Acta Scientific Microbiology (ISSN: 2581-3226)

Volume 9 Issue 12 December 2026

Research Article

Plant Sensation, Communication and Sentience: Evidence and Open Questions

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DOI: 10.31080/ASMI.2026.09.1643

Received: October 23, 2026

Published: November 19, 2026

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Abstract

This review examines current evidence on plant sensation, communication, and the unresolved question of sentience. Research in electrophysiology, plant physiology, chemical ecology, and network science demonstrates that plants detect diverse environmental stimuli and coordinate physiological responses through distributed signalling systems. Mechanical injury and other stimuli can initiate electrical, calcium-based, hydraulic, and chemical signals that propagate locally or systemically and influence defence, growth, and subsequent stress responses. Plants also affect neighbouring organisms through volatile organic compounds, while common mycorrhizal networks (CMNs) may facilitate resource or signalling-compound transfers under particular conditions. However, the extent, direction, and ecological significance of these transfers remain context-dependent, and the popular "Wood Wide Web" metaphor should not imply a forest-wide, intentional communication system. The review further compares distributed plant signalling with electronic networks as a conceptual framework for understanding coordination without a centralized controller, while distinguishing functional similarities from mechanistic equivalence. Although stimulus detection, systemic signalling, and stress priming are supported by substantial experimental evidence, whether these processes are accompanied by subjective experiences such as pain, pleasure, or suffering remains unresolved and requires further investigation using clearly defined concepts and appropriate experimental approaches. The review identifies research priorities, including selective genetic and pharmacological perturbations, synchronized multimodal measurements, network analysis, and controlled behavioural experiments, to investigate the mechanisms and limits of plant information processing. By integrating established physiological evidence with unresolved questions and testable research directions, this review provides a framework for evaluating claims about plant sentience without equating biological complexity with subjective experience.

Keywords: Plant Signalling; Plant Electrophysiology; Calcium Signalling; Volatile Organic Compounds; Common Mycorrhizal Networks; Stress Priming; Plant Sentience

Abbreviations

CMN: Common Mycorrhizal Network; Ca^{2+}: Calcium Ion; RNA: Ribonucleic Acid; siRNA: Small Interfering RNA; mRNA: Messenger RNA; VOC: Volatile Organic Compound; VOCs: Volatile Organic Compounds; ROS: Reactive Oxygen Species.

Introduction

The question "Do plants have feelings?" appears simple but brings together distinct biological and philosophical questions. Plant biology clearly establishes that plants are responsive,

integrated living systems [1]. Plants detect environmental conditions—including light, gravity, touch, water availability, pathogens, temperature, and herbivory—and convert these inputs into physiological responses [2,3]. Local events can initiate long-distance signals, alter gene expression, stimulate defensive chemistry, and modify responses to later stress [4-6]. The unresolved issue is whether any of these distributed regulatory processes are accompanied by subjective experience—in other words, whether there is "something it is like" to be a plant.

Debate is often complicated by the use of terms such as sensing, communication, cognition, consciousness, sentience, and feeling as though they were interchangeable. These terms refer to different concepts and should be defined carefully [7]. Sensing involves detecting a stimulus; information processing involves integrating signals in ways that influence physiological activity or growth. Sentience, by contrast, generally refers to the capacity for subjective experience, including experiences with positive or negative valence [8,9]. The detection of tissue damage must therefore be distinguished from the subjective experience of pain or suffering; nociception and pain are not equivalent [10].

Critical reviews emphasize that plants do not possess neurons, synapses, or a centralized nervous system comparable to those found in animals [11,12]. Whether such structures are necessary for every conceivable form of subjective experience remains a broader theoretical question, but their absence is not evidence that plant sentience has been demonstrated. Modern instruments can record electrical activity, calcium dynamics, and chemical emissions, yet complexity and coordinated responses alone do not establish awareness. To date, the evidence discussed in this review does not demonstrate that plant responses to damage or other stimuli are accompanied by subjective negative or positive experience [8,12,13].

