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Invited Review

Presence and bioaccumulation of microcystins and cylindrospermopsin in food and the effectiveness of some cooking techniques at decreasing their concentrations: A review

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ABSTRACT

Microcystins (MCs) and cylindrospermopsin (CYN) are among the cyanotoxins which occur naturally, produced by different cyanobacteria species when they grow or proliferate under favorable environmental conditions. From a toxicological point of view, their relevance is due to the deleterious effects that they have been reported to induce in a wide range of organisms, including humans. Cyanotoxins intake from contaminated water and food is an important source of human exposure. Various edible aquatic organisms, plants, and food supplements based on algae, can bioaccumulate these toxins. A thorough review of the scientific data available on this topic is provided, the studies on MCs being much more numerous than those focused on CYN. The scientific literature suggests that these cyanotoxins can be accumulated at concentrations higher than their respective recommended tolerable daily intake (TDI). Finally, the influence of different cooking procedures on their levels in food has been considered. In this regard, again studies on the matter dealing with CYN have been not yet raised. MCs contents have been reported to be reduced in muscle of fish after boiling, or cooking in a microwave-oven, although the effect of other traditional cooking processes such as frying, roasting or grilling have not been demonstrated.

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1. Introduction

Cyanobacteria are a group of more than 2000 species of prokaryotic organisms commonly named "blue-green algae", although nowadays they are classified as Gram-negative bacteria (Herrero and Flores, 2008; Woese, 2002). These blooms are frequent in tropical and subtropical regions (Hawkins et al., 1985; Hayman, 1992), but they have been detected in water bodies all over the world (Chorus and Bartram, 1999). Nowadays, the distribution of CYN-producing cyanobacteria is known to have extended into temperate regions, which emphasizes that the potential for human health risks is not limited to the tropics, but it is also relevant to temperate climates (Falconer and Humpage, 2006). They also have the capacity to adapt to several habitats worldwide (Ward et al., 1998) and have been known to grow in such extreme conditions as hot and cold deserts (Wynn-Williams, 2000).

Under certain environmental conditions (light, temperature, pH), and the eutrophication due to the abundance of nutrients, particularly phosphorus and nitrogen, these organisms can grow on a large scale to produce blooms. Although these blooms can appear in any season, most of the studies carried out have concluded that environmental conditions are best for growth at the end of summer and the beginning of autumn. Their life-span ranges between 2 and 4 months, although they can persist for a long time in some warm and subtropical regions (Chorus and Bartram, 1999). Sometimes, blooms produce toxins (cyanotoxins) from the secondary metabolism (Duy et al., 2000).

Exposure to cyanotoxins such as microcystins (MCs) and cylindrospermopsin (CYN) has led to the acute death of terrestrial and aquatic animals, and humans (Azevedo et al., 2002; Bourke et al., 1983; Carmichael et al., 2001; Malbrouck and Kestemont, 2006). Many aquatic animals are capable to live under the presence of cyanotoxins. Thus, mollusks, crustaceans, and fish can accumulate toxins in their bodies, becoming toxin reservoirs for animals higher up the trophic chain, including humans (Berry and Lind, 2010). Moreover, plants accumulate cyanotoxins and are a risk for humans (Crush et al., 2008; Mohamed and Al Shehri, 2009). For these reasons, cyanobacteria constitute a worldwide concern because of their effects on environmental pollution, toxicology, health, economy, animals, plants and humans.

The risks of exposure to cyanotoxins have been assessed and reviewed by several authors (Dietrich and Hoeger, 2005; Ibelings and Chorus, 2007). To protect consumers from the adverse effects of cyanobacterial peptide toxins, the World Health Organization (WHO) proposed a provisional upper limit in drinking water of 1 μg/L for MC-LR and a tolerable daily intake (TDI) of 0.04 μg/kg of body weight (WHO, 1998). Dietrich and Hoeger (2005) assumed that 80% of the MCs that were ingested on a daily basis came from contaminated drinking water and that the remaining 20% came from food or were inhaled. The data available in the literature have shown that a provisional TDI for CYN is of 0.03 μg/kg body weight (Humpage and Falconer, 2003).

