

Unlocking the Secrets of Plant Communication; plants sharing information underground

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Abstract

In the natural world, plants have long been underestimated in their capacity to communicate. Unlike their mobile animal counterparts, plants, rooted in one place, have evolved sophisticated chemical signaling mechanisms to interact with their environment and neighboring plants. This article delves into the intricate world of plant communication, focusing on the transmission of information through chemical signals. Plants release a wide array of compounds into the soil, such as Volatile Organic Compounds (VOCs) and secondary metabolites, which serve as messengers, alerting nearby plants to herbivore threats, resource competition, and nutrient availability. Mycorrhizal networks, akin to the internet of the plant world, play a crucial role in facilitating long-distance communication, resource sharing, and collective adaptation among plants. Moreover, plants have developed complex responses to these chemical signals, altering their growth patterns, defense mechanisms, resource allocation, and even phenotypic characteristics in response to environmental cues. Plant communication through chemical signals enhances adaptability and survival, with real-world examples illustrating its role in responding to threats and coping with challenging conditions. This communication fosters cooperation, resilience, and vitality within plant communities, influencing the fields of agriculture and ecosystem management. Nevertheless, the complexity of these signals and their interpretations poses a significant challenge, prompting ongoing research into the deciphering of these chemical languages and their broader ecological implications. The future of plant communication research holds promise, offering the potential to revolutionize our understanding of plant consciousness, agriculture, and conservation. This captivating realm challenges our perception of the plant kingdom, revealing the hidden secrets of underground communication that underpin the adaptability and resilience of the natural world.

Keywords

Plant Communication, Chemical Signaling, Mycorrhizal Networks, Herbivore Deterrence.

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1. Introduction

In the natural world, we often associate communication with animals that can move and make sounds or gestures. In contrast, plants are usually seen as quiet and isolated beings without ways to interact. However, under the surface, plants engage in a complex form of communication. This article aims to explain how plants communicate using chemical signals, which has evolved as a response to their stationary nature. Unlike animals, plants can't run away from threats or actively search for resources, so they have developed unique methods to share important information with nearby plants. In this article, the scientific details will be explored of how plants use molecular and physiological mechanisms for this communication, highlighting how this hidden language profoundly affects their growth and survival.

2. The Chemical Signaling Underground

Plant roots release a variety of chemicals into the soil. These chemicals serve as messengers, conveying important informa-

tion to neighboring plants. Plants release a variety of compounds into the soil to communicate with their neighboring plants. These compounds serve as messengers, conveying essential information about their environment. Compounds such as Volatile Organic Compounds (VOCs) easily evaporate into the air. When plants are under attack by herbivores, they often release VOCs as an alert signal to nearby plants. These compounds can warn neighboring plants of impending herbivore threats, allowing them to activate defense mechanisms.

Plants produce secondary metabolites, such as alkaloids, terpenoids, and phenolics. Some of these compounds serve as allelopathic chemicals that inhibit the growth of competing plants nearby. They can also act as signals to convey information about resource competition.

Roots exude a wide range of compounds, including sugars, amino acids, organic acids, and phenolic compounds. These exudates can signal nutrient availability and soil quality to neighboring plants. For example, the release of certain compounds can indicate the presence of nitrogen or phosphorus in the soil. Certain plants like members of the Brassicaceae family (e.g., mustard, broccoli) release glucosinolates into the soil. These compounds can serve as chemical warnings to nearby plants about herbivore activity or even activate defense mechanisms in the receiving plants. Mycorrhizal fungi form symbiotic relationships with plants, aiding in nutrient uptake. In such mutualistic partnership, plants release signaling compounds such as strigolactones to attract mycorrhizal fungi. This helps the plant access nutrients in the soil more effectively. Plants can also release enzymes into the soil to break down complex organic matter, making nutrients more accessible. This can indirectly signal nutrient availability to neighboring plants by altering the composition of soil resources. Some plants release compounds with antibacterial properties into the soil. These compounds can inhibit the growth of harmful soil-borne pathogens and protect nearby plants from diseases. Plants use hormones like ethylene and auxins as signaling molecules. Ethylene, for instance, can signal nearby plants to prepare for environmental stress, such as flooding or drought. By releasing these various compounds, plants can communicate vital information about their surroundings, including threats from herbivores, competition for resources, and the availability of nutrients. This chemical signaling not only helps them adapt and survive but also contributes to the complex and interconnected nature of plant communities in ecosystems.

