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PLANT CELL BIOLOGY

Regulating plastid plasticity

Plants can adapt to environmental and developmental cues by altering the phenotype of plastid organelles, which include photosynthetic chloroplasts and non-photosynthetic variants such as etioplasts. For example, in dark-grown plants exposed to light, etioplasts differentiate into chloroplasts (a process known as de-etiolation). New data published in *Science* indicate a crucial role for the ubiquitin–proteasome system in regulating such plastid plasticity.

Most plastid proteins are encoded by the nucleus and imported from the cytosol into plastids by the TOC (translocon at the outer envelope of chloroplasts) complex. Therefore, changes in the plastid phenotype must involve TOC-regulated changes in the plastid proteome. In chloroplasts, the main TOC components are TOC159, TOC33 and TOC75. A knockout mutation of TOC33 in *Arabidopsis thaliana*, *plastid protein import 1* (*ppi1*), results in pale green leaves as a result of defective chloroplasts.

Using chemically mutagenized *A. thaliana* plants, the authors found that mutation of *suppressor of ppi1 locus 1* (*sp1*) partially restored the chloroplast phenotype of *ppi1* plants. SP1 was shown to be an ubiquitin E3 ligase that is localized to the plastid outer membrane. In keeping with the known role of E3 ligases in ubiquitin-mediated proteasomal degradation of proteins, overexpression of SP1 accentuated the phenotype of *ppi1* plants. This suggested that SP1 regulates the plastid phenotype through turnover of the TOC machinery.

TOC complex protein levels were increased in *sp1* plants and decreased in either *ppi1* plants or plants overexpressing SP1. The authors could also rescue total TOC protein levels to a large extent in *sp1* and *ppi1* double-mutant plants. There were no changes in TOC transcript levels. Consistent with a role for SP1 in targeting TOC proteins for degradation, SP1 was shown to bind and ubiquitylate TOC components *in vitro* and *in vivo*, resulting in proteasomal degradation.

Together, the data indicate that SP1 regulates chloroplast biogenesis by mediating the turnover of TOC complex components by the ubiquitin–proteasome system. This turnover in turn regulates the plastid proteome by altering protein import. The physiological relevance of the process is shown by *sp1* plants being unable to undergo normal de-etiolation, which is a crucial process during seed germination.

Kirsty Minton

STUDIO 8

> “SP1 regulates chloroplast biogenesis by mediating the turnover of TOC complex components”

ORIGINAL RESEARCH PAPER Ling, Q. *et al.* Chloroplast biogenesis is regulated by direct action of the ubiquitin–proteasome system. *Science* **338**, 655–659 (2012)