Autophagy: Balancing zinc and iron in plants

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Nutrient imbalances can adversely impact crop health and agricultural productivity. The trace elements zinc and iron are taken up by the same transporters in plants, so zinc deficiency can result in excess uptake of iron. How does the plant cope with this imbalance? Researchers from Meiji University, Japan, reveal that autophagy, the process of intracellular self-degradation, may have an unexpected role in restoring zinc-iron balance in plants.

A balance of nutrients and minerals in the soil is essential for the optimal growth of plants. A deficiency or surplus of specific nutrients can have detrimental effects on the growth and health of plants, thus affecting the overall quality and quantity of agricultural produce. Nutrient imbalances have become increasingly prevalent, given the excessive heavy metal contamination from industrial activities.

Zinc, an essential trace element, is important for a number of important life processes. Interestingly, the uptake and transport of zinc and iron, another essential nutrient, is facilitated through a common group of proteins known as zinc- and iron-regulated transporter-like proteins (ZIPs). This means that a disturbance in this zinc-iron "seesaw" can thus lead to symptoms induced by their respective deficiencies. That is, if a soil doesn't have enough zinc, the ZIPs cope by increasing their uptake of iron, resulting in an increase in reactive oxidative species and chlorosis (yellowing of leaves). Conversely, an excess of zinc leads to decreased uptake of iron. How is the intra-cellular balance of these nutrients restored in such situations?

Probing deeper into the likely mechanisms of zinc-iron balance or "homeostasis," researchers from Meiji University, Japan, explored the potential role of autophagy, a process of self-degradation and recycling, in restoring zinc-iron balance in plant cells. Describing their study, published in *Trends in Plant Science*, corresponding author and Professor, Dr. Kohki Yoshimoto says, "While most studies have addressed the role of nutrient uptake and transport, we propose a novel model on how autophagy supplies mobile zinc and iron ions under zinc starvation and zinc excess stress, respectively; thus, balancing the intracellular zinc-iron seesaw to adapt to a wide range of environmental zinc concentrations."

Autophagy has been previously shown to increase the availability of zinc in plant systems. In Arabidopsis, a plant model system, atg mutants, which are deficient in autophagy responses, have lowered levels of zinc and exhibit severe chlorosis. Moreover, zinc deficiency is known to trigger autophagy, which resupplies mobile zinc ions for plant growth. In autophagy deficient mutants, however, this activation in impaired, leading to classic symptoms of zinc deficiency.

Excess zinc is also toxic to plants, and autophagy is the savior in such cases, too. Plants exhibit iron deficiency symptoms in zinc excess conditions. Autophagy is activated under zinc excess conditions to resupply mobile iron ions from non-mobile forms such as iron bound proteins. Autophagy improves the bioavailability of iron and suppresses the iron deficiency symptoms.

Moving on from the role of autophagy in zinc-iron homeostasis, researchers proceeded to elucidate nutrient sensing mechanisms responsible for activating autophagy. Transcription factors bZIP19 and bZIP23, belonging to the basic leucine zipper family, detect changes in the levels of intracellular zinc and accordingly regulate the expression of transporter proteins on the cell membrane. The researchers speculate that these proteins may be the regulators that switch autophagy response "on" or "off" depending on the status of zinc. A similar mechanism may also come into play in conditions of iron deficiency with excess zinc to restore iron levels.

Overall, autophagy functions as a feedback mechanism that can react to deficiency or excess zinc induced stress, and accordingly alter the bio-available fraction of nutrients in plant cells.

Dr. Yoshimoto says, "Our model provides a new perspective to metal homeostasis in plants. This can contribute to the development of new cultivation techniques and robust crop varieties that are resistant to nutrient level fluctuations. Furthermore, our findings may also be applied to human health to resolve zinc deficiency-induced symptoms, a major problem in developing countries."

More information: Daiki Shinozaki et al, Autophagy balances the zinc–iron seesaw caused by Zn-stress, *Trends in Plant Science* (2021). DOI: 10.1016/j.tplants.2021.06.014

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