AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 06 Issue: 01 January 2025 Article No: 33

Microbial Toxins in Aquatic Ecosystems

R. Arasi, R.J. Abisha, K.K. Shrivasanthan, V. Rani and D. Manimekalai
Department of Aquatic Environment Management, Fisheries college and Research Institute, Thoothukudi, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Tamil Nadu

SUMMARY

Microorganisms produce diverse bioactive compounds, including toxins, which can significantly harm aquatic ecosystems, human health, and economies. Cyanobacteria, a notable toxin producer, generate compounds like microcystins, cylindrospermopsin, anatoxins, and saxitoxins, often linked to harmful algal blooms (HABs). These toxins thrive under eutrophic conditions, warm temperatures, and high nutrient levels. Bacteria such as *Vibrio*, *Aeromonas*, and *Escherichia coli* contribute to aquatic toxicity, affecting aquatic organisms and contaminating seafood. Fungal mycotoxins, including aflatoxins and ochratoxins, also enter water systems through runoff, posing risks to organisms and human health. Environmental factors like nutrient enrichment, water temperature, salinity, and light availability exacerbate toxin production. Microbial toxins impact aquatic life through acute toxicity, bioaccumulation, and ecological imbalances. They alter microbial communities, reduce biodiversity, disrupt food webs, and impair nutrient cycling. Understanding and mitigating these toxins are essential to protecting aquatic ecosystems, human health, and the economy.

INTRODUCTION

Microorganisms are ability to produce diverse bioactive compounds such as hydrolytic enzymes, antibiotics, antitumorals and also toxins. Toxins can be produced by prokaryotes such as bacteria, in particular cyanobacteria, but also by eukaryotes such as dinoflagellates, diatoms, fungi (mycotoxins). These toxins have become a growing concern in aquatic ecosystems due to their ability to cause significant harm to aquatic life, disrupt ecosystems, and pose serious risks to human health. As the frequency of harmful algal blooms (HABs) and other toxin-producing events increases globally, understanding the role of microbial toxins in aquatic environments is crucial. Many of these microorganisms may be present in drinking water supplies or recreational waters. Moreover, the toxins have also great economical impact due to their deleterious effects.

Classification of Microbial Toxins

Toxins produced by cyanobacteria

1.Cyanotoxins:

Cyanotoxins are a diverse group of toxic compounds produced by cyanobacteria, which are photosynthetic microorganisms found in fresh, brackish and marine waters, nonacidic hot springs, hypersaline environments, Antarctic soils, rocks, ice and deserts. One the most known phenomena are the dense blooms of *Trichodesmium erythraeum* that produce a red discoloration of the water and gave the Red Sea its name. These occurrences can be partially attributed to the gradual eutrophication of the waterways, exposure to constant sunshine, warmth and availability of nutrients like phosphates and nitrates. Cyanobacterial blooms in temperate water bodies occur mostly during summer months. These toxins are notorious for their association with harmful algal blooms (HABs), which can occur when environmental conditions, such as warm temperatures, stagnant water, and nutrient over-enrichment (especially phosphorus and nitrogen), favor the rapid growth of cyanobacteria.

Microcystins: One of the most abundant types of cyanotoxins worldwide are microcystins (MC). Microcystins are a family of cyclic heptapeptides, with microcystin-LR being the most toxic and well-known variant. Microcystins is produced by *Microcystis aeruginosa*, *Planktothrix agardhii* and *Anabaena* sp. An increased incidence of primary liver cancer in China has been associated with the chronic ingestion of sub lethal doses of microcystins in raw drinking water. The main target of MC is the hepatocyte, the most common cell type in the liver. Death of hepatocytes leads to the destruction of the finer blood vessels of the liver and to massive hepatic bleeding. Microcystins are highly stable and can persist in water bodies even after the cyanobacterial cells that produced them have died, posing long-term risks.

Cylindrospermopsin: Unlike microcystins, cylindrospermopsin is a tricyclic alkaloid that inhibits protein synthesis in cells by disrupting ribosomal function. This toxin can cause multi-organ damage, primarily affecting the liver and kidneys. It can be produced by cyanobacteria like *Cylindrospermopsis raciborskii*, which thrives in both tropical and temperate climates, increasing its geographical range.