Microbial communities also participate in ecological communication through chemical cues, metabolites, and volatile compounds. Plant-associated bacteria and fungi in the rhizosphere interact with roots and can influence plant growth and defence. Microbial volatile compounds, in particular, can affect root development and plant responses, illustrating that plant signalling occurs within a wider ecological environment shaped by microbial as well as plant-derived signals [23]. These interactions are biologically important, but they should not be equated with conscious dialogue. Considering them places plant signalling within the broader microbial and ecological context relevant to this journal.

For clarity, four levels of plant–environment interaction are distinguished. First, plants detect physical or chemical changes through receptors, ion channels, and other sensory mechanisms. Second, they transmit and integrate signals to coordinate local or systemic responses. Third, prior conditions can alter later responses through acclimation, stress priming, and other forms of physiological plasticity. A fourth possibility—that these processes are accompanied by subjective experience—is sometimes proposed but remains unproven. The first three levels are supported by substantial empirical evidence; the fourth has not been established experimentally.

Pain illustrates the distinction between physiological detection and subjective experience. The revised International Association for the Study of Pain definition describes pain as an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage; it also distinguishes pain from nociception [10]. Detecting damage or initiating a protective response does not by itself demonstrate suffering. Plants have no demonstrated neural nociceptive pathway or centralized neural substrate comparable to those associated with conscious pain in animals [11,12]. Nevertheless, mechanical injury can trigger jasmonate responses, calcium waves, electrical changes, and broad changes in gene expression [3,15]. These findings establish complex damage detection and defence signalling, not subjective suffering.

To move beyond anthropomorphic analogies, claims about plant feeling must be evaluated through clearly defined concepts and measurable evidence. This critical review has four objectives: (i) synthesize evidence on what plants detect and how they signal internally and interact ecologically; (ii) compare distributed plant signalling with selected principles of electronic networks while distinguishing functional analogy from mechanistic identity; (iii) assess evidence and uncertainty concerning common mycorrhizal networks—the so-called "Wood Wide Web"—in light of recent critiques [14]; and (iv) identify experimental approaches, including selective perturbations, network analysis, and behavioural dissociation, that could test competing explanations of plant responses (Figure 1).

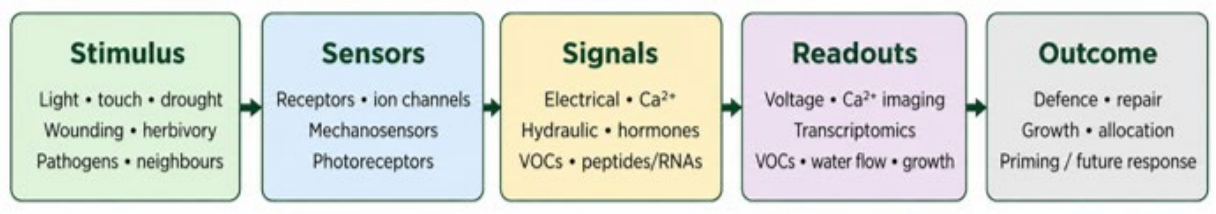


Figure 1: From Environmental Stimulus to Measurable Plant Response.

Source: Author's conceptual illustration based on concepts discussed in Toyota., et al. (2018), Lee and Seo (2022), and Karban (2021).

