ENLIGHTEN Agriculture

Volume: 1, Issue: 1, Jan 2025
Article ID: EA03

NATURE'S HELPERS: HOW BIRDS' ACOUSTIC SIGNALS INFLUENCE STOMATAL OPENING?

Abhishree Ramachandra

Scientist, Swansat Private Limited, Mumbai, India.
Email: abhishreeramachandra@gmail.com

Abstract

Stomata are minute epidermal openings on leaf surfaces regulating the vital process of photosynthesis and transpiration in plants. The opening and closing of stomatal apertures are regulated by many factors including turgor pressure changes, influenced by environmental and hormonal signals. Recently, birds are known to stimulate stomatal opening, by sending bird calls as "acoustic signals". Bird calls are perceived by plants via mechano-sensitive ion channels, influencing ionic changes, turgor changes, and facilitating stomatal opening. This article presents one of the interesting stories as to how birds can help plants to open stomata. It may seem to be as an unusual relation, but these feathered friends have an interesting relation with plants other than pollination, that supports healthy ecosystems. Understanding these associations offers new avenues in sustainable agriculture.

What are Stomata?

The stomata are minute openings on the leaf surfaces that regulate photosynthesis and transpiration, crucial for overall plant health. Stomata consist of a pair of specialized guard cells present in aerial surface of leaves covering mesophyll cells (Sarwat and Tuteja, 2017). Increase in guard cell turgor pressure led to a greater stomatal pore aperture, which enhances the rates of CO2 uptake for photosynthesis and water loss, via a process termed stomatal conductance (Hetherington and Woodward, 2003).

What triggers stomata to open?

The opening of stomata is triggered by various external factors including availability of water, CO2 levels in the atmosphere, humidity, temperature and internal factors like hormone levels mainly abscisic acid.

Recent research has revealed several signals that regulate stomatal openings in plants, encompassing a combination of environmental, hormonal, and molecular factors (Fig.1). Below are some key signals:

1. Environmental Signals: Light, CO2 concentration and humidity levels mainly influence stomatal opening. Blue light triggers stomatal opening via phototropins, activating H^+-ATPase in guard cells, which leads to ion influx and osmotic changes. Red light can also influence stomatal behavior indirectly through photosynthetic carbon assimilation. While low CO_2 levels promote stomatal opening, and high CO_2 levels typically cause stomatal closure the high vapor pressure deficit (low humidity) reduces stomatal aperture to prevent water loss (Driesen et al., 2020). Along with these factors higher temperatures can also enhance transpiration, influencing the dynamics of stomata (Hetherington and Woodward, 2003). The reactive oxygen species (ROS) generated by ozone exposure also triggers closure of stomata.

2. Hormonal Signals: Although abscisic acid (ABA) is the primary regulator of stomatal closure during drought stress, the cross-talk with other hormone regulate stomatal opening. The ABA activates ion efflux channels, leading to guard cell turgor loss, but auxin promote stomatal opening by enhancing proton pump activity and facilitating ion transport. The cytokinins, which are often antagonistic to ABA, promote stomatal opening under favorable conditions. Recently, strigolactones are also considered has emerging signals with potential roles in modulating stomatal responses under stress along with jasmonates, which facilitates stomatal closure in response to pathogen attack or abiotic stress (Sarwat and Tuteja, 2017).

3. Molecular and Intracellular Signals: Cytosolic calcium (Ca2+) changes act as a second messenger in guard cell signaling, mediating ABA, ROS, and other responses. The nitric oxide (NO) works with ABA to promote stomatal closure.

