DOI: https://doi.org/10.52756/lbsopf.2024.e03.001

Chapter- 1

Phycotoxins produced by Harmful Algal Blooms (HABs) and their role in human poisoning: A review

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Keywords: Phycotoxin, HABs, Domoic acid, Red tides or Green tides

Abstract:

Phycotoxins are highly potent natural toxins produced by specific marine algae and cyanobacteria during Harmful Algal Blooms (HABs), which often appear as water discolorations known as "Red Tides" or "Green Tides." These toxins are classified based on their chemical structure, mode of action, target tissues, and biological effects on human health. They pose an ongoing threat to public health, marine ecosystems, and the economy, particularly through seafood contamination and water pollution. Managing their impact requires a multidisciplinary approach at both local and global levels. Historical cases highlight the severity of phycotoxin contamination. For instance, in 2015, a bloom of the toxigenic Pseudo-nitzschia species along the West Coast of North America led to domoic acid contamination in crabs and clams, prompting harvesting closures and consumer advisories from public health authorities. Similarly, in September 2016, elevated toxin levels resulted in the closu-

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Dr. Somnath Das, Dr. Jayanta Kumar Das, Dr. Mayur Doke, Dr. Vincent Avecilla (eds.), Life as Basic Science: An Overview and Prospects for the Future Volume: 3. ISBN: 978-81-978955-7-9; pp. 01-19; Published online: 30th November, 2024

re of razor clam and mussel harvesting along the Oregon coast. In another incident, massive cyanobacteria blooms in Florida led to drinking water bans in some areas due to contamination concerns. These events underscore the need for ongoing public health surveillance, environmental monitoring, and scientific research to mitigate risks associated with phycotoxins. Despite advancements in marine science, research on human exposure and long-term health consequences remains limited, even as toxigenic species blooms increase globally. Currently, diagnosis and management of phycotoxin poisoning rely heavily on clinical symptom interpretation, exposure history assessment, and identification of contamination sources. Several phycotoxins are neurotoxic, potentially fatal, or linked to chronic health effects. However, human intoxications often go misdiagnosed, underreported, or unrecognized by public health authorities, creating challenges for effective management and epidemiological tracking. To reduce risks, stronger regulatory frameworks, public health vigilance, and awareness among healthcare providers—especially in regions with frequent HAB occurrences—are crucial. However, certain populations face a higher risk of exposure, including recreational shellfish harvesters, anglers, children, and Indigenous coastal communities. Additionally, human poisoning incidents can arise globally due to the consumption of contaminated seafood, whether through travel or the importation of products from regions with insufficient food safety regulations and limited analytical testing. To address these challenges, continued research, improved diagnostic tools, and enhanced monitoring systems are essential for the early detection, prevention, and management of phycotoxin-related health risks.

Introduction:

Phycotoxins by Hurtful Algal Blooms (HABs) are an open well-being concern around the world, flare-ups persistently occur, geographic distribution changes and grows, and modern poisons are recognized, expanding the chance of human exposure and harmful events (Anderson et al., 2012; Tang et al., 2024; Stoner et al., 2024). Climate alters and natural contamination is variables embroiled in the appearance, geographic dispersion and recurrence of HABs and phycotoxins (Pulido, 2016). Topographical extensions of HABs, such as Pseudo-nitzschia species, known to synthesize domoic acid, continue to occur. HABs unfavorably affect the economy, nourishment, and water accessibility, locally and/or through trade, sports, amusement and tourism. A few later occasions depict the extent of HAB's natural contamination of aquatic biological systems and nourishment, as well as its effect on the economy and populace hazard in a few North American locales. HABs and phycotoxins are common natural contaminants of fresh, brackish and seawater, and include: i) Cyanobacteria blooms (CyanoHABs) toxins “cyanotoxins”, specially contaminants of soft water stores and drinking water, with direct risk to human wellbeing (Pírez et al., 2013; Raja et al., 2015; Grattan et al., 2016). ii)Marine biotoxins/marine algal toxins by dinoflagellates and diatoms can gather at high concentrations in different tissues of aquatic living beings such as bivalve molluscs and fish, entering the nourishment chain, and threatening consumer's wellbeing. Public health warnings are issued for particular blooms and poisons based on data collected on distinguished toxins, contamination levels of water or specific seafood items, depuration times, and regulatory levels for each product and toxin group. A viable case is the domoic acid contamination of crab and clams that occurred in California November 2015, which lead to a Consumer Caution by California Department of Public Health (CDPH), showing levels of domoic acid in crabs that exceed US federal safety limits of 20 parts per million (ppm) within the meat and 30 ppm within the viscera, with the most elevated level recorded of 190 ppm in a yellow rock crab within the Monterey locale.