This paper aims to summarize the scientific literature on the accumulation of MCs and CYN in animals and plants destined for human consumption and elucidate the risk of intoxications. The presence of MCs and CYN in food algae supplements is also reviewed and the risk of consumption evaluated. Finally, the literature on how cooking processes affect the increase or decrease in cyanotoxin levels in food and how they can be used to prevent human intoxications is also studied.

1.1. Classification of cyanotoxins

Cyanotoxins are a diverse group of natural substances produced by several species of cyanobacteria. Traditionally, in terms of their toxic effects, cyanotoxins can be classified into four different groups (Ressom et al., 1994; Teneva et al., 2005):

- Dermatotoxins are produced by several species of the genera *Lyngbya*, *Schizothrix*, *Anabaena*, *Anacystis*, *Microcystis* and *Nodularia*. Contact with dermatotoxins causes severe dermatitis, eye irritation and respiratory tract inflammation (Arthur et al., 2006). They also interfere with the immune system and the detoxication mechanisms of some substances.
- Irritant toxins are of a lipopolysaccharide nature (LPS), and are the external components of the cell membranes of most cyanobacteria. Exposure to LPS has been related to gastrointestinal problems, skin or eye irritation, and allergic reactions (Funari and Testai, 2008).
- Neurotoxins have an alkaloid structure and block neurotransmission, which can produce death by respiratory paralysis (Sivonen, 1998). Different types of neurotoxins have diverse mechanisms of action: anatoxin-a and homoanatoxin-a are produced by several genera of cyanobacteria (*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, *Planktothrix*, *Oscillatoria*, and *Microcystis*), and Saxitoxin (paralytic shellfish poison) is produced by both cyanobacteria and dinoflagellates. Anatoxin-a(s), however, is a neurotoxin structurally unrelated to the above mentioned neurotoxic alkaloids. This toxin is an organophosphate and its mechanism of action is the irreversible inhibition of acetylcholinesterase (Mahmood and Carmichael, 1986).
- Hepatotoxins are composed of various cyclic peptides which inhibit protein phosphatases 1 and 2A. They have a high capacity to induce tumors in liver (Humpage et al., 2000a; Sivonen and Jones, 1999). The toxins in this group are microcystins and nodularins.
- Cytotoxins have several target organs, mainly the liver and kidney, and can therefore produce a large variety of symptoms (Funari and Testai, 2008). Cylindrospermopsin is one of these cyanotoxins, an alkaloid with a cyclic guanidine.
- Considering the diversity of cyanotoxins, in the present review we have focused on the presence and bioaccumulation of two types of them in the food web. One of these types of cyanotoxins is the group, microcystins (MCs), and the other is cylindrospermopsin (CYN). They were chosen because they are two of the cyanotoxins that put health at most risk nowadays because humans can be exposed to them by several pathways: recreational water activities, contaminated drinking water or contaminated food (especially fish, crustaceans, bivalves, vegetables, or even contaminated algae supplements).

1.2. Microcystins

Microcystins are cyanotoxins that are produced by several genera of cyanobacteria, including *Microcystis*, *Anabaena*, *Plankhotrix*, *Nostoc*, *Anabaenopsis*, and *Hapalosiphon* (Prieto et al., 2007). MCs are the most widespread group of cyanotoxins. They are cyclic heptapeptide molecules containing both L- and D-amino acids and an unusual hydrophobic C_{20} Damino acid commonly known as ADDA (3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid). The ADDA moiety is critical to the mode of MC toxicity (Song et al., 2006). There are over 80 different MCs (Gurbuz et al., 2009), which differ mainly in the two L-amino acids at positions 2 and 4, and the demethylation of Derythro-β-methylaspartic acid and/or *n*-methyldehydroalanine at positions 3 and 7, respectively. The most common, and also the most extensively studied, are MC-LR (2: Leucine, 4: Arginine), MC-RR (2: Arginine, 4: Arginine), and MC-YR (2: Tyrosine, 4: Arginine) (Fig. 1), of which MC-LR is the most toxic (Sivonen and Jones, 1999). Most of them are water soluble and stable in different conditions of light, pH and temperature. The