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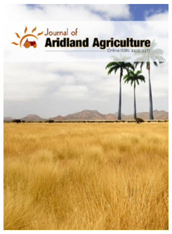

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Problems and use of cyanobacteria for environmental improvement – A Review

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ABSTRACT

Cyanobacteria were considered harmful to other living organisms, due to their microcystin content. In addition, uncontrolled populations of cyanobacteria, also known as algal blooms, occur both naturally and as a result of human activity, leading to the development of more complex problems. These microorganisms are currently receiving a lot of attention, as several investigations have considered successful applications of reducing exposure to nature, causing reduced risks to ecosystems, and providing benefits to human life. This study aims to provide answers to current problems, by providing a different perspective on cyanobacteria. Furthermore, it is for the benefits of cyanobacteria for the environment in accordance with the recommendations in some of the literature on previous research results.

KEY WORDS: Cyanobacteria, algae bloom, microcystin, harmful, utilization

INTRODUCTION

Cyanobacterial harmful algae blooms have been recognized as a problem worldwide, resulting from the inherent detrimental effects, although the presence in the ecosystem is not widely recognized. Cyanobacteria, also known as blue-green algae (N. A. Herrera *et al.*, 2015) are a group of bacteria characterized by numerous structural features (El Gamal, 2010). These microorganisms are autotrophic, which are primary producers in aquatic systems, hence categorized as algae (Picardo *et al.*, 2019). Also, due to the chlorophyll a content and the presence of related compounds (El Gamal, 2010), cyanobacteria are able to perform photosynthesis, which is a process that provides the primary source of energy for most forms of life on Earth (Axmann *et al.*, 2014; Bortoli *et al.*, 2014; Kimambo *et al.*, 2019). Furthermore, they are also highly adaptive, with the capacity to grow autotrophically (Picardo *et al.*, 2019), heterotrophically (Atteia *et al.*, 2013), or mixotrophically (Subashchandrabose *et al.*, 2013).

Morphologically, blue-green algae have been identified in diverse forms, including filamentous (Kurmayer *et al.*, 2016), unicellular (Atteia *et al.*, 2013), colony as well as multicellular, and they are taxonomically grouped under prokaryotes (Bortoli *et al.*, 2014). These microorganisms are considered as gram-negative, despite the demonstration of both gram-negative and gram-positive properties using electron microscopy.

Some strains have very rich chemistry and are capable of producing a wide range of bioactive compounds with varying properties (El Gamal, 2010; Picardo *et al.*, 2019), of which some are beneficial and have been applied in many valuable products (Axmann *et al.*, 2014). Meanwhile, other forms yield a variety of toxic and possibly harmful compounds, in the form of secondary metabolites, termed cyanotoxins, attributed as one of the most important groups of natural toxins (Picardo *et al.*, 2019; Kimambo *et al.*, 2019; EPA, 2015a; Griffith & Gobler, 2020). Therefore it is necessary to establish microcystin exposure pathways, which summarize several studies on the dangers, to enhance the ease of understanding.

The complete characterization of cyanobacteria is the main study here, which is related to its presence in aquatic ecosystems; knowledge obtained from exposure pathways to microcystin; direct effects of toxins on human health; danger of low dose exposure for the ecosystem; the safety of food and food supplements made from cyanobacteria, given the tendency to accumulate in plants and animals; the best use of microcystin; and the use of cyanobacteria as processing and/or remediation of polluted environments. It is all based on recommendations from the previous research literature.

ALGAL BLOOM

Environmental Factors

The continuous aging of water bodies has been attributed to natural and anthropogenic activities (Martins *et al.*, 2017;

Sinha *et al.*, 2018). This also affiliated with alteration in land-use practices, urbanization, and agricultural activities, which tend to change the sediment loading, as well as increase nutrient delivery in watersheds. Finally, great changes are experienced due to eutrophication (Herrera *et al.*, 2015; Janssen *et al.*, 2014), and climate change (Aguilera *et al.*, 2018). This eutrophication is considered to pose serious threats 16, and known to influence the growth of cyanobacterial (Clark *et al.*, 2017), which consequently forms the algal bloom (Merel *et al.*, 2013; Song *et al.*, 2009; Wilkinson *et al.*, 2020) that defined as the rapid and uncontrolled growth of algae (Bennett, 2017).

