AGC kinases in plant development and defense

More than 100,000 publications demonstrate that AGC kinases are important regulators of growth, metabolism, proliferation, cell division, survival and apoptosis in mammalian systems. Mutation and/or dysregulation of these kinases contribute to the pathogenesis of many human diseases, including cancer and diabetes. Although AGC kinases are also present in plants, little is known about their functions. We demonstrated that the AGC kinase OXIDATIVE SIGNAL-INDUCIBLE1 (OXI1/AGC2-1) regulate important developmental processes and defense responses in plants. The summary of recent progress also demonstrates that we are only beginning to understand the role of this kinase pathway in plants.

PDK1 Activates AGC Kinases

An important second messenger in plant signaling is phosphatidic acid (PA) which can be synthesized either by phospholipase D or by a phospholipase C pathway which generates diacylglycerol that is phosphorylated to PA via diacylglycerol kinase. Both lipases are activated in response to many biotic and abiotic stress signals. Recently, it was demonstrated that also the beneficial fungus Piriformospora indica is able to stimulate PA synthesis in Arabidopsis. Therefore, the second messenger PA may integrate various external signals in plants to activate and coordinate appropriate downstream responses. While mammalian PDK1 integrates signals from receptors that stimulate the production of phosphatidylinositol-3,4,5-trisphosphate, the plant PDK1 binds to different signaling lipids, including the second messenger PA. Thus, although the lipid stimuli are different, animal and plant PDK1 convert phospholipid information into activation of AGC kinases.

Key words:

AGC kinases, reactive oxygen species, plant stress, plant microbe interaction, plant pathogen

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Interestingly, Arabidopsis Pti1-4 was recently shown to form protein complexes with MPK3 and MPK6 and could therefore mediate OXI1 regulation of the MPKs.  

The endophytic fungus *P. indica*, a cultivable basidiomycete of Sebacinales, colonizes the roots of many plant species including Arabidopsis. The fungus stimulates growth, biomass and seed production of the hosts and promotes nitrate and phosphate uptake and metabolism. *P. indica* also confers resistance against abiotic and biotic stress. In a genetic screen for Arabidopsis mutants which do not respond to *P. indica*, we have identified OXI1 as the responsible gene.

In Arabidopsis and rice, kinases of the PTI1 family were identified as interacting partners and kinase targets of OXI1 making them downstream components of OXI1 signaling. PTI1 proteins are Ser/Thr protein kinases that share strong sequence identity to tomato PTI1 (Pto-interacting 1). In tomato, PTI1 is phosphorylated by the Ser/Thr kinase Pto conferring resistance to *P. syringae* expressing the effector AvrPto and positively regulates the cell death response triggered by Pto. On the contrary, rice Pti1a inhibits disease resistance and cell death and is negatively regulated by OsPDK1-OsOXI1.

The Arabidopsis genome encodes 39 members of the AGC protein kinase family and they are involved in various signaling pathways including blue light and auxin signaling. Among the AGC kinases, OXI1 was shown to be required for reactive oxygen species (ROS)-mediated responses in Arabidopsis such as root hair elongation and for disease resistance to biotrophic pathogens such as the oomycete *Hyaloperonospora arabidopsidis* and *Pseudomonas syringae* bacteria. The kinase activity of OXI1 itself was induced by H2O2, wounding, cellulase and various elicitor treatments mimicking pathogen attack. Furthermore, as oxil mutant plants are impaired in the activation of mitogen-activated protein kinase (MAPK)3 and 6 are downstream factors of OXI1 and regulate the balance between growth and defense responses.

**Figure 1.** The beneficial fungus *Piriformospora indica* stimulates PA synthesis which activates PDK1 and subsequently OXI1 and AGC2-2. On the other hand, OXI1 can also be activated by environmental challenges, including pathogens in a PDK1-independent manner via H2O2. PTI1-4 and the MAPKs MPK3 and 6 are downstream factors of OXI1 and regulate the balance between growth and defense responses.
Open Questions

Figure 1

References


