Focus on Ubiquitin in Plant Biology

Ubiquitin and ubiquitin-like modifiers are small proteins that are covalently joined via their C-terminal carboxyl group to substrate proteins, often on a Lys residue, thereby modifying the stability, localization, or function of the target. Although ubiquitin is present in all eukaryotes, plants have an inordinate fondness for ubiquitin, as judged by the plethora of ubiquitin-protein ligases encoded in the plant genome. In fact, approximately 6% of Arabidopsis (Arabidopsis thaliana) protein-coding genes are suspected to have functions related to ubiquitin modification. Thus, it is not surprising to find that ubiquitin plays critical roles in diverse aspects of plant biology, from growth and development to responses to biotic and abiotic stimuli. This special focus issue of Plant Physiology assembles recent advances in our understanding of the functions and regulation of this fascinating protein modification system in plant biology.

Although best known as a tag for proteasomal degradation, it is increasingly apparent that ubiquitination can trigger other outcomes as well. Ubiquitin on a target molecule can itself be a substrate for further ubiquitination, and both the extent of ubiquitination and the Lys residue chosen for ubiquitin chain formation influence the fate of the modified protein. Moreover, ubiquitinated proteins associated with membranes can undergo distinct fates, including proteasomal degradation, as in endoplasmic reticulum-associated protein degradation, or internalization from the plasma membrane, often followed by vacuolar degradation.

Plant hormones regulate every aspect of plant life, and the ubiquitin/proteasome system (UPS) plays central roles in all known plant hormone signaling pathways. Many plant hormones rely on relief of transcriptional repression to initiate signaling, and targeting a repressor for ubiquitin-mediated proteasomal degradation in response to the hormone is a recurring theme in plant hormone signaling pathways. The unprecedented findings that auxin and jasmonoyl-l-t-le can directly bind their cognate ubiquitin-protein ligases (or the ligase-repressor complex) to speed degradation of the corresponding repressors provided critical breakthroughs in our understanding of hormone signaling and expanded our thinking on possible mechanisms for linking small molecule perception and response. The ubiquitin-protein ligases functioning as auxin and jasmonate receptors nicely demonstrate how a hormone-stimulated ubiquitin-protein ligase complex can constitute a concise signaling pathway. Other hormone receptors acting in the nucleus, such as those recognizing GAs, also depend on ubiquitin-mediated destruction of associated repressors. However, even hormones using more traditional membrane-localized receptors, such as ethylene, critically involve ubiquitin-dependent degradation in the signaling process.

As evidenced by the discovery that ubiquitin-protein ligases can act as hormone receptors, plant biologists have made fundamental contributions to the ubiquitin field in general. Another area where this broad contribution is apparent is the studies of the CONSTITUTIVE PHOTOMORPHOGENIC9 signalosome (CSN), an evolutionarily conserved protein complex that regulates ubiquitin-targeted proteasomal degradation. CSN components were originally identified genetically as factors inhibiting light-induced development and have subsequently been found to regulate cullin-type ubiquitin-protein ligases (an enormous family in plants) by removing a ubiquitin-like modifier from the scaffold subunit, thus promoting reprogramming of these multisubunit ligases in response to different needs of the plant.

In addition to hormone and light signaling, the UPS plays important roles in plant interactions with pathogens and other microbes. For example, in plant-virus interactions, the host UPS can act in antiviral defense by targeting viral proteins for degradation, or it can be hijacked by the invading viruses for their own benefit; for example, during viral suppression of the plant RNA silencing defense. UPS-related proteins also participate in many other aspects of plant immunity, from pathogen recognition to signaling reactions during pathogen-associated molecular pattern- and effector-triggered immunity responses. Finally, the host UPS is involved in plant genetic transformation by Agrobacterium tumefaciens, both during defense response to the bacterial challenge and to the bacterial effector proteins exported into the host cell, and as a mechanism subverted by the bacterium to expose its T-DNA for integration into the plant genome.

We thank the authors of the Update articles featured in this issue for their thoughtful insights on key findings and emerging issues in this ever-expanding field and appreciate those who submitted relevant research articles for inclusion. We hope that these articles, along with future additions incorporated in the online Focus Collection on Ubiquitin in Plant Biology, will be a valuable resource to readers seeking to expand their understanding of the myriad roles of ubiquitin and ubiquitin-like modifiers in plant biology.

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