How plants breathe: A mathematical approach

Luis Wilfrido Atienza
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lw.atienza@gmail.com

We all know that plants take in carbon dioxide and give off oxygen. This exchange of carbon dioxide and oxygen is a basic fact, but the mechanism that allows this to happen is actually the subject of a lot of study. Even without going into the chemical reactions that result in the release of oxygen, scientists have turned to complex mathematical models to study, at the cellular level, the mechanisms that make the gas exchange that we are so familiar with possible.

A paper published in PLoS ONE by Allen Nazareno, of the University of the Philippines Los Baños, and Bryan Hernandez, of Malayan Colleges Laguna, looks into this, using powerful analytical tools and mathematical modelling to gain insight into the behavior of the cells that allow plants to effectively take in carbon dioxide and release oxygen.

Most plants have microscopic openings, called stomata, on the undersides of their leaves. These stomata allow carbon dioxide to enter a plant and allow oxygen to exit. Essentially they allow the plant to breathe.

However, open stomata also leave plants vulnerable to the elements. For example, water can also exit plants through the stomata, and too much water loss can cause harm.

Plants are able to manage all these factors through pairs of specialized cells that border each opening. These are called guard cells, and they can block the opening—not only preventing the exchange of carbon dioxide and oxygen but also preventing water from leaving—or leave it unobstructed, depending on the circumstances.

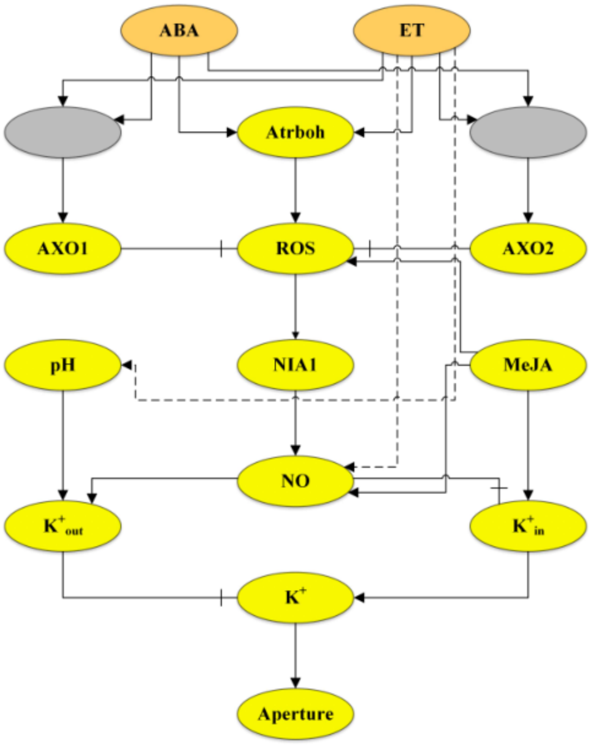
Since plants don't have brains that can perceive situations and react accordingly, they need to rely on an expansive network of hormones and chemical reactions. These hormones and other chemicals all respond to different kinds of stimuli and work together to open and close the stomata as needed. For example, if the air outside the leaf is too hot or dry, the stomata should remain closed, or too much water will be lost. But this also needs to be balanced with the plant's need for carbon dioxide. Stomata will also tend to open at night, when it is cooler. All these reactions happen because of different chemical signals responding to different outside stimuli that tell the stomata to close or open.

Nazareno and Hernandez sought to find a mathematical model to best represent this network of chemicals and their effects on the stomata. To do this, they used a method called logical modelling. Through this kind of modelling, the interactions among many different factors, and their effects, can be studied. In this case, these factors are the chemicals that affect the stomata, and the outcome is whether the stomata are open, closed, or partially open.

Nazareno and Hernandez focused on the effects of three important hormones that can signal to the stomata that they should close or open. These hormones are abscisic acid (ABA), ethylene (ET), and methyl jasmonate (MeJa).

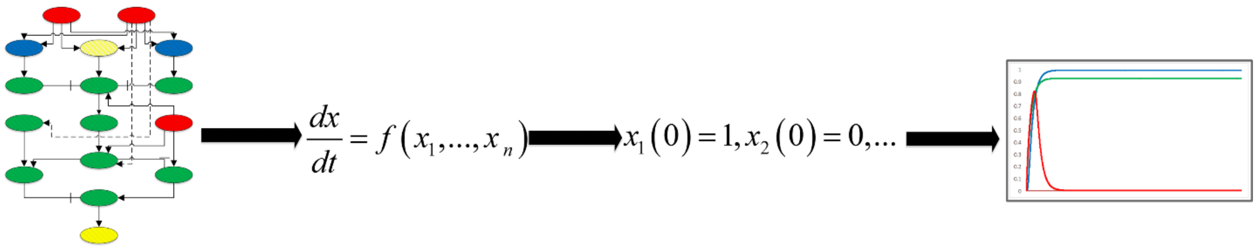
Scientists have been able to determine that each of these three hormones sends a signal to close the stomata. However, they each trigger a different chain reaction to send this signal. And what is still unclear is how they react with *one another*. For example, while both ABA and ET will result in stomata closing, the stomata will not close if *both* are present.

The ways that these hormones interact with one another, and with other chemical signals in plants, are still the subject of a lot of research, and Nazareno and Hernandez's mathematical modelling is an effective way to gain some insight into the complex network of interactions.



The schematic used by the researchers, to show the chain reactions that ABA, ET, and MeJa cause, as well as possible connections that a model could help verify (shown by the broken lines)

To find an effective model, the researchers tested 16 possible models, each backed by 13 different differential equations. Each model made different assumptions about this network of chemical reactions. For example, one model would assume that a certain chemical in the network was affected by ABA, while another model assumed that it wasn't. These were all tested and compared to actual data until the most accurate model emerged, one that most closely followed real-life results. Such a model can now be used to observe how all these chemicals and hormones interact with one another under different circumstances.



A schematic diagram of how the researchers created a mathematical model from the interactions between different chemicals

Another important aspect of using logical modelling is that it can predict the effects of different combinations of factors. Finding an effective logical model of stomatal closure through these hormones, then, would make it much easier to predict the reactions of plants to the presence of these hormones and their interactions with other chemicals. A working, simulated model of these interactions would make studying this fundamental aspect of a plant's physiology much easier, and much more effective.

Similar studies have been conducted, using different types of modelling to study these hormones. Nazareno and Hernandez's research is an important contribution to this effort and can be utilized by many future studies that look into this fundamental aspect of plant physiology.

Luis Wilfrido Atienza graduated from the Ateneo de Manila University, with a BS in Biology, and a minor in poetry. He currently works as a copywriter for a sustainability agency, and spends some of his free time writing about science.