Short Communication

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Volatile organic compounds production from bacteria: implications to polluted water bodies

Abstract

Contaminated water bodies have the potential to emit volatile organic compounds (VOCs) and bioaerosols, which can affect air quality and human health in surrounding areas. The objective of this study is to present evidence on the production of VOCs and their relationship with bacterial composition and emissions detected in areas near contaminated bodies of water, through a review of the scientific literature on VOCs, bioaerosols and emissions associated with polluted water bodies, complemented with evidence reported in articles from our working group regarding pollution rivers in Puebla, Mexico. This study shows a review of VOC microbial production and a table of genus/component association as part of the obtained results. VOCs (e.g., Ammonia, H_2S, Ethanol, Butanol, Acetaldehyde, Diacetyl, Acetone, 2,3-Butanediol, Dimethyl sulfide DMS, indole). VOCs detected near polluted rivers in Puebla, México are correlated with the bacterial composition of total suspended particles. This shows a relationship between bacteria and emissions of VOCs, the detection of potentially pathogenic genera indicates an increased microbiological risk for nearby populations.

Keywords: VOCs, bioaerosols, air quality, contaminated rivers

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Abbreviations: VOCs, volatile organic compounds; TSP, suspended total particles; EC, emerging contaminants; mVOCs volatile organic compounds by microorganisms

Introduction

Air pollution from particulate matter is one of the leading causes of morbidity and mortality linked to environmental pollution.[1,2] When considering an integrative view of contamination, highly contaminated water bodies can act as additional sources of volatile emissions and bioaerosols produced by water aerosolization and microbial processes associated with organic matter and fecal waste.[3–5] These emissions include volatile organic compounds (VOCs), microorganisms, and resistance genes that can travel with particles and affect nearby populations.[6,7]

In recent decades, the production of volatile organic compounds by microorganisms (mVOCs) has gained importance as an ecological issue, and as a factor affecting environmental health, plant-microbe interactions, and air quality.[8–10] Classical studies show that bacteria and fungi produce alcohols, ketones, aldehydes, sulfurs, terpenes, and indoles through intra- and inter-rein interactions, affecting plant growth, induced resistance, microbial competition, antibiosis, and stress adaptations.[11–13] The mVOC 4.0 project has recently enabled the systematic description of thousands of microbial volatile compounds across multiple species. This allows for easier comparison of chemical fingerprints observed in environmental studies and their relationship with community composition.[14] Additionally, it has been documented that VOCs from microbial communities can enter the atmosphere, undergo oxidation, form secondary organic aerosols (SOA), and impact local air quality, especially in areas with multiple biological and anthropogenic sources.[15,16] These advances suggest evidence the integration of chemical, microbiological, and atmospheric, particles.

The reviewed literature indicates that microbial VOCs play communicative and inhibitory roles (pheromones, antimicrobial compounds, plant growth modulators), and that their production is strongly influenced by environmental factors such as temperature, humidity, nutrients, and microbial community composition.[17,18] In the context of contaminated rivers, the co-occurrence of fecal-indicative compounds (indoles, coprostanol) and genera capable of producing diverse volatiles suggests that part of the airborne volatile signature originates from active microbial metabolism in sediments and the water column, in addition to anthropogenic sources (pesticides, solvents, livestock activities).[19,20]

Methodology

A total of 28 scientific publications related to mVOCs, bioaerosols, and emissions from contaminated water bodies were reviewed to develop this article. The selected literature includes studies focused on microbial metabolism, environmental VOC detection, atmospheric transport of biological particles and evidence reported in articles from our working group regarding Pollution Rivers in Puebla, México, was also considered, where volatile compounds were collected and analyzed TSP to evaluate the association between microbial communities and volatile emissions.

Analysis of interactions near contaminated water bodies

Recently the authors studied the total suspended particles near two rivers in Puebla, México. In the chromatographic analysis of extracts, the following compounds were detected and confirmed: cyclohexanol (CHnol), cyclohexanone (CHone), methyl 2-(methylthio) acetate (M2MTA), 2-butoxyethanol (E2B), benzaldehyde (BzA), phenol (Phen), dimethyl trisulfide (DMTS), and 2,5-dithiahexane (25DTH), UTIM, the least contaminated site, was dominated by *Bacillus* ≈64%, with minor contributions from *Firmicutes* and *Proteobacteria*. At ICATEP (Nexapa), *Bacillus* decreased to ≈43%, accompanied by a relative increase in pathogenic *Proteobacteria*, with *Pseudomonas* representing ≈19%. UPMP (Atoyac), the most contaminated site, exhibited *Bacillus* at ≈41% and higher microbial diversity, including *Lactobacillales, Pseudomonas, Enterobacter, Pantoea, Salmonella,* and *Citrobacter*.[21]