The event provoked the closing of the year-round rock crab fishery and postponing the recreational and commercial Dungeness crab seasons (Pulido, 2016). Built-up regulatory parameters, monitoring, and framework capabilities permitted local preventive activities to minimize the risk of intense human exposure. Determination and treatment of intoxication are based on the history of exposure, identification of the contamination event, separation of the toxic compound and creation of organism at the source, displaying side effects related to each group of toxins. Emergency clinical management may help to anticipate serious complications, including death. Long-term disabilities may follow the intense event, e.g., amnesia and epilepsy seen during the domoic acid human harming event in Canada in 1987. Even though less is known about the harmful impacts induced by chronic, repeated exposure, some mycotoxins are carcinogenic or are connected to persistent degenerative neurologic disorders such as Amyotrophic Lateral Sclerosis (ALS). Human health impacts associated with the most common phycotoxins from HABs, cyanobacteria, and marine algae are summarized. Although not talked about here, information from household animals and wildlife intoxication has been key in the identification and follow-up of health impacts, intense and constant exposure in mammals, acting as sentinels for human health hazards, e.g. ocean lions and domoic acid. Experimental information helps to understand mechanisms of activity, distribution, target tissues, and biological effects and to set up rules, policies, and regulations. Anthropogenic activities, counting nutrient contamination, huge utilize of coastal regions, alteration in the dynamics of water streams, leakage of species through ships ballast waters, take part to the worldwide spread of HABs. The availability of detergents also may be a significant anthropogenic movement, and in the last decades, there has been an exponential increment in their utilization. Climate alter incorporates sea acidification, changes in temperature, stratification, and sections in nutrients induced by precipitation and light. Temperature is one of the most natural variables that influences the structure and composition of phytoplankton community (Ianora et al., 2011), global warming in truth acts on a few stages of development and improvement of the blooms, influencing germination, photosynthesis, supplement take-up and other physiological activities, supporting toxin production in HAB species. Poisoning through the ingestion of phycotoxin-contaminated seafood is the leading reported impact that HABs have on people (Figure 1). The poisoning preparation includes the bio-concentration of the phycotoxins by filter-feeding fauna

(generally bivalve molluscs, e.g., *Mytilus* spp.) which themselves are, for the most part, unaffected by these compounds. Other vectors incorporate certain marine gastropods (e.g. whelks and moon

snails), a few shellfish (e.g. crabs), echinoderms and fish (e.g., a few planktivorous fishes or belonging to the Tetraodontidae family) that obtain biotoxins through the nourishment web (Schroeder and Bates, 2015). Phycotoxins gathered in seafood tissues can stay for significant lengths of time after the bloom has declined in the seawater. Further, these biotoxins are not devastated by cooking or by the preparation of seafood products, and because they don't have particular scents or tastes, they can be identified only through specialized research facility testing.

A phycotoxin-producing organism, such as the dinoflagellates *Dinophysis acuta* or *Alexandrium catenella*, is bioaccumulated by shellfish, which are apparently not affected by saxitoxin or lipophilic biotoxins (Anderson et al., 2014; Bragg et al., 2015). Consumption of contaminated shellfish is a traditional way of diarrhetic or paralytic poisoning (DSP, PSP). Alternatively, some toxicogenic species attach to surfaces (macrophytes, corals) by an endogenous mucus (e.g., *Gambierdiscus, Ostreopsis, Prorocentrum lima*). Fragments of corals or macrophytes covered by the microalgae enter the food web through ingestion by herbivorous fish. This is the transmission mechanism of ciguatera fish poisoning (CFP). Certain fish can also experience some sort of poisoning (Mattei Mattei et al., 2014).