Materials and Methods

This article is a critical narrative review, not an original experimental study, systematic review, or meta-analysis. A targeted, non-systematic literature search and citation-tracing approach was used to identify publications relevant to plant stimulus detection, electrophysiology, calcium and hydraulic signalling, volatile-mediated interactions, microbial ecological communication, common mycorrhizal networks (CMNs), stress priming, and plant sentience. Search concepts included combinations of the terms "plant electrical signalling," "calcium wave," "systemic wound response," "plant volatile communication," "microbial communication," "quorum sensing," "rhizosphere interactions," "common mycorrhizal network," "wood-wide web," "plant stress priming," "plant habituation," "plant sentience," and "plant consciousness." The original search record did not document a fixed database list or a defined start-and-end date; therefore, this review does not claim a database-specific or date-bounded systematic search. Literature was selected purposively on the basis of its relevance to the review questions, its focus on experimentally investigated mechanisms or critical evaluation of those mechanisms, and the availability of sufficient bibliographic information for identification. Foundational experimental studies, peer-reviewed research articles, and critical reviews were considered; sources that did not directly inform the stated themes were not included in the synthesis. Bibliographic details and DOI metadata were checked against publisher pages and/or bibliographic records where available. Reference-list tracing was used to identify relevant earlier work and counterarguments. The review is purposive rather than exhaustive: no preregistered protocol, formal screening log, or quantitative synthesis was used, and no claim is made that all literature on these topics was captured. Claims are considered in relation to the mechanism measured, experimental context, causal evidence, and reproducibility. Evidence that a plant responds physiologically is not treated as direct evidence of subjective feeling.

Internal signal integration and the critique of plant neurobiology

Mechanical, chemical, and biological receptor systems

Plants lack eyes, ears, and a single centralized sensory organ, but they detect environmental conditions through diverse receptor systems. Photoreceptors—including phytochromes, cryptochromes, and phototropins—respond to light quality, wavelength, direction, and photoperiod, influencing photomorphogenesis, circadian rhythms, and flowering [16]. Roots respond to gravity, with statolith sedimentation in root-cap cells contributing to gravitropic responses. Mechanical stimuli such as wind, bending, and touch can activate mechanosensitive ion channels in cell membranes, producing changes in membrane potential and intracellular calcium concentrations [17].

Chemical sensing is similarly diverse. Plant tissues respond to hormones, nutrient availability, volatile organic compounds (VOCs), and molecular patterns associated with herbivores or pathogens [2,18]. Local injury can initiate signals that affect distant tissues. Toyota., *et al*. (2018) showed that wounding can trigger glutamate-dependent, long-distance calcium signalling involved in plant defence. This signalling can interact with electrical potentials, hydraulic changes, and mobile molecules, including RNAs, contributing to whole-plant coordination [4,15] (Figure 2).

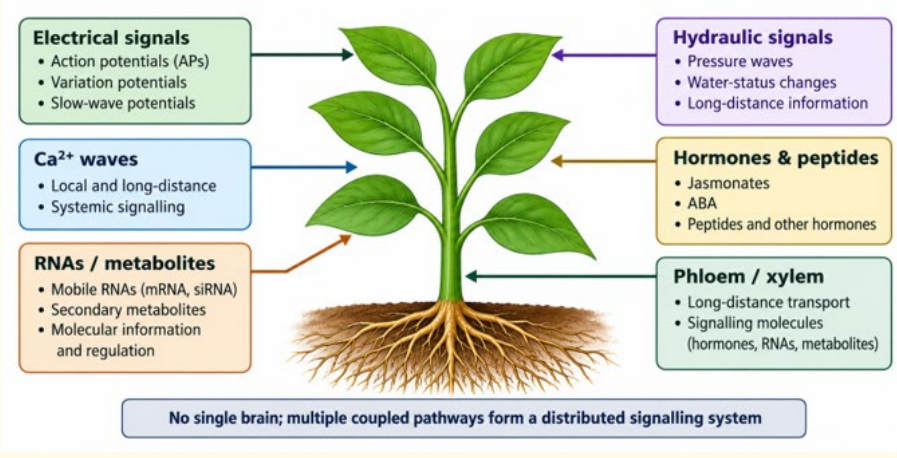


Figure 2: Internal Communication Network of a Plant.

Source: Author's conceptual illustration based on concepts discussed in Toyota., *et al*. (2018), Lee and Seo (2022), and Barbosa-Caro and Wudick (2024).

The evidential bounds of "Plant Neurobiology"

The term "plant neurobiology" was introduced to draw attention to the integrated and communicative properties of plants [1]. Critics argue that the term can invite misleading comparisons with animal nervous systems [12,19]. Plants do not possess neurons, synapses, a brain, or a centralized sensory-processing centre as animals do [11]. Plant signalling instead involves ion movement across cell membranes, communication through plasmodesmata, and transport through vascular tissues such as xylem and phloem. A plant can therefore be described as a distributed biological system in which roots, stems, meristems, and leaves exchange signals and resources without a single central controller.

