Inventory of animal contamination by cyanotoxins in Africa

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ABSTRACT

This study reviews work on the accumulation of cyanotoxins in fish and various animals in Africa. Microcystins (MC-LR, MC-RR, and MC-YR) appear to be the main contaminating toxin in fish and other animals. In fish, the highest concentration (1917 $\mu g.kg^{-1}$) was detected in the whole body of a small species of fish (*Rastrineobola argenta*) consumed whole by the populations around Lake Victoria. In large species, the intestine (followed by the liver) is the organ that accumulates the most cyanotoxins; up to 3059 $ng.g^{-1}$ in Algerian common carp. Fish muscle accumulates little or no cyanotoxins in most publications and *Oreochromis niloticus*, a phytoplanktonophagous species widely consumed by the African populations, remains the most studied species. In other animal species, cases of cyanotoxin mortality were reported in most publications in southern and central Africa and only one publication in North Africa. No study on this subject has been referenced in other parts of Africa.

Keywords: accumulation, cyanotoxins, fish, other animals, Africa

Introduction

The massive introduction of organic matter and nutrients (nitrogen, phosphorus) by direct discharges of effluents (domestic, industrial and agricultural), the flow of contaminated runoff water after their passage on agricultural surfaces and not agriculture, and atmospheric fallout into surface waters, disrupts the natural balances of aquatic ecosystems [1]. This effluent discharges added to the effects of global warming lead to massive primary production or eutrophication of aquatic environments [2; 3; 1]. Freshwater algae, a natural part of the aquatic ecosystem, can grow uncontrollably under appropriate environmental conditions, such as stagnant water, warm, nutrient-rich water, and sometimes produce toxins that are harmful to the lives of other organisms such as fish, aquatic mammals, birds and even humans that use these waters for their basic needs [4; 5]. Thus the cyanotoxins produced by cyanobacteria or blue algae are metabolites which, depending on their effects on vertebrates, are classified into hepatotoxins (microcystins, nodularins), cytotoxins (cylindrospermopsin), neurotoxins (saxitoxins, anatoxins), dermatoxins, and general irritants (lipopolysaccharides) [6]

The first studies conducted in the context of cyanotoxin contamination of aquatic environments have often been triggered by the dermatological conditions, gastroenteritis or the death of infected persons as in Zimbabwe [7] and Brazil [8], or even the death of animals staying around the contaminated water bodies [**9; 10**].

The aspect of the bioaccumulation of cyanotoxins in aquatic animals has been addressed much more by North African authors, and those from the Lake Victoria region and South Africa (eg [11]; [12]; [13] ; [14]). This work is a review of the study already carried out in Africa in the context of contamination of vertebrates by cyanotoxins in order to take stock of research in this subject.

This bibliographic review took into account the theses and articles published on the study carried out in Africa. This study was carried out using the Google Scholar and PubMed search engines.

1. Different types of cyanotoxins analyzed in aquatic animals in Africa

In the majority of the study carried out on animal mortality due to exposure to cyanotoxins, microcystins (MC) appear to be the main toxin in the contamination of water consumed by animals and therefore causing the death of these animals. Three microcystin variants (MC-LR, MC-RR and MC-YR) have been detected in most cases ([**15]; [16]; [17**]). In addition, nodularin has been implicated in South Africa in the death of a dog and cattle ([**18**] and [**19**]). Finally, one study found anatoxin-a in the tissue from carcasses of flamingos in Lake Bogoria in Kenya [**9**] and another found cylindrospermopsin (CYN) in Egypt [**20**].

2. Contamination of fish by cyanotoxins in Africa

The study concerning the contamination of fish by cyanotoxins in Africa is not sufficient enough given the amount of study carried out on this subject. The vast majority of the study carried out on this subject concerns North Africa and the countries around Lake Victoria. Just like in water, microcystins are the most studied and detected variants in fish tissue.

2.1. North Africa

Mohamed and Bakr (2018) studied during one year (October 2012 to September 2013) the concentration level of cylindrospermopsin (CYN) in a fish pond and the fishes that are found in it in Egypt. The concentration level was between 0.3-2.76 µg. L^{-1} in pond water and between 0.4-2.37 µg. L^{-1} in phytoplankton biomass. They found that CYN accumulated in the tissues of Tilapia fish (*Oreochromis niloticus*) in the range of 417 ng.g^{-1} in the intestines, 1500 ng.g^{-1} in the livers, and 280 ng.g- ^{1} in the flesh [20]. This study showed that the consumption of fish from aquaculture by the population could be dangerous to their health.

Amrani (2016) did his thesis work on the bioaccumulation of cyanotoxins in fish from aquaculture production in Lake Oubeïra in Algeria. This study was carried out from April 2010 to March 2011 on two species of fish *Cyprinus carpio* (common carp) and *Anguilla anguilla* (European eel). During the study period, the results obtained showed that the genus Microcystis was the most dominant and the *microcystin* concentrations vary between 0.028 to 13.4 µg MC-LR equivalent. L^{-1} [**12**].

