also its molecular-cellular features, or in other words, which ion channels are involved in the transmission of these signals. It has been known since 1875 that such electrical signals exist in plants, but no one knew before what type of information was transmitted via these signals or that stress information could be transmitted from plant to plant through touching leaves of the same or different plant species.


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How complex are these processes?

The degree of complexity of the electrical connections used by plants for communication between photosystems is amazing. We have demonstrated experimentally that these electrical signals regulate how absorbed energy is used. Let us imagine a tree that has about a thousand leaves. How do some of them inform others how to manage the absorbed light, how much of it should be dissipated in the form of heat and fluorescence, and how much should be allocated to the electrical charge separation (photochemistry)? Our latest discovery demonstrates that each reaction center in the chloroplasts communicates with all other reaction centers not only within the plant, but also between touching leaves of different plants. A single chloroplast contains several thousand reaction centers. A cell contains up to several dozen chloroplasts, and a leaf contains thousands of cells. A small tree has about a thousand leaves, and several trees whose crowns touch may have a total of even several thousand leaves, which form a network of connections. This works out as trillions of possible communication links between reaction centers in photosystems in a small tree and even quintillions of such links between specific trees. This network of connections is almost as complex as in the brain and the nervous system of mammals – which is simply incredible! That's why we called this process "network-acquired acclimation" (NAA).

Of course, plants don't have brains, yet such a network of connections that constantly signals, analyzes, and processes information can, as a systemic network, alter the fate of the absorbed photons (the quantum division of absorbed energy in photosystems). We can compare this to the response of the pupil of the eye to changing light intensity, which is regulated in a similar way. In addition, plants remember this information physiologically. This is called physiological memory, and we also have it. Trained muscles remember training – after a heart transplant, the recipient may feel the need to do sports, such as long-distance running, because the donor's heart was used to such exercise. Along with the heart, we transplant its nervous system, and the heart is, after the brain, one of the most innervated organs. In the recipient's body, it "demands" a similar rhythm of exercise. Similar physiological memory and stress memory can be found in plants, and we called it light memory or cellular quantum memory. The name comes from the fact that plant leaves physiologically remember excess light stress, or the highest light intensities from the past (several days), for better acclimation and protection against infections. To remember excess light stress, leaf cells – or more specifically their photosystems – must be equipped with a molecular quantum mechanism capable of precisely counting the number of photons absorbed per unit time. In 2010, 2015, and 2020, we discovered that the protein responsible for "counting" absorbed photons and for excess light stress memory is the photosystem II 22kDa, or PsbS, which regulates the process of non-photochemical energy quenching.

Interview by **Justyna Orłowska, PhD**

Further reading:

Ciszak K., Kulasek M., Barczak A., Grzelak J., Maćkowski S., Karpiński S.M., PsbS is required for systemic acquired acclimation and post-excess-light-stress optimization of chlorophyll fluorescence decay times in Arabidopsis, *Plant Signaling & Behavior* 2015.

Gorecka M., Lewandowska M., Dąbrowska-Bronk J., Białasek M., Barczak-Brzyżek A., Kulasek M., Mielecki J., Kozłowska-Makulska A., Gawroński P., Karpiński S.M., Photosystem II 22kDa protein level – a prerequisite for excess light-inducible memory, cross-tolerance to UV-C and regulation of electrical signalling, *Plant, Cell & Environment* 2020.

Szechyńska-Hebda M., Lewandowska M., Witoń D., Fichman Y., Mittler R., Karpiński S.M., Aboveground plant-to-plant electrical signaling mediates network acquired acclimation, *The Plant Cell* 2022.