This organization can be compared, at an abstract systems level, with distributed computing, where interconnected components can maintain function through redundancy and local responses [20]. The analogy has limits: plant tissues are living, metabolically active, and developmentally remodelled, whereas electronic networks operate through different physical mechanisms. Damage to a leaf may prompt local repair and changes in signalling or growth elsewhere, but this should not be described as digital "rerouting" in a literal sense. "Distributed biological information processing" is therefore a more precise description than treating plants as having a nervous system. Claims about cognition or sentience require evidence beyond the observation of coordinated responses. A typical experimental design for systemic wound signalling includes baseline measurements, controlled wounding, monitoring of signal propagation, measurement of downstream responses, and appropriate controls (Figure 3).

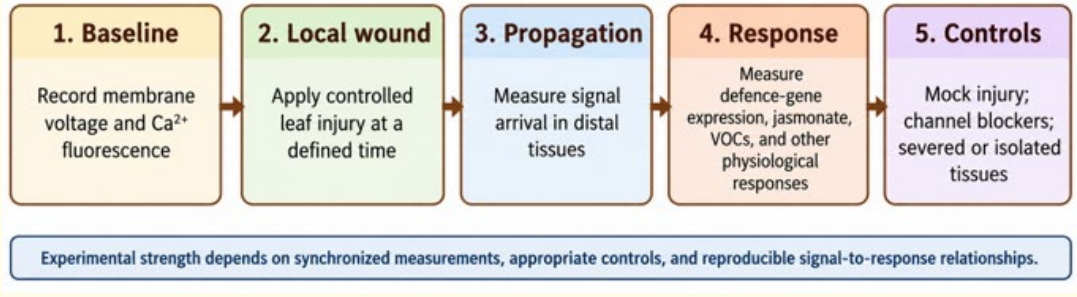


Figure 3: Typical Laboratory Experiment for Systemic Wound Signaling.

Source: Author's conceptual illustration based on concepts discussed in Toyota., *et al*. (2018) and Lee and Seo (2022).

The principal measurement approaches, their research questions, and the limits of the conclusions that can be drawn from them are summarized in Table 1.

Measurement	Typical Question	What It Establishes	What It Does Not Establish	References
Voltage	Does a stimulus alter membrane potential and propagate?	Electrical signalling	Subjective experience	[5,15]
Ca^{2+} imaging	Does a local event trigger systemic calcium dynamics?	Spatial/temporal signal integration	Pain or awareness	[3,17]
Hydraulics	Does water status change and propagate?	Hydraulic communication	Conscious perception	[15]
VOCs	Does one plant alter another plant's physiology?	Interplant cue/signalling	Intentional communication	[6,18,21,23]
Transcriptomics	Which genes respond after the signal?	Downstream molecular response	Feeling	[3,15]
Behaviour/growth	Does the plant alter growth or defence?	Adaptive output	Conscious decision	[27,28]

Table 1: Experimental Sensation Measurement Framework.

Ecological communication and a critical analysis of the wood wide web

Above-ground volatiles and multi-species interconnection

Above-ground plant interactions can involve volatile organic compounds (VOCs). Herbivore-damaged tissues release mixtures of compounds, including green-leaf volatiles and terpenes [18]. Nearby plants may detect these airborne cues and alter their defensive physiology, sometimes becoming primed to respond to later herbivore attack [21]. The strength and ecological relevance of these effects vary with plant species, distance, airflow, environmental conditions, and the compounds involved [2]. Such effects can be described as chemical signalling or cue-mediated interactions; they do not imply intentional or conscious dialogue between plants (Figure 4).