For example CHnol and CHone are part of the products of metabolized hydrocarbons by strains of some yeasts of the genera *Candida* and *Trichosporon*.[22] Bioprocesses have even been developed for the production of useful products, starting with cyclohexane, which is transformed in different stages into CHnol and CHone by the participating microorganisms.[23] Similarly, DMS and dimethyl trisulfide have microorganism mediated synthesis pathways.[24,25]

Bacteria in polluted water are capable of generate emissions of VOCs as is shown in Table 1. *Pseudomonas* was observed to produce the greatest diversity of VOCs,[26] including acetaldehyde, diacetyl, DMS, indole, ethene, α-pinene, guaiacol, and 2-furanmethanol. Other genera, such as *Bacillus, Enterobacter,* and *Citrobacter*, also produced multiple VOCs,[26–28] many of which are associated with unpleasant odors and potential toxic or irritant effects.

Table 1 Association between bacterial genus and reported volatile compounds (mVOCs)

VOC	Genres associated
Acetic acid	Lactococcus, Enterococcus, Citrobacter, Salmonella, Cronobacter, Shewanella, Cedecea, Acinetobacter, Pantoea, Bacillus, Pseudomonas, Enterobacter, Kluyvera, Geobacillus, Raoultella
Lactic acid	Lactococcus, Enterococcus, Citrobacter, Cronobacter, Shewanella, Cedecea, Bacillus
Ammonia (NH_3)	Enterococcus, Citrobacter, Salmonella, Cronobacter, Shewanella, Cedecea, Acinetobacter, Pantoea, Enterobacter, Kluyvera, Raoultella
Hydrogen sulfide (H_2S)	Salmonella, Cronobacter, Shewanella, Cedecea, Citrobacter, Enterobacter, Kluyvera, Raoultella
Ethanol	Citrobacter, Cronobacter, Shewanella, Cedecea, Bacillus, Pseudomonas, Enterobacter, Kluyvera, Geobacillus
Butanol	Bacillus, Geobacillus
Acetaldehyde	Citrobacter, Cronobacter, Shewanella, Cedecea, Enterobacter, Kluyvera
Diacetyl	Lactococcus, Pseudomonas
Acetone	Bacillus, Geobacillus, Shewanella
2,3-Butanodiol	Bacillus, Enterobacter
Putrescine	Enterococcus, Citrobacter, Salmonella, Cronobacter, Cedecea, Enterobacter, Kluyvera, Raoultella
Cadaverine	Citrobacter, Salmonella, Cronobacter, Enterobacter, Kluyvera
Dimethyl sulfide (DMS)	Shewanella, Cronobacter, Cedecea, Pseudomonas, Citrobacter
Indole	Pseudomonas
Isovaleric acid	Bacillus
Histamine	Raoultella
Ethene (ethylene)	Pseudomonas, Penicillium
α-Pinene	Pseudomonas,
Ajoene	Pseudomonas (biotransformación)
2-Furanmethanol	Pseudomonas

In the studies sites, both contaminant concentrations and microbial diversity decreased with distance from the polluted water bodies, may be an evidence of that the contaminated water is the primary source.

The integrated results indicate that water bodies with high organic and fecal loads act as local sources of VOCs and bioaerosols. The spatial correlation—higher chemical signals and greater microbial diversity in the most contaminated areas—suggests an aerosolization mechanism (bubbling, droplet breakup, wind-driven removal) that transfers both organic compounds and microorganisms from the aqueous to the airborne phase. Similar processes have been described in wastewater treatment plants and coastal estuaries, where the transfer of chemical signals and microorganisms to the atmosphere has been observed.

Conclusion

The analysis of the literature shows a strong relationship between bacteria and emissions of VOCs. This is confirmed in the results of the experimental stud of organic compounds near highly polluted water bodies in México. Metagenomic analysis indicates that the most contaminated site exhibits higher microbial diversity, including genera associated with the production of multiple VOCs. Besides, the detection of potentially pathogenic genera indicates an increased microbiological risk for nearby populations, particularly under chronic exposure or in vulnerable groups. Further research—including temporal and spatial sampling, absolute quantification, and resistance characterization—is required to assess health risks and design effective mitigation measures more comprehensively.

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Conflicts of interest

The authors declare no conflicts of interest in the source documents.

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