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IRRIGATING FOOD CROPS WITH WATER CONTAINING CYANOBACTERIA BLOOMS

Irrigating food crops with water containing cyanobacteria blooms

Primary inquiry: Small horticulture growers have been watering their crops with surface water containing a cyanobacterial bloom, before selling their crops at local markets.

- a) Can irrigation of food crops using surface water affected by cyanobacteria blooms result in bioaccumulation of cyanotoxins in these crops?
- b) Can cyanotoxins bioaccumulate to a concentration that might cause a public health concern?

Please note: The information provided here is for the purpose of addressing a specific inquiry and is not subjected to external review. The information offered does not supersede federal, provincial, or local guidance or regulations.

Background

Cyanobacteria are naturally occurring microscopic organisms found in fresh, brackish, and marine water. Under certain conditions they can rapidly proliferate and cause a cyanobloom, known as a harmful algal bloom (HAB) when cyanotoxins are produced. Only some species of cyanobacteria produce cyanotoxins, which can target different organs, e.g., the liver, nervous system, skin, etc. The most common cyanotoxin is microcystin (MC), of which there are almost 100 different variants.¹ Chronic exposure to one of its many variants, microcystin-LR (MC-LR), has been classified as Group 2B, possibly carcinogenic to humans.² Acute exposure to cyanotoxins can result in vomiting, diarrhoea, skin irritation, rash, fever, and headache, amongst other symptoms.³ Exposure to cyanotoxins typically occurs via drinking or inhalation of contaminated water, skin contact during swimming or showering, consumption of fish or shellfish grown in contaminated water bodies, or consumption of food crops irrigated with contaminated water.⁴ Health Canada has



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guidelines for total MC in drinking water (1.5 µg/L)⁵ and recreational water (20 µg/L).⁶ Please refer to cyanobacteria in freshwater^{3,7} for further information on cyanobacteria and cyanotoxins.

We approached this inquiry through:

1. consultation with a qualified professional with experience in drinking water treatment, and a Food Safety Specialist from the BC Ministry of Agriculture;
2. a rapid academic literature search; and
3. an internet search for public health documents from other jurisdictions.

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Consultation

An Environmental Manager at a drinking water treatment plant provided quantitative data regarding cyanobacteria/cyanotoxin concentrations in waterbodies and information on the procedure followed if cyanobacteria are detected in a lake. If cyanoblooms are visible, the cyanobacteria species are identified to genera level. If this step identifies harmful toxin-producing genera, water samples are taken and sent to a laboratory with capabilities for cyanotoxin analysis. Treatment plants will typically order the analyses of total MC and some of its more common variants, e.g., LR, YR, RR, LA, LF, LW. Other cyanotoxins may be analyzed, e.g., cylindrospermopsin, anatoxin-a, nodularin, saxitoxins, and/or domoic acid, depending on the local situation and history of blooms in the waterbody.

Cyanotoxins can occur year round, including in winter, but often only at trace amounts (i.e., below Health Canada's guidelines for total MC in drinking water of 1.5µg/L). In some waterbodies, cyanotoxins can be very slow to degrade to non-detectable concentrations. At this drinking water treatment plant, the highest concentration of MC-LR seen since data collection started was 100 µg/L during a bloom that lasted the best part of a year. Water is tested a minimum of once per month, and more often if a complaint arises or a bloom is spotted. Note that waterbodies in other locales across Canada may encounter cyanotoxin concentrations outside of the ranges given here (e.g., water samples analysed by Health Canada have shown total MC concentrations as high as 2000 µg/L⁸), and procedures may differ between treatment facilities.

A Food Safety Specialist with the BC Ministry of Agriculture was consulted regarding agricultural practices. Currently, there are no federal or provincial legislation/regulations regarding the inspection of horticulture crops during the growing season. However, once new federal regulations under the Safe Food for Canadians Act comes into force, all producers who ship outside of the province will have to register with the Canadian Food Inspection Agency (CFIA) and may be subject to inspection.

