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Trends in
Plant Science

Spotlight

Plants 'cry' for help through acoustic signals

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Plants perceive sounds, while responses to these sounds were already known. A breakthrough is the discovery by Khait *et al*. that stressed plants emit various informative ultrasonic sound signals, which can be categorized according to plant species, stress type, and stress severity. This discovery may change how plants are cultivated.

Stressed plants emit ultrasonic sounds

It is well established that plant–environment interactions are coordinated through chemical signaling molecules. However, a lesser-known but remarkable fact is that sound can also serve as a physical signal between plants and their biotic environment. Of note, plants are able to perceive sounds and respond according to these sounds (e.g., sound of flying bees induces the production of sweeter nectar) [1]. Several other types of sounds are involved in regulating ionic levels (Ca^{2+}, K^+) and reactive oxygen species homeostasis to facilitate signaling and can even modify gene expression [2]. Vibrations in plants have been observed in response to both biotic and abiotic stimuli, which can trigger cellular signaling cascades [2,3]. However, until recently, airborne sound emissions in plants had not been detected.

A recent breakthrough by Khait *et al*. revealed that plants emit airborne ultrasonic sound signals (~20–100 kHz) as a stress response, which can be classified according to plant species, stress type, and stress severity [4]. These sounds are beyond the human hearing range (20 Hz–20 kHz), but have the potential to be heard by insects and others animals up to the distance of 3–5 m [4]. The authors conducted a study in which tomato and tobacco plants were grown in a controlled environment chamber and subjected to drought and wounding stress. Acoustic signals from plants were recorded in acoustic chambers and a greenhouse. Two microphones were used for each plant at a distance of 10 cm. When tomato and tobacco plants were exposed to stress, they emitted an average of 35.4 and 11.0 airborne sounds per hour, respectively, under drought conditions, and 25.2 and 15.2 sounds per hour, respectively, under cutting injury. No sounds were recorded in control plants over 500 h of recordings. Under drought stress, the average peak sound intensity for tomato plants was 61.6 **decibels sound pressure level (dBSPL)** (see Glossary), while for tobacco plants, it was 65.6 dBSPL. However, wounding stress resulted in an average peak sound intensity of 65.6 dBSPL for tomato plants and 63.3 dBSPL for tobacco plants. Moreover, similar sound emissions were observed in wheat and corn plants under drought stress, as well as in grapevine, cactus, and henbit plants under cutting injury. Additionally, these sound emissions were also detected in tomato plants when they were infected with tobacco mosaic virus (TMV) [4].

Next, authors employed machine learning algorithms to develop models that successfully identified the specific sounds emitted by plants, according to the type and severity of stress, and were able to distinguish them from background greenhouse noises such as wind and air-conditioning [4]. Plants displayed a distinct temporal pattern in emitting these sounds. For example, under drought stress, few sounds were emitted at the beginning, followed by an increase in sound emission at 4–5 days, which then gradually decreased as the plants became more severely dehydrated. The emission of sounds also exhibited a **bimodal peak** pattern throughout the day, with one major peak occurring in the morning (8:00–12:00) and a smaller peak in the afternoon (16:00–19:00), denoting the approximate hours of natural daylight. This can potentially link with stomatal conductance because similar bimodal peak patterns were noticed during day time in tomato plants [5]. The maximum number of sounds were observed when the soil volumetric water contents (VWCs) were less than 0.05, while almost no sounds were emitted at VWC values greater than 0.1. Interestingly, the plant transpiration rate was found to be highly correlated with the number of sound emissions on an hourly basis under drought stress, with a clear peak occurring before noon and lower emissions at night; this can be associated with stomatal conductance, as similar patterns were observed, peaking around noon [6]. However, while the transpiration rate decreased on a daily basis due to dehydration, the number of sound emissions remained relatively constant [4].