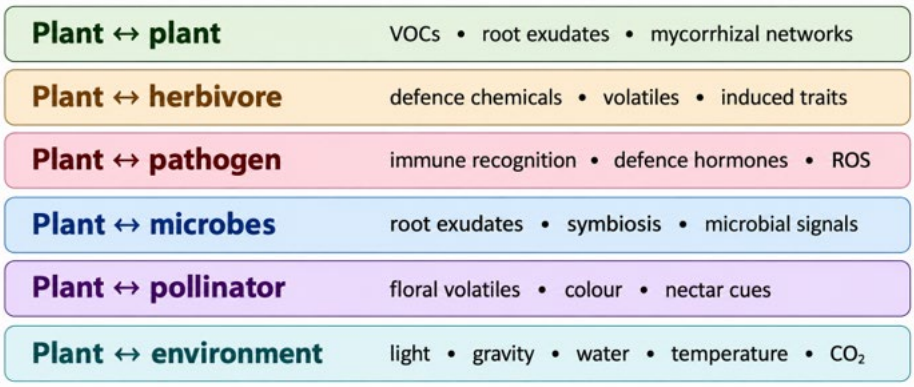


Figure 4: Plant Communication Across Biological Boundaries.

Source: Author's conceptual illustration based on concepts discussed in Heil and Karban (2010), Karban., *et al.* (2014), Karban (2021), and Sharifi and Ryu (2018).

Plant interactions also occur below ground and across species boundaries. Root exudates influence the rhizosphere, including microbial communities and associations with beneficial organisms; some studies also report plant responses to cues associated with related or neighbouring plants [22]. Microbial volatiles can affect root development and plant defence [23]. Flowers likewise combine visual traits, nectar chemistry, and volatile compounds that influence pollinator behaviour. These interactions demonstrate biologically consequential information transfer and response, but they do not in themselves establish conscious communication.

Deconstructing the "Wood Wide Web" metaphor

Below ground, fungal hyphae associated with plant roots can sometimes connect the roots of more than one plant, forming common mycorrhizal networks (CMNs). The popular expression "Wood Wide Web" captures the possibility of below-ground interconnection but can misleadingly suggest a single, intentional, forest-wide communication system. Simard., *et al*. (1997) reported carbon transfer between tree species associated with shared ectomycorrhizal fungi under field conditions. Subsequent reviews have cautioned that the extent, ecological importance, and interpretation of transfers through CMNs are not always well established and that some claims have been amplified beyond the available evidence [14,24].

A cautious interpretation distinguishes demonstrated mechanisms from claims that remain insufficiently supported. Evidence-supported points: mycorrhizal fungi form associations with plant roots, and fungal hyphae can connect roots under some conditions. Movement of resources or signalling compounds has been reported in particular systems, but its magnitude, direction, mechanism, and ecological consequences depend on the organisms and experimental context [25]. Claims requiring stronger evidence: that forests generally operate as one integrated communication network; that mature trees reliably identify and preferentially nourish their genetic offspring through fungal connections; that fungal hyphae transmit warnings in a manner equivalent to animal nerves; or that CMNs imply forest consciousness. Fungi are living organisms with their own physiology and resource demands, not simply passive conduits controlled by plants.

Distributed networks versus local electronic networks

Comparing plant signalling with local electronic networks offers a conceptual way to discuss decentralized information processing. Both can be represented as nodes connected by pathways through which signals or effects propagate, and neither necessarily requires a single central controller [20]. The comparison is functional and abstract, not evidence that plant and electronic networks share the same mechanisms. Plant networks involve living tissues, metabolism, chemical signalling, growth, and repair; electronic systems rely on engineered components and electrical or optical transmission (Figures 5 and 6).