Irrigation water contaminated with cyanobacteria remains a low/non-priority issue for various reasons. Firstly, there has never been an illness outbreak associated with the consumption of food crops linked to cyanotoxins. Secondly, large-scale commercial horticulture producers do not want to risk clogging their irrigation pipes with bloom scum and incur cleaning/replacement costs. Thus, when a cyanobloom occurs in the water source, producers switch water sources to protect their irrigation systems. However, this primarily refers to large commercial horticultural producers and may not apply to small growers, or "backyard" growers who typically use less advanced irrigation systems or may even water crops manually. Thirdly, the end of the growing season for most horticultural crops, except root vegetables, occurs at approximately

the same time as the end of a typical cyanobloom season, thus providing only a small window of potential exposure via this route.

In addition, BC producers are being encouraged to switch from overhead spray irrigation to ground or underground irrigation systems, whereby only the roots of plants are exposed to irrigation water. For many food crops, this means edible portions of the plant would not come into contact with cyanobacterial-contaminated water.

Rapid Academic Literature Search

The literature scan conducted here was limited to the last five years; however, some older documents may have been included. Databases including UBC EbscoHost (with access to Medline, CINAHL, and Biomedical Reference Collection), Web of Science, and Google Scholar were searched using the following terms:

- cyanobacteri OR cyanophyta OR "blue-green bacteria" OR cyanoHAB OR "harmful algal bloom" OR cyanotoxin OR microcystin OR "anatoxin-a producing tychonema") AND
- agricultur* OR farming OR vegetable OR garden OR irrigat* OR harvest
- rule OR guidance OR guideline OR regulation OR operation OR legislation
- advisory OR notification OR restriction OR limit OR response

A secondary search specifically for Canadian literature was also undertaken, using the same databases and search terms as above, and the following search terms:

- (canad* OR "british columbia" OR coast OR atlantic [more provincial/regional terms used in Ebsco; limitations with Google Scholar]).

These searches turned up 56 documents/articles/reports/guidelines, of which nine scientific articles were directly relevant to irrigation of food crops, and others provided relevant information such as food safety, water quality guidelines, etc. Findings from the scientific literature are grouped by plant type, i.e., leafy greens, root vegetables, brassicas, herbs and spices, and fruit (Table 1).

CYANOBACTERIA ACCUMULATION IN FOOD CROPS

Various factors may limit or enhance bioaccumulation of cyanotoxins, including, but not limited to, the species being grown; the plant stage when exposed to cyanotoxins, i.e., seedlings or adult; cyanotoxin concentration in the irrigation water; duration and frequency of irrigation with contaminated water; amount of water used for irrigation; type of irrigation, e.g., sprinkler, drip, manual, etc.; soil bacteria present; soil type in which the plants are grown; duration/intensity of sunlight exposure; temperature; and humidity. Further, maximum cyanotoxin concentrations produced by cyanoblooms do not always coincide with maximum bloom density; toxicity can persist for days or even weeks after a bloom has disappeared.⁵

LEAFY GREENS

Six studies examined bioaccumulation of cyanotoxins in lettuce and arugula irrigated with cyanotoxin-contaminated water.⁹⁻¹⁴ Different irrigation volumes, doses, and growing conditions were used (Table 1). Regardless of the variation in experimental design or irrigation conditions, bioaccumulation concentrations typically increased with increasing MC concentrations in irrigation water (Table 1). However, some results differed despite similar volumes of water and doses of MC being applied. For example, no bioaccumulation occurred after very low irrigation concentrations were used, i.e., 0.5 and 0.65 µg/L.⁹ By contrast, another study showed irrigation with 0.5 µg/L resulted in bioaccumulation concentrations of 8.31 µg/kg fresh weight (FW).¹³ These irrigation concentrations are less than Health Canada's guidelines for total MC in drinking water.⁵