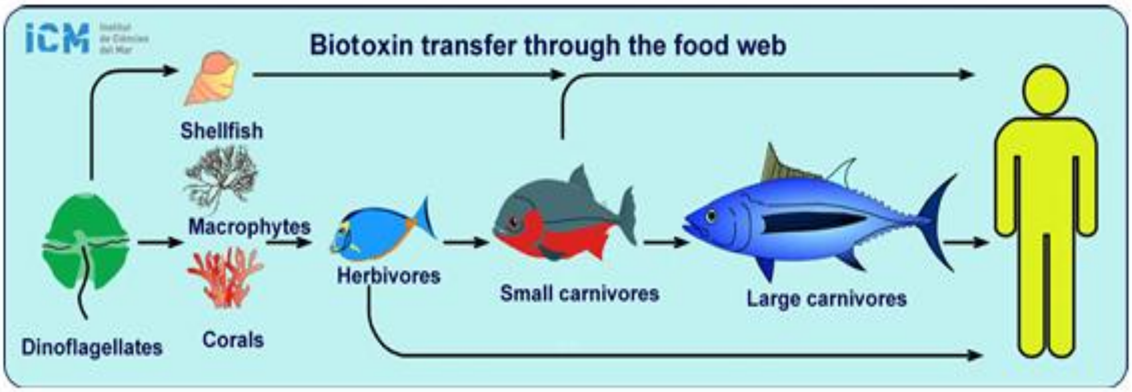

Figure 1: Phycotoxin transfer pathways through the marine food web to humans (Berdalet et al., 2015) [Source: https://doi.org/10.1017/S0025315415001733].

Effects of Phycotoxin on human health:

In mammals, antagonistic health impacts associated with phycotoxins and HABs can happen through verbal, respiratory or dermal exposure to the toxins, their metabolites, or their creating organisms in aquatic or earthbound environments. For people, the most elevated dangers are: (1) Ingestion of seafood contaminated with toxins created by diatoms and dinoflagellates and respiratory exposure through mist concentrates. (2) Exposure to soft water contaminated with cyanotoxins (Ferrão-Filho & Kozlowsky-Suzuki, 2011; Drobac et al., 2013; Farrer et al., 2015) through drinking water, freshwater fish, dermal exposure, e.g., washing in contaminated lakes, or through contaminated equipment or liquids. The poisonous effects of cyanotoxins and marine algal toxins are depicted in people, the mechanism of activity, displaying side effects, clinical disorders and forecast (Koreivienė et al., 2014; Hardy et al., 2015).

Most of the data available deals with acute exposure and effects. A few toxins are neurotoxic and can be deadly, but with appropriate clinical administration, some may completely recover. Marine algal toxins are recognized as contaminants of aquatic environments, with destructive natural impacts but without recognized unfavorable health impacts in humans.

Table 1: Cyanotoxins Biological and Human Health Effects.

Cytotoxins	Mechanism	Symptoms	Source	Prognosis
Hepatotoxins				
Cylindrospermopsin (CYN) (Kinnear, 2010; Weirich & Miller, 2013; Méjean & Ploux, 2021)	Inhibition of Protein Synthesis, ribosomal protein synthesis by interfering with RNA and DNA transcription. The inhibition is irreversible, causing delayed cytotoxic effects.	Symptoms up to several days' after exposure or later. Gastroenteritis abdominal pain, vomiting, bloody diarrhea, acute liver inflammation. Liver and kidney failure, hay fever, asthma	Cyanobacteria species such as *Cylindrospermopsis raciborskii*, *Aphanizomenon ovalisporum*, and *Raphidiopsis curvata*.	Chronic exposure linked to cancer e.g., colon
Microcystin MCs	Inhibition of Protein Phosphatases (PP1 & PP2A) Microcystins trigger ROS production	Nausea, vomiting, diarrhea, jaundice, liver failure. Hepatic fibrosis, cirrhosis, increased risk of liver cancer.	cyanobacteria (blue-green algae), primarily *Microcystis*, *Anabaena*, *Planktothrix*, and *Nostoc* species.	Can be lethal. Exposure: drinking water, contaminated dialysis fluid, soft water recreational environments (Azevedo et al., 2002; Banack et al., 2015)
Nodularin (Chen et al., 2013; Brezeștean et al., 2022)	Inhibition of Protein Phosphatases (PP1 & PP2A), Cytoskeletal Disruption & Hepatocyte damage	Diarrhea, vomiting, goose bumps, weakness, liver hemorrhage	Cyanobacteria, primarily *Nodularia spumigena*	_
Neurotoxins				
Anatoxin-a /Homoanatoxin-a (Méjean et al., 2014; Colas et al., 2021)	Agonist at Nicotinic Acetylcholine Receptors (nAChRs).	Muscle twitching, cramping staggering, paralysis, convulsions,	Cyanobacteria species such as *Anabaena*, *Planktothrix*, and *Aphanizomenon*.	Can be lethal

