East Asian Journal on Applied Mathematics
doi: 10.4208/eajam.2024-068.270524

Vol. **15**, No. 4, pp. 701-715
November 2025

Dynamical Behaviors of Seed-Plant Stoma

Xue Cong and Dan Hu*

School of Mathematical Sciences, Institute of Natural Sciences, and MOE-LSC, Shanghai Jiao Tong University, Shanghai 200240, China.

Received 19 April 2024; Accepted (in revised version) 27 May 2024.

Abstract. Stomata are important for plants as nodes linking the transpiration process and photosynthesis process. Accurate regulation of stomatal aperture balances water loss and carbon-dioxide uptake. In a recent work, a mathematical model is developed for seed-plant stomata, which exhibits rich dynamical behaviors and can semi-quantitatively explain responses of the stomata to environmental changes. In this work, we numerically study the dynamical behaviors of the stomatal model using phase diagrams with respect to a few important parameters. The phase diagrams are helpful for further validation of the model and experimental measurements of model parameters.

AMS subject classifications: 65M10, 78A48

Key words: Stoma, dynamics, water potential, aperture, phase diagram.

1. Introduction

Stomata are tiny openings on the surface of plants. In most plants, they are mainly distributed on the lower surface of leaves. A stoma is enclosed by a pair of bean-shaped (or dumbbell-shaped in grasses) guard cells [10]. The aperture of a stoma is dynamically changing: the stoma opens wider when the guard cells absorb water and expand their size; whereas the stoma closes when the guard cells lose water. For seed plants, guard cells are surrounded by subsidiary cells that help the guard cells to actively control the stomatal aperture [8–10, 12, 19, 30, 32].

When stomata open, water inside the plants evaporates into the air and carbon dioxide diffuses into the leaves through the stomata. The speed of gas exchange is crucially controlled by stomatal aperture. From this point of view, stomata are the key apparatuses of plants that control water evaporation and carbon-dioxide uptake, thus play an important role in both transpiration and photosynthesis of plants [13, 15]. By regulating stomatal aperture, plants are able to accurately balance water loss and carbon dioxide acquisition [13, 16, 17, 19].

*Corresponding author. *Email addresses:* congxue2014@163.com (X. Cong), hudan80@sjtu.edu.cn (D. Hu)

Due to the importance of stomatal dynamics in plant physiology, there has been a long exploration history to understand the working mechanisms of stomata [3,4,21,23,24,29]. For particular plant species, experimental measurements have provided quantitative relations between stomatal aperture and the turgor pressure of guard cells [6,8,9,20], between stomatal conductance and evaporation speed [7], and between potassium content in guard cells and its water potential [1,18]. Conductances for water transportation in plants are also quantitatively measured for different plants [28]. These quantitative studies has allowed researchers to develop mathematical models to describe the dynamics of stomata [5].

In a recent work [5], a mathematical model for seed-plant stoma has integrated the passive mechanical interaction between the guard cells and subsidiary cells and the active regulation stomatal aperture via potassium flux between guard cells and subsidiary cells. Fig. 1 fully explains the main elements of the thesis in the work [5]. This model successfully explained many experimental observations [8,10,11,16,18,23], such as the counterintuitive "Wrong-way Response" phenomena [23,29], in which stomatal aperture decreases when water supply increases. Consistent to experimental observations [10,22,23], the model also predict multiple dynamical behaviors, including periodic oscillation, damped oscillation, and stable steady states, under different environmental conditions and parameters. Among the many physical, environmental, or specie-specific parameters, a few of them can change significantly or sensitively influence the stomatal dynamics.

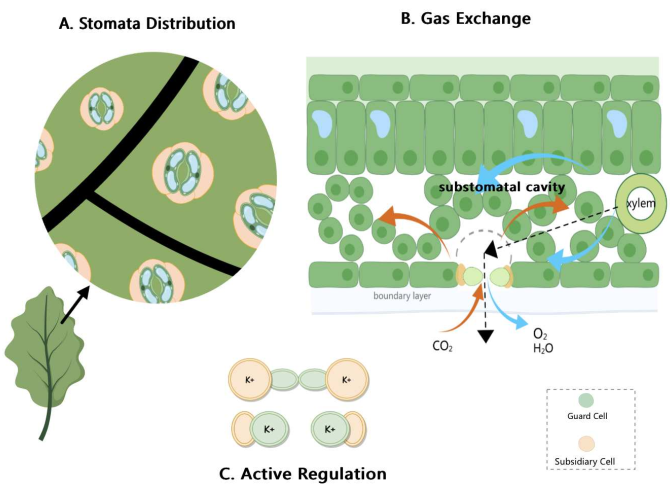

Figure 1: Stomata on leaves regulate water loss and carbon-dioxide uptake. A) Top view of adaxial surface of the leaf. Stomata distributes on the leaf. Veins formed by xylems supply water to the leaf. B) Gas exchanges. Water supplied by the xylem reaches the sub-stomatal cavity through leaf cells and the air space in the leaf and diffuses into the air through the stoma. Carbon-dioxide also diffuses into the leaf through the stoma. C) Active regulation of stomatal aperture. When the subsidiary cells (shown in light yellow) absorbs water and expand their size, the stomata closes; whereas when the guard cells (shown in light green) absorbs water, the stoma opens wider. Active movement of potassium ions changes the osmotic pressure in the cells and regulate the turgor pressure in these cells.