

ROLE OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN PEST MANAGEMENT

Yashwant^{1*} and Dr. Gajendra Chandrakar²**Abstract: -**

Plant volatile organic compounds (VOCs) are important chemical signals that mediate plant–plant and plant–insect interactions. Major VOC classes include terpenoids, phenylpropanoids, green leaf volatiles, and amino acid derivatives. These compounds contribute to herbivore defense, pollinator attraction, natural-enemy recruitment and defense priming in neighbouring plants. Herbivore-induced plant volatiles (HIPVs) can repel pests while attracting predators and parasitoids, thereby strengthening indirect plant defense. VOCs also influence plant competition, kin recognition, and ecological communication. Their agricultural potential includes push–pull strategies, synthetic semiochemicals and genetic engineering of crop VOC profiles for sustainable pest management. However, environmental variation, ecological context-dependency, non-target effects and formulation costs remain important challenges. Understanding VOC biosynthesis, signalling, and ecological functions through multi-omics, ecological modelling, and synthetic biology can support environmentally sustainable crop protection and improved agricultural productivity.

Introduction:

Volatile organic compounds (VOCs) are low-molecular-weight, carbon-containing chemicals released into the air by plants and other organisms. Because they readily disperse through the atmosphere, VOCs can act as important chemical signals between organisms. In plants, they are involved in

several biological processes, including attracting pollinators, defending against herbivores and pathogens, and communicating with nearby plants (Almeida *et al.*, 2023).

Terpenes are among the most abundant and diverse groups of plant VOCs. They are commonly associated with plant resins and contribute strongly to the characteristic scents

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of flowers and other plant tissues (Farré-Armengol *et al.*, 2016). Although producing these compounds requires considerable metabolic energy, their widespread occurrence indicates that they provide important ecological benefits. Plant VOCs influence interactions at different trophic levels by attracting pollinators, deterring herbivores, recruiting natural enemies of pests, and facilitating communication between neighboring plants (Zhou & Jander, 2022; Wetzels & Whitehead, 2025). For example, VOCs released by plants under herbivore attack can act as warning signals to nearby plants, allowing them to prepare their defenses before they are attacked themselves (Farmer & Ryan, 2022).

resulted in a highly complex chemical communication system between plants and insects. Understanding this system is particularly important for agriculture because VOCs may be used to repel insect pests and attract their natural enemies, potentially reducing dependence on synthetic pesticides (Montagné, 2025).

Biosynthesis, Diversity, and Emission of Plant Volatile Organic Compounds

1. Major Biosynthetic Pathways

Plants produce VOCs through several major metabolic pathways, including the terpenoid, phenylpropanoid/benzenoid, fatty-acid-derived, and amino-acid-derived pathways (Wetzels & Whitehead, 2025). Terpenoids form the largest and most