This algal bloom is strongly influenced by environmental conditions, including temperature (Dreher *et al.*, 2019; EPA, 2015a; EPA, 2015b; Scavia *et al.*, 2014; Song *et al.*, 2009), light Intensity, pH, salinity, dissolved oxygen (Griffith & Gobler, 2020; Scavia *et al.*, 2014), changes in species diversity (Ritson *et al.*, 2014), turbulence nutrients, e.g., nitrogen (Gobler *et al.*, 2007), phosphate (D'Angelo & Wiedenmann, 2014) and carbon (Merel *et al.*, 2013), as well as competing/grazing of bacteria and phytoplankton (Gobler *et al.*, 2007; Ramanan *et al.*, 2016). The affected ecosystems are often characterized by the presence of cyanotoxins (Janssen, 2019).

Presence and Movement

Currently, many people assume the growth of cyanobacteria is constrained to aquatic ecosystems. Cyanobacterial blooms have increased in frequency worldwide within the last decades, posing a threat to water supplies and recreational areas (Aguilera *et al.*, 2018; Janssen *et al.*, 2019; Picardo *et al.*, 2019). These microorganisms are produced in most aquatic ecosystems, including lakes (Scavia *et al.*, 2014; Zhang *et al.*, 2012), reservoirs (Takahashi *et al.*, 2014), ponds (Clark *et al.*, 2017), lagoon (Paldavičiene *et al.*, 2015), rivers (Picardo *et al.*, 2019), estuarine (Preece *et al.*, 2017), bay (Estepp & Reavie, 2015), and oceans (Bennett, 2017). However, research has proved cyanobacteria adaptability to a wide range of habitats, there in water, soil, air, corals (Rädecker *et al.*, 2015), and also in the chips for laboratory-scale research with the addition of nutrients resembling the natural conditions (Girault *et al.*, 2019). There is growth potential in areas with very low water content, arid environments, alongside tolerability to high salinity, as seen in hypersaline ponds (Subashchandrabose *et al.*, 2013).

Several factors have a significant impact on the presence of cyanobacteria in air, providing information on the emission effectiveness, transport, and deposition (Wiśniewska *et al.*, 2019). These microorganisms also have the capacity to moving along the water column (Wilkinson *et al.*, 2020), and precipitate out, after residing in the sediments for months, and even years, at a concentration of approximately one order of magnitude higher than the value recorded for surface water (Takahashi *et al.*, 2014).

MICROCYSTIN

Classes

There are four classes of cyanotoxins with a high impact on drinking water, encompassing microcystin, cylindrospermopsin, anatoxin, and saxitoxin (He *et al.*, 2016). In addition, cyanobacteria produces an incredible diversity of peptides and other compounds (Miles *et al.*, 2013), although only microcystin has been intensively studied. This consists of over 80 variants (Kist *et al.*, 2012) with 100 different congeners 10, of which microcystin–LR (MC-LR) stands out for the high distribution and toxicity (Martins *et al.*, 2017), followed by MC-YR, MC-LA, MC-YM and MC-RR 1. Furthermore, MC-LR has a provisional limit of 1 mg/L, based on the recommendation of World Health Organization (WHO) (Tsagkaris *et al.*, 2019), although all are considered as toxins (Kist *et al.*, 2012; Weng *et al.*, 2019) due to the possibility of poisoning in humans and animals as well as plants (Fontanillo & Köhn, 2018).

Photolysis and Hydrolysis

Cyanobacteria are phototrophic microorganisms (Merel *et al.*, 2013). The microcystin reported undergoes a slow photochemical breakdown in the presence of full sunlight. This the reason for the low vulnerability of groundwater to form algae compared with surface waters, for the deeper sources are characterized by a slower rate of a possible breakdown. The process velocity is depending on the pigment concentrations, light intensity, humic substances, and microcystin congener. Moreover, cyanobacteria exhibit a strong resistance for the extreme habitats, as a study shows the survivability of cyanobacteria in the outer space, and also under UV radiation within 548 days (Ramanan *et al.*, 2016).

Some cells are capable of migrating to the marine environment, lyse, and further release toxin into the water (Gibble & Kudela, 2014). Most toxins are intracellular, which is discharged following the rupture or death of the cell, while the extracellular forms comprise less than 30% of the total microcystin concentration in the source water. Conversely, both varieties are possibly present in treated water, depending on the handling processes. Microcystin is reported as relatively stable and resistant to chemical hydrolysis or oxidation at near-neutral pH, while higher or low pH values and temperatures above 30°C have been affiliated with slow hydrolysis.

