【Grant-in-Aid for Transformative Research Areas（Ｂ）】

Spin-glass type developmental system: A new framework to understand flexible morphogenesis of sessile multicellular organisms

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Purpose and Background of the Research

● Outline of the Research

Sessile multicellular organisms, such as plants and macroalgae, which attach to solid bases, including soil and rock surfaces, are morphologically flexible. Such flexibility is a survival mechanism, with low proactive migration ability. However, further studies are required to better understand developmental mechanisms for such flexibility. In this research, we focus on variations in cellular polarity during organism development. In contrast to well-known cases of consistent cellular polarity, which are temporarily and spatially consistent throughout the tissue, plants show varied cellular polarity in some tissues during development (Fig. 1). By abstracting cellular polarity similarly to "spin" in physics and assuming the tissue as a collective entity of spins, we aim to determine the macroscopic mechanisms of the whole tissue. We hypothesise that the randomness of cellular polarity generates flexibility in organ morphology and tackle this hypothesis through associations between experimental and theoretical studies.

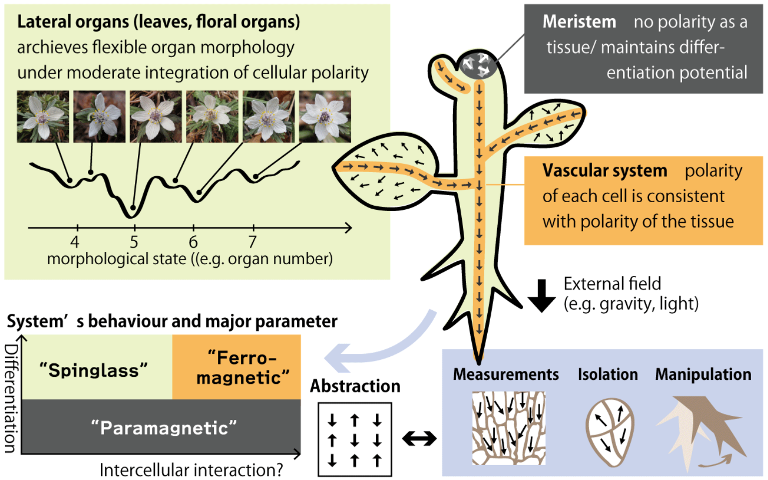

Figure 1. Outline of the research

● Morphological flexibility in plants and macroalgae

Numerous plants and macroalgae exhibit a high morphological flexibility, even in genetically identical cases; for example, different leaf shapes of dandelions and petal numbers of Ranunculus flowers on one plant. Such flexibility may be due to differences in environmental factors and developmental stages. However, published research indicates that many biological processes are stochastic, and even macro-scopic phenotypes can be affected by stochasticity at the molecular and cellular scales.

● Cellular polarity in plant tissue and abstraction as spin system

Cellular polarity is important for the morphogenesis of multicellular tissues, and is determined at subcellular scales, such as the intracellular localisation of specific molecules, density gradients, asymmetry in shape, and mechanical properties of cells. Cellular polarity regulates tissue morphogenesis through cell division and growth, and tissue structure is fed back to the cellular level by chemical or mechanical signals. Inputs from the external environment, such as gravity, light, and water currents, are also important for the development of sessile multicellular organisms.

Such complex subjects may be simplified by abstraction, to illustrate the mechanisms of the system. In spin systems, the macroscopic status can be changed by microscopic characteristics, such as spin-spin interactions. We suggest abstracting cell status only by the polarity as in "spin," which increases understanding of the fundamental behaviours of the morphogenesis of multicellular tissue and the development of organs to individual scales.

Expected Research Achievements

We proceed with a cycle between experiments and mathematical modelling. We estimate the spin-spin interactions from experimental data on cellular polarity, incorporate them into mathematical models, and validate the model results using isolated or manipulated experimental systems (Fig. 2).

● Quantification of cellular polarity distribution

We will quantify the correlation of the polarity between neighbouring cells and the distribution of polarity in a tissue to estimate the signs and strengths of the interactions between spins.

● Analyses of the relation between randomness in cellular polarity and flexibility in macroscopic morphology

The order of cellular polarity in tissues will be measured and compared with organ-level morphological flexibility, to test our hypothesis that "the randomness of cellular polarity generates flexibility in organ morphology."

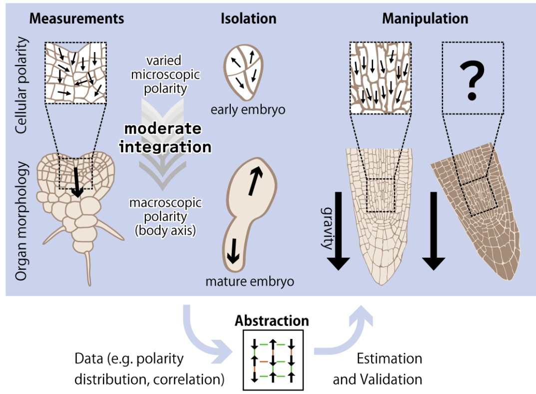

Fig. 2. Cycle between experiments and abstract model.

● Examination of body axis formation in isolated systems

An isolated cultivation system of zygotes will be used to determine how the body axis is formed from a small number of cells without clear polarity or external information.

● Evaluation of responses to external field

The response of each cell to external environmental changes and the reconstruction of the body axis will be evaluated.

By proceeding with the cycle between the above experimental systems and mathematical modelling, we aim to elucidate the major factors that switch between the three states found in plant development: the undifferentiated state, the robust state in which cellular polarity is consistent throughout the tissue, and the flexible state in which cellular polarity is variable and multiple forms can appear.

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