After seven days irrigation with 5 or 10 µg/L of MC-LR, no bioaccumulation occurred in arugula, while in lettuce, concentrations ranging from approximately 50 to 100 µg/kg FW were detected.¹¹ Daily irrigation of lettuce for 15 days with total MC up to 12.5 µg/L in 100 ml solutions resulted in detection of concentrations ranging from 8.31 to 177.8 µg/kg FW.¹³ Similarly, daily irrigation for 15 days with a total MC of 13 µg/L in 100 mL solutions resulted in a maximum concentration of 158.35 µg/kg FW in lettuce leaf tissue.⁹ These irrigation concentrations are less than Health Canada's guidelines for total MC in recreational water (20 µg/L).⁵

The highest irrigation concentration used was 2100 µg/L, a dose that came from lake water collected while under a cyanobloom.¹² Lettuces were watered every third day for 12 days, with resultant bioaccumulation concentrations ranging from 740 to 840 µg/kg dry weight (DW) in the shoots of the plants. (Note that 1 g of dry weight tissue is equivalent to 10 g fresh weight,¹³ thus reporting in dry weight increases the observed concentrations). The highest bioaccumulated concentration observed was 2487 µg/kg DW, from lettuces grown on a farm and irrigated with unknown concentrations

of cyanotoxin (Table 1). The lettuces had visible cyanobacterial cells on their leaves that were not removed by rinsing with non-contaminated water. Produce was discarded.¹⁰

Assuming a 60 kg person consumes 40 g of lettuce leaves per day, concentrations bioaccumulated in lettuce under some of these conditions would exceed the World Health Organization's (WHO) tolerable daily intake (TDI; i.e., the total daily amount of a chemical that has been deemed safe to consume over a person's lifetime) of 0.04 µg MC-LR/kg body weight (BW), for lower irrigation concentrations irrigated for multiple days, or at higher concentrations after only a single day of exposure.¹⁵ Further details can be found in Machado et al.¹⁵

A single study examined depuration (i.e., the excretion or metabolic breakdown of toxins from the plant) of MC from lettuce plants.¹¹ After seven days of irrigation with contaminated water, MC-LR concentrations accumulated to 100 µg/kg FW. Lettuce plants were subsequently irrigated with non-contaminated water. After seven days' depuration, this concentration had reduced to approximately 30 µg/kg FW, showing the potential for depuration as a means to reduce consumer exposure.

ROOT VEGETABLES

Two studies examined root vegetables – carrot¹⁶ and radish.¹⁴ Carrots were irrigated twice weekly for 14 or 28 days with 40 mL water containing 10 or 50 µg/L MC-LR. MC-LR was detected at concentrations of 5 µg/kg FW.¹⁶ Radishes were grown in plantations using contaminated well water; hence exact concentration at irrigation is unknown. Total MC concentration detected in radishes was 1200 µg/kg FW (Table 1).

BRASSICAS

One study examined cabbage¹⁴ and another, broccoli.¹⁷ Microcystin (probably MC-YR) concentration at irrigation was unknown, but was detected in cabbage leaf tissue at 70 µg/kg FW.¹⁴ After 20 days of daily exposure to 1 or 10 µg/L, MC-LR was only detected in the roots of broccoli at very low concentrations (range 0.9 to 2.4 µg/kg FW),¹⁷ not in the edible part.

HERBS & SPICES

One study examined herbs (dill, parsley)¹⁴ and another examined mustard.¹⁷ Dill and parsley were irrigated with water containing microcystin (probably MC-YR), of unknown concentration. Parsley roots accumulated slightly more MC-YR compared to the leaves (approximately 300 versus 250 µg/kg FW), whereas concentrations were higher in dill leaves compared to roots (approximately 200 versus 150 µg/g FW).¹⁴ Mustard was exposed daily for 19 days to 1 or 10 µg/L of MC-LR. Low concentrations were detected in the plant roots (range 2.5 to 2.6 µg/g FW).¹⁷