	Persistent Nerve Stimulation (Depolarizing Blockade)	gasping, respiratory failure, death by suffocation		
Cytotoxins	**Mechanism**	**Symptoms**	**Source**	**Prognosis**
beta-Methylamino-L-alanine (BMAA) (Yan et al., 2020)	Excitotoxicity via Glutamate Receptors Incorporation into Proteins (Misfolding & Aggregation). Oxidative Stress & Mitochondrial Damage	Amyotrophic Lateral Sclerosis (ALS), Parkinson's Disease (PD), and Alzheimer's Disease (AD).	cyanobacteria such as *Nostoc*, *Anabaena*, and *Microcystis*.	Chronic exposure linked to chronic neurodegenerative conditions:Amyotrophic Lateral Sclerosis
Saxitoxins (STXs) (Gad & Gad, 2004; Jeon et al., 2024; Pinto et al., 2024)	Voltage-Gated Sodium Channel (NaV) Blockade. Reversible and Highly Potent Blocker	Paralytic Shellfish Poison: Nausea, vomiting. peri-oral burning ataxia, drowsiness, paraesthesia, fever, tachycardia, muscular paralysis, respiratory failure, death	freshwater cyanobacteria *Aphanizomenon*, *Dolichospermu*, *Lyngbya*.	Death can occur within 2-12 hours after exposure. Good prognosis after 24hr, requiring good medical support system.
Irritants and Dermatotoxins				
Aplysiatoxins (Cho, 2006; Nagai et al., 2019)	Uncontrolled cell proliferation. Tumor Promotion & Carcinogenesis	Skin irritation, asthma like symptoms	marine cyanobacteria such as *Lyngbya* and *Trichodesmium*	_
Lyngbyatoxin (Weirich & Miller, 2013; Biessy et al., 2024)	Excessive cell growth (hyperplasia). Increased Intracellular Calcium (Ca^{2+}) Levels	Smooth muscle contraction. Skin irritation	marine cyanobacterium *Lyngbya majuscula*	_

Table 2a: Marine Algal Toxins Diatom and Dinoflagellates: Biological and Human Health Effects.

Toxin group	Vector	Mechanism	Symptom	Syndrome	source
Azaspiracids (AZAs) (Twiner et al., 2012; Yang et al., 2024)	Shellfish Bivalves Mollusks	Cytoskeletal Disruption & Cell Death. Alteration of Ion Channels & Cellular Signaling	Food: Nausea, vomiting diarrhea, abdominal pain. Similar to DSP	Azaspiracids Poisoning (AZP)	Dinoflagellate *Azadinium spinosum*
Brevetoxins (BTX / PbTX) (Katwa & Brown, 2014)	Shellfish Bivalves Mollusks	Persistent Activation of Voltage-Gated Sodium Channels (NaV). Cardiovascular & Gastrointestinal Toxicity	Food: nausea, vomiting, diarrhea, paresthesia, cramps, bronchoconstriction, paralysis, seizures and coma Aerosol inhalation: Rhinorrhea Asthma-like symptoms	Neurotoxic Shellfish Poisoning (NSP) (Hurley et al., 2014)	Marine dinoflagellate *Karenia brevis*
Ciguatoxins (CTXs): Pacific (P-CTX), Caribbean (C-CTX), and Indian Ocean (I-CTX)	Tropical and sub-tropical fish e.g.:eels, snappers, groupers, mackerels, jacks or barracudas	Neurotoxic: Opens sodium channels by binding site. Influx of Na, provoke action potentials, cell swell, and blebs on cell's surface	Food: Vomiting, diarrhea, nausea, tingling, itching hypotension bradycardia arthralgia, myalgia hyporeflexia, dysphagia, ataxia paralysis	Ciguatera Fish Poisoning (CFP) Severity and type of symptoms varies with the type of CTX (Friedman et al., 2008; Brett & Murnion, 2015)	Marine dinoflagellate *Gambierdiscus spp.*