Cavitation in the stem could be a possible explanation for sound emission. The cohesion-tension model suggests that the attractive forces between water molecules cause them to adhere and form a continuous column inside the xylem vessels. Tension (i.e., negative pressure) is created in the xylem as a result of transpiration, which in turn aids in the movement of water from the roots to the shoot. Exposure of plants to drought, TMV infection, or cutting stress can lead to xylem cavitation. Cavitation is characterized by the presence of air bubbles or gas-filled voids,

Glossary

Bimodal peak: a statistical distribution with two distinct peaks, indicating two different populations or modes within the data.
Decibels sound pressure level (dBSPL): logarithmic measure used to quantify the intensity or loudness of sound wave.
Resonance frequency: vibration at maximum amplitude in responses to stimuli.

which impede the uninterrupted flow of the water column (Figure 1). When air bubbles form and move through the xylem, they cause vibrations in the surrounding water, which in turn creates sound waves that can be detected by specialized equipment [7]. The trachea diameter of different plant species was also closely linked with the emission of variable sound frequencies, lower sounds being emitted in plant species with wider tracheas [4]. Prior findings reinforced this notion as negative association observed among xylem diameter and **resonance frequency** [8]. The emission of sounds in response to drought and cutting stress differs between the two stress types due to the different rates of air intrusion. Cutting injury involves a rapid and high rate of air intrusion through the trachea. In contrast, drought stress is characterized by a gradual decrease in water supply, resulting in lower pressure and a slower rate of air intrusion in the xylem. Thus, cutting stress leads to the rapid and short-lived formation of air bubbles in xylem vessels while drought stress leads to a gradual and prolonged formation of air bubbles. The duration of the sound emission and the timing of its occurrence also differs between the two types of stress. Cutting injury causes sound emission for a shorter time period, with the majority of sounds emitted on the first day. In contrast, in the case of drought stress, sound emission persists for a longer time period, with the majority of sounds emitted on subsequent days [4].

In a nutshell, when faced by some biotic and abiotic stresses, plants emit distinct sounds that are specific to the type and severity of the stress. These sounds may serve as a signal to other plants and animals in the proximate environment (Figure 1).

Concluding remarks and future perspectives

Khait *et al*. recently showed that plants experiencing some stresses emit airborne

