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Role of Microbial Volatile Organic Compounds in Plant Disease Management

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Plant diseases caused by bacterial, fungal, and oomycete pathogens pose a major threat to global agricultural productivity and food security. Conventional disease management strategies rely heavily on chemical pesticides, which raise concerns regarding environmental safety, pathogen resistance, and human health. In recent years, microbial volatile organic compounds (mVOCs) have emerged as a promising, eco-friendly alternative for plant disease management. These low-molecular-weight compounds are produced by diverse soil- and plant-associated microorganisms and can act over long distances without direct physical contact. mVOCs influence plant–pathogen interactions by directly inhibiting pathogen growth, inducing systemic resistance in plants, modulating plant physiology, and shaping the rhizosphere microbiome. This article reviews the sources, chemical nature, and mechanisms of action of microbial VOCs in suppressing plant diseases. Current experimental evidence, application strategies, challenges, and future prospects for integrating mVOCs into sustainable plant disease management programs are discussed.

Keywords: microbial volatile organic compounds, biological control, plant–microbe interactions, induced systemic resistance, sustainable agriculture

Introduction

Plant diseases account for substantial yield losses worldwide and significantly impact agricultural sustainability. Chemical fungicides and bactericides have traditionally been the primary tools for disease control; however, their extensive use has led to environmental contamination, development of resistant pathogen strains, and negative effects on non-target organisms. These limitations have intensified the search for alternative, sustainable disease management strategies. Biological control using beneficial microorganisms has gained increasing attention. Among the diverse mechanisms employed by biocontrol agents, the production of microbial volatile organic compounds (mVOCs) represents a relatively recent and rapidly expanding area of research. Unlike diffusible antibiotics or lytic enzymes, mVOCs are small, volatile molecules that can diffuse through soil pores and air spaces, enabling them to act without direct contact between the microorganism, the plant, and the pathogen.

Microbial Volatile Organic Compounds: Definition and Sources

Microbial volatile organic compounds are low-molecular-weight (<300 Da), lipophilic compounds with high vapor pressure, enabling easy evaporation and diffusion. They belong to diverse chemical classes, including:

- Alcohols (e.g., 2,3-butanediol)
- Ketones (e.g., acetoin)
- Alkanes and alkenes
- Terpenes
- Sulfur-containing compounds

- Aromatic compounds

A wide range of microorganisms produce mVOCs, including:

- **Bacteria:** *Bacillus*, *Pseudomonas*, *Streptomyces*, *Serratia*
- **Fungi:** *Trichoderma*, *Fusarium*, *Aspergillus*, *Penicillium*
- **Actinomycetes:** especially soil-dwelling species

These microbes are commonly found in the rhizosphere, phyllosphere, endosphere, and compost ecosystems.

Mechanisms of Action in Plant Disease Management

Direct Antagonism of Plant Pathogens

One of the most well-documented roles of mVOCs is their direct inhibitory effect on plant pathogens. Certain VOCs suppress pathogen growth by:

- Inhibiting spore germination
- Disrupting cell membrane integrity
- Interfering with enzyme activity and metabolism
- Causing oxidative stress

For example, VOCs produced by *Trichoderma* spp. and *Bacillus subtilis* have been shown to inhibit major fungal pathogens such as *Botrytis cinerea*, *Fusarium oxysporum*, and *Rhizoctonia solani*.

Induction of Plant Systemic Resistance

Beyond direct toxicity to pathogens, mVOCs can act as signaling molecules that prime plant defense responses. Exposure to specific microbial VOCs triggers induced systemic resistance (ISR), which enhances the plant's ability to defend itself against a broad range of pathogens.

Key features of VOC-mediated ISR include:

- Activation of jasmonic acid (JA) and ethylene (ET) signaling pathways
- Upregulation of defense-related genes
- Increased production of pathogenesis-related proteins
- Enhanced accumulation of phenolics and phytoalexins

Compounds such as acetoin and 2,3-butanediol produced by *Bacillus* spp. are well-known elicitors of ISR in several crop species.

Modulation of Plant Growth and Physiology

Many mVOCs simultaneously promote plant growth while enhancing disease resistance. This dual function is particularly valuable in sustainable agriculture. VOCs may:

- Stimulate root and shoot growth
- Improve nutrient uptake
- Enhance chlorophyll content and photosynthesis
- Increase tolerance to abiotic stresses, indirectly reducing disease susceptibility

Healthier plants often exhibit improved resilience against pathogen invasion.