Toxin group	Vector	Mechanism	Symptom	Syndrome	source
Domoic acid group (Bates, 2016)	Shellfish Mollusks Crustaceans Fish (Mazzillo et al., 2010)	Cardiotoxic: Excitatory neurotoxin, analogue of glutamate – acts through glutamate receptors.	Vomiting, diarrhea arrhythmia cardiovascular collapse. Confusion, memory loss, seizure, coma, death	Amnesic Shellfish Poisoning (ASP)	marine diatoms of the genus *Pseudo-nitzschia*
Okadaic acid (OA) and dynophysistoxins (DTXs) (Corriere et al., 2021)	Shellfish Bivalve Mollusks	Inhibit protein phosphatases 1 (PP1) and 2A (PP2A). Increased intestinal fluid secretion (diarrhea)	Severe diarrhea, nausea, and abdominal pain.	Diarrheic Shellfish Poisoning (DSP)	dinoflagellates *Dinophysis spp.* and *Prorocentrum spp.*.
Palytoxins (PlTXs) and PlTX like compounds (Wieringa et al., 2014)	Shellfish Bivalve Mollusks, Crab, Fish e.g. Sardines Anchovies	Disrupt cellular ion homeostasis, leading to severe cardiovascular, muscular, and neurological effects	Nausea, vomiting fever rhabdomyolysis, vasoconstriction heart and renal failure, delayed haemolysis Rhinorrhea, cough bronchoconstriction	Haff Disease	Dinoflagellates *Ostreopsis spp.*

Table 2b: Marine Algal Toxins by Diatoms and Dinoflagellates without Known Human Health Effects.

Toxin Group	Vector	Mechanism	Source
Cyclic imines Spirolides(SPXs), gymnodimines (GYMs), pinnatoxins (PnTXs) pteriatoxins (PtTXs)	Shellfish Bivalves Mollusks	Experimental data: Neurotoxic. Fast acting Experimental in rodents parenteral toxicity more potent than oral	Dinoflagellate *like Alexandrium ostenfeldii*, *Karenia selliformis*

(Otero et al., 2011)			
Pectenotoxins (PTXs)	Shellfish Bivalves Mollusks	Disruption of Actin Cytoskeleton. Inhibition of Phosphorylation Pathways	*Dinophysis* species (dinoflagellates)
Yessotoxins (YTXs) (Tubaro et al., 2014; Alfonso et al., 2016)	Shellfish	Disruption of Calcium Homeostasis. Decrease cyclic AMP, activate cellular phosphodiesterases (PDEs)	Dinoflagellates

Cyanotoxin impacts on human health:

Cyanotoxins are secondary metabolites produced by cyanobacteria that pose toxic threats to various living organisms, including humans (Ibelings et al., 2014; Paerl, 2014). These toxins are classified into distinct chemical groups based on their structure and composition, including: Cyclic peptides: Microcystins and nodularins (Chen et al., 2013), Alkaloids: Anatoxin-a, anatoxin-a(s), saxitoxins, cylindrospermopsin, aplysiatoxin, lyngbiatoxin-a, Lipopolysaccharides (LPSs). Cyanotoxins can also be categorized based on their physiological effects and target tissues: Hepatotoxins: Affect the liver, Neurotoxins: Target the nervous system, Cytotoxins: Cause cellular damage, Dermatoxins: Affect the skin, Irritant toxins: Cause inflammatory responses. Among the neurotoxic cyanotoxins, key compounds include anatoxin-a, homoanatoxin-a, and β-Methylamino-L-alanine (BMAA). Chronic and repeated exposure to BMAA has been linked to neurodegenerative disorders such as Amyotrophic Lateral Sclerosis (ALS). The harmful effects of BMAA have been extensively studied in relation to dietary exposure from the seeds of *Cycas circinalis*, a plant traditionally consumed by the indigenous populations of Guam Island. More recently, the presence of BMAA has also been identified in certain species of diatoms (Jiang et al., 2014), broadening concerns regarding its potential environmental and health impacts. Harmful cyanobacteria, particularly those capable of forming dense blooms, pose a growing global threat to aquatic ecosystems. Their proliferation is primarily driven by anthropogenic nutrient enrichment—such as agricultural runoff, wastewater discharge, and industrial pollution—alongside the accelerating effects of climate change. These environmental stressors have led to the frequent occurrence of toxic cyanobacterial blooms in freshwater bodies, including lakes, reservoirs, and soft-water systems worldwide (Glibert et al., 2014; Brooks et al., 2016). The toxins released by these microorganisms can severely disrupt biodiversity, destabilizing aquatic ecosystems and posing significant risks to both wildlife and human health. Despite their harmful effects, certain cyanotoxins exhibit bioactive properties that hold promise for pharmaceutical and biotechnological applications (Zanchett and Oliveira-Filho, 2013). Some of these compounds have demonstrated potential as:

- Antimicrobial agents – Compounds that can inhibit or destroy harmful bacteria and other pathogens.

- Algaecides – Substances that suppress the growth of undesirable algal species.
- Cytotoxic agents – Compounds capable of targeting and eliminating malignant cells.
- Immunosuppressive agents – Substances that can modulate immune responses, which may be beneficial in conditions such as autoimmune disorders and organ transplant procedures.
- Enzyme inhibitors – Molecules that interfere with enzymatic processes, which can be exploited for therapeutic interventions.

Certain cyanotoxins have shown potential for anticancer applications, particularly those that act as protease inhibitors and cell cycle regulators. One notable example is Curacin A, a compound derived from marine cyanobacteria that has been investigated for suppressing tumour growth by interfering with microtubule dynamics, a key mechanism in cancer cell proliferation (Carmichael & Boyer, 2016).

Marine Algal Toxins cause Seafood Poisoning Syndromes:

Marine algal toxins, primarily produced by dinoflagellates and diatoms, are potent compounds that contaminate seawater ecosystems. These toxins accumulate in the tissues of aquatic organisms, particularly bivalve mollusks (e.g., mussels, oysters, clams, cockles, and scallops), as well as shellfish and fish, ultimately entering the food chain. As filter feeders, bivalve mollusks can concentrate both chemical and microbiological contaminants, making them a significant vector for seafood poisoning. The consumption of contaminated fish and shellfish remains one of the leading causes of marine toxin-related illnesses worldwide. Marine algal toxins pose serious threats to human health, marine wildlife, economies, and ecosystems. To mitigate these risks, international regulations and safety standards have been established to ensure seafood quality, particularly given its role as a major globally traded commodity. However, limited resources and analytical capabilities in developing nations hinder the effective detection of mycotoxins, potentially masking severe environmental health concerns and seafood safety issues.

Table 2 outlines the major clinical conditions associated with marine algal toxins produced by dinoflagellates and diatoms. These toxins can cause illness through ingestion of contaminated seafood, inhalation of aerosolized toxins, or direct skin and eye contact. The most well-documented marine toxin-related seafood poisoning syndromes include: Diarrheic Shellfish Poisoning (DSP), Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP), Neurotoxic Shellfish Poisoning (NSP), Azaspir acid Shellfish Poisoning (AZP), Ciguatera Fish Poisoning (CFP). Additionally, Palytoxin (PlTX)-related disorders include: Palytoxicosis, Clupeotoxism, PlTX-like Myotoxic Syndrome (Haff Disease) – Characterized by severe muscle pain (myalgia), muscle breakdown (rhabdomyolysis), and dark urine (myoglobinuria) following the consumption of cooked freshwater or brackish water fish. Unlike other PlTX toxicities, Haff Disease is primarily myotoxic rather than neurotoxic. There is growing public health concern regarding PlTX poisonings from inhalation, skin contact, and eye exposure, particularly during the handling of contaminated soft corals in aquariums (Pelin et al., 2016).

Medical Management of Phycotoxins:

Currently, the diagnosis of phycotoxin poisoning primarily relies on a combination of clinical symptomatology and exposure history. Medical professionals assess whether an individual has consumed contaminated food or water, and they often attempt to identify the presence of toxins in these sources. Additionally, an estimation of the quantity of contaminated food or water ingested is conducted to determine the potential toxin exposure level. From an epidemiological perspective, phycotoxin poisoning is commonly documented through reports of acute poisoning incidents, outbreaks related to the consumption of contaminated seafood, and cases linked to exposure in affected oceanic environments. However, mild cases may go undiagnosed as individuals might not seek medical attention, either due to the transient nature of their symptoms or the lack of awareness regarding phycotoxin-related illnesses. Furthermore, respiratory and skin reactions caused by phycotoxins can often be misinterpreted as allergic responses, leading to potential underreporting or misdiagnosis.