Anatoxins: Anatoxin-a is a potent neurotoxin that acts as a cholinergic agonist, binding to nicotinic acetylcholine receptors and causing overstimulation of muscles, leading to paralysis and respiratory failure. Anatoxin-a(s), on the other hand, inhibits acetylcholinesterase, preventing the breakdown of acetylcholine and causing similar neurotoxic effects. These toxins are produced by cyanobacteria such as *Anabaena* and *Aphanizomenon*.

Saxitoxins: These are a group of neurotoxins that block voltage-gated sodium channels in neurons, preventing the propagation of nerve impulses and leading to paralysis. Saxitoxins are produced not only by cyanobacteria but also by certain marine dinoflagellates, making them a concern in both freshwater and marine environments. The accumulation of saxitoxins in shellfish can lead to paralytic shellfish poisoning (PSP) in humans.

Nodularin: This toxin has only been found in *Nodularia spumigena*. Like microcystins, nodularin is a potent tumor promoter that may also act as a carcinogen/tumor initiator

2.Toxins Produced by Other Bacteria in Aquatic Environments

Bacterial toxins in aquatic environments are often associated with pathogenic bacteria that can infect both aquatic organisms and humans. These toxins can cause a range of diseases, from gastrointestinal illnesses to more severe systemic infections.

Vibrio Toxins: They are highly abundant in aquatic environments, including estuaries, marine coastal waters and aquaculture facilities. They also appear to be highly associated with marine organisms like fish, mollusks and shrimps, which are important food products for human consumption. Vibrio organisms present another important feature: they can attach to the exoskeletons of crustaceans and other marine organisms of the zooplankton, producing biofilms. Their close relationship with zooplankton can be a survival strategy to resist to environmental stresses like starvation or antibiotic presence.

Vibrio cholerae, Vibrio parahaemolyticus and Vibrio vulnificus are three Vibrio species considered serious human pathogens. The main virulence factor associated to *V. cholerae* pathogenesis is the production of the potent cholera toxin (CT). Cholera is characterized by a voluminous watery diarrhea, leading to rapid dehydration. The characteristics of V.vulnificus infections include fever, chills, nausea, hypotensive septic shock and secondary lesion formation on the extremities of the body. Primary septicemia is the most lethal infection, with about 50% mortality rate. These bacteria are often found in warm, brackish waters and can contaminate seafood, posing a risk to consumers.

***Aeromonas hydrophila*:** Aeromonas spp. are members of Aeromonadaceae that cause both intestinal and systemic infections in humans. Aeromonas hydrophila colonizes aquatic environments and is also isolated from food products. Although gastroenteritis occurs generally in young children, it has been frequently associated with the travel's diarrhea. Furthermore, the cases of septicemia are often fatal. This species can express several virulence factors, including hemolysins, proteases, adhesins,lipases/phospholipases and toxins.

Escherichia coli: Shigella dysenteriae this E. Coli toxin is also known as verotoxin due to its effect in vero cells. Infections in humans may result in water diarrhea, bloody diarrhea or in the hemolytic uremic syndrome (HUS), characterized by acute renal failure,hemolytic anemia and other severe symptoms. The kidney and the gastrointestinal tract are the most affected organs, but lungs, heart, central nervous system and pancreas can also be targeted.

Botulinum Toxin: Produced by *Clostridium botulinum*, botulinum toxin is one of the most potent neurotoxins known. It inhibits acetylcholine release at neuromuscular junctions, leading to flaccid paralysis. While botulinum toxin is primarily associated with foodborne botulism, it can also contaminate water sources, particularly in environments with low oxygen levels where *C. botulinum* can thrive.

Shiga Toxin: Produced by certain strains of *Escherichia coli* (e.g., E. coli O157), Shiga toxin can cause severe gastrointestinal disease and hemolytic uremic syndrome (HUS), a condition that leads to kidney failure. Shiga toxin-producing *E. coli* can contaminate water bodies through fecal runoff, posing a risk to both human and animal health.

