Toxicon xxx (2013) 1–14

Contents lists available at ScienceDirect

Toxicon

journal homepage: www.elsevier.com/locate/toxicon

Spatial and thematic distribution of research on cyanotoxins

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ARTICLE INFO

Article history:
Received 29 March 2013
Received in revised form 8 September 2013
Accepted 11 September 2013
Available online xxxx

Keywords:
Microcystin
Nodularin
Cylindrospermopsin
Anatoxin
Saxitoxin
BMAA
Aplysiatoxin
Lyngbyatoxin
Geography
Economy
Bibliometry

ABSTRACT

Cyanobacteria in surface water are well known for their ability to form toxic blooms responsible for animal mortality and human poisoning. Accompanying major progress in science and technology, the state of knowledge of cyanotoxins has dramatically increased over the last two decades. The bibliometric approach applied in this study shows the evolution of research and identifies major gaps to be filled by future work. Although publication rates have gradually increased from one hundred to three hundred articles per year since the 1990s, half of the literature available focuses on microcystins and another quarter on saxitoxins. Other cyanotoxins such as beta-N-methylamino-L-alanine or cylindrospermopsin remain vastly disregarded. Moreover, most of the publications deal with toxicity and ecology while other research areas, such as environmental and public health, require additional investigation. The analysis of the literature highlights the main journals for the communication of knowledge on cyanotoxins but also reveals that 90% of the research is originated from only ten countries. These countries are also those with the highest H-index and average number of citation per article. Nonetheless, the ranking of these countries is significantly altered when the amount of publications is normalized based on the population, the number of universities, the national gross domestic product or the government revenue. However, the lower amount of publications from Eastern Europe, Africa and South America could also reflect the lack of monitoring campaigns in these regions. This lack could potentially lead to underestimating the prevalence of toxic cyanobacterial blooms and the diversity of toxins worldwide.

1. Introduction

Cyanobacteria are ubiquitous microorganisms that exist mainly in marine and freshwater environments, but are able to subsist in infertile areas and extreme temperatures (Mur et al., 1999). These photosynthetic prokaryotes and potential precursors of the ozone layer are primarily known for their frequently occurring blooms in surface water worldwide (Merel et al., 2010a, 2013; Svrcek and Smith, 2004). This phenomenon, often consisting of the accumulation of cells and the formation of a green layer at the surface, typically arises in eutrophic water with a high concentration but a specific ratio of nutrients (Downing et al., 2001; Heisler et al., 2008). Beyond their anti-aesthetic characteristic, cyanobacterial blooms are also a significant health concern due to their ability to perform the biosynthesis of harmful metabolites called cyanotoxins, which can be responsible for animal deaths as well as human poisonings (Briand et al., 2003; Chorus et al., 2000; Kuiper-Goodman et al., 1999; Merel et al., 2013).

Cyanotoxins encompass a wide range of molecules often classified in three categories, according to their target

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0041-0101/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.toxicon.2013.09.008

organ (Merel et al., 2013; van Apeldoorn et al., 2007). Hepatotoxins affecting the liver are probably the most common and refer to a group of structurally different compounds (Codd et al., 2005) including over 90 variants of microcystin (MC), 9 variants of nodularin (NOD) and 3 variants of cylindrospermopsin (CYL). Similarly, neurotoxins affecting the nervous system consist of multiple metabolites, among which 20 variants of saxitoxin (STX), 3 variants of beta-N-methylamino-L-alanine (BMAA), 5 variants of anatoxin-a (ANTX-a) and a single variant of anatoxin-a(s) (ANTX-a(s)) are included. Dermatotoxins, which induce skin irritation, mainly include multiple but poorly characterized lipopolysaccharides (LPS), constituents of the cyanobacteria membrane that exhibit toxicity only once released in the surrounding water as a result of cell breakdown. Other dermatotoxins such as 3 variants of lyngbyatoxin (LTX) and 2 variants of aplysiatoxin (APTX) have also been identified in marine environments but have not been reported in freshwater (van Apeldoorn et al., 2007). However, the list of cyanotoxins is expected to keep increasing in the coming decades due to the perpetual progress in analytical science allowing the detection and identification of new compounds.