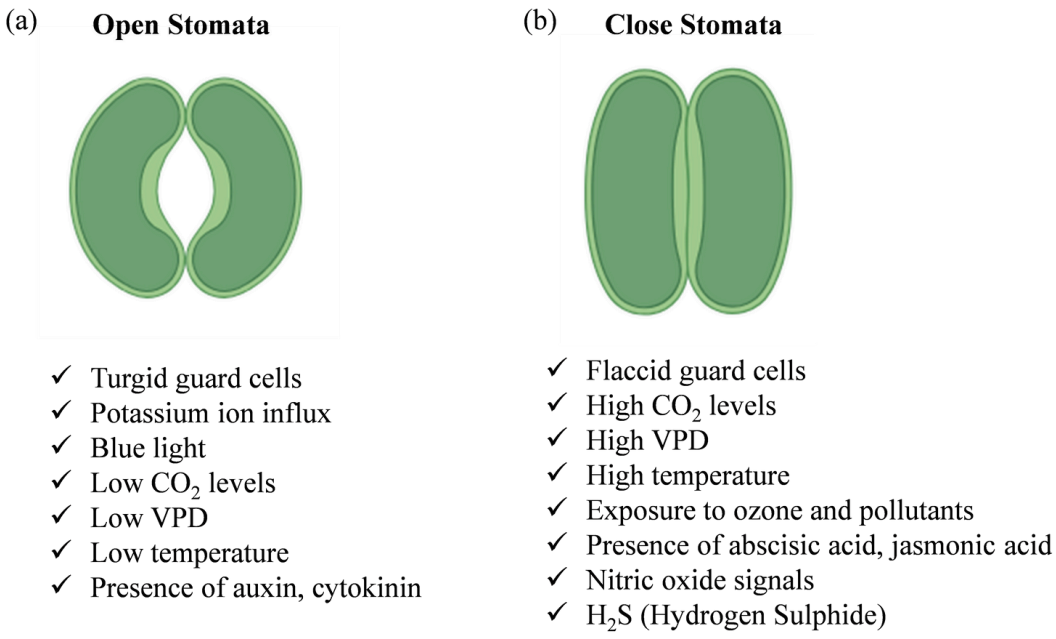

Fig.1: Factors influencing opening (a) and closing (b) of stomata. Illustration created using biorender.com

The K^+ and Cl^- ion channels are key players in regulating guard cell osmotic pressure during stomatal movements (Hetherington and Woodward, 2003). Also, sucrose and other sugars act as signaling molecules influencing stomatal aperture based on energy demands.

4. Novel Signals and Crosstalk: Recently hydrogen sulfide (H_2S) identified as a modulator of stomatal closure via interaction with ROS and NO. Theguard cell-specific peptides like RALF (Rapid Alkalinization Factor) can alter stomatal dynamics. Secondary messengers like phosphatidic acid and inositol phosphates are known to regulate guard cell signaling pathways (Driesen et al., 2020). Along with these signals, the circadian rhythm tightly controls diurnal patterns of stomatal opening and closure in plants. These signals interact in a complex network to optimize gas exchange and water use efficiency while responding to environmental and physiological changes.

The bird- plant connection

Interactions between birds and plants are diverse and play crucial roles in maintaining ecosystems. Beyond the well-known roles of pollination and seed dispersal, birds engage in surprising interactions with plants that support ecological balance. Most known relation is that the birds use plants as nesting sites or shelter. Some other common interactions include seed dispersal (Ornithochory) and pollination (Ornithophily) by birds. Certain insectivorous birds feed on plant pests, reducing herbivory and supporting plant health. For example, blue tits eat aphids and caterpillars on plants. Birds and plants often form mutualistic interactions, where birds get food (nectar or fruit), while plants get pollinated or their seeds dispersed. In some cases, birds can compete with plants for resources or cause harm, such as when some birds steal nectar without-aiding pollination (nectar robbing) (Anderson et al., 2016). These interactions are vital for maintaining ecological balance, plant biodiversity, and healthy ecosystems. The response of plants to their surrounding atmosphere particularly to sound signals (bioacoustics) was first document during 1960s by T. C. Singh, at Annamalai University in India. He experimented by playing classical music for plants. He noticed significant increase in the crops' height as well as their overall biomass. In another study, Dan Carlson patented his research on auditory fertilizer called "Sonic Bloom," in 1985. He made a statement that "Every cell wall or cell membrane maybe functions as an eardrum." These studies showed the importance of sound signals in plant development, thus opening the new field of bioacoustics (Petrescu et al., 2017). Plant detect the vibrations from the chewing of their shoots by herbivores, this triggers defense response by producing toxins (Kollasch et al., 2020). Another such example of sound perception by plants is when vibrations are induced by buzzing bees in flower petals, triggering nector production (Pujiwati et al., 2018; Raguso et al., 2020). However, further studies are required to confirm whether plants respond to sounds directly or to the vibrations induced by sounds.