Legionella pneumophila: Legionella pneumophila is the pathogenic organism responsible for the Legionnaires disease, a potential. lethal pneumonia that results from the ability of this bacterium to survive and replicate in macrophages.The human infection occurs mostly by inhalation of aerosols generated by domestic and environmental water sources

3. Mycotoxins

Mycotoxins are secondary metabolites produced by fungi, often associated with agricultural products, but they can also enter aquatic systems through runoff, decaying organic matter, or direct contamination.

Aflatoxins:

Produced mainly by *Aspergillus flavus* and *Aspergillus parasiticus*, aflatoxins are some of the most potent naturally occurring carcinogens, particularly affecting the liver. Aflatoxins can contaminate crops such as corn and peanuts, and through agricultural runoff, they can reach aquatic ecosystems, where they pose risks to both aquatic organisms and animals that consume contaminated water or feed.

Ochratoxins:

Ochratoxins, particularly ochratoxin A, are nephrotoxic compounds produced by *Aspergillus* and *Penicillium* species. They can contaminate various food products and water sources, leading to chronic kidney disease in humans and animals. In aquatic environments, ochratoxins may accumulate in fish and other organisms, posing risks to predators and humans.

Fumonisins:

Fumonisins are a group of toxins produced by *Fusarium* species, particularly *Fusarium verticillioides*. These toxins disrupt sphingolipid metabolism, leading to liver and kidney damage, and are associated with neural tube defects. Fumonisins can enter aquatic systems through soil and crop runoff, affecting aquatic life and potentially contaminating drinking water.

Toxins produced by prokaryotes related to aquatic environments.

Mode of action	Toxin name	Produced by
Membrane permeabilizing toxins	Act	*A. hydrophila*
	α-Hemolysin	*E. coli*
	Bifermentolysin	*C. bifermentans*
	Botulinolysin	*C. botulinum*
	Chauveolysin	*C. chauvoei*
	Histolyticolysin O	*C. hystolyticum*
	Novyilysin	*C. novyi* A
	Perfringolysin O	*C. perfringens*
	Septicolysin O	*C. septicum*
Toxins affecting membrane traffic	Botulinum neurotoxin	*C. botulinum*
Toxins affecting signal transduction	Cholera toxin	*V. cholerae*
	Heat-labile enterotoxin	*E. coli*
Toxins affecting protein synthesis	Cholix toxin	*V. cholera*
	Exotoxin A	*P. aeruginosa*
	Shiga toxin (verotoxin)	*E. coli*
	Lgt1	*L. pneumophila*
	RtxA	*V. vulnificus*
	RtxA	*L. pneumophila*
Toxins inhibiting protein function	Cylindrospermopsin	*Cyl. raciborskii*
		Umezakia natans
		Aph. ovalisporum
		Raph. curvata
		A. bergii

Environmental Conditions Promoting Toxin Production

The production of microbial toxins in aquatic ecosystems is heavily influenced by a variety of environmental conditions. Understanding these conditions is crucial for predicting and mitigating the occurrence of harmful algal blooms (HABs) and other toxin-producing events that can severely impact aquatic ecosystems and human health. Below are the key environmental factors that promote the production of microbial toxins:

1. Nutrient Enrichment (Eutrophication)

Nutrient enrichment, particularly with nitrogen and phosphorus, is one of the primary drivers of toxin production in aquatic ecosystems. This process, known as eutrophication, often results from agricultural runoff, sewage discharge, and industrial pollution. Elevated levels of phosphorus and nitrogen in water bodies stimulate the growth of cyanobacteria and algae, some of which produce toxins.

Cyanobacteria, in particular, thrive in nutrient-rich environments, leading to the formation of dense blooms that can produce cyanotoxins like microcystins, anatoxins, and cylindrospermopsin. The ratio of nitrogen to phosphorus in water bodies can influence the composition of microbial communities. A high nitrogen-to-phosphorus ratio tends to favor the growth of toxin-producing cyanobacteria over other types of algae, increasing the likelihood of toxin production.