Metabolism

Microcystin conjugates with glutathione and cysteine to increase solubility and facilitate excretion. Moreover, several studies have investigated the role of glutathione homeostasis and lipid peroxidation in microcystin-induced liver toxicity. However, as the potential risk of numerous cyanobacterial metabolites remains unknown. These processes are versatile, featuring rapid switching between modes (Subashchandrabose *et al.*, 2013). Some scientists have affiliated the removal of microcystin to the incidence of biodegradation, as some bacteria have been reported capable of decomposing MC-LR. These include

Arthrobacter, Brevibacterium, Rhodococcus, Paucibacter, Sphingomonas (Pseudomonas).

Sources and Pathways

Microcystin-RR identified in most soils (Xiang *et al.*, 2019), which is introduced through contacts with land plants by agriculture activities, especially along with contaminated irrigation water sources (Cao *et al.*, 2018). This has led to high land invasion (Gibble & Kudela, 2014), characterized by the occurrence of microalgae on buildings, trees or roofs (Wiśniewska *et al.*, 2019).

Furthermore, microcystin also can spread into the surrounding environment (Takahashi *et al.*, 2014), especially for the aerosolized cyanobacteria, which is passively transported through the air. The vitality of these organisms depends on adaptation and the ability to react actively to the changing environmental conditions (resilience) (Fröhlich-Nowoisky *et al.*, 2016). Also, cyanobacteria are mainly emitted into the atmosphere from water surfaces, and soil (Wiśniewska *et al.*, 2019).

Exposure to cyanotoxins occurs through absorption, dermal, respiratory/inhalation, and hemodialysis/intravenous, while some research concluded oral/ingestion of contaminated drinkable water and food as the main source. These possibly lead to acute or chronic toxicity in humans and animals (Picardo *et al.*, 2019), while the use of Microcystin-contaminated irrigation water was identified as the dominant pathway of accumulation in vegetables and soils.

Facilitated transport is necessary for uptake of Microcystin into organs and tissues, as well as for export. Several studies have produced information on the possible distribution through the digestive, respiratory and circulatory tracts. Microcystin was also detected in the villi of the small intestine, blood plasma, liver, lungs, kidneys, gill tissue, ileum, heart, large intestine, and spleen. The toxin is capable of inducing damage to distribution tissues, including vascular structures and gills (Martins *et al.*, 2017). While in plants, based on the study conducted on rice plants, the greatest concentrations of microcystin was recognized in the leaves, following a process translocation from the roots (Cao *et al.*, 2018).

Bioaccumulation

This process is possibly affected by various factors, including the exposure route, duration, and concentration of Microcystin in their food resources (Dong *et al.*, 2012), as well as bioaccumulation capacity and incomplete depuration after contact (Paldavičiene *et al.*, 2015). The toxin accumulates on the seafloor (Takahashi *et al.*, 2014), in snail (J. Zhang *et al.*, 2012), in fish tissues (Dong *et al.*, 2012), in various mammal organs, including muscle, liver, kidney, heart, lung, spleen, gastrointestinal tract and gonads, consequently leading to potential damage. Microcystin also affects vegetables and soils (Xiang *et al.*, 2019), rice (Cao *et al.*, 2018), cereals, corn, peanuts, soybeans, and spices, among others during maturation, storage, and transportation (Picardo *et al.*, 2019). This toxin biomagnifies and persists in the medium of co-occurrence, and poses a large potential ecological risk within the food chains (Gibble & Kudela, 2014; Z. Wang *et al.*, 2017). Furthermore, cyanotoxin persistence after agricultural land applications require urgent attention (Quilliam *et al.*, 2015).

Microcystin is potentially risky to life and the environment, and the following considerations were reported in some studies:

1) Death (Vasconcelos *et al.*, 2013), which occurred to the steers (Dreher *et al.*, 2019) and the freshwater terrapin species (Nasri *et al.*, 2008).
2) Genotoxicity effect, where continuous exposure to low concentrations of purified microcystic extracts, activates cellular oxidative stress, subsequently causing genotoxicity and other mutagenic action.
3) Damage to organs and tissues has been observed in the immune and brain cells of mammals (Takser *et al.*, 2016), cardiac, lung, intestine and spleen of mice (Al-hazmi, 2020), male reproductive system (testis) (Lone *et al.*, 2015), and also the antioxidant enzymes in fish; in the order of liver > gill > muscle (Isibor, 2017).
4) Growth reduction was reported in plants exposed to microcystin, which significantly decreased root growth and activity, featuring induced lipid peroxidation, and also a decline in the crown and lateral root number (Cao *et al.*, 2018). While in yellow catfish experienced a significant reduction in growth rate after 30 days of dietary exposure (Dong *et al.*, 2012).