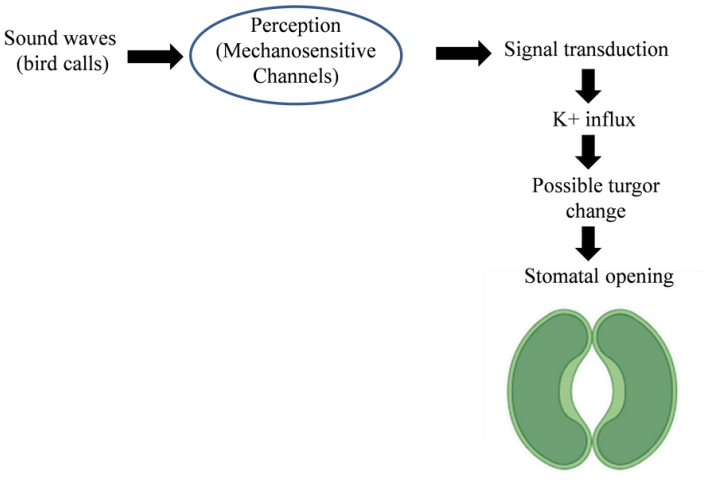

Fig. 2. Possible mechanism of stomatal opening in response to sound waves.

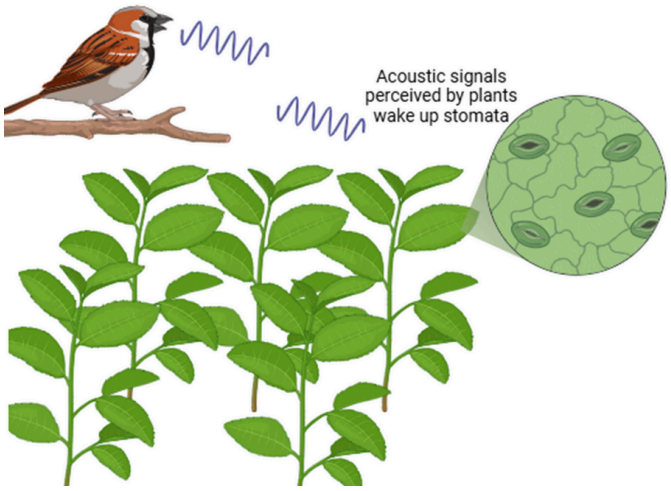

Fig. 3. Graphical representation showing influence of bird's acoustic signals on stomatal opening. Illustration created using biorender.com

The bird- stomata connection

Since plants can perceive natural sounds in the form of bird calls form their surroundings, the present article has tried to uncover the interaction between bird-stomata. Studies have documented that when bird move around the plants, they stimulate or create microclimates by stirring up the air. This creates small changes in humidity and temperature triggering stomatal opening. This is beneficial for plants during warmer conditions (Appel et al., 2014). The bird chippings can serve as bioacoustic (sound) signals that influence stomatal opening (Mishra et al., 2016). The calls can be potentially perceived by plants through mechanoreceptors (sensitive to sound waves or vibrations) present on the membrane (Pujiwati et al., 2018). These signals perceived by the cuticle regulate epidermal patterning, also influencing stomatal development (Bird and Gray, 2003). Plants generally perceive sounds through mechano-sensitive ion channels. These vibrations trigger alterations in the extracellular matrix, regulating stomatal opening, (Shih et al., 2014) but the potential mechanism behind is yet to be confirmed.

Bird calls during daytime act as sound signals to wake up stomata

Studies have shown that sound waves act as stimuli (Pagano and Del Prete, 2024). The vibrations created by bird chippings can stimulate plant's sensory systems (Mishra et al., 2016). The plants have the ability to respond to various frequencies and certain sound waves (Hussain et al., 2023) which enhance the activity of stomatal guard cells (Pujiwati et al., 2018). The sound waves are perceived by mechano-transmitters present on the cell surface, these signals triggers influx of K+ ions bringing changes in the turgor pressure of the guard cells causing stomata to open (Fig. 2.). The plants have internal biological clocks called circadian rhythms which regulate all the physiological processes throughout the life cycle of plant (Creux and Harmer, 2019). Bird calls, particularly in the morning, act as acoustic cues that signal the start of daylight, promoting stomatal opening to facilitate photosynthesis. When stomata open in response to these acoustic signals, plants can take in more CO2 (Pujiwati et al., 2018), thereby enhancing photosynthesis, which is crucial process for plant growth (Fig. 3). The bird droppings showcase a healthy ecology. And also, the sound from bird chippings encourages plants to open their stomata thus affecting plants growth and development (Appel et al., 2014).

