

Plants, Sound and a Splash of Colour: A Mini-Review

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Abstract

Plant-insect interactions are essential for pollination, crop productivity, and agricultural sustainability; nonetheless, the sensory mechanisms that shape these interactions remain poorly understood. This mini-review examines emerging evidence on plant-produced sound and floral colour and their potential roles in plant-pollinator interactions. It considers acoustic emissions associated with xylem cavitation and water stress, which may convey information about plant physiological condition and influence the behaviour of insects interacting with plants. The review also examines insects' ability to detect plant-associated acoustic signals, alongside studies of floral iridescence and nanoscale petal structures that can modify the visual cues perceived by pollinators. The review further considers how plant characteristics, insect biology, predators, plant age, nectar availability, pollutants, soil conditions, and light may confound these complex interactions. Understanding the combined effects of acoustic and visual signals may provide new perspectives on plant-pollinator ecology and its relevance to crop production. Future research integrating controlled experiments, acoustic and optical measurements, ecological observations, and artificial-intelligence-based modelling could help clarify the biological significance of these signals and their potential applications in sustainable agriculture. Overall, the available evidence suggests that plant sensory ecology is a promising area for investigating how environmental stress, plant signalling, and pollinator behaviour interact within agricultural ecosystems.

Keywords: Plant-Insect Interactions; Confounders; Floral Iridescence; Pollination; Entomophily; Xylem Cavitation; Ecoacoustics

Highlights

- Plant acoustic emissions may provide information about plant physiological stress and water status.
- Plant-insect interactions are driven by multiple environmental and biological factors.
- Floral iridescence can influence the visual signals used by insect pollinators.
- Visual and acoustic plant signals may contribute to crop pollination.
- Integrating ecoacoustics, optical biology, and AI modelling may support future agricultural research.

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Introduction

Pollination plays an important role in clinical nutrition [1] because it affects the abundance of essential nutrients in food crops [2,3] during a time-lagged era of anthropogenic change [4-6] and increasing global population demands. This article focuses on entomophily (e.g. bees, butterflies, moths), which pollinates fragrant, colourful flowers by transferring pollen grains from anther to stigma in exchange for nectar [7]. Two notable aspects of pollination efficiency are discussed: one due to 'high-frequency sound signals from plants relative to increased water stress, warning of poor plant health and the need for, e.g. laying insect eggs elsewhere; thus reducing pollination, *vide supra*'; and another due to light diffraction from long, ordered, cuticular striated nanostructures on a petal surface overlaying iridescent epidermal cells producing UV-visible spectra [8], identified specifically by some insects according to their visual perspective, e.g. bees. This paper now discusses the role of iridescence/light diffraction from petal-surface ridge nanostructures in pollination.

Pliny the Elder, in the writings of *Naturalis historiae*, reminds us in the introduction to his book about insects that 'Nature is nowhere to be seen in greater perfection than in the very smallest of her works'. The authors marvel at Nature's (al)luring colouration and smell, timing, mutual shapes and structure, etc. and co-evolution (sic) of pollinating insects with gymnosperms and angiosperms [9,10]. The ensnaring mechanism whereby the insect alights on the petal seeking nectar is likened to the simile poem of the 'spider and the fly' the alluring petal around the plant's reproductive apparatus contains conical epidermal cells with a range of potential surface functionality such as petal colour, petal reflexing, scent production, petal wettability and pollinator grip. The conical cells are a defining feature of the petal, being rarely found elsewhere, e.g. leaves [11], and usually point in the direction of the potential pollinator; generally, the adaxial part of the flower. Some of these factors have been evaluated using scanning electron microscopy. In field experiments by Glover's team [12], it was found that using the *mixta* mutant of *Antirrhinum majus* [13], which contains a null allele of the MYB-related transcription factor necessary to initiate conical cell outgrowth and its isogenic wild type, both phenotypically similar, that the presence/absence of seed in tagged flowers indicated a pollinator visit/no visit. The results showed that conical petal cells increased the likelihood of pollination. Flower Iridescence produced by petal striated nanostructures acting as diffraction gratings [14] enables bumble bees (*Bombus terrestris*), for example, to distinguish it from the flower colour's changing appearance.