Shaping the Rhizosphere Microbiome

mVOCs can influence microbial community composition in the rhizosphere by selectively inhibiting pathogens or favoring beneficial microbes. This indirect mechanism contributes to disease suppression by creating a microbiome that is less conducive to pathogen establishment.

Experimental Evidence and Case Studies

Numerous in vitro and in planta studies demonstrate the disease-suppressive potential of mVOCs. For example:

- *Trichoderma harzianum* VOCs significantly reduced damping-off disease caused by *Pythium* spp.
- *Bacillus amyloliquefaciens* VOCs suppressed bacterial wilt and enhanced resistance in tomato plants
- Fungal VOCs from *Muscodor* spp. exhibited broad-spectrum antifungal activity

These studies highlight the versatility of mVOCs across different plant–pathogen systems.

Application Strategies in Agriculture

Potential strategies for utilizing mVOCs in plant disease management include:

- Inoculation of VOC-producing biocontrol agents into soil or seed coatings
- Use of VOC-producing microbes in greenhouse and controlled-environment agriculture
- Development of VOC-based biofumigants
- Integration with existing integrated pest management (IPM) programs

Advances in formulation and delivery systems are crucial to ensure consistency and efficacy under field conditions.

Challenges and Limitations

Despite their promise, several challenges limit the large-scale application of mVOCs:

- Variability in VOC production under field conditions
- Short persistence due to volatility
- Complexity of VOC mixtures and synergistic effects
- Regulatory hurdles and lack of standardized evaluation methods

Additionally, environmental factors such as soil type, temperature, and moisture can influence VOC diffusion and effectiveness.

Future Perspectives

Future research should focus on:

- Identifying key VOCs responsible for disease suppression
- Understanding molecular mechanisms of plant perception of VOCs
- Developing stable and scalable delivery systems
- Exploring synergistic effects between mVOCs and other biocontrol mechanisms
- Conducting long-term field trials

Integrating genomics, metabolomics, and synthetic biology may enable the design of optimized microbial strains with enhanced VOC-mediated biocontrol activity.

Conclusion

Microbial volatile organic compounds represent a powerful and environmentally friendly tool for plant disease management. Through direct pathogen inhibition, induction of plant defenses, and modulation of the plant microbiome, mVOCs offer a multifaceted approach to disease control. Although challenges remain in translating laboratory findings to field applications, continued research and technological advances hold great promise for incorporating mVOCs into sustainable agricultural systems.

References

1. Bitas, V., Kim, H. S., Bennett, J. W., & Kang, S. (2013). Sniffing on microbes: Diverse roles of microbial volatile organic compounds in plant health. *Molecular Plant-Microbe Interactions*, 26(8), 835–843. https://doi.org/10.1094/MPMI-10-12-0249-CR
2. Effmert, U., Kalderás, J., Warnke, R., & Piechulla, B. (2012). Volatile mediated interactions between bacteria and fungi in the soil. *Journal of Chemical Ecology*, 38(6), 665–703.
3. Farag, M. A., Ryu, C. M., Sumner, L. W., & Paré, P. W. (2006). GC–MS SPME profiling of rhizobacterial volatiles reveals prospective inducers of growth promotion and induced systemic resistance in plants. *Phytochemistry*, 67(20), 2262–2268.
4. Groenhagen, U., Baumgartner, R., Bailly, A., Gardiner, A., Eberl, L., Schulz, S., & Weisskopf, L. (2013). Production of bioactive volatiles by different *Burkholderia ambifaria* strains. *Journal of Chemical Ecology*, 39(7), 892–906.
5. Kanchiswamy, C. N., Malnoy, M., & Maffei, M. E. (2015). Chemical diversity of microbial volatiles and their potential for plant growth and productivity. *Frontiers in Plant Science*, 6, 151. https://doi.org/10.3389/fpls.2015.00151
6. Kai, M., Effmert, U., Berg, G., & Piechulla, B. (2007). Volatiles of bacterial antagonists inhibit mycelial growth of the plant pathogen *Rhizoctonia solani*. *Archives of Microbiology*, 187(5), 351–360.