FRUIT

Tomatoes were irrigated every third day for two weeks with 500 mL water containing 100 µg/L of MC-LR. After one week, MC-LR was detected in the green and mature tomatoes (54 and 10.8 µg/kg FW, respectively).¹⁸ However, after two weeks of irrigation, MC-LR was below detection limits. Concentrations in the green and mature tomatoes did not exceed the WHO's TDI based on average consumption by a 60 kg person.¹⁵ Concentrations were considerably higher in the root and leaves of the plants; however, because these portions of the plant are not eaten, no health risk is posed.¹⁸

Public Health Documents and Grey Literature

As described previously, an internet search was conducted to identify documents from public health agencies and other organizations regarding irrigation of food crops with cyanobacterial-contaminated water, using the search terms outlined in the academic literature search.

Health Canada has set a maximum acceptable concentration (MAC) of 1.5 µg/L for total MC in drinking water and 20 µg/L for total MC in recreational water bodies.⁵ There are no MACs set for any other cyanotoxin in drinking water, and no guidelines or regulations set on MC-LR in water used for the irrigation of food crops. The Canadian Water Quality Guidelines¹⁹ provide some guidance for irrigation water quality. However, their focus is primarily on physical and chemical parameters, such as heavy metals; and plant, human, and animal pathogens, and how these affect crops. Toxins such as MC-LR are not discussed.

Furthermore, in Canada, there is little in the way of legislation that addresses the quality of irrigation water. For example the Fresh Fruit and Vegetable Regulations (C.R.C., c. 285)²⁰ under the Agricultural Products Act²¹ stipulates that water used for post-harvest washing and rinsing must be potable, but it does not provide any requirements for irrigation water. This federal legislation applies to produce that is imported, exported, or shipped between provinces. It would not apply to locally grown produce sold at a local market. Where there is a lack of legislation, producers are encouraged to follow better practices. However, these practices also focus on wash and rinse water rather than the irrigation water, with the emphasis on microbial quality.²²

The US FDA guidelines on agricultural water used for irrigation refer only to *E. coli* and microbial quality, not to cyanobacteria-contaminated water.²³ However, frequently asked questions about cyanobacteria posted by Oregon Public Health²⁴ noted that if any of the four cyanotoxins they monitor for (anatoxin-a, cylindrospermopsin, microcystins, or saxitoxins) are above their

drinking water guidelines, then the water should not be used for washing, preparing, or cooking food, nor should it be used for irrigating food crops. However, if below their guidelines (1.6 µg/L for total MC for people over six years old), water can be used to irrigate food crops, as long as contaminated water on any crops is allowed to dry completely in sunlight before consuming, and measures are taken to ensure no children or animals drink the water.

Knowledge Gaps

CANADIAN CONTEXT

None of the studies examined here were conducted in Canada. Currently, there are no regulations or guidelines on the use of water potentially affected by cyanoblooms, used for food crop irrigation in Canada. Because microcystins have been detected in waterbodies in every Canadian province over the last decade,²⁵ there is a need for better evidence regarding public health implications of exposure to food crops irrigated with water containing cyanotoxins that can be used to inform policy and regulation.

LIMITED RESEARCH

For the period examined, only a small number of primary research articles were available, and the methods used varied, making comparison of and generalization between food crops difficult. Furthermore, there is a lack of field-based experiments examining irrigation of food crops under real conditions, i.e., on farms growing salable produce.

The literature focuses on MC-LR research and largely neglects the bioaccumulation of other cyanotoxins into food crops, most likely because MC are regarded as having the most important health implications of the cyanotoxins.⁵ Research is lacking on the frequency and intensity of watering, different delivery methods, e.g., spray, ground, or sprinkle irrigation, and if these might mitigate bioaccumulation, as well as risks to farmers or farm workers from these delivery methods, i.e., inhalation of water from spray irrigation.

Only one study on depuration was found, and this examined only two species—lettuce and arugula.¹¹ Further depuration work on a wider range of food crops is necessary. A wider range of food crops, including fruit and berries, should be examined, with a focus on the edible portions.

