Lighting up the plant hormone 'command system'

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Light is not only the source of a plant's energy, but also an environmental signal that instructs the growth behavior of plants. As a result, a plant's sensitivity to light is of great interest to scientists and their research on this issue could help improve crop yields down the road. Similarly understanding a plant's temperature sensitivity could also help improve agriculture and feed more people. Two new papers from Carnegie's Zhiyong Wang laboratory identify key aspects of the hormonal responses of plants to changes in light and heat in their environments. Their work is published online July 22 by *Nature Cell Biology.*

To have optimal exposure to sun light, plants must grow differently depending on the lighting conditions. For example, when a seed germinates underground, it must elongate its stem rapidly to reach the surface of soil; when a plant is shaded by its neighbor, it also elongate its stem to outcompete for sun light; whereas expanding leaves is the priority for plants under full sun light. On the other hand, like all organisms, plant growth and development is also regulated by internally produced chemical signals, namely hormones. How plants coordinate their responses to light and hormonal signals is an outstanding question of great interest to scientists and importance to crop yield. It is believed that identification of the central regulatory mechanism that integrates multiple environmental and hormonal signals has great potential for improving crop yield. Such a central regulatory mechanism is the focus of the two papers from the Wang lab.

The light-induced transition from a developmental pathway that leads to slim seedling with yellow folded leaves, called etiolation, to a developmental pathway that leads to short stem and expanded green leaves, called de-etoilation, has been extensively studied for many years. This research led to the discovery, 15 years ago, of the steroid hormone brassinosteroid, which is found throughout the plant kingdom and regulates many aspects of growth and development.

Mutant plants that are deficient in brassinosteroid that are grown in the dark, show features of plants grown in the light. They also have defects at many phases of the plant life cycle, including reduced seed germination, dwarfism, and sterility.

The physiological effects of brassinosteroids are very similar to those of gibberellin, another hormone. But the relationship between these two hormones has been unclear at the molecular level. Recent studies of Wang and his colleagues have elucidated the molecular pathway through which brassinosteroid alters gene expression and explored the relationship of the two hormones.

In the two Nature Cell Biology papers, Wang and his team identified key junctions between the molecular pathway that transduces the brassinosteroid signal and those for the light, temperature, and gibberellin signals. The studies explain how multiple environmental and hormonal signals regulate plant growth and development. The studies also elucidate a biochemical "command system" that integrates a wide range of signals into growth regulation.

In contrast to the widely held concept that environmental signals affect endogenous hormones to alter plant growth, the study by Wang found surprisingly that light does not affect brassinosteroid. Instead, brassinosteroid has major effects on the sensitivity of plants to light by not only altering the levels of proteins mediating light responses, but also providing an essential partner for a transcription factor, named PIF4, that is directly inactivated by the photoreceptor phytochrome. The brassinosteroid-activated BZR1 protein and dark-stabilized PIF4 protein form a complex that drives expression of genes required for the etiolation process.

By contrast, light removal of PIF4, or the absence of BZR1 caused by brassinosteroid deficiency, leads to de-etiolation and inhibition of cell elongation. The study also shows that the growth response to high temperature, known to be mediated by PIF4, also requires BZR1-PIF4 complex formation. The study therefore revealed a new function of brassinosteroid in gating the responses to light and temperature, likely according to the internal physiological conditions.

Brassinosteroid and gibberellin are two major growth-promoting hormones that induce similar growth responses in higher plants. Wang and his team demonstrate that the effects of gibberellin on cell elongation depend on the presence of brassinosteroid and active BZR1 protein in the nucleus. This is because gibberellin removes a class of inhibitory proteins, named DELLAs, which inactivate BZR1, and thereby allow BZR1 to regulate gene expression more effectively. Without brassinosteroid and BZR1, gibberellin has little effect on cell growth.

The research indicates that brassinosteroid provides an essential factor required for cell elongation growth, whereas gibberellin provides another layer of quantitative control of the activity of this factor. Because gibberellin is known to be affected by environmental conditions, such as light and stresses, and brassinosteroid level varies greatly in different organs, the interactions among PIF4, DELLAs and BZR1 appear to form the "command system" that effectively integrates information of environmental condition, endogenous situation, and developmental program into the "decision" about growth.

Taken together, this research demonstrates that the interdependent relationships between brassinosteroid, elements of the gibberellin pathway, and phytochrome-interacting factors form a "command system" of sorts, which controls key growth processes and responses to environmental signals.

"This command system seems not only to accept various inputs, but also to send branches of output signals, too, because each component acts interdependently on shared targets, but also independently on unique sets of target genes," Wang said. "This complex network contains multiple layers and controls major plant growth and developmental processes. We believe this network will be a major target for engineering high-yielding crops."

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