A study established the poor tendency from low-dose exposure to Microcystin-LR administered over long-term to cause chronic liver disease in normal liver, or exacerbate existing hepatitis (Labine *et al.*, 2017). Conversely, there were different opinions on the sufficiency for low concentrations present in the environment to promote severe damage in organisms (Pamplona-Silva *et al.*, 2018). This study, therefore, affiliates the health risks with the dosage, which is also posed by repeated exposure.

Despite the numerous studies on cyanobacteria, not much is explained about the direct effects on humans, as most investigations were conducted with animals and plants. This limitation is due to a lack of information on other exposure, and also uncertainty regarding the adequate control for confounding factors during the study. These include Hepatitis B infection, as well as industrial and wastewater discharges to the same surface water sources. Also, information on methods of risk reduction against the uncertainty of oral exposure to human health is limited.

UTILIZATION OF CYANOBACTERIA

In addition to the dangers of microcystin produced by Cyanobacteria previously discussed, Cyanobacteria attracts more and more attention to the production of some valuable products (Axmann *et al.*, 2014). It is necessary to explore the possibility of adopting environmentally friendly applications of cyanobacteria in the provision of worldwide solutions in the aspect of mitigating the energy crisis, alleviating the problem of plastic, solving the waste and wastewater problems, as well as the clean production. The diverse, ubiquitous and easily available in nature, make cyanobacteria potentially being a suitable candidate for various purposes (Deviram *et al.*, 2020).

Several studies have been conducted to improve the benefits of cyanobacteria to human life. These bacteria have proven their possible roles in the world, in providing clean and sustainable energy, also other valuable products include food (Sathasivam *et al.*, 2019), dietary supplements (Costa *et al.*, 2019; Scoglio, 2018), high-value chemical products (Case & Atsumi, 2016), medicines (Noreña-Caro & Benton, 2018; Sathasivam *et al.*, 2019), bioenergy (Aoki *et al.*, 2018; Deviram *et al.*, 2020; Quiroz-Arita *et al.*, 2017), bioplastics, and wastewater treatment (Abdel-Raouf *et al.*, 2012; Deviram *et al.*, 2020; Subashchandrabose *et al.*, 2013). However, an experiment tested into mice that had been dietary fed for 6 months with the AFA Klamath blue-green algae, resulted in excellent health with the liver in perfect condition (Clark *et al.*, 2017). This study, further suggested the absence of an indirect relationship between the use of cyanobacteria and the ingestion route of exposure for humans.

Large scale application of cyanobacterial biofactory is still a technical challenge because of the yields and the ommoditization of products. However, the development of a feasible cyanobacterial biofactory can be enhanced through synthetic biology efforts, relying on the natural ability of cyanobacteria to synthesize carbohydrates and peptide (Noreña-Caro & Benton, 2018). Therefore, the further study of the harvesting and extracting, the environmental and economic feasibility, and also the development characterization methods for the physical properties and chemical composition of cyanobacteria utilization result products are necessary.

In the current progress, the use of cyanobacteria is for wastewater treatment and remediation of polluted environment. The use of cyanobacteria is still rarely found in scientific research, and is limited to wastewater with high concentrations of phosphate and nitrate (Gothalwal & Chillara, 2013). It was reported the cadmium deconcentration method by Nostoc calcicola cyanobacterium (Zhao *et al.*, 2015), which can be applied to remediate the environment contaminated with other metals (Mani & Kumar, 2014; Yin *et al.*, 2012). In the future, waste treatment and phytoremediation using cyanobacteria are expected to receive more attention. Especially is the implementation of biodiversity (Mangkoedihardjo & Samudro, 2014; Samudro & Mangkoedihardjo, 2020) both among microorganisms and between living organisms.

CONCLUSION

Although some applications are currently under debate due to the concern about the toxin accumulation in processed products such as food and dietary supplements. However, the use of cyanobacteria is prospective for environmental quality improvement. Cyanobacteria can be used for wastewater treatment and restoration of polluted environments. In-depth research is certainly needed to make effective use of it.

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