3. Mycorrhizal Networks: The Internet of the Plant World

Mycorrhizal fungi form symbiotic relationships with plants, creating vast underground networks. These networks allow plants to exchange not only nutrients but also information. Mycorrhizal networks represent a fascinating facet of plant biology, akin to the internet of the plant world. These intricate underground partnerships between plants and mycorrhizal fungi have evolved over millions of years, resulting in remark-

able ecological interactions that go beyond nutrient exchange. Mycorrhizal networks enable plants to communicate, share resources, and collectively adapt to their environment over extensive distances.

At the heart of this underground internet are mycorrhizal fungi, which form mutually beneficial relationships with plant roots. Plants provide these fungi with carbohydrates produced through photosynthesis, while the fungi, in turn, extend their hyphal networks into the soil, greatly expanding the plants' reach for water and nutrients. This partnership allows plants to tap into resources that would be otherwise inaccessible.

But it's not just nutrients that flow through these networks; information does too. Plants can transmit chemical signals and messages via the mycorrhizal fungi. When a plant encounters stress, such as an herbivore attack or a drought, it can release chemical signals into the mycorrhizal network. These signals travel through the fungal hyphae, much like data packets through an internet cable, and reach neighboring plants.

One of the most remarkable aspects of mycorrhizal communication is the ability to convey alarms. When a plant is under attack, it can release VOCs into the mycorrhizal network. These VOCs act as distress signals, alerting nearby plants to the danger. In response, neighboring plants can activate their defense mechanisms, such as producing chemicals to deter herbivores. Beyond alarms, mycorrhizal networks facilitate resource sharing. In times of nutrient scarcity, a well-nourished plant can transfer excess nutrients, such as carbon, through the network to aid a struggling neighbor. This kind of cooperation ensures the overall health and resilience of the plant community.

Mycorrhizal networks can span considerable distances, allowing plants to communicate not just with their immediate neighbors but also with those further away. This long-distance communication is essential, especially in ecosystems with widely spaced or isolated plants. It fosters a sense of connectivity and collaboration among plants, much like the global reach of the internet. The mycorrhizal internet confers adaptive advantages to plant communities. It enables collective responses to environmental challenges, helping plants collectively navigate changing conditions, respond to threats, and optimize resource utilization. In this way, mycorrhizal networks contribute to the overall resilience and vitality of plant ecosystems.

4. Plant Responses to Communication; how Plants React to Chemical Signals

Plants are not passive recipients of chemical signals from their neighbors; they have evolved sophisticated mechanisms to respond to these messages. When they detect specific chemical cues in their environment, they can alter their growth patterns, adjust their defense mechanisms, or prepare for future environmental changes. Plants can adjust their growth patterns based on chemical signals they receive. For example, if a neighboring plant is crowding them, they might grow taller to

compete for sunlight. Conversely, if they sense competition is low, they may invest more resources in root growth to access nutrients below ground.

In response to chemical signals that indicate herbivore attacks or pathogen threats, plants can activate their defense mechanisms. They might produce toxic compounds, such as alkaloids or phenolics, to deter herbivores or synthesize antimicrobial compounds to fend off pathogens. Chemical signals can prompt plants to synthesize secondary metabolites. For instance, when neighboring plants release certain volatile organic compounds (VOCs) indicating herbivore damage, nearby plants may start producing compounds that make them less palatable to herbivores, effectively protecting themselves.

Plants can alter the growth and architecture of their roots based on chemical signals. When they sense nutrient-rich areas nearby, they might extend their roots in that direction to access those resources more effectively.

Chemical signals can influence how plants allocate resources. If a neighboring plant is struggling, a healthy plant may transfer excess nutrients through underground networks to provide support, ensuring the overall well-being of the plant community. Plants can use chemical signals to anticipate environmental changes. For instance, if they detect a decrease in soil moisture levels through chemical cues, they may start conserving water by closing their stomata or shedding leaves to reduce transpiration. Some plants synchronize their flowering and seed production based on chemical cues from neighboring plants. This strategy can optimize pollination and seed dispersal, increasing the chances of successful reproduction. In plant communities, chemical signaling can foster cooperation. For example, when one plant is attacked by herbivores, it may release VOCs to alert neighboring plants. Those nearby plants may then prime their own defenses, creating a collective response to herbivore threats. Plants also exhibit phenotypic plasticity, meaning they can alter their physical characteristics in response to environmental cues. Chemical signals play a role in triggering these changes, allowing plants to adapt to their surroundings more effectively.

5. Survival Strategies: How Plant Communication Enhances Adaptability

Plant communication through chemical signals plays a vital role in enhancing adaptability and survival within plant communities. Let's take some real-world examples of how this communication system helps plants respond to threats like herbivore attacks and cope with challenging conditions like drought.

