Flowering rooted in embryonic gene-regulation

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Credit: AI-generated image (disclaimer)

Researchers at the Gregor Mendel Institute of Molecular Plant Biology of the Austrian Academy of Sciences—and the John Innes Centre, Norwich, United Kingdom, have determined that gene-regulatory mechanisms at an early embryonic stage govern the flowering behavior of Arabidopsis later in development. The paper is published in the journal *PNAS*.

How do early life events shape the ability of organisms to respond to environmental cues later in their life? Can such phenomena be explained at the mechanistic level? GMI group leader and co-corresponding author Michael Nodine counters these questions with a clear statement: "Our research demonstrates that gene-regulatory mechanisms established in early embryos forecast events that have major physiological consequences long after they are initiated."

What if springtime could last longer?

Developmental phase transitions are controlled by precise quantitative regulation of gene expression. Decades of research on the Arabidopsis floral repressor FLC (Flowering Locus C), which is produced by default in a plant embryo following fertilization, has revealed the involvement of multiple molecular pathways that regulate its expression levels. Ultimately, these pathways converge to set FLC expression levels such that flowering only occurs in response to favorable environmental cues. In other words, the regulation mechanisms ensure that plants overwinter before flowering, a process called "vernalization," as opposed to flowering multiple times a year (rapid cycle habit). However, the exact molecular interactions regulating FLC expression at specific developmental stages have remained poorly understood.

Early life decisions impact flourishing in adulthood

The team around GMI group leader Michael Nodine and Professor Dame Caroline Dean, group leader at the John Innes Centre, Norwich, UK, investigated the antagonistic functions of the FLC activator FRIGIDA (FRI) and repressor FCA (Flowering time control protein) at specific stages of Arabidopsis embryonic development. The researchers, including first author Michael Schon and co-author Balaji Enugutti, Ph.D. student and post-doctoral researcher in the Nodine group at GMI, respectively, lifted the mysteries on the plant's embryonic mechanisms that determine flowering behavior. Namely, they found that FCA promotes the attachment of a poly-adenine (poly-A) tail near the transcription start site of the FLC mRNA, which produces the shorter and non-functional FLC protein. On the other hand, FRI promotes the attachment of the poly-A tail further downstream in the FLC mRNA, thus resulting in the longer and functional version of FLC. In addition, the team found that the maximal antagonistic effect of FRI against FCA takes place at the early heart stage of embryo development. FRI thus leads to increased FLC expression levels and, ultimately, ensures vernalization-dependent (delayed) flowering.

Setting the stage for blooming

With these findings, the researchers show that the FLC transcript is antagonistically regulated in a co-transcriptional manner (as the mRNA is being transcribed), and that these effects take place within an early developmental stage in the plant embryo. Additionally, they propose that the FLC antagonist FCA acts by establishing a specific chromatin state in the early embryonic developmental stages, which later induces a rapid cycle flowering habit without vernalization. On the other hand, this repressed chromatin state is prevented by the FLC activator FRI within the early heart stage, thus maintaining an FLC high transcriptional state that persists in later developmental stages and leads to overwintering behavior.

"Our findings demonstrate that opposing functions of co-transcriptional regulators at a very specific developmental stage set the quantitative expression state of FLC," says GMI group leader Michael Nodine. "Understanding how gene regulatory mechanisms established early in life can influence processes that occur much later is of general interest in animals and plants. Our findings will be of interest to researchers investigating RNA-mediated and epigenetic regulation of gene expression, as well as mechanisms controlling developmental phase transitions including flowering time."

More information: Michael Schon et al, Antagonistic activities of cotranscriptional regulators within an early developmental window set FLC expression level, *Proceedings of the National Academy of Sciences* (2021). DOI: 10.1073/pnas.2102753118

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