Understanding how plants withstand harsh conditions remains major research challenge

October 10 2016, by Natalie Van Hoose

Jian-Kang Zhu, distinguished professor of plant biology, studies how plants respond to harsh environments - how they manage to survive in the face of drought, too much salt in the soil or when temperatures are too hot or cold. Credit: Purdue Agriculture/Vincent Walter

Understanding how plants sense and cope with harsh conditions such as drought, too much salt in the soil or extreme temperatures could help researchers develop tougher crops—an essential step to improving agricultural productivity, environmental sustainability and global food security.

But while scientists have made some headway in decoding plants' stress signaling pathways and defense mechanisms, many key questions remain unanswered, says a review by Jian-Kang Zhu, distinguished professor of plant biology in the Department of Horticulture and Landscape Architecture.

"So many scientists have been working on these research questions, but we still don't see a lot of new crop varieties with improved drought resistance or tolerance to heat or cold," he said. "It's like cancer research - so important, so many people working on this problem and many papers published each year. But can we say we understand cancer enough to develop treatments that really work well? It remains a huge challenge. The same is true for drought and other major abiotic stresses."

Because plants can't relocate when conditions get rough, their survival depends on quickly detecting changes in the environment and deploying the right defense strategies. During a severe drought, for example, many plants will slow or stop growth, redirecting energy resources to protecting themselves from stress-related damage. This strategy requires a plant to overhaul its metabolism and reprogram gene expression. But when conditions become favorable again, it must quickly dismantle its defense responses to resume normal growth and development.

Understanding how these processes work could help researchers boost crop resilience, an increasingly critical need as the global population grows and climate change intensifies.

But despite major advances in molecular biology, genomics and CRISPR gene-editing technology, many details of plant stress signaling pathways—how cells sense and interpret cues from the environment and direct biological responses—remain a mystery.

"The initial sensing or detection of stress in plants is still pretty much a black box," Zhu said.

Scientists can often determine a gene's function by silencing or deleting it and observing the changes that result. But in plants, many genes are able to carry out similar jobs. Knocking out a plant gene could cause another gene to "step in" to fulfill its role, obscuring the link between a gene and its function. Adding to the complexity is the plant cell's ability to sense stress in its various components—for example, the cell membrane, chloroplasts, or nucleus – and integrate these signals to trigger a defense response.

"You can't deduce the relationship between gene and function," Zhu said. "But sensors are so important that once you remove the entire suite of them, the plants don't live anymore. That also makes them difficult to study."

The Zhu lab, however, has played an important role in advancing knowledge of stress responses in plants. Zhu and his team discovered a core pathway known as SOS, the first abiotic—that is, non-living—stress signaling pathway identified in plants. SOS is involved in sensing and reacting to excess amounts of salt in soil, which can inhibit enzyme activity in plants.

Identifying similar pathways that direct drought response continues to present obstacles. Whereas some plant responses involve one or a few genes, drought can affect everything in plants, "every cellular process, every metabolic enzyme," Zhu said. This complexity makes it difficult to parse out which part of a plant's genome could be manipulated to improve drought resistance and how to do this without inadvertently causing negative effects on plant health.

But the main players involved in many plant stress responses appear to be a family of enzymes known as SnRK protein kinases. Discovered in animals and yeast in the early 1990s, these kinases were later found in plants and seem to have evolved from energy sensing pathways, "which makes sense," Zhu said.

"All these stress factors suppress or inhibit energy production, especially in plants," he said. "Drought or extreme temperatures inhibit photosynthesis, which in turn means there is not enough energy supply to grow and synthesize cellular components."

In addition to highlighting unsolved research questions, Zhu emphasized the need to study how various signaling pathways in plants communicate and interact with one another. How does a stress signaling pathway affect metabolism, growth and nutrient absorption, for example? Similarly, he pointed out that researchers tend to study a single stress factor in a plant grown in a sterile environment, yet plants in nature are often hammered by multiple challenges simultaneously. Studying how these different stresses together impact plants is key to gaining a more accurate understanding of conditions in the field, Zhu said.

For Zhu, researching plant stress responses can feel like walking in a tunnel and realizing the light at the end is much farther away than he originally thought. But the more he learns about how sophisticated and adaptive plants are, the more impressed he is.

"I continue to be amazed at how 'smart' and advanced these immobile organisms can be. A few billion years of evolution really resulted in things we can't intuitively imagine."

More information: Jian-Kang Zhu. Abiotic Stress Signaling and Responses in Plants, *Cell* (2016). DOI: 10.1016/j.cell.2016.08.029

Provided by Purdue University