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PHYTONCIDAL MIMICRY IN PLANTS AS A STRATEGY FOR INSECT PEST CONTROL

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Abstract. This article examines the mechanisms underlying the emergence of phytoncidal mimicry in plants, the processes involved in its manifestation, its ecological significance, and the prospects for its practical application. One of the most pressing challenges of modern agriculture is the development of environmentally sustainable methods for controlling insect pests without causing adverse effects on ecosystems as a whole. Although phytoncidal mimicry remains a relatively understudied phenomenon, it represents a promising approach to addressing pest-related challenges in agriculture. In this context, the topic is both scientifically relevant and worthy of further investigation due to its potential contribution to the development of sustainable pest management strategies.

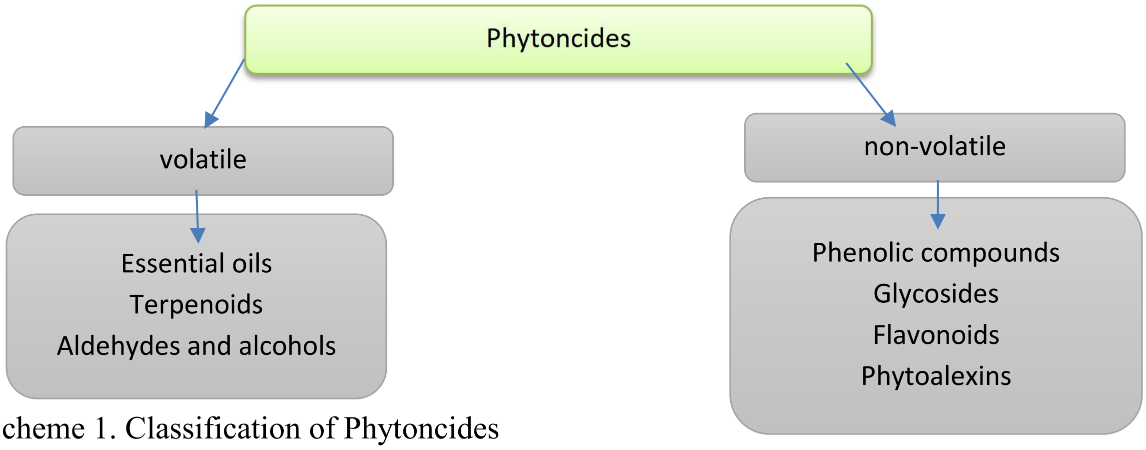
Keywords: phytoncides, mimicry, pheromones, parasitic insects, agriculture, imitation, terpene synthases.

One of the most pressing challenges of the modern era is environmental pollution. Ensuring stable and high agricultural yields requires effective protection of crops against pests and diseases. At present, this task is largely accomplished through the use of chemical pesticides. These compounds play a crucial role in the control of agricultural pests of various origins and have become an integral component of modern crop protection systems. However, their impact is highly controversial. While chemical pesticides provide effective protection against biological agents that threaten crop productivity, they also constitute a significant source of environmental contamination. Their widespread application can adversely affect non-target organisms, disrupt ecological balance, and contribute to the accumulation of toxic substances in natural ecosystems. Consequently, the search for environmentally sustainable alternatives to conventional pesticides has become an important priority in contemporary agricultural science.

Modern pesticides comprise a wide range of chemical compounds that are toxic to agricultural pests; however, they may also exert toxic effects on non-target organisms, including species that pose no threat to agriculture and even humans. Although pesticides are intended to control harmful organisms, these target species constitute no more than approximately 0.5% of the total biotic population of the biosphere. Nevertheless, the effects of pesticide application extend far beyond the intended targets and can impact a broad spectrum of living organisms [3][4].

As sessile organisms, plants have evolved numerous defense mechanisms to protect themselves against herbivorous insects and other pests. Among the most intriguing and relatively understudied of these mechanisms is phytoncidal mimicry—the ability of plants to release volatile biologically active compounds that imitate the chemical signals of other organisms or alter insect behavior in ways that reduce herbivory and pest pressure.

Phytoncides are generally volatile organic compounds produced by plants that possess antimicrobial and insecticidal properties. These substances can repel herbivorous insects, inhibit the growth and development of pathogenic microorganisms, and influence the physiology and behavior of insects. Through these functions, phytoncides play an important role in the natural defense systems of plants and contribute to their ecological interactions with other organisms [3].