Summary

Cyanotoxins can bioaccumulate in food crops irrigated with cyanotoxin-contaminated water. The amount of bioaccumulation depends on the cyanotoxin concentration in irrigation water, the duration, frequency, and timing of irrigation, irrigation method used, the species being examined, and the age of the plants, i.e., seedlings or mature plants. Depending on the amount consumed, this may lead to consumption of food produce that exceeds the WHO TDI for a 60 kg person.^{15,26} Concentrations of cyanotoxins used for irrigation in studies where the TDI could be exceeded¹²⁻¹⁵ were within the range of MC-LR concentrations detected from waterbodies in Canada.⁸ MC-LR is stable at temperatures up to 300°C, thus cooking produce will not remove or reduce bioaccumulated toxins.²⁷ Hence, there may be a risk to consumers exposed to produce irrigated with cyanotoxin-contaminated water at higher concentrations. This could be a particular issue for vulnerable populations, e.g., children, pregnant women, immunosuppressed individuals, or the elderly.

Health Canada currently has no MAC guidelines or regulations set for cyanotoxins, total MC, or MC-LR in irrigation water. However, large commercial producers appear less likely to produce crops affected by cyanotoxins because of their use of advanced irrigation systems, meaning they will switch water sources as soon as a bloom threatens the irrigation piping, and/or their use of ground/underground rather than overhead spray, irrigation. By contrast, small or “backyard” producers using less advanced, or even manual irrigation, appear more likely to introduce cyanobacteria and cyanotoxins to their crops. Small producers may also be unaware of whether or when their irrigation water is affected by cyanoblooms, or if they were aware, lack knowledge on why this may pose a risk and what can be done to mitigate risk.

When cyanotoxin concentrations in the water source become elevated, producers should be encouraged to ensure their food crops will not become contaminated by, for example, switching to an alternative water source or treating the existing source, if this is cost effective. Important to note is that concentrations bioaccumulated by plant tissue increase with increasing toxin concentration in the irrigation water, and that cyanobacterial cells are unable to be rinsed off lettuce leaves and thus cannot be removed by the consumer.¹⁰

There are still many gaps in knowledge around this issue. Reasonable public health measures may include the following:

- increased awareness and education of this issue;
- knowledge of which waterbodies frequently experience cyanoblooms;
- knowledge of when cyanoblooms are occurring and what the effects of cyanotoxins are;
- knowledge of the ability of food crops to bioaccumulate cyanotoxins;
- knowledge of how long a toxin can remain bioavailable in the water after a bloom has disappeared;
- testing of irrigation water sources throughout the relevant crop growing seasons.

While we know using water affected by cyanoblooms of cyanotoxin-producing species for irrigation of food crops can result in bioaccumulation of cyanotoxins, which in some cases potentially exceed the WHO TDI, whether or not this bioaccumulation could pose a human health risk, or how great a risk is presented, remains uncertain. Furthermore, climate change effects on increasing temperatures is likely to promote more frequent and longer cyanobloom seasons,²⁸ by changing bloom timing and cyanobacterial dominance.²⁹ Further research on risk assessment, risk mitigation, bioaccumulation, and depuration of cyanotoxins is needed.

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Table 1. Bioaccumulation of microcystins in food crops irrigated with cyanotoxin-contaminated water, showing different watering conditions and irrigation doses used for each study.