The detection of microcystins in the different organs of the two fishes, by the PP2A test, showed that the common carp has a high accumulation of toxins in the intestines (371 - 3029 ng. g^{-1}) while the European eel accumulates more in the liver (86 - 333 ng. g-^{1}). In addition, the high concentration of MC in the muscles (32.9 - 680 ng. g^{-1}) of common carp could constitute a danger to the health of the populations which consume it [21].

Mohamed and collaborators (**2003**) previously carried out a study on the same subject, bioaccumulation in *Oreochromis niloticus* in Egypt. The highest amount of microcystins, assayed by ELISA (Enzyme-linked immunosorbent assay) was recorded in the intestines (821 ng. g^{-1} fresh weight), followed by the liver (531.8 ng. g-^{1}) and kidneys (400 ng. g-^{1}). The lowest amounts of MCYST were detected in the muscles (102 ng. g^{-1}) [**11**].

2.2 Sub-Saharan Africa

Furthermore, in Uganda, **Nyakairu and collaborators (2010)** studied the distribution of microcystins in the tissues of two fish species *Oreochromis niloticus* and *Lates niloticus* from Lake Victoria. The presence of MC-RR, MC-LR and MC-YR in different organs (intestine, muscle, and liver) was determined through liquid chromatography coupled with a mass spectrometry detector (LC-MS / MS). The fresh weight content of MC in *Oreochromis niloticus* from Lake Mburo was 1312.08 ng. g^{-1} in the intestine, 208.65 ng. g^{-1} in the muscles and 73.10 ng. g^{-1} in the liver and in the Murchison's bay it was found 1479.24 ng.g^{-1} in the intestine, 9.65 ng.g^{-1} in muscles, and 48.07 ng.g^{-1} in the liver, while for *Lates niloticus* from Murchison's bay it was 27.78 ng.g^{-1} in the intestine, 1.86 ng.g^{-1} in the muscles and 3.74 ng.g^{-1} in the liver. They have shown that the intestine accumulates more followed by the liver and muscle [**15**].

Poste and collaborators (2011) carried out a comparative study of the distribution of microcystins in the tissues of several species of fish of different trophic levels from Uganda and the United States. The microcystin concentrations assayed by the ELISA method ranged from 0.5 to 1917 µg.kg^{-1} and from 4.5 to 215.2 µg.kg^{-1} fresh weight (by weight) in muscle tissues and in the whole body, respectively. They have also shown that *Rastrineobola argentea*, a small zooplankton cyprinidae from Lake Victoria eaten whole, records the highest concentration of microcystins [13].

In *Oreochromis grahami*, a heavy consumer of cyanobacteria, the concentration of microcystin-RR in whole fish was between 0.41–0.79 µg. g^{-1} fresh weight [22]. This study was initiated after the discovery of carcasses of flamingos in Lake Bogoria in Kenya. This study showed that microcystins are probably the cause of death in these birds.

Semyalo and collaborators (2010) also carried out work on the bioaccumulation of microcystins in the tissues of Nile tilapia (*Oreochromis niloticus*). This study was carried out on two Ugandan water bodies (Lake Mburo and Murchison Bay of Lake Victoria). The concentration of MCs (LR, RR, and YR) in the digestive tract (Stomach, intestine with their contents), muscle, and liver was determined by liquid chromatography coupled with a mass spectrometry detector (LC / MS / MS). They found that the concentration of MCs in the fish digestive tract correlated positively with that in water with a maximum of 300 and 390 µg.kg^{-1} wet weight in Lake Mburo and Murchison Bay, respectively. The maximum found in the liver was 87.89 µg.kg^{-1} wet weight at Murchinson Bay and in muscle 5 and 6 µg.kg^{-1} wet weight at Murchinson Bay and Lake Mburo respectively [16].

In Africa, **Nchabeleng and collaborators (2014**), studied the bioaccumulation of microcystins in the liver and muscle of two species of fish, *Labeo rosae* and *Oreochromis mossambicus* found in the Loskop dam. ELISA analyzes revealed the microcystin concentrations of 1.72 µg MC-LReq kg^{-1} in the liver and 0.19 µg kg^{-1} in the muscles of *Labeo rosae*, and 2.14 µg MC-LReq kg^{-1} in the liver and 0.17 µg kg^{-1} in the muscles of *Oreochromis mossambicus*. These concentrations indicate, according to them, that the consumption of the flesh of these fish could constitute a risk to human health [23].

Most recently, **Simiyu and collaborators (2018**) also carried out work on Lake Victoria in the Gulf of Nyanza. They quantified the concentration of microcystin in the phytoplankton biomass of the lake and in small fish composed mainly of *Rastrineobola argenta*. They used three assay methods: ELISA, PPIA, and LC-MS / MS. The concentrations obtained by the PPIA method vary between 25 and 109 ng.g^{-1} dry weight of fish against 14 ng MC g^{-1} in lake water [14]. In Ethiopia, in the Koka reservoir, **Zewde and collaborators (2018**) detected and quantified by LC-ESI-HRMS, three variants of microcystins (MC-LR, -RR, -YR) in the liver of four wild fish. Nile tilapia (*Oreochromis niloticus*), common carp (*Cyprinus, carpio*) and African sharp-toothed catfish (*Clarias gariepinus*). Concentrations ranged from 2.23 µg. g^{-1} PS of MC-RR to 591.60 µg. g^{-1} PS of MC-LR in the liver and below the detection limit in muscle [24]. Their study was the first in Ethiopia on this subject and suggests a further study to prevent health risks from cyanotoxins in fish.