Scheme 1. Classification of Phytoncides

Phytoncidal mimicry is a form of chemical defense in which a plant “mimics” odors associated with danger, unsuitable food sources, or the presence of predators. Unlike the direct production of toxic compounds, this mechanism relies primarily on the transmission of chemical information that influences insect behavior [6].

Several mechanisms of phytoncidal mimicry have been identified:

Mimicry of unsuitable or harmful food sources. Chemical cues emitted by plants signal to insects that the host is toxic, of poor nutritional quality, or infected. For example, certain species of wormwood (Artemisia spp.) and mint (Mentha spp.) produce specific essential oils that deter herbivorous insects.

Attraction of natural enemies. Damaged plants may release volatile compounds that attract predatory insects or parasitoids, which subsequently attack herbivorous pests. For instance, maize plants emit volatile phytoncides following herbivore damage, attracting parasitic wasps that contribute to pest suppression.

Mimicry of alarm pheromones. Some plants produce compounds that resemble insect alarm signals. The perception of these compounds induces avoidance behavior in herbivorous insects, causing them to abandon or avoid the host plant [7].

The present article focuses specifically on the mechanism of alarm pheromone mimicry in plants.

Many insects, including ants, aphids, termites, and other social or gregarious species, utilize alarm pheromones—volatile chemical compounds released in response to predator attacks or other threats. These pheromones trigger rapid dispersal of colonies, defensive responses, and cessation of feeding, the latter being particularly relevant to the present study. In aphids, for example, the principal alarm pheromone is (E)-**β-farnesene**, which serves as a key signal indicating the presence of danger [8].

Over the course of evolution, certain plant species have acquired the ability to synthesize compounds structurally and functionally similar to insect alarm pheromones. As a result, insects perceive these plants as potentially hazardous environments and leave them before substantial feeding damage occurs. This response reduces the likelihood of pest colonization and can significantly enhance plant resistance to herbivorous insects. Such interactions represent a remarkable example of chemical communication across kingdoms and highlight the potential of phytoncidal mimicry as a sustainable strategy for biological pest management.

Notably, plants do not synthesize these compounds continuously. In most cases, their production is induced only after the plant has been damaged by herbivorous insects.

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The activation of these defensive signaling pathways is primarily mediated by plant hormonal systems. Several key signaling molecules are involved in the regulation of defense gene expression:

Jasmonates (jasmonic acid) — predominantly activated in response to insect herbivory and mechanical tissue damage.

Salicylic acid — more commonly associated with defense against pathogens, although it also participates in the regulation of herbivore-induced responses.

Ethylene — acts as a signaling molecule that enhances and coordinates plant stress responses.

Following the activation of these signaling pathways, genes encoding defense-related enzymes are expressed. Among the most important are:

Lipoxygenases (LOXs), which initiate the biosynthesis of green leaf volatiles (GLVs);

Cytochrome P450 monooxygenases (CYP450s), which catalyze the modification and diversification of numerous secondary metabolites;

Terpene synthases (TPSs), responsible for the biosynthesis of terpenes, including compounds such as farnesene.

Terpenes are particularly significant because they frequently function as the chemical signals involved in phytoncidal mimicry and insect behavioral manipulation [8].

At the genomic level, this process can be described as a multistep signaling cascade. Initially, plant damage occurs and is recognized through the detection of specific elicitors, such as components of insect oral secretions. This recognition event activates signaling pathways that induce transcription factors, including MYC2, a central regulator of jasmonate-mediated defense responses. Subsequently, genes involved in the biosynthesis of secondary metabolites are upregulated, leading to the production and emission of volatile organic compounds. These volatiles function as defensive signals that can repel herbivores, attract natural enemies of pests, or mimic insect alarm pheromones, thereby reducing the likelihood of successful colonization by herbivorous insects.