When a plant is under attack by herbivores, it can release volatile organic compounds (VOCs) into the air. Nearby plants can detect these VOCs and interpret them as a warning signal. As a response, these neighboring plants may activate their defense mechanisms. For instance, they might start producing chemicals that are unpalatable to herbivores or initiate

the synthesis of toxins that deter herbivore feeding. This coordinated defense strategy can help reduce herbivore damage and increase the overall chances of survival for the plant community.

Some plants release chemical compounds known as allelopathic substances to inhibit the growth of nearby competing plants. By doing so, they reduce competition for vital resources such as water, nutrients, and sunlight. This strategy ensures that they have access to the resources they need for survival and growth.

During periods of drought or water scarcity, plants can communicate through mycorrhizal networks and root exudates. When a well-hydrated plant detects dry conditions, it can share water and nutrients with neighboring plants through these underground networks. This resource-sharing not only helps the struggling plants survive the drought but also fosters a sense of cooperation within the plant community. Chemical signals can also prepare plants for impending drought conditions. When a neighboring plant senses decreasing soil moisture levels, it can release signals that trigger anti-drought responses in nearby plants. These responses might include closing stomata to reduce water loss through transpiration, altering root growth to access deeper water sources, or modifying leaf characteristics to conserve water. Some plants synchronize their flowering based on chemical cues from neighboring plants. By coordinating their flowering times, they increase the likelihood of successful cross-pollination. This adaptation ensures the continuation of their species, even in challenging environmental conditions. Use of chemical signals to establish symbiotic relationships with beneficial soil microbes is another strategy. These partnerships enhance nutrient uptake, particularly in nutrient-poor soils, which contributes to the plants' adaptability and overall health.

In these real-world examples, plant communication through chemical signals helps plants respond to threats and adapt to environmental challenges. It underscores the cooperative nature of plant communities and highlights how interconnectedness and information-sharing contribute to the resilience and survival of individual plants and entire ecosystems. Plant communication serves as a powerful strategy for navigating the complexities of the natural world.

6. Challenges and Ongoing Research

The fascinating world of plant communication has long intrigued scientists, challenging them to uncover the intricate ways in which plants communicate with each other and their environment. While it is evident that plants can transmit information through chemical signals, the complexity of these signals and their interpretations presents a significant challenge.

One of the primary modes of plant communication is through volatile organic compounds (VOCs) and other chemical signals. However, deciphering the precise meaning of each chemical and the context in which it is used is a daunting task. The diversity of chemical signals emitted by plants can vary

widely depending on the species, environmental conditions, and the presence of other organisms, making it challenging to identify consistent patterns. Understanding the context in which plants emit and interpret signals is crucial. Plants may release chemicals to warn neighboring plants of herbivore attacks or to compete for resources. Deciphering when and why these signals are used is complex.

Plants use a combination of chemical, electrical, and mechanical signals for communication. Studying these diverse signaling modalities and how they interact poses a significant challenge.

7. Ongoing Research and Future Scope

Scientists are developing sophisticated analytical tools, including mass spectrometry and gas chromatography, to identify and quantify the myriad chemical compounds involved in plant communication. This enables a more detailed understanding of the chemical signals' composition and variations. Along with this, advances in genetics and molecular biology have allowed researchers to manipulate and study the genes responsible for producing signaling compounds. This approach provides insights into the genetic basis of plant communication. Ongoing research focuses on ecological interactions and the role of plant communication in ecosystems. Understanding how plants communicate with other organisms, such as beneficial microbes or insects, has far-reaching implications for agriculture and conservation. Machine learning algorithms and data analysis techniques are also being employed to analyze vast datasets of chemical emissions and responses. These tools can help identify complex patterns and correlations that may not be apparent through traditional methods.

The field of plant communication is poised for exciting breakthroughs in the coming years. Researchers hope to unravel the specific meanings of different chemical signals, decode the context in which they are used, and gain a more comprehensive understanding of the sophisticated language of plants. Such discoveries could have profound implications for agriculture, ecology, and even our understanding of plant consciousness.

8. Conclusion

Studying plant communication is a challenging but rewarding endeavor. As scientists continue to overcome obstacles and develop innovative research methods, we can look forward to a deeper understanding of the complex and intriguing ways in which plants communicate with each other and their environment. This knowledge may ultimately revolutionize how we approach agriculture, conservation, and our relationship with the plant kingdom. The world of plant communication is a captivating realm that challenges our understanding of the plant kingdom. As we continue to unlock the secrets of how plants share information underground, we gain valuable insights into the resilience and adaptability of the natural world. By harnessing this knowledge, we may find innovative ways

to coexist harmoniously with the plant life that surrounds us, benefiting both agriculture and the environment.

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