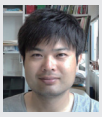
LABORATORY OF PLANT DEVELOPMENT AND PHYSIOLOGY



Specially Appointed Associate Professor
KAWADE, Kensuke

Adjunct Professor (BIO-NEXT Project, ExCELLS): *TSUKAYA, Hirokazu*
Postdoctoral Fellow: *NOZAKI, Mamoru*
SOKENDAI Graduate Student: *ST CLAIR, Griffin*
Visiting Graduate Student: *TOMOI, Takumi*
Technical Assistant: *YAMAGUCHI, Chinami*
Secretary: *HACHISUKA, Midori*

Development and metabolism are intertwined with one another during organogenesis. This interaction is essential to maintain the metabolic state in a developmental context-dependent manner. There is also a growing awareness that metabolism plays an instructive role in developmental processes. This emerging picture depicts metabolism as a critical system not only for sustaining physiological conditions, but also regulating developmental patterning by coordinating various cellular processes. However, it largely remains unclear how this interaction is established in multicellular organisms. We aim to reveal as-yet-unknown relationships between developmental and metabolic processes, and their biological meaning, by elucidating molecular mechanisms in the system. To address this, we use a trans-omics approach including metabolome and transcriptome analyses using *Arabidopsis thaliana* as a model, in conjunction with standard molecular genetics and biochemistry techniques.

I. Cytochrome P450 epoxidase for embryonic patterning

To uncover the hidden relationships between development and metabolism, we performed quantitative phenome screening using *A. thaliana* mutants of orphan cytochrome P450 genes. As a result of this screening, we discovered the *cyp77a4* mutant, which exhibits irregular embryonic patterning as evidenced by its developmental defects, such as a cup-shaped cotyledon morphology (Figure 1). Although CYP77A4 is the first cytochrome P450 reported that is able to catalyze the epoxidation of unsaturated fatty acids in plants, its function in development is unknown.

Through the use of auxin-related reporters, we determined that CYP77A4 is essential for polar auxin transport via proper localization of PIN1 (an auxin efflux carrier). Interestingly, unlike other enzyme mutants defective in auxin dynamics in ubiquitous tissues, the *cyp77a4* mutant was associated with defects specifically in embryos. Furthermore, our double mutant analysis found that *CYP77A4* and *CYP77A6* (the phylogenetically closest gene to *CYP77A4*) are functionally independent. Based on these findings, we propose that the metabolic requirement for polarity establishment via auxin dynamics differs between tissues, and that in embryos this depends on a CYP77A4-dependent metabolic pathway. These findings may augment our understanding of fatty-acid epoxidation by uncovering a new developmental function of the epoxidase (Kawade *et al*., 2018).

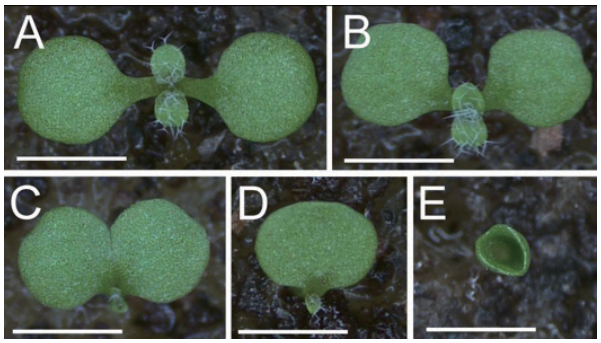


Figure 1. Irregular arrangement of cotyledons in the *cyp77a4* mutants. (A-E) WT-like (A), abnormally arranged (B), single (C and D), and cup-shaped (E) cotyledons in the *cyp77a4-3* mutants. Bars = 2 mm.

II. The role of the developmental signal intertwined with metabolism

ANGUSTIFOLIA3 (AN3) is a transcriptional co-activator, which promotes cell proliferation in leaves. We recently showed that AN3 forms an expression gradient along a proximal-to-distal developmental axis to regulate cell proliferation dynamics in time and space (Kawade *et al*., 2017; Figure 2). To gain further insights into how AN3 contributes to tissue patterning, we conducted transcriptome and metabolome analyses using *an3* mutants. We found that AN3 regulates a transcriptional network for oxygen homeostasis. Our metabolic profiling detected characteristic features of redox disturbance in the *an3* mutants. Although cell proliferation is an essential process for tissue patterning, reactive oxygen species are generated through energy production. It would be interesting to assume that the AN3 signal may solve the argument surrounding cell proliferation and oxidative stress, in plant development.

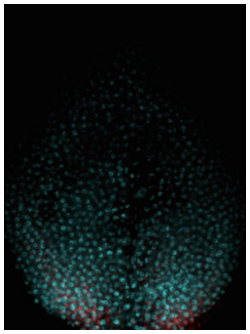


Figure 2. A merged image of the leaf primordia (around 200-μm length) expressing genetically engineered mobile or immobile AN3 (cyan or red, respectively). The distribution of the mobile AN3 gradually spreads along the leaf proximal-to-distal axis (from down to top), which is broader than that of the immobile one.

Publication List:

〔Original papers〕

● Ferjani, A., Kawade, K., Asaoka, M., Oikawa, A., Okada, T., Mochizuki, A., Maeshima, M., Hirai, M.Y., Saito, K., and Tsukaya, H. (2018). Pyrophosphate inhibits gluconeogenesis by restricting UDP-glucose formation *in vivo*. Sci. Rep. *8*, 14696.
● Kawade, K., Li, Y., Koga, H., Sawada, Y., Okamoto, M., Kuwahara, A., Tsukaya, H., and Hirai, M.Y. (2018). The cytochrome P450 CYP77A4 is involved in auxin-mediated patterning of the *Arabidopsis thaliana* embryo. Development *145*, dev168369.