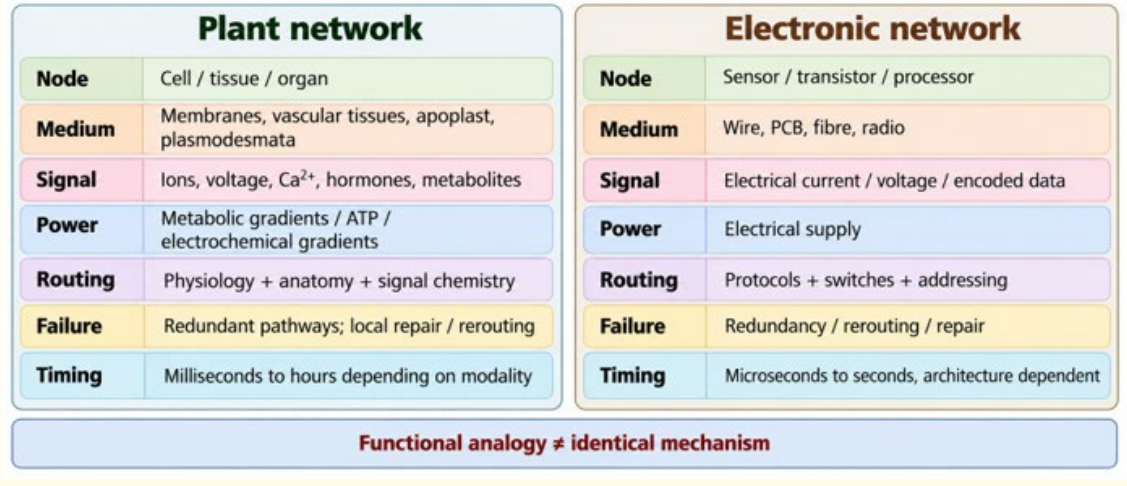


Figure 5: Functional Comparison between Plant Signalling and a Local Electronic Network.

Source: Author's conceptual illustration, generated with AI assistance and reviewed by the author, based on concepts discussed in Baran (1964), Brenner., *et al*. (2006), and Barbosa-Caro and Wudick (2024). The comparison is conceptual, not mechanistic.

Feature	Plant Network	Local Electronic Network	Important Difference	References
Nodes	Cells, tissues, organs	Sensors, processors, switches	Plant nodes are living and continuously remodelled	[1,20]
Links	Plasmodesmata, vascular pathways, air, fungi	Wires, fibre, radio waves	Plant links carry resources and signals together	[4,15]
Signal	Voltage, ions, Ca^{2+}, hormones, VOCs	Encoded electrical/optical data	Plant signals are chemically and physically diverse	[3,4,15,17]
Power	Metabolic and electrochemical gradients	Electrical supply/battery	Plants generate and redistribute energy biologically	[4,5]
Addressing	Receptor distribution and connectivity	Digital addressing/routing protocols	Plants do not use digital addresses	[20]
Timing	Milliseconds to hours	Microseconds to seconds	Biological chemistry imposes slower, diverse scales	[5,15]
Memory	Molecular, physiological, epigenetic	Electronic/digital storage media	Plant memory alters the physical state of the network	[26,27]
Repair	Regeneration, localized regrowth, redundancy	Redundant components/maintenance	Plants can actively replace destroyed organs	[4,15]
Control	Decentralized and distributed	Centralized or distributed	Both can operate without a single core controller	[1,20]
Noise	Environmental and biochemical variability	Electrical/interference noise	Plants exploit variability instead of suppressing it	[2,18]
Learning	Priming, phenotypic plasticity, habituation	Algorithmic parameter updates	Fundamentally distinct mechanisms and adaptive meanings	[26,27]
Sentience	Unresolved/Currently unproven	Not inferred from architecture	Connectivity alone does not establish internal experience	[8,12,13]

Table 2: Structural and Functional Comparison: Plant Networks versus Local Electronic Networks.

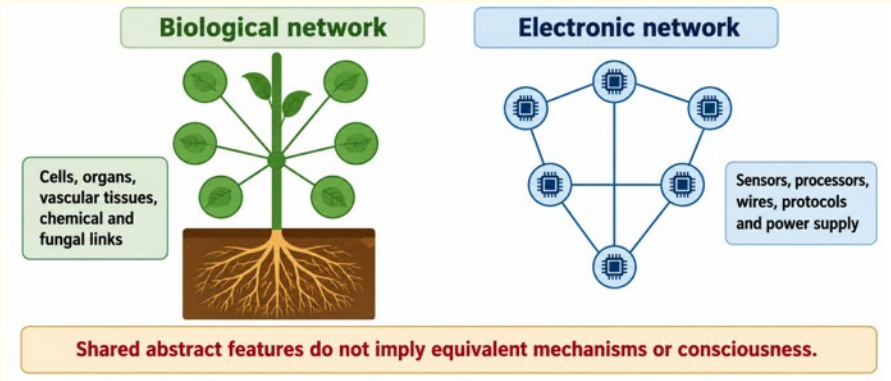


Figure 6: Biological Network Topology versus Electronic Systems Layout.