Sound generation in xylem sap

Water transport via the xylem [14,15] may be modelled as a catenary process [16], where the pressure in the xylem sap is negative (e.g. -1 to -3 MPa) under soil drought or high sap flow. The xylem, with its evolutionary sessile, rigid structure designed to contain cytoplasm rather than be overcome by osmotic inflow at the expense of motility, is subject to continuous tension, loss of cohesion and homogeneous and heterogeneous cavitation [17,18]; the former arising from lack of cohesion in metastable water (i.e. liquid water is under greater tension than the surrounding pressure) in the xylem but hasn't vapourised because no air bubble has formed. It is essential for pulling water from roots to leaves; within the volume of xylem conduits, though, it is more unlikely in xylem sap at the negative pressure, e.g. -15 MPa, which must be less than -20 MPa [17], and the latter as a result of loss of adhesion between metastable water and conduit walls, with the formation of subsequent emboli blocking water flow in the lumen [19]; and upon bursting, it releases acoustic energy emissions at a range of frequencies [20] as 'clicks'/ultrasonic frequencies, which occur as a result of thermal instability, e.g., drought and subsequent onset of plant disease or injury. Such a model can accommodate sap nutrient zones. A vulnerability curve as a function of xylem pressure potential can be modelled [19] for the plant of interest. At bursting, the large negative pressure becomes zero, and energy is partly converted into sound energy over a range of frequencies from audible to ultrasonic [20,21]. These sound waves, which can be detected up to 5 m away, are generally of low intensity (as measured by sound pressure level (dB SPL)) and high frequency (kHz). Table 1 shows sound properties from Kait., *et al.*'s experiments on cut and dry tomato and tobacco plants.

From the airborne sound signals emitted in an acoustic box or greenhouse and recorded (20 - 150 kHz) from tomato (*Solanum lycopersicum*) and tobacco (*Nicotiana tabacum*) plants under different treatments, viz. drought stress and cutting of the stem, before

Plant	Nh ⁻¹ dry	Nh ⁻¹ cut	Mpsi dry	Mpf dry	Mpsi cut	Mpf cut
Tomato	35.4 (6.1)	25.2 (3.2)	61.6 (0.1)	49.6 (0.4)	65.6 (0.2)	57.3 (0.7)
Tobacco	11.1 (1.4)	15.2 (2.6)	65.6 (0.4)	54.8 (1.1)	63.3 (0.2)	57.8 (.7)
Units	Per hour	Per hour	dB SPL	dB SPL	kHz	kHz

Table 1: The number of sound signal episodes per hour (N), mean peak sound pressure intensity (Mpsi), and mean peak frequency (Mpf) for dry and cut tomato and tobacco plants in an acoustic box environment. The experimental design included controls that did not affect the main findings. Data courtesy of Khait., et al. 2023 [22].

recording [22], the properties and results are contained in table 1. Cut, soft stems and dehydrated plants generally produce different ultrasound waves, ceteris paribus. Cut plants release more air bubbles than those under water stress, so a ‘diminished’ signal ensues; soft stems produce clearer signals than rigid, more wooden ones.

Moths and grasshopper mice’s hearing distance

Female moths can hear plant sounds emitted at a distance [22], e.g. 10 cm, and prefer to lay eggs on healthy, silent tomato plants [23]. When deafened, moths did not show this preference. These laboratory-raised moths have had no prior exposure to plants and may therefore have these biosonic responses embedded in their evolutionary DNA. The keywords implied by Shakespeare are for the bee read moth; for suck read pollination; for cowslip (*Primula veris*) with soft stem read tomato plant; for bell read hearing/sound location/bat. Keit., et al. estimated [22] the distance at which a moth and grasshopper mouse [24] could detect signals from a tomato plant using a sound propagation equation: ‘cSPL – 20*log10(R/R1) – α(R-R1) + log2.7 = HT, where HT is the hearing threshold of a moth or a grasshopper mouse (set to 35 and 10 dB SPL Re 20 μPa, respectively [25]), cSPL is the mean emitted plant sound pressure level, set to 65 dB SPL based on their recordings [22]. R is the detection distance (m), R1 is the recording distance of the plant, and α is a frequency-dependent atmospheric attenuation factor (1.6 dB/m at the most intense emission frequency) for the average temperature and humidity levels in the area (26°C at night and 80%, respectively). It is possible that understanding how plants perceive vibration in various forms may lead to an underdeveloped aspect of ecology, viz. ecoacoustics [24], and that they use the same acoustic energy [24,26] to further evaluate their environment.