2. Water Temperature

Water temperature plays a critical role in the growth and toxin production of many microorganisms, particularly cyanobacteria and certain algae. Higher water temperatures, often linked to climate change, create favorable conditions for the proliferation of toxin-producing microorganisms. Cyanobacteria, for example, prefer temperatures between 20°C and 30°C, and their growth rates increase significantly in warm water.

This can lead to more frequent and intense harmful algal blooms. In lakes and reservoirs, thermal stratification occurs when surface waters warm up and become less dense than deeper waters, creating a stable layering effect. This stratification can concentrate nutrients in the surface layer, providing an ideal environment for cyanobacteria to thrive and produce toxins.

3. Light Availability

Light availability is another crucial factor that influences the production of toxins by photosynthetic microorganisms, such as cyanobacteria and algae. Adequate sunlight is necessary for photosynthesis, which drives the growth of cyanobacteria and algae. In clear, shallow waters where light penetration is high, these microorganisms can proliferate rapidly, leading to increased toxin production. However, excessive shading or turbidity can limit light availability and reduce the growth of these organisms.

4. Water Flow and Circulation

The flow and circulation patterns of water bodies significantly impact the distribution and concentration of nutrients and microorganisms, influencing toxin production. Slow-moving or stagnant waters, such as those found in lakes, ponds, and reservoirs, are more prone to eutrophication and the accumulation of nutrients. This creates ideal conditions for the growth of cyanobacteria and algae, which can produce toxins. Stagnant conditions also prevent the dispersion of these organisms, allowing dense blooms to form.

In stratified water bodies, the lack of vertical mixing can lead to the accumulation of cyanobacteria in the upper layers, where they can access sunlight and produce toxins. Conversely, periodic mixing events, such as those caused by wind or changes in water level, can disrupt stratification, bringing nutrients from the bottom to the surface and potentially triggering toxin-producing blooms.

5. pH and Alkalinity

The pH and alkalinity of water can influence the growth of certain microorganisms and their ability to produce toxins. Cyanobacteria generally prefer alkaline conditions, with an optimal pH range of 7 to 9. In these conditions, they can outcompete other microorganisms, leading to an increased likelihood of toxin production. Alkaline conditions can also affect the availability of dissolved carbon dioxide, which is essential for photosynthesis. In waters with higher pH, the form of carbon dioxide available can favor cyanobacterial growth, further promoting toxin production.

6. Salinity

Salinity levels influence the types of microorganisms that dominate in aquatic ecosystems, affecting toxin production. Different cyanobacteria and algae thrive in freshwater, brackish, or marine environments. For instance, freshwater cyanobacteria like *Microcystis* produce microcystins, while marine dinoflagellates like *Karenia brevis* produce brevetoxins. Changes in salinity due to freshwater influx or evaporation can shift microbial community composition, potentially favoring toxin-producing species.

Some toxin-producing microorganisms, such as *Anabaena* and *Aphanizomenon*, can tolerate a range of salinities, allowing them to produce toxins in both freshwater and slightly saline environments.

7. Presence of Other Microorganisms

The presence of other microorganisms can influence the production of toxins through competitive interactions, symbiosis, or predation. In nutrient-rich environments, toxin-producing microorganisms may outcompete other species for resources, leading to dominance in the ecosystem and increased toxin production. Conversely, in environments with a diverse microbial community, competition can limit the growth of toxin producers.

Certain bacteria can enhance the growth and toxin production of cyanobacteria through symbiotic relationships, providing essential nutrients or growth factors. Cyanophages, viruses that infect cyanobacteria, can influence the dynamics of cyanobacterial populations. In some cases, viral lysis of cyanobacteria can lead to the release of toxins into the water column, exacerbating the effects of blooms.

Ecological and Biological Impacts of Microbial Toxins

Microbial toxins in aquatic ecosystems can have profound ecological and biological effects, influencing everything from individual organisms to entire ecosystems. These impacts are often interconnected and can have cascading consequences for biodiversity, ecosystem function, and human health.

1. Impacts on Aquatic Organisms

Fish and Invertebrates:

Toxicity: Many microbial toxins are acutely toxic to fish and invertebrates. For example, microcystins can cause liver damage and death in fish. Saxitoxins and brevetoxins are neurotoxins that affect the nervous system, leading to paralysis and death in fish and shellfish.

