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RESEARCH ARTICLE

Plant Bioacoustics: A System of Plant-Sound Relationship

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ABSTRACT

Bioacoustics is a field of study that examines the production of sound and how it affects living things. Numerous plant species' physiology, behaviour, and eventual survival have all been greatly influenced by sound and its usage in communication. A better framework for future research may be developed along with a greater understanding of how various organisms interact acoustically with plants if the acoustic link between plants and animals is understood. A re-imagination of our knowledge of these organisms is anticipated to result from the systematic investigation of the functional and evolutionary importance of sound in plant life. This will also stimulate the emergence of new ideas and viewpoints regarding the communicative complexity of plants. The primary goal of this study is to examine some information about the bioacoustics interaction between plants and animals their sound, and ecology, including potential techniques of sound production employed by plants. The importance of acoustical research in plant ecology, as well as its potential mechanisms and future applications, are covered in this paper. The first section of this article reviews how plants amplify and transmit sounds produced by insect pests. The second section looks at surprising examples of carnivorous plants that show how plants have evolved to reflect but also enhance animal sounds, potentially revealing new angles in research on the interactions between animals and plants. The discussion then focuses on the mechanisms by which plants produce sound through transpiration stress and photosynthesis, as well as a potential model for these mechanisms.

Keywords: Bioacoustics, plant physiology, plant communication, plant, and animal interaction

INTRODUCTION

Communication is a universal phenomenon that occurs whenever living things communicate information with one another, regardless of how biologically organised they are. Many plant species behaviour, and ultimately their success, has been greatly influenced by sound and its usage in communication. Similar circumstances apply to plants and such sound generation by plants is known as plant acoustics. Plants may use sound, but we haven't been able to fully investigate what ecological and evolutionary ramifications this might have for a plant's survival. The ability to make sound is very beneficial for plants, and the use of sound to learn about their environment would be especially beneficial given how quickly and cheaply acoustic signals can transfer. By influencing response in other organisms, including plants and animals, both sound emission and detection also have adaptive significance in plants.

The idea of communications in plants has long been viewed as a contentious fringe theory, Because the sharing of information in plants was believed to involve cues i.e. incidental aspects of the environment that haven't been modified by natural selection to have a particular meaning for intended recipients and therefore, in the opinion of the majority of scholars, should not be regarded as communication signals (Monika Gagliano; 2012), instead of signals i.e., characteristics that have evolve for a particular communication role (Scott-Phillips 2007). However, as more researchers get interested in plant communication studies, this perspective is rapidly receiving great attention (Gagliano *et. al.*, 2017).

Traditionally, bioacoustics has aimed to record and analyse the sounds that various animal species make concerning their natural environments. No matter how cognitively and/or socially engrained this selective attention on animals as the primary sound source in a setting may be (Monika Gagliano; 2012), it is unquestionably constricting. In reality, plants are one form of biotic component that produces sound and is typically ignored because they can be found in practically every habitat (Monika Gagliano; 2012). It is well known in the literature that plants produce their cacophony of sounds in addition to the audible sounds made when rains land on or the wind blows through plant leaves and branches (Monika Gagliano; 2012). The current review aims to lay the groundwork for a methodical investigation into the numerous benefits, ecological, as well as ultimately evolutionary importance of acoustic communication among plants.

Acoustic interactions between animals and plants

Animals and plants interact acoustically in a significant and powerful way. Animal sounds can be reflected and transmitted by plants. However, buzz-pollination, in which pollinating insects (mainly bees) employ vibrations to emerge and extract pollen off the flowers, has been investigated by entomologists for decades. Species from 65 distinct plant families produce buzz-pollinated flowers, which are thought to have separately evolved several times. A currently published review article on buzz-pollination (Krishna, Keasar; 2018) noted that while much research has been done on the behaviour as well as signals produced by pollinating insects, relatively little work has been done on how mechanical structures of flowers may well have coevolved to allow species-specific stimulation of pollen release. Perhaps there are still more intriguing acoustic interactions between animals and plants to study.

