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Microbial Volatiles

New players in the field of agriculture

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What are Microbial volatile compounds?

Volatile organic compounds abbreviated as VOCs (more specifically microbial volatile compounds [MVCs]) are complex combinations of small, odorous compounds (<C15) characterized by low molecular weights and high vapor pressures and derive from different biosynthetic pathways. MVCs can evaporate, diffuse, cross the membranes and can travel long distances from their site of origin via air, soil, and solution. These properties make these volatile compounds ideal signalling molecule that can interfere in plant growth, development and signalling processes.

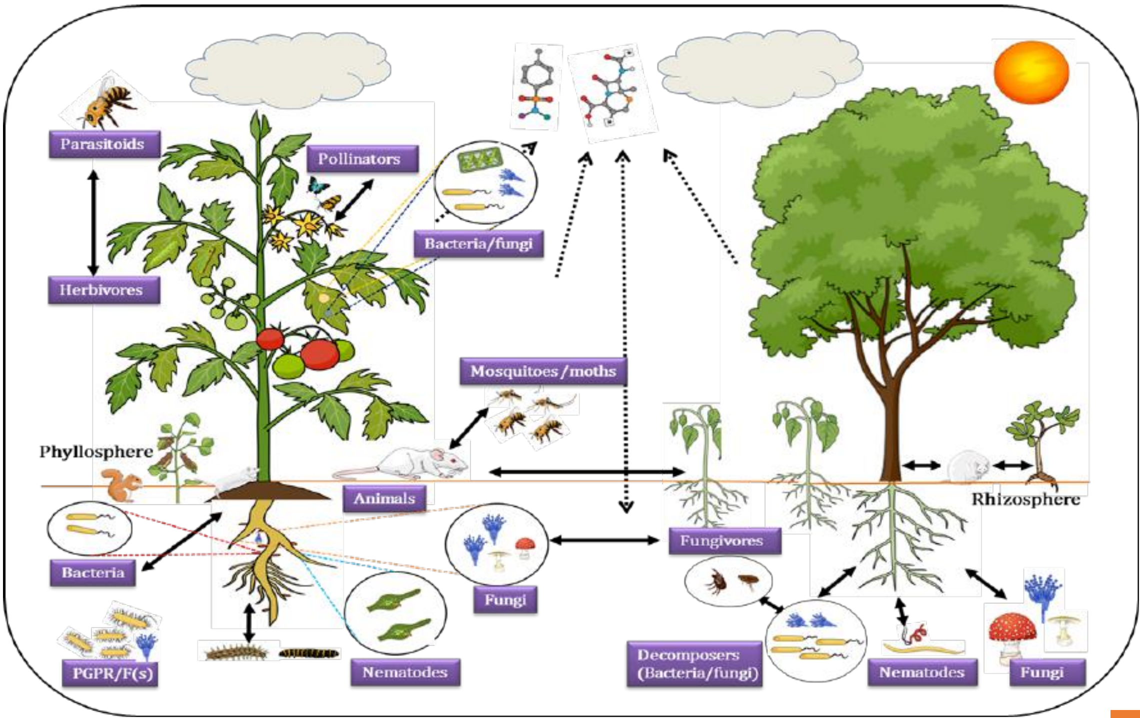

Figure: How MNCs interact in the environment. Known and hypothesized roles of microbial volatile organic compounds (VOC) in mediating organismal interactions within and across kingdoms. The double-headed arrows denote VOC-mediated organismal interactions. Anthropogenic and biogenic VOC enter the surrounding atmosphere, potentially affecting the environmental quality and ecosystem health. Soils function as both sources and sinks of VOC. Certain VOC produced by plant growth–promoting rhizobacteria (PGPR), such as 2,3-butanediol, induce plant growth and stress resistance.

Dr. Herrington and his workers in 1995 first time reported that the mixture of volatile compounds from bacterial Streptomyces sp. can inhibit the growth of fungal spores and can aid in plant growth promotion. Unfortunately, this study remained unnoticed until 2003 when a group of scientist from the Republic of Korea, first time reported the role of microbial VOCs in plant growth promotion and development process which opened a new era of scientific research and studies. Till then a lot of studies being carried out by researchers independently or in collaborations all over the world reporting the role of microbial volatile compounds in plant development processes. Till now more than two thousands of microbial compounds ranging from alkanes, alkenes, alcohols, ketones aldehydes, terpenes, benzenoids, nitrogen and sulfur-containing compounds etc., have been reported from >1000 of bacterial and fungal species and submitted to Microbial Volatile Database (MVOCs Database) created by a group of scientists from Germany (Lemfack and co-workers).

Not surprisingly, microbial VOC seem to perform diverse and critical functions such as

1. Plant growth promotion,
2. Induction of resistance (systemic or induced),
3. Change in root system architecture
4. Increasing tolerance against abiotic stresses (salt or drought tolerance) and
5. Altering plant hormones level,
6. Suppression of plant pests and pathogens.