Poisoning symptoms resulting from the consumption of phycotoxin-contaminated seafood can manifest within minutes to several days after ingestion (Picot et al., 2012). These toxic effects can arise from the consumption of various seafood products, including fish and shellfish—whether freshwater or marine, cooked or raw, locally sourced or imported. The risk of exposure is not limited to any specific geographic region, as poisoning may occur both during travel to endemic areas and after returning home. Public health surveillance plays a crucial role in monitoring and managing phycotoxin-related illnesses. The assessment of the population's dietary habits, recreational activities, and cultural seafood consumption practices is essential for identifying at-risk groups (Diaz, 2015). Individuals at heightened risk of exposure due to social and occupational practices include recreational shellfish harvesters, fishermen, and Indigenous communities residing in coastal regions, where seafood forms a significant part of their diet. Multiple factors, including age, pre-existing medical conditions such as renal insufficiency, and the quantity and type of contaminated seafood consumed, influence the severity of intoxication. Public health management of outbreaks requires a thorough investigation into the source of contamination. This involves examining food samples to identify specific toxins, which is critical in determining the extent of an outbreak and implementing necessary control measures. Despite the diversity of phycotoxins, each possessing distinct mechanisms of action, clinical manifestations, and prognostic implications, acute poisoning due to neurotoxic phycotoxins commonly affects multiple organ systems. These include the gastrointestinal (GI), cardiovascular, respiratory, and nervous systems. Gastrointestinal symptoms generally appear first, while neurological manifestations may be delayed, emerging minutes to days after exposure. The severity and frequency of symptoms often escalate over time, particularly in the hours following the consumption of contaminated seafood. Timely reporting of suspected poisoning cases to public health authorities is vital for tracking outbreak events, facilitating epidemiological investigations, and maintaining a comprehensive database for future reference. Even mild cases should be documented to ensure a more accurate assessment of the public health burden. Currently, there are no specific biomarkers available to confirm the diagnosis of phycotoxin poisoning or to definitively detect exposure. However, some laboratory tests may provide supportive evidence. For instance, in cases of Haff Disease, which is associated with a PITX-like myotoxic compound, urine tests measuring myoglobin levels can assist in diagnosis. Similarly, certain experimental assays for detecting saxitoxins (STXs) in urine exist, though they require further validation and standardization. In cases of acute poisoning, emergency medical management should be well-coordinated and tailored to the patient's clinical presentation. While mycotoxins are not explicitly included in standard toxicological guidelines, general supportive care principles, as outlined by Thompson et al. (2014), remain applicable. Treatment for phycotoxin poisoning is largely symptomatic and supportive, as no specific antidotes are currently available. Management strategies vary depending on the toxin group and its mechanism of action. For example, in cases of suspected domoic acid intoxication **(**Kirkley et al., 2014), antiepileptic medications and drugs that modulate glutamate receptors may be used to manage seizures and neurotoxicity (Boushey et al., 2016). In saxitoxin (STX) poisoning**,** respiratory support is often required due to its paralytic effects. Given the serious and potentially fatal nature of phycotoxin poisoning, early recognition and prompt intervention are essential to improving patient outcomes. Ongoing research and improvements in diagnostic methodologies are necessary to enhance the detection, treatment, and prevention of these toxin-related illnesses.

Limited information is currently available regarding the long-term effects of repeated exposure to neurotoxic phycotoxins or their combinations. However, the potential developmental toxicity of domoic acid and its association with epilepsy warrant significant attention due to their implications for public health. Emerging evidence suggests that domoic acid exposure may be a preventable risk factor for epilepsy and neurobehavioral disorders. Rapidly accumulating data from experimental research, wildlife poisoning incidents, and studies on chronic exposure support a causal relationship between prolonged domoic acid exposure and neurological consequences. Furthermore, laboratory studies have demonstrated that domoic acid can cross the placenta during pregnancy and may also be present in breast milk, posing potential risks to developing fetuses and nursing infants. Raising consumer awareness is crucial, particularly for pregnant and lactating women, who may be more vulnerable to the effects of phycotoxin exposure. This is especially important during contamination outbreaks, as seen in recently reported cases. To better understand and mitigate these risks, dietary assessments should be conducted to estimate exposure levels and guide public health recommendations.