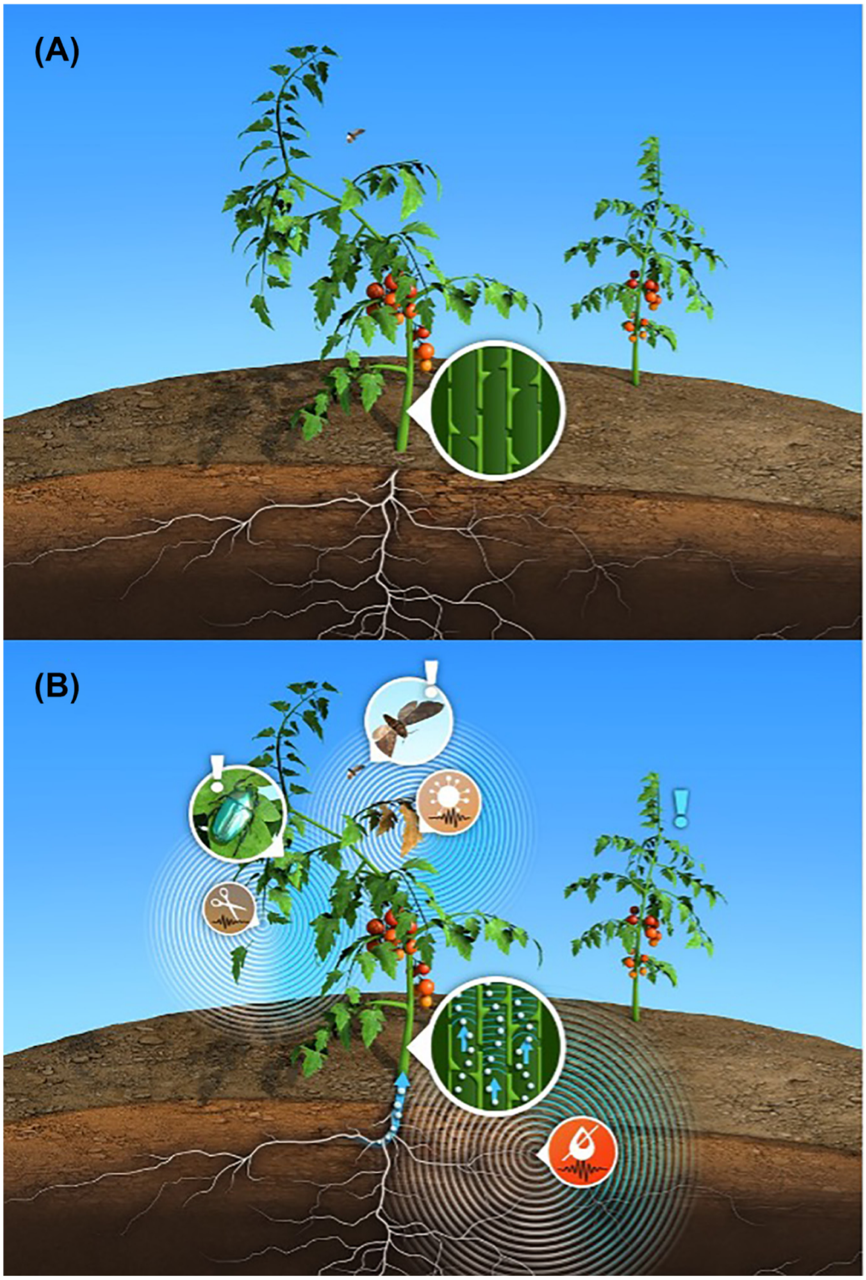

Figure 1. Plants emit sounds in response to some stressors, which may possibly be perceived by other organisms. (A) Under nonstressed conditions, there are no bubbles in the xylem that cause acoustic signals (xylem indicated by the circular inlet in the figure). (B) Stressors such as soil drying, mechanical stress, or viral infection, can lead to cavitation, the presence of air bubbles or gas-filled voids in the xylem (indicated by bubbles or voids in the xylem in the circular inlet in the figure). The movement or bursting of these bubbles and voids cause specific vibrations that are characteristic of the stress and may be detectable by neighboring plants or insects (indicated by the exclamation marks). Further research is needed to determine the potential impact of these acoustic signals on other organisms. However, the unique acoustic signature of each stressor could be harnessed in remote agriculture and horticulture for precision farming.

ultrasonic sounds, which can be classified according to the type of stress, severity of stress, and species of the plant [4]. Despite observing these findings in multiple plant species, sounds from the woody parts could not yet be detected by Khait *et al*.; here, more research is anticipated. To get more insights about plant sound emissions under stress, it is worthwhile to evaluate other plant species at various growth stages. For instance, crops may emit specific sounds when experiencing nutrient deprivation, which may be related to the plant water status and thus the rate of air intrusion in the xylem. This premise should be investigated, as it could facilitate the practice of managing plant nutrients in pursuit of environmental sustainability. In order to promptly detect and notify the nutritional and health status of plants, a custom-designed acoustic detection system should be developed. This system should be capable of discerning various stress factors such as dehydration, diseases, and pathogen attacks. Further research encompassing a wider range of biotic and abiotic stressors is necessary to determine the effectiveness of specific sound signals in this context. The system needs to be connected to a central amplifying module that triggers automated responses to address the stress before significant damage occurs. Such a system should be implemented in both controlled agri- and horticulture, as well as under open field conditions, and could be combined with remote sensing techniques [9]. It could, for instance, incorporate the evaluation of sound signals in conjunction with other indicators, such as absorption and reflection of specific wavelengths of electromagnetic radiation, to further optimize precision agriculture or horticulture applications. This discovery by Khait *et al*. has the potential to innovate crop management and significantly impact precision agriculture practices.

Acknowledgments

We thank the DFG (grant number 499216091) and the Research Foundation Flanders (FWO, grant 1S29122N) for support.

Declaration of interests

No interests are declared.

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https://doi.org/10.1016/j.tplants.2023.05.015

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