Just several papers have gotten a lot of attention. Rosette plants released larger levels of chemical defenses (glucosinolates as well as anthocyanins) once real caterpillars began to feed on the leaves (Appel and Cocroft; 2014). This was accomplished by playing back caterpillar feeding sounds or "munching" in the absence of actual caterpillars. In other words, the chemical defenses of the plant were "stimulated" by sound. Utilizing piezoelectric actuators supported by a leaf, the caterpillar noises were first captured with something like a laser Doppler vibrometer and afterwards replicated as closely as possible to the duty cycle and origin level of the original signals. Two plants had playback applied, while two more had an actuator connected but none. This is the greatest illustration of animal-plant acoustic interactions because playbacks of air currents and leafhopper insect sounds that cover the same spectral range as that of the caterpillars were also attempted.

Several ant species that live in plants have warning signals that they can send to the entire colony by hitting their bodies just on the stem of the plant. Nobody is certain that plants could have developed effective ways to amplify these signals. This is also a good example of animal-plant acoustic interactions.

Bat Attraction to Mutualistic Carnivorous Plants using Acoustic Attraction

Animal signal transmission is greatly assisted by plants. Michael Schöner from the University of Greifswald revealed throughout his research on plant bioacoustics special session that diverse bat species pollinate about 250 genera of tropical plants. The petals and blooms of these plants produce a powerful reflection of bat ultrasonic signals across a wide range of aspect angles, according to a close analysis of a number of these species. The absence of these structures affected bats' capacity to find and pollinate the plants (Schöner *et.al.*, 2016).

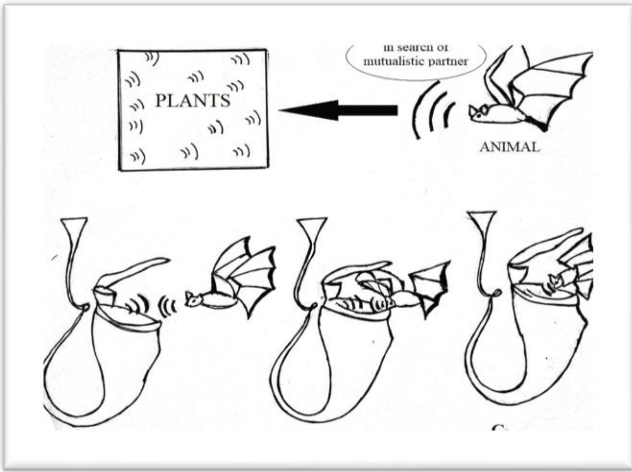

Figure 1: Acoustic Attraction of Bats to Mutualistic Carnivorous Plants *Nepenthes hemsleyana*

A pitcher plant (*Nepenthes hemsleyana*) features a concave structure in the outer wall that functions as a reflector. This plant is a mutualistic (mutual benefits) host for a few bat species, whose faeces fertilise the plant. Echo-reflective features in a Paleotropical plant are attractive to bats. The exposed rear wall of *N. hemsleyana* effectively reflects acoustic signals at a variety of angles of sound incidence, according to insonifications (Shown in Fig 1). Additionally, the pitchers exhibit a species-specific spectral structure that aids bats in recognising *N. hemsleyana* pitchers by echo-acoustic detection. Bats displayed a strong predilection for pitchers with undamaged reflectors (Schöner et, al. 2016). They reject them as roosts because they required more time to locate pitchers in which the reflector was gone.

Intriguingly, pitchers with larger reflectors were recognized faster and approached more frequently in the congested environment. This implies that natural selection might cause pitchers to grow larger reflectors, which would encourage more bat visits and a consequent increase in nutritional consumption. The bats should be able to detect *N. hemsleyana* pitcher plants with the reflector because of the small beam width of their calls (Schöner et, al. 2016). The results indicate that *N. hemsleyana* uses the bats' perceptual bias to its advantage to echo-acoustically attract them. As a result, the plants have access to more nitrogen and the bats can locate and enter appropriate day roosts more quickly. The representative spectral directional pattern of *N. hemsleyana* pitchers' near walls demonstrates that this structure is a multidirectional echo reflector similar to the dish-shaped foliage of *M. evenia*. This structure is lacking in relative plant *N. rafflesiana* that's why they do not attract bats. The idea that unrelated Neotropical angiosperms pollinated by bats as well as Asian carnivorous plants have convergent characteristics that precisely mirror bats' echolocation calls emphasises the role of evolution in explaining these findings.