Conclusion

The use of sound signals by birds and plants to communicate exemplifies the remarkable interdependence found in nature. Delving deeper into these processes unveils fascinating mechanisms by which the organisms interact and exchange information. This not only broadens our understanding of plant physiology but also highlights the sensory capabilities of plants. Plants have the ability to hear music, further research is

needed to check whether stomata act has analogous structure to ears in plants. Understanding the intricate relationship between birds and plants opens avenues for innovative practices in sustainable farming, enhancing ecosystem resilience and productivity.

A tiny step in the direction of farmer-bird-friendly methods

To foster and protect valuable relationship between birds and plants, the following bird-friendly measures can be adopted:

1. Planting Native Vegetation: Grow native plant species to create essential habitats that attract and support local bird populations.
2. Proving Water Resources: Establish small ponds or birdbaths to encourage birds and improving local biodiversity.
3. Minimize Pesticide Usage: Reduce the pesticides usage to promote healthier bird populations and preserve their natural habitats.

Happy Bird Watching!

References

Appel, H. M., & Cocroft, R. B. (2014). Plants respond to leaf vibrations caused by insect herbivore chewing. Oecologia, 175(4),1257–66.

Anderson, S. H., Kelly, D., Robertson, A. W., & Ladley, J. J. (2016). Pollination by birds. In Why birds matter: Avian ecological function and ecosystem services (p. 73).

Bird, S. M., & Gray, J. E. (2003). Signals from the cuticle affect epidermal cell differentiation. New Phytologist, 157(1), 9–23.

Creux, N., & Harmer, S. (2019). Circadian rhythms in plants. Cold Spring Harbor Perspectives in Biology, 11(9), a034611.

Driesen, E., Van den Ende, W., De Proft, M., & Saeys, W. (2020). Influence of environmental factors light, CO2, temperature, and relative humidity on stomatal opening and development: A review. Agronomy, 10(12), 1975.

Hetherington, A. M., & Woodward, F. I. (2003). The role of stomata in sensing and driving environmental change. Nature, 424(6951), 901-908.

Hussain, M., u Rahman, M. K., Mishra, R. C., & Van Der Straeten, D. (2023). Plants can talk: a new era in plant acoustics. Trends in plant science, 28(9), 987-990.

Kollasch, A. M., Abdul-Kafi, A. R., Body, M. J., Pinto, C. F., Appel, H. M., & Cocroft, R. B. (2020). Leaf vibrations produced by chewing provide a consistent acoustic target for plant recognition of herbivores. Oecologia, 194, 1-13.

Mishra, R. C., Ghosh, R., & Bae, H. (2016). Plant Acoustics: In the search of a sound mechanism for sound signaling in plants. Journal of Experimental Botany, 67(15), 4483–4494.

Pagano, M., & Del Prete, S. (2024). Symphonies of Growth: Unveiling the Impact of Sound Waves on Plant Physiology and Productivity. Biology, 13(5), 326.

Petrescu, Ş., Mustatea, R., & Nicorici, I. (2017). The influence of music on seed germination of Beta vulgaris L. var. cicla L. Journal of Young Scientist, 5, pp.67-72.

Pujiwati, I., Aini, N., Sakti, S. P., & Guritno, B. (2018). The Effect ofHarmonic Frequency and SoundIntensity on the Opening of Stomata,Growth and Yield of Soybean(Glycine max (L.) Merrill). Pertanika Tropical Agricultural Science, 41(3), 963–974.

Raguso, R. A., Harder, L. D., & Johnson, S. D. (2020). Does acoustic priming 'sweeten the pot'of floral nectar? Ecology Letters, 23(10), 1550-1552.

Sarwat, M., & Tuteja, N. (2017). Hormonal signaling to control stomatal movement during drought stress. Plant Gene, 11, 143-153.

Shih, H. W., Miller, N. D., Dai, C., Spalding, E. P., & Monshausen, G. B. (2014). The receptor-like kinase FERONIA is required for mechanical signal transduction in Arabidopsis seedlings. Current Biology, 24(16), 1887–1892.

***