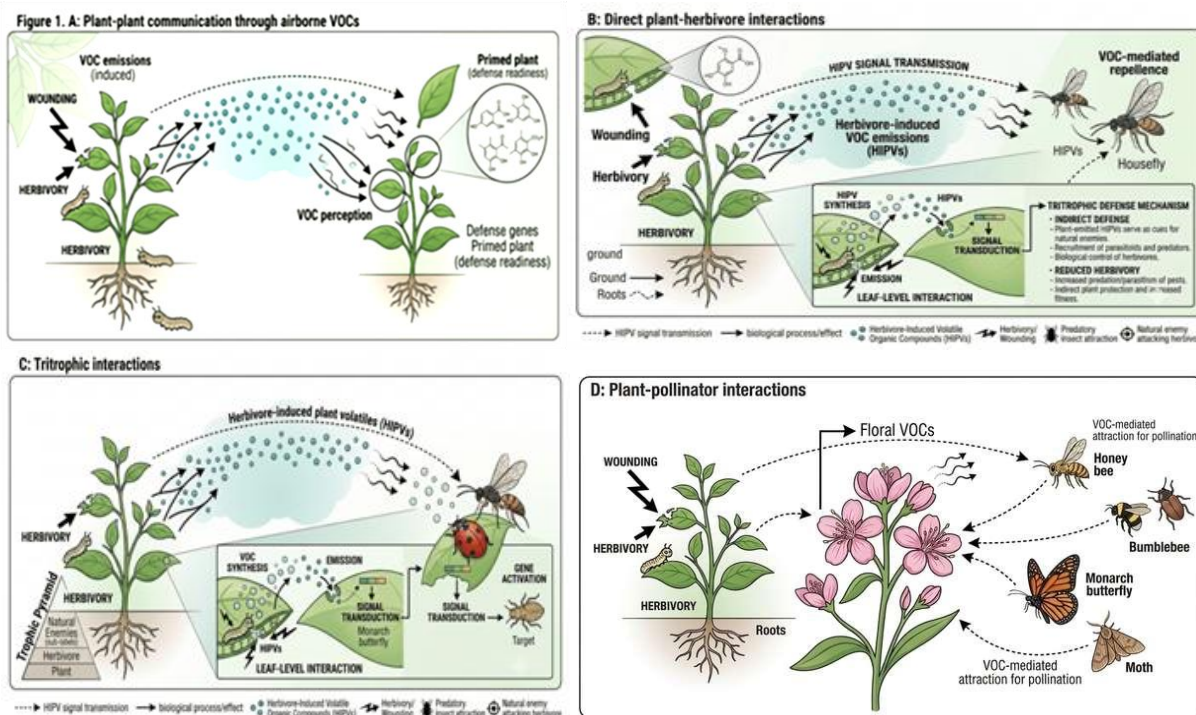


Fig:1. VOC-mediated interactions in a natural ecosystem

structurally diverse group of plant VOCs. They are produced through two major pathways: the cytosolic mevalonic acid (MVA) pathway and the plastid-localized methylerythritol phosphate (MEP) pathway. Monoterpenes (C_{10}) and sesquiterpenes (C_{15}) are especially important because they contribute to plant defense, communication, and pollinator attraction (Kalyani *et al.*, 2026).

Amino-acid-derived VOCs are mainly produced from branched-chain amino acids such as leucine, isoleucine, and valine, as well as sulfur-containing amino acids such as methionine.

These compounds contribute to the characteristic aromas of flowers and fruits and can also play roles in attracting pollinators and defending plants against herbivores.

2. Constitutive and Induced VOC Emissions

Plant VOC emissions can generally be divided into two categories: constitutive and induced emissions. Constitutive VOCs are released continuously under normal conditions, whereas induced VOCs are produced or released in response to environmental or biological stimuli (Zhou & Jander, 2022; Wetzel & Whitehead, 2025).

Constitutive VOC emissions are particularly common in flowers and fruits, where they contribute to pollinator attraction and reproductive success. In comparison,

vegetative tissues usually release smaller amounts of VOCs under normal conditions. However, VOC production can increase considerably when plants experience herbivore attack, mechanical injury, or environmental stress (Kalyani *et al.*, 2026).

Herbivore-induced plant volatiles (HIPVs) are released when insects feed on plant tissues. Their composition and quantity can differ substantially from those of constitutively emitted VOCs. The production of HIPVs is regulated by several plant hormone signalling pathways, particularly those involving jasmonic acid, salicylic acid, and ethylene (Mobarak *et al.*, 2025). Plants can also distinguish between simple mechanical damage and actual herbivore feeding by VOC production and release are influenced by both plant characteristics and environmental conditions. Factors such as temperature, light intensity, humidity, and nutrient availability can affect the detecting herbivore-associated molecular patterns (HAMPs) present in insect oral secretions (Zhou & Jander, 2022).

3. Factors Influencing VOC Emission Patterns

VOC production and release are influenced by both plant characteristics and environmental conditions. Factors such as temperature, light intensity, humidity, and nutrient availability can affect the amount and

composition of VOCs released by plants (Zhou & Jander, 2022). Environmental stresses, including drought, ozone exposure, and increased atmospheric CO₂, can also alter VOC emission patterns. The effects of these factors may vary depending on their intensity and the combination of stresses experienced by the plant.

4. Chemical Diversity and Ecological Information Content

The wide variety of compounds present in plant VOC blends provides important information for ecological interactions. A single plant can release many different volatile compounds, and the proportions of individual compounds can influence how the signal is interpreted by other organisms. Therefore,

differences in VOC composition may affect how plants interact with insects and other organisms in their environment (Wetzel & Whitehead, 2025).