Source: Author's conceptual illustration, generated with AI assistance and reviewed by the author, based on concepts discussed in Baran (1964), Brenner., *et al*. (2006), and Robinson and Draguhn (2021). The comparison is conceptual, not mechanistic.

The evidential limits of memory, cognition, and valence

Plant memory and habituation: Limits of mental-state inference

Plant stress priming is well documented: an earlier exposure can alter the response to a later challenge. In this limited physiological sense, the plant retains an effect of its history, which may lead to faster or stronger defence or acclimation responses [26]. Proposed mechanisms include epigenetic changes, chromatin remodelling, persistent transcriptional activity, and the maintenance of signalling components. The relative contribution of these mechanisms varies across species and stress contexts [27]. Such "memory-like" effects should not be confused with conscious recollection.

Claims of habituation in plants—particularly reports involving repeated, harmless stimulation of *Mimosa pudica*—remain debated [28]. A reduction in leaf-closing responses after repeated stimulation may reflect habituation, but receptor adaptation, motor-tissue fatigue, or changes in turgor must be ruled out with appropriate controls. A system can retain the effects of past events through changes in its physical or biochemical state without subjective awareness. Thus, evidence of altered future responses does not by itself establish conscious memory.

Phenomenon	Evidence in Plants	Main Alternative Explanation	Implication for Consciousness	References
Stress priming	Strongly established across species	Persistent molecular or epigenetic state	Does not establish subjective feeling	[26]
Habitual response	Empirically reported (e.g., Mimosa)	Sensory adaptation or motor tissue fatigue	Suggests adaptive plasticity; insufficient for sentience	[28]
Context dependence	Increasing experimental evidence	Complex multi-layer physiological feedback	Informative regarding distributed cognition, not awareness	[27]
Transgenerational	Reported in multiple stress systems	Epigenetic inheritance/ chromatin changes	Represents historical biological memory, not recollection	[26]
Flexible trade-offs	Observed in growth/ resource allocation	Optimization via localized physiological rules	Directly relevant to the decentralized cognition debate	[27]
Subjective recall	No direct empirical evidence	Not applicable	Remains an unresolved/unsupported claim	[8,12,13]

Table 3: Cognitive Phenomena and Evidential Status.

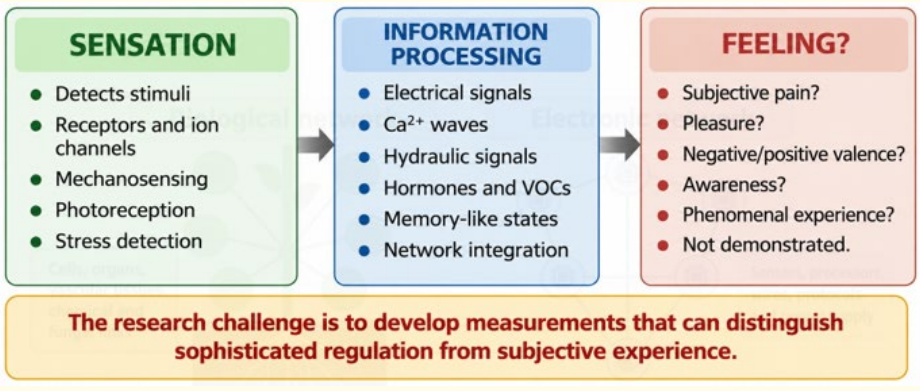


Figure 7: Conceptual Distinction between Sensation, Information Processing, and Feeling.