Bioaccumulation: Toxins can accumulate in the tissues of aquatic organisms through the food web. This bioaccumulation can lead to chronic health effects in predators, including humans. For example, domoic acid, produced by diatoms, can cause amnesic shellfish poisoning in humans and severe neurological damage in marine mammals.

Behavioral Changes: Toxins can alter the behavior of aquatic organisms, affecting foraging, predator avoidance, and reproductive success. For instance, fish exposed to cyanobacterial toxins may exhibit reduced swimming activity and altered predator-prey dynamics.

Microbial Communities:

Competition and Dominance: Toxin-producing microorganisms can outcompete other species for resources, altering microbial community composition. For instance, cyanobacterial blooms can dominate in nutrient-rich conditions, reducing the diversity of other phytoplankton and impacting overall ecosystem health.

Decomposition and Nutrient Cycling: The decomposition of toxin-producing microorganisms can influence nutrient cycling in aquatic systems. For example, the breakdown of cyanobacterial blooms can lead to increased nutrient availability, potentially fueling further algal growth and creating a feedback loop.

2. Impacts on Ecosystem Function

Biodiversity Loss: The dominance of toxin-producing microorganisms can lead to the decline of sensitive species, reducing biodiversity. This loss of biodiversity can compromise ecosystem resilience and stability.

Habitat Alteration: Harmful algal blooms (HABs) can alter physical and chemical properties of aquatic habitats. For example, dense algal blooms can reduce light penetration, impacting submerged aquatic vegetation and altering habitat structure for fish and invertebrates.

Food Web Disruption: The presence of toxins can disrupt trophic interactions by affecting primary producers, which in turn impacts herbivores, predators, and decomposers. For instance, the death of fish and shellfish due to toxins can affect predators that rely on these species for food.

Nutrient Dynamics: The decomposition of toxin-producing microorganisms can lead to changes in nutrient dynamics, influencing the growth and composition of other microbial and plant communities. This can affect overall ecosystem productivity and nutrient cycling.

CONCLUSION

Microbial toxins in aquatic ecosystems represent a critical environmental and public health issue. These toxins, produced by cyanobacteria, bacteria, and fungi, can lead to harmful algal blooms, disrupt aquatic ecosystems, and pose serious health risks to humans through contaminated drinking and recreational waters. The economic impact is also significant, encompassing costs related to water treatment, healthcare, and the loss of recreational and commercial activities. Effective management strategies are essential to mitigate these impacts. This includes regular monitoring of water quality, controlling nutrient inputs to prevent eutrophication, and employing physical, chemical, and biological treatments to manage harmful algal blooms. Continued research and innovation, along with strengthened policies and regulations, are crucial for protecting water resources and ensuring the health and safety of both aquatic life and human populations.

REFERENCES

Alexander, M., 1971, Microbial Ecology (Wiley, New York) 511 p.

Applegate, K.L. and J.R. Chipley, 1973, in: Advances in Applied Microbiology, D. Perlman (ed.) Vol. 16 (Academic Press, N.Y'.) pp. 97--110.

Atherton, L.G., D. Brewer and A. Taylor, 1974, in: Mycotoxins, I.F.H. Purchase (ed.) (Elsevier, New York) pp. 29--68.

Bishop, R.E. (2005) Fundamentals of exotoxin structure and function. Concepts in Bacterial Virulence (eds. W. Russell & H. Herwald), pp. 1–27, Karger, Basel.

Landsberg, J.H., 2002. The effects of harmful algal blooms on aquatic organisms. Reviews in Fisheries Science, 10(2), pp.113-390.

Paerl, H.W. and Millie, D.F., 1996. Physiological ecology of toxic aquatic cyanobacteria. Phycologia, 35(6S), pp.160-167.

Schantz, E.J. and Johnson, E.A., 1992. Properties and use of botulinum toxin and other microbial neurotoxins in medicine. Microbiological reviews,56(1), pp.80-99.

Schlievert, P.M., 1982. Enhancement of host susceptibility to lethal endotoxin shock by staphylococcal pyrogenic exotoxin type C. Infection and immunity,36(1), pp.123-128.