On the question of displaying perfect floral iridescence, and non-ens or imperfection, one plausible explanation is that strategic hiding, camouflage, or disruptive colouration could be advantageous, whereas the foraging pollinator would be disadvantaged by reduced floral bounty.

With colours, sometimes in abundance, disruption of the pollinator’s ability to identify the floral target may be impaired, so Glover’s group posed the question, ‘Could the iridescence disrupt an insect’s perception of pigment colour and thus produce disruption of colour identity? Figure 1 summarises their data on testing of this hypothesis (their figure 3 [7]), Pointillism [27] is a form of painting combining small, coloured dots together to form a continuum of a blend of tones, a hue, in the eye and mind of the observer. An example is an imperfect diffraction grating and the associated spectra produced by Bragg’s reflections, as received by receptors in the visual space of the potential pollinator (e.g. bumblebee), as illustrated in figure 1. The artificial synthetic polymer surfaces are intended to resemble the petal nanostructures, but more detail on construction and evaluation would be useful. To test the iridescence-strong pigment disruption hypothesis, bees were conditioned on blue targets and tested for twenty visits to blue targets, with an equal number of red distractors. Figure 1A showed that perfect iridescence disrupted colour identity less than imperfect (floral) iridescence. This contrasted with purple-

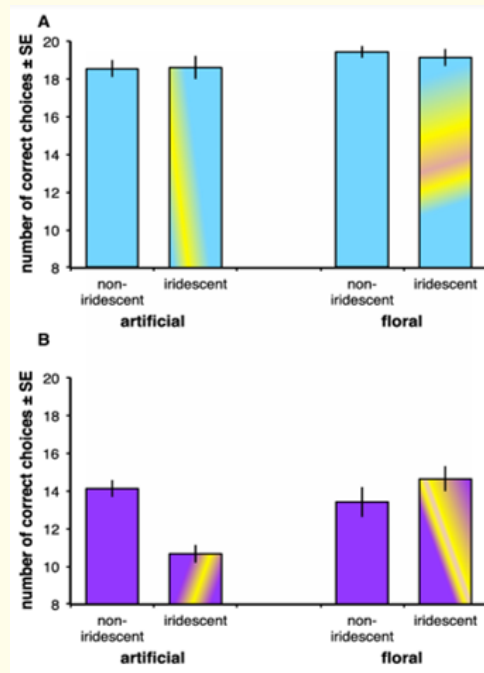


Figure 1: (A) Mean preference ($\pm$ SEM; out of 20 choices) of bees for blue disks when trained to blue and presented with both blue disks and red distracter disks, comparing floral and artificial surfaces (iridescent or non-iridescent). (B) Mean preference ($\pm$ SEM; out of 20 choices) of bees for purple disks when trained to purple and presented with equal numbers of purple target and blue-purple and red-purple distracter disks, comparing floral and artificial surfaces (iridescent or non-iridescent). Open access (Without modification) under the CC BY-NC-ND license (Courtesy: Whitney, et al. 2016 [7]).

trained bees and purple targets with purple-blue and purple-red distracter disks when bee colour space was farther apart than blue and red (Figure 1B). Partially QED. So much for a splash of colour in crop pollination, when flavonoids can alter pigment colour; e.g. anthocyanin (water-soluble) can turn red, purple, or blue depending on acidity, neutrality, or alkalinity. Much more work is needed, particularly with the environment, habitat and season.

Concluding Remarks

This short article has briefly explored the production of sound in xylem sap and its potential role as a warning siren to deter pollinators from entering flowers or from depositing their oviposition load, subject to iridescent mechanisms in play: mechanisms that are so important in agriculture and food production. It must be said that only the lid has been lifted on a metaphorical veneer of entomophily. Take, for example, confounding factors in plant-insect interactions on the plant side (e.g. nectar, plant age) and on the insect side (e.g. predators (spiders), life stage; pollution (e.g. gases, pesticides, water contaminants), soil, and light). Using AI tools to model sound production, pollination, and plant/insect characteristics may bring additional benefits to agriculture.

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Conflict of Interest

None to declare.

Author's Contributions

Concepts-DWW and HJWD; Writing mainly DWW; Reference compilation/checking with some writing-PJ; Editing and reviewing-HSB, PJ, and IGT.

Ethics

Not needed; narrative only.

Data

No data generated.

Conflict of Interest

The authors declare no conflict of interest.

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