



Interplay of heavy metal accumulation, physiological responses, and microbiome dynamics in lichens: insights and future directions

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Abstract Lichens are increasingly recognised as valuable bioindicators for environmental heavy metal pollution due to their sensitivity to spatial and temporal variations in pollution levels and their ability to adapt to diverse and often harsh habitats. This review initially examines the mechanisms of metal absorption in lichens, including particulate entrapment, ion exchange, and intracellular absorption, as well as

their physiological responses to abiotic stressors such as heavy metal exposure and desiccation. In the latter part, we compile and synthesise evidence showing that secondary metabolites in lichens are significantly influenced by metal concentrations, with varying impacts across different species. Although extensive research has addressed the broader physiological effects of heavy metal hyperaccumulation in lichens, there remains a significant gap in understanding the direct or indirect influences of heavy metals on the lichen microbiome, possibly mediated by changes in secondary metabolite production. Our review integrates these aspects to propose new research directions aimed at elucidating the mechanisms underlying physiological responses such as resilience and adaptability in lichens. Overall, this review highlights the dynamic interplay between microbiome composition, secondary metabolite variation, and metal accumulation, suggesting that these factors collectively contribute to the physiological responses of lichens in polluted environments.

Highlights

- Lichens employ diverse mechanisms for heavy metal accumulation.
- Heavy metal accumulation triggers physiological stress responses and DNA damage.
- Secondary metabolites further help alleviate heavy metal toxicity in lichens.
- Heavy metal accumulation shifts lichen microbiomes.
- Lichens serve as model systems for biomonitoring air pollution.

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Abbreviations

ROS	Reactive oxygen species
TBARS	Thiobarbituric acid reactive substances
NO	Nitric oxide
GSH	Glutathione