VOC-Mediated Plant–Insect Interactions

1. Direct Defense: Repellence and Toxicity

Plant VOCs can directly protect plants from herbivorous insects by acting as repellents, feeding deterrents, or toxins. Several terpenoids and phenylpropanoids can reduce herbivore feeding and egg-laying behavior (Wetzel & Whitehead, 2025; Mobarak *et al.*, 2025). For example, monoterpenes such as camphor and 1,8-cineole can deter some generalist herbivores, particularly when present at relatively high concentrations. These chemical defenses can

Table 1. Major classes of plant volatile organic compounds, their biosynthetic pathways, representative compounds and functions

VOC Class	Biosynthetic Pathway	representative Compounds	Functions
Phenylprop anoids/Benz enoids	Shikimate/phenylalanine pathway	Methyl salicylate, eugenol, benzaldehyde, 2 phenylethanol	Defense signaling, floral scent, pollinator attraction, antimicrobial activity
Amino acid derivatives	Branched-chain amino acid/methionine pathways	Isobutyraldehyde, 3 methylbutanol, dimethyl sulfide, methional	Floral and fruit aroma, pollinator attraction, defense against generalist herbivores
Fatty acid derivatives (GLVs)	Lipoxygenase pathway	(Z)-3-hexenal, (Z)-3 hexenol, (Z)-3 hexenyl acetate	Early herbivore warning signals, plant–plant communication, natural enemy attraction
Terpenoids	MVA/MEP pathways	Limonene, β caryophyllene, linalool, α -pinene	Herbivore defense, pollinator attraction, plant signaling, natural enemy recruitment

help plants reduce herbivore damage while other defense mechanisms are activated.

2. Indirect Defense: Attraction of Natural Enemies

One of the most important functions of HIPVs is their ability to attract natural enemies of herbivores, including predatory insects, parasitoid wasps, and entomopathogenic nematodes (Zhou & Jander, 2022; Wetzel & Whitehead, 2025; Mobarak *et al.*, 2025). When herbivores feed on a plant, the plant can release a specific mixture of VOCs. This mixture may differ from the VOCs released after mechanical injury alone.

These herbivore-associated signals can help predators and parasitoids locate their prey or hosts. For example, parasitoid wasps of the genus *Cotesia* can respond to VOC blends released by caterpillar-infested plants, helping them locate suitable hosts. Some VOCs can also have more than one function. Methyl salicylate, for example, can discourage certain aphids while attracting beneficial organisms such as predatory ladybeetles and parasitoid wasps (Kalyani *et al.*, 2026).

3. Pollination: Floral Volatiles as Pollinator Attractants

Floral VOCs are important components of plant–pollinator interactions. The scent produced by flowers is often characteristic of a particular plant species and can help pollinators recognize suitable flowers

(Baskaran & Saravanan, 2024; Montagné, 2025). Different groups of pollinators are associated with different floral scent profiles. Bee-pollinated flowers, for example, commonly produce sweet scents rich in terpenoids and benzenoids (Baskaran & Saravanan, 2024).

Flowers pollinated by moths often produce strong, sweet scents that become more pronounced at night, matching the activity patterns of nocturnal pollinators. Beetle-pollinated flowers may produce fruity or fermenting odors, while carrion-mimicking flowers produce unpleasant odors that attract flies and beetles. These differences show how floral VOCs can help plants attract particular groups of pollinators.

VOC-Mediated Plant–Plant Interactions Airborne Communication and Defense Priming

Plants are capable of responding to VOCs released by neighboring plants that are under herbivore attack. When exposed to these airborne signals, nearby plants may activate defense-related genes and become better prepared for a possible attack. This process is known as **defense priming** (Farmer & Ryan, 2022).

Several compounds, including green leaf volatiles (GLVs), methyl salicylate, and different terpenoids, have been associated with plant–plant signaling (Zhou & Jander, 2022;

Farmer & Ryan, 2022). GLVs are particularly important because they can be released very quickly after plant tissue is damaged. As a result, neighboring plants may detect these compounds and strengthen their defensive responses before being directly attacked.