Do plants produce sound…!

It has recently been believed that plants can emit sound waves. Specifically, plants produce audio acoustic emissions (10–240 Hz) at the lower end of the audio spectrum and ultrasonic acoustic emissions (UAE) at 20–300 kHz. These acoustic emissions have been detected and described multiple times over the past 45 years, with the UAE receiving the most attention (Monika Gagliano;2012). Numerous authors have easily taken use of these coincidental by-products of the physiological and biomechanical cavitation processes to identify cavitation, notably in plants undergoing drought stress (Rosner at al. 2006; Monika Gagliano 2013). Although it is undeniable that cavitation can result in acoustic emissions, it has always seemed highly improbable that every acoustic event was solely attributable to cavitation (R Laschimke et al. 2006; Jansen S, Schenk HJ 2015). Recent research shows that plants produce sounds apart from dehydration and cavitation-related procedures (Monika Gagliano; 2012).

Mechanism of sound production by plants

It is still uncertain how exactly plants generate sound. However, the ultimate mechanisms of sound production throughout all eukaryotes may be largely preserved since the biophysical principles there at molecular and cellular levels may not be all that different. Animals have evolved specialised morphological structures and organs to make sound, whereas plants are unlikely to contain these organs. The exact mechanisms of sound production have been the subject of research, yet it is not completely known. The various possible mechanisms that plants may use to produce sound are listed below.

Water-transport system as a way of sound production in plants

The acoustic emissions have been detected and described multiple times over the past 45 years, especially in the UAE receiving the most attention (Monika Gagliano; 2012). Acoustic emissions are typically attributed to the sudden release of tension inside a plant's water transportation system during cavitation when fluid is transported via transpiration out from roots through the xylem to the leaves (Venturas et al., 2017). While dissolved air in water expands in xylem channels, it eventually leads to the formation of air bubbles (embolism), obstructing the channels and impairing their ability to passage water (Jensen et al., 2016; Lambers et al., 2019). Numerous authors have opportunistically used acoustic signals as an indicator of cavitation, notably in plants under drought stress, even though they are only emitted as a fortuitous by-product of physiological-biomechanical metabolic activities of cavitation (Rosner at al. 2006; Gagliano *et. al.*, 2017). Other studies, however, contend that the source of these plant sounds is not cavitation disturbing the pressurized water column but rather a typically stable bubble system of the xylem conduits that can transport water in a travel peristaltic pattern (Hirson *et al.*, 2018). Since there are so many acoustic signals produced by plants, it has always seemed implausible that all of them are caused by cavitation alone (Monika Gagliano at al., 2012; Gagliano *et. al.*, 2017). However, recent research has shown that plants can produce sounds without being affected by dehydration or cavitation-related procedures (Monika Gagliano; 2012). Despite the fact that numerous research studies suggest that may be a potential mechanism for sound production in plants.