Source: Author's conceptual illustration, generated with AI assistance and reviewed by the author, based on concepts discussed in Taiz., *et al*. (2019), Segundo-Ortin and Calvo (2022), and Hansen (2024).

The missing valence: Why plant consciousness remains unproven

Sentience is generally associated with subjective experience, including positive or negative valence. Plants detect tissue damage and initiate complex defensive responses, but current evidence does not demonstrate that these responses are accompanied by an unpleasant or pleasant experience [8]. Movements such as the closure of a Venus flytrap or the growth of a climbing vine can be investigated through ion transport, water movement, osmotic changes, and differential cell expansion. Explaining these processes physiologically does not prove that subjective experience is impossible; it does mean that such experience cannot be inferred from movement or response alone.

Some researchers have considered whether theories such as Integrated Information Theory could provide a framework for discussing consciousness beyond conventional neural systems [29]. However, applying a theoretical framework or calculating network complexity does not independently demonstrate that a system has subjective experience. Figure 7 distinguishes stimulus detection, information processing, and the question of feeling; Figure 8 summarizes signalling across cellular, whole-plant, and between-organism levels. These levels of organization are relevant to the debate, but their presence should not be treated as proof of consciousness.

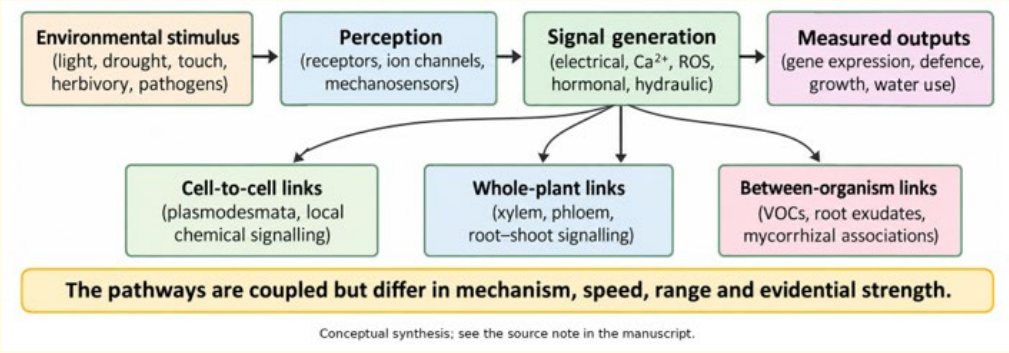


Figure 8: Signal Pathways Across Cellular, Whole-Plant, and Between-Organism Levels.

Source: Author's conceptual illustration, generated with AI assistance and reviewed by the author, based on concepts discussed in Toyota., *et al*. (2018), Karban (2021), and Karst., *et al*. (2023).

Conclusion

The evidence reviewed shows that plants detect environmental stimuli and coordinate local and systemic responses through electrical, calcium-based, hydraulic, and chemical signalling. Plants also interact with neighbouring organisms through volatile compounds, root-associated microbes, and, in some contexts, common mycorrhizal networks. These processes demonstrate complex physiological regulation and biological information transfer. However, the available evidence does not establish that plants have subjective experiences of pain, pleasure, or suffering. Accordingly, plant sensing and signalling should be distinguished from sentience, and comparisons with electronic networks should remain conceptual rather than mechanistic.

Future Research Directions

Future research should combine synchronized measurements of electrical, calcium, hydraulic, and chemical signals with selective genetic or pharmacological interventions. Network measures such as connectivity, modularity, path length, and resilience should be linked to independently validated biological outcomes. Controlled behavioural experiments should distinguish similar outward responses arising from different physiological states. Researchers should define in advance what observations would support or challenge competing hypotheses and should not treat complexity, persistence, or flexibility alone as evidence of subjective experience.

AI Disclosure Statement. Generative AI tools were used to assist in preparing and refining the conceptual illustrations included

in this review. The author reviewed the illustrations, checked their scientific content against the cited literature, and takes full responsibility for their accuracy and presentation. AI tools were not used to generate experimental data or to perform data analysis.

Conflict of Interest

The author declares that there is no conflict of interest.

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