3. Contamination of other animals by cyanotoxins in Africa

After the death of a bull terrier after drinking water from Lake Zeekoevlei near Cape Town in South Africa, **Harding and collaborators (1995)** carried out investigations which led to the discovery of blooms of cyanobacteria in the said lake dominated by *Nodularia spumigena* and where the presence of nodularin was confirmed [18]. Other cases of sheep and cattle deaths have been investigated by **van Halderen and collaborators (1995**). Three foci of mortality of these animals were observed; the water consumed by animals in the first two foci was dominated by *Nodularia spumigena* and that of the last was dominated by *Microcystis sp*. The presence of microcystin-LR has been demonstrated in the third focus through high-pressure liquid chromatography [19].

Krienitz and collaborators (2003) have tried to understand the cause of death of several flamingos that migrated to different lakes in East Africa (Kenya, Tanzania, and Uganda). Their study demonstrated the presence of microcystins (MC-LF, MC-LR, MC-RR, and MC-YR) and anatoxins-a in water at varying concentrations and in the flamingo at 0.196 µg. g^{-1} fresh weight for microcystins and 4.34 µg.g-1 fresh weight for anatoxin-a [9]. **Nonga and collaborators (2011**) also identified cyanobacteria and their toxins as the cause of death of many flamingos in Tanzania. Three microcystin variants (MC-LR, MC-RR, and MC-YR) were detected in the tissues of flamingo carcasses with a concentration of 22 ± 16 µg.g^{-1} fresh weight of MC-LR in the liver [17].

In October 2005, the death of 12 turtles of the species *Emys orbicularis* and *Mauremys leprosadans* were observed in Lake Oubeira in Algeria. The death of these two turtle species was observed during a bloom of *Microcystis spp*. The total microcystin content of the phytoplankton biomass was 1.12 mg MC-LReq.g^{-1} dry weight while it was 1192.8 mg MC-LReq.g-1 dry weight in the liver of M. *leprosa* and 37.19 mg MC -LReq.g-1 dry weight in the viscera of *E. orbicularis* [25]. According to these authors, this mortality was due to exposure to microcystins.

In Kruger National Park in South Africa, zebra, wildebeest, and white rhino mortalities have been attributed to exposure to microcystins [26]. From the point of view of these authors, in addition to the climate, hippopotamus contributes to the eutrophication of the ponds and park puddles by providing nutrients through their excreta (urine and faeces) [26; 27]. Hence the development of cyanobacteria (especially *Microcystis spp*.) And the production of toxins causing the death of these animals.

Most recently, **Wang and collaborators (2021**) incriminated cyanotoxins as the cause of death of 330 African elephants (*Loxodonta africana) in* Botswana between May and June 2020. According to them, the climate (low precipitation and high evaporation) is responsible for the development of cyanobacteria blooms and the production of their toxins, especially MCs, in park puddles and ponds in hot and dry weather. Thus, the eastern and southern areas of Africa would be areas at high risk of exposure to cyanotoxins for megafauna and even for humans due to global warming [10].

Recapitulation

In fish, the highest concentration was detected in the whole body of a small species of fish (*Rastrineobola argenta*) consumed whole by the population. In large species, the intestine (followed by the liver) is the organ that accumulates the most cyanotoxins. The muscle or flesh of fish, an organ consumed by populations, accumulates little or no cyanotoxins in most publications. We had these same conclusions in a study to be published. In addition, *Oreochromis niloticus*, a phytoplanktonophagous species widely consumed by the African populations, remains the most studied species.

In other animal species, cases of cyanotoxin mortality have been reported in most of the publications in the area around Lake Victoria for birds and in South Africa in domestic and wild animals. Only one publication in North Africa mentioned turtle mortality. No study on this subject has been referenced in other parts of Africa.

The rise in temperatures, salinity, and human activities lead to the massive development of cyanobacteria to the detriment of other phytoplankton taxa. Thus, cyanobacteria, which form blooms and produce toxins in water bodies, constitute a health risk to animal populations and even to humans. In natural areas, especially parks, large herbivorous mammals also contribute to the nutrient enrichment of water bodies through their urine and feces. In addition, global warming is an adjunct to these two causes of the eutrophication of water bodies in Africa.

Conclusion

It is concluded that the accumulation of cyanotoxins in fish and other animals in Africa is the subject of this review, and it is well established. The monitoring of water bodies must become a necessity for African governments in order to prevent health risks due to exposure to cyanotoxins.

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