Agricultural Applications and Sustainable Pest Management

1. Push–Pull Strategies

The push–pull strategy is an important example of how knowledge of plant chemical communication can be applied to pest management. It combines repellent signals that push pests away from the main crop with attractive plants or chemical cues that pull pests toward trap crops or other managed areas (Mobarak *et al.*, 2025).

A well-known example is the management of stemborers in East African maize production systems. Intercropping maize with *Desmodium* species can discourage stemborer moths from settling on maize, while attractive trap crops such as Napier grass can be planted around field margins. Together, these approaches can reduce pest pressure on maize and support biological control (Kalyani *et al.*, 2026).

2. Synthetic Semiochemicals and Attract-and-Kill Systems

Research on insect responses to VOCs has also led to the development of synthetic semiochemicals for pest management. These

compounds can be used in attract-and-kill systems, where pests are drawn toward traps or bait stations containing insecticides or biological control agents (Wetzel & Whitehead, 2025; Mobarak *et al.*, 2025).

Such approaches may provide greater selectivity than broad-spectrum pesticides and can be compatible with biological control. However, their success depends on factors such as the concentration of the compound, its release rate, environmental conditions, and the behavior of the target insect (Kalyani *et al.*, 2026).

3. Genetic Engineering of VOC Profiles

Recent developments in genetic engineering and synthetic biology have created new opportunities to modify VOC production in crop plants (Zhou & Jander, 2022; Mobarak *et al.*, 2025). By modifying genes involved in VOC biosynthesis, researchers can potentially increase the production of compounds that repel herbivores or attract their natural enemies. For example, increasing the expression of terpene synthase genes may enhance the release of particular terpenoids with defensive functions. Such approaches could contribute to the development of crops with stronger and more targeted natural defenses (Kalyani *et al.*, 2026).

Challenges and Limitations

Although VOC-based pest management has considerable potential,

several challenges need to be addressed before these approaches can be widely adopted.

1. Ecological context dependency:

The effectiveness of a particular VOC can vary between agroecosystems. A compound that works well under one set of environmental conditions may have weaker or even undesirable effects under different conditions (Wetzel & Whitehead, 2025; Mobarak *et al.*, 2025).

2. Habituation of natural enemies:

Predators and parasitoids may become accustomed to persistent or unreliable VOC signals. This could reduce the effectiveness of long-term strategies based on attracting natural enemies (Mobarak *et al.*, 2025).

3. Overlap between chemical signals:

Similar VOCs may be released in response to different stresses, including herbivore feeding, pathogen infection, and oxidative stress. This overlap can make it difficult to interpret and manipulate plant signals accurately under field conditions (Mobarak *et al.*, 2025).

4. Economic and technological limitations:

The production, formulation, and application of synthetic semiochemicals can be expensive and technically demanding. Developing affordable and efficient delivery systems will be particularly important for smallholder farmers.

Future Research Scope

1. Integration of Multi-Omics Approaches

Combining genomics, transcriptomics, proteomics, and metabolomics can provide a more complete understanding of VOC production and signaling. These approaches can help researchers identify genes involved in VOC biosynthesis, understand natural differences in VOC production, and determine how plants and insects detect and respond to volatile signals.

2. Ecological Modelling for Optimizing VOC-Based Strategies

Ecological modelling can help researchers predict how VOC-based pest-management strategies may perform under different environmental and agricultural conditions (Mobarak *et al.*, 2025). Models that consider factors such as climate, spatial distribution, timing, and insect behavior could help determine when and where particular VOC-based approaches are most effective.

3. Harnessing Synthetic Biology

Synthetic biology offers promising opportunities to develop crops with optimized VOC profiles for improved pest resistance (Zhou & Jander, 2022; Mobarak *et al.*, 2025). Researchers may be able to modify or combine biosynthetic pathways to produce volatile blends that provide stronger protection against pests while having minimal effects on

beneficial insects. However, before such technologies are widely used, their ecological risks and possible effects on non-target organisms need to be carefully evaluated.

Conclusion

Plant VOCs are essential chemical signals regulating plant–plant and plant–insect interactions, including defense, pollination, and natural-enemy recruitment. Their application in push–pull strategies, semiochemicals, and synthetic biology offers promising approaches for sustainable pest management. Future research should focus on multi-omics, ecological modelling, and climate-resilient VOC technologies.

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