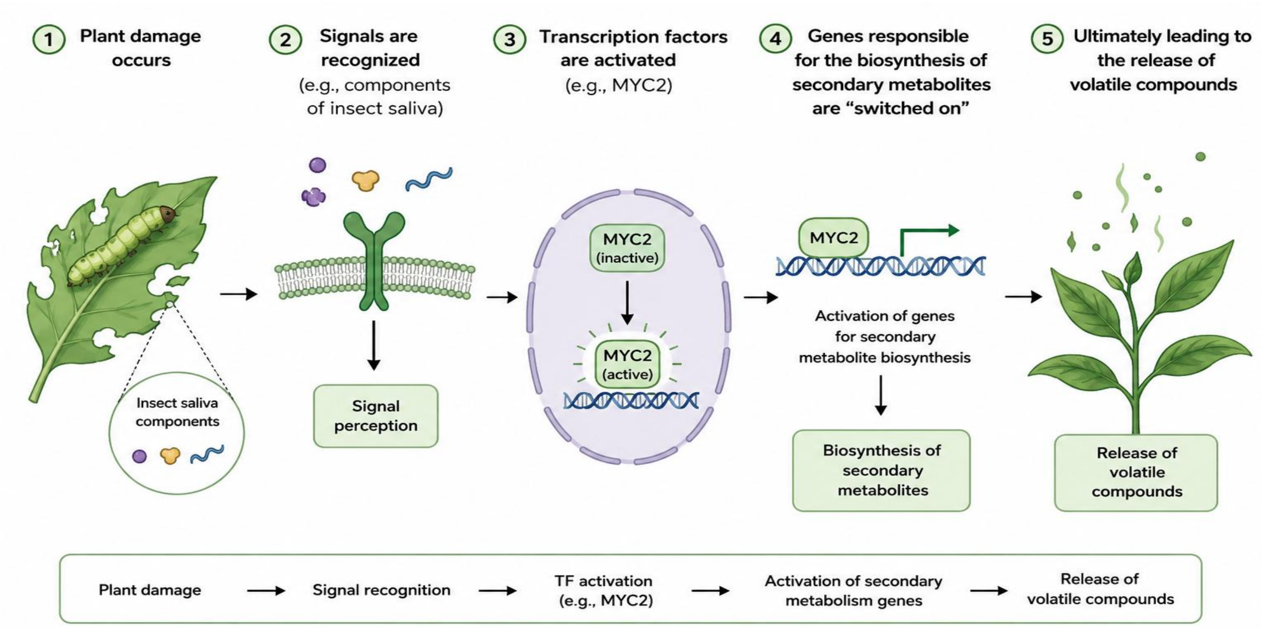

Figure 2. Phytoncidal Mimicry Triggered by Plant Damage

It is important to emphasize that plants do not intentionally reproduce or “copy” insect pheromones. Rather, this phenomenon is the result of evolutionary selection, whereby the production of chemical compounds resembling insect signaling molecules conferred a selective advantage and was therefore favored over successive generations.

As noted above, phytoncidal mimicry is frequently inducible rather than constitutive, meaning that the production of mimetic compounds is activated only under specific conditions, such as herbivore attack. This inducible strategy offers several ecological and physiological advantages. First, it reduces the metabolic costs associated with the continuous synthesis of defensive compounds. Second, it minimizes the risk of attracting non-target or potentially harmful organisms. Finally, inducible defenses enable plants to tailor their responses to particular herbivores or environmental conditions, thereby increasing the efficiency and specificity of their protective mechanisms. Such flexibility represents an important adaptive feature that enhances plant fitness while optimizing resource allocation.

The application of phytoncidal mimicry holds considerable promise for modern agriculture, as it has the potential to reduce reliance on chemical pesticides, provide an environmentally friendly means of crop protection, and contribute to the development of sustainable agroecosystems. It should be noted that plants do not produce exact replicas of insect hormones in the strict physiological sense. Instead, they emit volatile chemical signals that interact with insect sensory systems rather than directly affecting their endocrine regulation. Nevertheless, the functional outcome is similar: insects respond as though they have received an alarm signal, leading to avoidance behavior and reduced feeding activity.

Currently, significant research efforts are focused on exploring the practical application of this phenomenon. Promising approaches include the transfer of terpene synthase (TPS) genes into economically important crop species, the development of cultivars capable of producing (E)-β-farnesene, and the use of RNA-based regulatory technologies to enhance plant defense signaling pathways and increase the production of protective volatile compounds [8].

The study of phytoncidal mimicry provides valuable insights into the complex chemical interactions between plants and insects and offers new opportunities for the advancement of sustainable agriculture and biological plant protection. By exploiting naturally evolved defense mechanisms, future crop protection strategies may achieve effective pest control while minimizing ecological disturbance and reducing dependence on synthetic chemical inputs.

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