1. Role of MVCs in plant growth promotion, disease resistance, and tolerance

Analysis, application and comparison studies of several MVCs have suggested that 2,3-butanediol, indole, dimethyl disulfide is a major VOC produced by several bacterial species like *Bacillus*, *Pseudomonas*, *Erwinia* mediated growth promotion in *Arabidopsis*, nicotiana, tomato plants. Plant hormones and its derivatives such as ethylene, methyl jasmonate, methyl salicylate and auxin secreted by microorganisms affect the growth and fitness of plants by modulating processes such as pathogenesis, defense, and tolerance to environmental stresses, alteration in root system architecture, nutrient recycling and utilization. For example, unknown VOCs produced from *Bacillus* sp., affected the growth and root architecture of *Arabidopsis thaliana*. Similarly, exposure of *Nicotiana attenuata* plants dimethyl disulfide (DMDS) containing volatile mixture produced by *Bacillus* sp. improved plant growth by improving S nutrition availability and removing the requirement of S for energy demanding processes. Furthermore, DMDS volatiles were found to protect tobacco and corn plants against *Botrytis cinerea* and *Cochliobolus heterostrophus* by directly inhibiting the pathogens and by inducing systemic resistance in the plants. 2,3-butanediol- an MVC produced from *Bacillus* sp. not only induced systemic tolerance (IST) to salt stress in Arabidopsis plants but also improved tolerance to both drought tolerance and disease resistance in it.

Recent advances in bioinformatics technologies made it easier to investigate the expression of certain genes influenced by MVCs. In addition to plant growth promoting bacteria and fungi, there is growing evidence that MVCs from phytopathogens also promotes plant growth. For example, Arabidopsis, maize and pepper plants exposed to MVCs, emitted by the phytopathogen *Alternaria alternata* were shown to have enhanced photosynthetic capability, as well as higher concentrations of cytokinins (CKs) and sugars. MVCs emitted by pathogenic *Fusarium oxysporum* promoted the growth of Arabidopsis and tobacco plants by affecting auxin transport and signaling. The soil-borne pathogen *Rhizoctonia solani* produced an array of MVCs that promoted plant growth, accelerated plant development, changed plant VOC emissions, and induced insect resistance.

2. Role of MVCs in plant disease control

Microbial volatiles play an important role in both atmospheric ("above-ground") and soil ("below-ground") ecosystems. In agriculture, the interest in microbial VOCs is for their potential as biological control (biocontrol) agents to control fungal, bacterial and other pests to employ a more environmentally sound pest management strategy by reducing fungicide use on crop plants.

Without any direct contact between the strains, the volatiles of wild-type antagonistic *F. oxysporum* and its bacterial consortium inhibited the fungal growth of a plant pathogenic strain of *F. oxysporum* causative agent of wilt disease in plants. These volatile signals also participate in priming neighboring tissues and plants for stronger and more rapid defense responses in case they are attacked. Some VOC contributes to defense via their antimicrobial activities. For example, tomato leaves treated with chitosan oligosaccharide, a degradation product of the fungal cell wall, induced the production of VOC that inhibit fungal pathogen growth. The VOCs of the endophyte *Muscodor albus* also can be used to control soil-borne diseases caused by *Rhizoctonia solani*, which causes damping-off of broccoli, and *Phytophthora capsici*, which causes root rot of bell pepper. In addition to the inhibitory effects of certain VOCs on deleterious soil-borne organisms, stimulation or enhancement of soil-borne biocontrol agents may be another desired effect. When studied for their potential to be used together as biological control agents of plant pathogens, the volatiles emitted by *Trichoderma atroviride* increased the expression of a primary biocontrol gene of *Pseudomonas fluorescence*. VOCs from *M. albus* were used as "myco-fumigation agent" against peach pathogens, *Penicillium expansum*, *B. cinerea*, *Monilinia fructicola* and significantly reduced the growth of common building fungi. Furthermore, the VOCs of *Oxyporus latemarginatus* isolated from red peppers inhibited the mycelial growth of several plant pathogens known to damage post-harvest fruit and reduced post-harvest decay of apples caused by *B. cinerea* and *Rhizoctonia* root rot of moth orchid.

Besides, the emission of VOCs by fungi may be an efficient way of defending against fungal feeders. For example, 1-octen-3-ol produced by the mushroom *Clitopilus prunulus* deterred banana slugs (*Ariolimax columbianus*) from consuming the mushrooms. On the other hand, some fungal VOCs provide location cues for host selection in fungivorous arthropods. 1-octen-3-ol produced by the wood-rotting white rot fungus *Trametes gibbosa* serves as an attractant for fungus-eating beetles (Coleoptera). Another species of white rot, *Trametes versicolor*, produced sesquiterpenes such as d-cadinene, followed by b-guaiene, isoledene and g-patchoulene, which attracted frugivorous beetles in behavioral experiments.

3. Future perspectives

Microbial VOCs have several advantages over traditional biocontrol agents. Being volatile in nature, it can travel a long distance and don't need to associate with the plant physically. MVCs are active in micromole concentration and a little amount of compound is enough to induce the desired effect. Recent advances have shown that MVCs play important signaling roles in plant-microbe interactions and can be a novel strategy to be applied as growth inducers with potential use in agricultural species. There are sufficient relevant pieces of evidence available those support the idea that MVCs acts as ideal info-chemical or signal molecules for eliciting growth, development and induce ISR/IST. However, the potential of MVCs as a diffusible signaling molecule that interferes with plant development and its defense cannot be ignored, but it is also true that we are far behind in understanding its potential role in biocontrol, and its practical applicability in the field. A deeper understanding of the active mechanisms, dose size, and environmental conditions may serve to highlight the commercial potential of MVCs as a cost-effective base material in the development of next-generation pesticides and fertilizers.