Prevention of Human Phycotoxins Exposure:

The primary strategies for managing the risks associated with mycotoxins include prevention, achieved through regulatory policies and monitoring systems and early warning mechanisms issued by public health organizations to minimize the occurrence of human poisoning incidents. The most effective way to prevent poisoning is to avoid consuming non-commercially harvested shellfish that have not been tested for phycotoxins (Knaack et al., 2016). However, cultural and traditional dietary practices, such as recreational shellfish picking, may increase the likelihood of exposure. Travellers visiting regions with limited food safety regulations are also at risk and may experience symptoms of intoxication upon returning home. Raising awareness about environmental conditions and systematically documenting HAB events are essential for preventive management and the development of predictive models. Detailed clinical records, including dietary history, symptom progression, and timely reporting to public health authorities, are critical for accurate diagnosis, outbreak tracking, and effective risk management.

Conclusion:

Phycotoxins and their associated health effects represent a significant global public health concern, necessitating increased awareness and proactive management strategies. This summary highlights the most common poisoning syndromes caused by these marine biotoxins and underscores the importance of enhanced awareness among healthcare professionals and consumers (Lawrence et al., 2011; Paredes et al., 2011). Improved knowledge and vigilance will lead to more effective clinical management, better case reporting, and the expansion of epidemiological databases, all of which are crucial for tracking and mitigating the impact of these toxins. However, addressing the full scope of human health risks posed by phycotoxins requires a multidisciplinary, international effort. A comprehensive understanding of their effects involves detailed exposure assessments, including data on seafood consumption patterns and contamination levels in marine and freshwater environments. Each phycotoxin group presents distinct characteristics that must be studied in-depth, such as the specific organisms responsible for toxin production, the vectors through which they enter the food chain, their toxicological properties (including toxicokinetics), biological effects, associated clinical symptoms, and overall prognosis following exposure. While acute poisoning syndromes have been well documented, the long-term effects of chronic, low-dose exposure remain poorly understood. Identifying and validating biomarkers for phycotoxin exposure is critical for advancing the diagnosis, detection, and monitoring of human health risks. The development of such biomarkers would significantly enhance disease surveillance, improve epidemiological tracking, and allow for more precise risk assessments. Certain vulnerable populations require special attention due to their heightened risk of exposure and potential long-term health consequences. These include Indigenous Arctic communities and Native American populations along the American West Coast, whose traditional diets heavily rely on seafood, as well as pregnant women, nursing infants, and individuals with pre-existing health conditions. Emerging research suggests that chronic exposure to certain phycotoxins may be linked to serious health conditions such as cancer, neurodegenerative diseases, and developmental disorders, further emphasizing the need for targeted surveillance and risk reduction strategies. In addition to preventive measures, there is an urgent need to develop effective antidotes for phycotoxins with potentially fatal effects. This remains a major scientific and medical challenge, requiring further investment in research and innovation. Until specific treatments are available, public health efforts must focus on prevention, early detection, and symptomatic management to minimize the impact of phycotoxin-related illnesses. Moving forward, international collaboration, advancements in diagnostic tools, and continuous public health monitoring will be essential in protecting populations from the risks associated with phycotoxin exposure. Through a coordinated and evidence-based approach, the global community can work toward reducing the burden of these marine toxins and safeguarding human health.

Conflict of interest:

The authors state that they do not have any competing interests.

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HOW TO CITE

Debkumar Sahoo, Santosh Kumar Bera, Prabad Pratim Pal, Dipak Kumar Tamili, Nithar Ranjan Madhu and Sudipta Kumar Ghorai (2024). Phycotoxins produced by Harmful Algal Blooms (HABs) and their role in human poisoning: A review. © International Academic Publishing House (IAPH), Dr. Somnath Das, Dr. Jayanta Kumar Das, Dr. Mayur Doke and Dr. Vincent Avecilla (eds.), *Life as Basic Science: An Overview and Prospects for the Future Volume: 3*, pp. 01-19. ISBN: 978-81-978955-7-9 doi: https://doi.org/10.52756/lbsopf.2024.e03.001