A hypothetical model of sound production in plants

The exact mechanism of how plants make sounds is still not known. The specialised morphological organs and/or structures that animals have acquired to generate sound are unlikely to exist in plants; at the cellular and molecular levels, the biophysical principles might not be significantly different, and within this model, the major mechanism of sound production throughout all eukaryotes could be greatly conserved. The first thing to remember is that objects which vibrate emit sound waves, and in every eukaryote, cells, as well as their parts, vibrate as a result of intracellular motions brought about by cellular processes such as the action of motor proteins and the cytoskeleton (Howard 2009; Liew *et. al.*, 2015). Cytoplasmic streaming is indicated by a blue arrow (Figure 2B). The group of mechanochemical enzymes, which includes motor proteins such as myosin, uses chemical energy from the disintegration of ATP among actin filaments to produce mechanical motion and, as a result, vibrations (Figure 2C). These nanomechanical motions have been observed using atomic force microscopes in a variety of systems, ranging from microscopic microbial cells to vertebrate cardiomyocytes (also known as heart cells; Monika Gagliano; 2012). Additionally, auditory hair cells specifically, spontaneous oscillations that aid in the active amplification of small noises in hearing, (Hudspeth A. J. *et. al.* 2014) to minuscule microbial cells, including Saccharomyces cerevisiae, common baker's yeast, which has motions in the range of 0.8-1.6 kHz (Pelling *et. al.*, 2004). Because they are anchored in tissue and consequently surrounded by other cells, distinct cells are influenced by the mechanical characteristics of nearby ones. Eventually, this results in a collective phase also known as coherent excitation which makes the signal stronger. Theoretically, it has been predicted that in plants, the combined radiation intensity of several cells will be sufficient for noticeable impacts, producing sonic fluxes in the 150 to 200 kHz range. Whether these mechanical vibrations and sound waves could travel long distances within and outside of the organisms (Figure 2D to A), plants may communicate with other plants or even other organisms through sound.

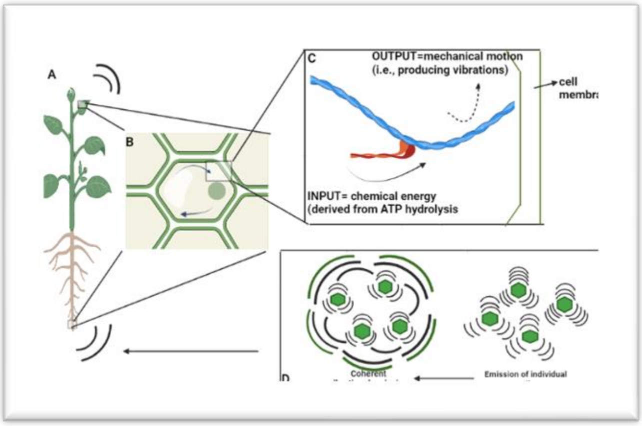

Figure 2: A hypothetical model of sound production at the cellular and molecular levels in plant

Based on the above-mentioned study, plants produce sound and can "receive" them as well. Whatever, the source or mechanism for these sounds, it is still true that plants emit sounds. Indeed, in addition to the folkloristic and somewhat esoteric accounts of the impact of sound, especially music, upon vegetation (Smith *et.al.*, 2015; Monika Gagliano; 2013), Plants vary their germination and development rates in response to sound waves of various frequencies, according to decades of scientific research (Fernandez-Jaramillo *et.al.*, 2018). In addition, sound waves cause alterations in the physiological and molecular points of polyamines as well as significant phytohormones e.g., abscisic acid and indole acetic acid. Along with antioxidant enzyme regulation the oxygen intake, the production of soluble proteins and RNA (Fahad et al., 2015) and the most significant are gene expression regulation (Jeong *et. al.* 2004).

Scientists were dismissive of the evidence that bats could use sound to orient for more than a century; it was this scepticism that prevented the finding of laryngeal echolocation in such species (Telling 2009). Today, bats' use of ultrasounds not only perfectly exemplifies the idea of biosonar and echolocation in nature, but recent research utilising playback tests has also shown the usefulness of these ultrasonic signals for bats to interact among conspecifics (Jones 2008). There are currently insufficient investigations on plants and sound, hence it is currently unable to make any definitive judgements about the potential bioacoustics capabilities of these organisms (Mancuso, et al. 2012; Gagliano, Renton, et al. 2012).

CONCLUSION

Knowledge of how plants generate and respond to sound is still significantly restricted and needs more in-depth research. We know even less about how plants might employ acoustic signals and also what possible ecological roles sound may play in a plant's life, making it a big challenge for future studies to elucidate the mechanisms through which plants produce and interpret acoustic signals. Although researchers now have suggestions indicating sound as stimuli alter some features of plant behaviours, physiology, or morphology. But still, the questions remain and the future scope of research. In plants, sound emission and detection may both be useful for adaptation, but there is currently a lack of reliable data regarding both processes, particularly reception.

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