Humans are typically exposed to cyanotoxins through the ingestion of contaminated food, the ingestion of contaminated drinking water, and the accidental ingestion/inhalation or dermal adsorption of toxin during recreational activities in waters affected by a toxic bloom (Merel et al., 2013). For instance, STX, also known as paralytic shellfish poison, has been associated with multiple human intoxications through seafood, resulting in numbness, paralysis and death (Kuiper-Goodman et al., 1999). CYL was also shown to be responsible for the Palm Island mystery disease in Australia, when the toxin occurring in the drinking water supply induced severe gastroenteritis in the local population and resulted in over 100 hospitalizations (Bourke et al., 1983; Byth, 1980; Griffiths and Saker, 2003). Similarly, the occurrence of MC variants in water was reported as the cause of epidemic gastroenteritis and lethal human poisonings (Jochimsen et al., 1998; Pouria et al., 1998; Teixeira et al., 1993) leading the world health organization to release a guideline of 1 μg/L of the common variant MC–LR as the maximum concentration in drinking water (WHO, 1998). Consequently, several studies have investigated the early detection of cyanobacteria in surface water (Bastien et al., 2011; Brient et al., 2008) and the fate of cyanotoxins during several drinking water treatment processes such as membrane filtration (Teixeira and Rosa, 2006, 2005), adsorption on activated carbon (Hnatukova et al., 2011; Ho et al., 2011), ozonation (Brooke et al., 2006; Rodríguez et al., 2007; Shawwa and Smith, 2001) or chlorination (Ho et al., 2010; Merel et al., 2010b, 2009).

The health concerns related to toxic cyanobacterial blooms as well as the constant progress in science over the last two decades have dramatically increased the number of studies on the topic. While several recent review papers provide a scientific state of the art (Merel et al., 2013; Sharma et al., 2012; Westrick et al., 2010), this article aims to provide a world overview of research on cyanotoxins from a different perspective by focussing on spatial and thematic distribution. The study also intends to evaluate the scientific knowledge available using bibliometric tools in order to identify research gaps and highlight efficient vectors of communication.

2. Methodology

2.1. Selection of cyanotoxins

Cyanotoxins are comprised of a wide number of compounds. This study aims to be as exhaustive as possible by considering all the toxins usually described in key references and illustrated in Fig. 1. However, no variant-specific data was collected since such level of detail was not considered relevant. Moreover, since variants are named after their toxin family, it was assumed that the lack of variant-specific searches would not impair the data set. For instance, any article obtained when searching for the variant “microcystin-LR” would be included among those obtained when searching for “microcystin”.

2.2. Data collection

The publications related to cyanotoxins were retrieved through the Thomson Reuters Web of Science database. Preliminary statistics were obtained when searching by “topic” for publications regarding any of the toxins in Fig. 1 between the year 1900 and the year 2012. The articles retrieved were subsequently filtered by publication year, country, journal title, funding agency, research area, document type and language. More details were also obtained by combining these different filters and searching for each toxin individually. In this paper the results regarding ANTX-a and ANTX-a(s) were combined under ANTX.

Data regarding the number of universities per country were obtained through the International Association of Universities (URL available in the web references section) in December 2012. In this study, the term university refers to higher education institutions offering at least a post-graduate diploma/degree.

Demographic plus economic data such as National Gross Domestic Product (NGDP) and General Government Revenue (GGR) were obtained through the International Monetary Fund (URL available in the web references section). For all countries, NGDP and GGR were considered in US dollar equivalent in order to ensure a comparison as homogeneous as possible.

2.3. Data handling

Research on cyanotoxins was preliminary assessed by plotting directly the amount of publications per toxin or per country on graphics, tables or maps. Then, demographic factors were also considered and the annual amount of publications was normalized based on the population of each country and the number of universities. Similarly, economic factors were also incorporated in order to assess the investment of each country in research, and the annual amount of publications was normalized based on NGDP and GGR (both expressed in billion US dollars). However, assigning on average one year for data collection plus six

Please cite this article in press as: Merel, S., et al., Spatial and thematic distribution of research on cyanotoxins, Toxicon (2013), http://dx.doi.org/10.1016/j.toxicon.2013.09.008