microbial biotechnology

Highlight

Dark side of cyanobacteria: searching for strategies to control blooms

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Summary

Cyanobacteria are ecologically one of the most prolific groups of photosynthetic prokaryotes in marine and freshwater habitats. They are primary producer microorganisms and are involved in the production of important secondary metabolites, including toxic compounds such as cyanotoxins. Environmental conditions promote massive growth of these microbes, causing blooms that can have critical ecological and public health implications. In this highlight, we discuss some of the approaches being addressed to prevent these blooms, such as control of nutrient loading, treatments to minimize growth or monitoring interactions with other species.

Cyanobacteria are oxygen-producing microorganisms that use sunlight as an energy source to convert carbon dioxide (CO_2) into biomass. These photosynthetic microorganisms are the dominant primary producers in aquatic ecosystems and contribute substantially to primary production in terrestrial ecosystems. In water bodies such as sea coasts and lakes, these microorganisms can form dense blooms in certain environmental situations, e.g. when eutrophication, CO_2 concentration, water temperature and/or high light intensity increase (Gobler et al., 2017; Huisman et al., 2018; Ullah et al., 2018). Blooms can cause water quality problems, increase turbidity and smother submerged aquatic vegetation. Microbial degradation of senescent blooms produces oxygen depletion that leads to hypoxia and anoxia, resulting in the death of fish and benthic invertebrates (Rabalais et al., 2010). In addition, these blooms can cause odour and taste in waters which interferes with the use of these water bodies as drinking water reservoirs. A more serious problem is the production of toxins by cyanobacteria that can cause pathologies when ingested by birds, mammals and/or humans (Merel et al., 2013; Paerl, 2017).

Although algae blooms have been known since ancient times, several studies indicate that they are currently increasing globally, mainly due to climate change. A US predictive model indicates that the average number of days with harmful cyanobacterial blooms will increase from about 7 days per year per body of water under current conditions to 18–39 days in 2090 (Chapra et al., 2017). The 2019 intergovernmental panel on climate change assessment reported that the occurrence of harmful algal blooms, their toxicity and risk on natural and human systems are projected to continue increasing together with warming and rising CO_2 in the 21st century (Pörtner et al., 2019). Furthermore, the analysis of satellite images obtained over three decades has shown that blooms have increased in freshwater lakes and marine oceans around the world, concluding that climate change is not the only factor involved in the increase in massive cyanobacterial blooms (Ho et al., 2019; Hallegraeff et al., 2021).

One of the main factors involved in blooms is eutrophication. Water enrichment with nitrogen (N) in combination with phosphorus (P) due to agricultural and industrial processes contributes to the blooms, especially by non-N_2-fixing *Microcystis* spp. which are often the dominant bloom-forming cyanobacteria in lakes. An interesting aspect is how N availability and speciation influence the growth of cyanobacteria, their persistence and the production of the toxins. This aspect has been addressed in Environmental Microbiology (*EMI*) by Krausfeldt et al. (2020) who demonstrated how different N sources (ammonium, nitrate and urea) influence metabolism and toxin (microcystins) composition in *Microcystis aeruginosa*. A series of assays using both stable-labelled

nitrogen isotopes and metabolomic approaches were carried out. The study revealed that different N sources provoked differences in global metabolism, toxins quotas and congener composition. They observed a higher production of the most toxic microcystin congener in cells grown in urea, which has important implications in agriculturally influenced water bodies. Moreover, urea is also a source of C and provides a competitive advantage for cyanobacteria during algal blooms, particularly when CO_2 levels are low. Future studies should address the interplay between N speciation and factors such as temperature, pH and, in particular, the interaction with heterotrophic bacteria (Krausfeldt *et al.*, 2020).

Several strategies have been developed to prevent cyanobacterial blooms. Nutrient management implies a reduction of nutrient inputs such as N and P fertilizers and can be a good strategy to mitigate blooms. Chemical treatments can eradicate cyanobacteria, but these treatments can also provoke lysis of cells and release toxins. Although low concentrations of hydrogen peroxide (H_2O_2) appear to be an effective method to eliminate cyanobacteria blooms (Barrington and Ghadouani, 2008; Matthijs *et al.*, 2012), this approach is not always effective. A recent report by Weenink *et al.* (2021) in *EMI* showed that there is interspecific protection in which green algae protect cyanobacteria from these treatments. Studies conducted by Weenink *et al.* (2021) demonstrated, under laboratory and field conditions, that the high H_2O_2 degradation rates by green algae such as *Chlorella* spp. protect freshwater cyanobacteria against oxidative stress. The interaction between both species does not seem to be reciprocal and cyanobacteria may even suppress the growth of the green algae. Interspecific protection implies that higher H_2O_2 concentrations will be necessary to suppress cyanobacterial blooms. However, the amount of H_2O_2 that can be applied in lakes is limited because it can affect other sensitive organisms such as zooplankton and the costs may be unaffordable (Weenink *et al.*, 2021). Although recent studies suggest that two consecutive H_2O_2 applications at low concentrations are more effective in controlling species such as *Microcystis* (Daniel *et al.*, 2019), whole-ecosystem experiments are needed to provide deeper insight regarding the alteration of the plankton community and mitigation of cyanobacterial blooms.

Another important aspect is that cyanobacterial blooms are intimately coupled with the dynamics of bacterial community composition (Woodhouse *et al.*, 2018). The role that bacteria can play in the development and maintenance of blooms is highlighted in a study also published in *EMI* by Zuo *et al.* in Lake Taihu in China. This lake has been undergoing cyanobacterial blooms for decades due to an increase in the *Microcystis* population. Intensive studies of the conditions triggering cyanobacterial populations growth have identified the importance of abiotic factors, but the influence of biotic factors, such as the presence of heterotrophic bacteria, is yet unclear. A high-throughput 16S rRNA sequencing and principal component analysis approach suggested that the growth of the α-proteobacteria *Phenylobacterium* was correlated with the toxin profiles obtained in the lake. Furthermore, field and laboratory studies were carried out and determined that *Phenylobacterium* strains can help *Microcystis* maintain dominance over time. However, it is not clear how the influence of bacteria on cyanobacteria is achieved. These studies open a new field of research and unravelling the mechanisms underlying these interactions would be very useful for the control of cyanobacterial blooms (Zuo *et al.*, 2021).

Due to the different plankton composition and differences in blooms influencing factors, prevention and control methods have not been shown to be effective alone. Strategies to control water quality must be tailored to local environments. In this regard, each water body should be analyzed to determine its species composition and what combination of factors promotes cyanobacterial blooms at the site. Therefore, efficient monitoring methods for the early detection of cyanobacterial blooms are needed. Among those currently in use, chlorophyll fluorescence probes, which allow real-time monitoring of cyanobacteria, are highly effective. In addition to these probes, others can be developed to monitor cyanobacteria-specific accessory pigments, i.e. phycobilins. We envisaged the use of drones equipped with sophisticated detectors for remote sensing and early detection of cyanobacterial blooms.

On the other hand, global environmental regulation is needed. In recent years, it has been shown that the increase in the number of blooms is related to nutrients released from aquaculture activities (Hallegraeff *et al.*, 2021) or agricultural fertilizers (Huisman *et al.*, 2018; Navedo and Vargas-Chacoff, 2021). These activities together with increased temperature, CO_2 concentration or low oxygenation play a key role in the occurrence of new cyanobacterial blooms in different regions. Artificial intelligence to handle global data sets related to algal blooms, climate factors and eutrophication are needed to predict future blooms and take mitigation measures in advance.

Conflict of interest

None declared.

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