Irrigation dose ($\mu\text{g/L}$)*	Bioaccumulation concentrations (range, $\mu\text{g/kg}$)	Watering conditions	Source
LEAFY GREENS			
Lettuce, <i>Lactuca sativa</i>			
Total MC 0.65, 2.5, 6.5, 13 MC-LR 0.5, 2, 5, 10 MC-RR 0.15, 0.5, 1.5, 3	Not detected at lowest doses, i.e. <0.65 39.31 – 158.35 FW 32.00 – 143.35 FW 6.32 – 15.00 FW	Range of doses delivered in 100 mL water daily for 15 days. 40-day-old lettuce plants used in this experiment.	Bittencourt-Oliveira et al. 2016
MC-LR 5, 10	~50 – 100 FW	Irrigated every 3 days for 7 days (day 1, 4, 7) with 100 mL water. Plants maintained at 25°C, 10:14 h light:dark. 40-day-old lettuce plants used.	Cordeiro-Araújo et al. 2016
Total MC 0.62, 2.5, 6.23, 12.5	8.31 – 177.8 FW Greater accumulation occurred at higher irrigation doses	Adult plants sprayed daily with 100mL water containing the different doses, for 15 days.	Hereman & Bittencourt-Oliveira 2012
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	<100 – ~400 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009
Total MC 2100 This dose came from lake water sampled during a cyanobloom	300 – 870 DW (roots) 740 – 840 DW (shoots)	Watered for 12 days, on days 3, 5, 8, 10, 12, with 100 mL contaminated water applied to either the roots only, or to the foliage. 42-day-old lettuce used.	Crush et al. 2008
MC-LR 3.23±0.11 $\mu\text{g/mg}^*$ DW (bloom and scum)	94 – 2487 DW	Crop grown on a farm under natural conditions. Visible cyanobacteria cells unable to be washed off the lettuce. Crop withdrawn from sale.	Codd et al. 1999
Arugula/rocket/rucola			
MC-LR 5, 10	ND	Irrigated every 3 days for 7 days (day 1, 4, 7) with 100 mL water. Plants maintained at 25°C, 10:14 h light:dark. 30-day-old arugula plants used.	Cordeiro-Araújo et al. 2016
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	<100 – ~ 400 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009
ROOT VEGETABLES			
Carrots, <i>Daucus carota</i>			
MC-LR 10, 50	5 FW Did not distinguish bioaccumulation concentration based on irrigation dose	Irrigated twice a week for 14 or 28 days with 40 mL with water containing MC-LR. Plants were 1 or 2 months old.	Machado et al. 2017
Radish, <i>Raphanus sp.</i>			
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	<300 – 1200 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009

Irrigation dose ($\mu\text{g/L}$)*	Bioaccumulation concentrations (range, $\mu\text{g/kg}$)	Watering conditions	Source
BRASSICAS			
Broccoli, <i>Brassica oleracea</i>			
Total MC 1, 10	Only MC-LR detected, only detected in plant roots. 0.9 – 2.4 FW. Did not distinguish bioaccumulation concentration based on irrigation dose	47-day-old plants, watered daily for 20 days. 23°C, 50% relative humidity, 10:14 light:dark	Järvenpää et al. 2007
Cabbage, <i>Brassica oleracea</i>			
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	<100 – ~800 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009
FRUIT			
Tomatoes, <i>Lycopersicon esculentum</i>			
MC-LR 100	FW	Using 2-month-old plants at flowering and fruit maturation stages. Watered once every 3 days for 2 weeks with 500 mL of contaminated water.	Gutierrez-Praena et al. 2014
Roots	ND – 1635.2		
Leaves	ND – 12298.2		
Fruit – green tomato	<LD – 5.4		
Fruit – ripe tomato	<LD – 10.8		
HERBS AND SPICES			
Dill, <i>Anethum graveolens</i>			
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	~150 – 800 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009
Parsley, <i>Petroselinum crispum</i>			
Probably MC-YR 0.3 – 1.8; however, concentration at irrigation unknown	~300 – 800 FW	Watering conditions unknown.	Mohamed & Al Shehri 2009
Mustard, <i>Sinapis alba</i>			
Total MC 1, 10	2.5 – 2.6 FW Only MC-LR detected, and only detected in plant roots. Did not distinguish bioaccumulation concentration based on irrigation dose	47-day-old plants, watered daily for 20 days. 23°C, 50% relative humidity, 10:14 light:dark	Järvenpää et al. 2007

FW – fresh weight;

DW – dry weight;

ND – not detected;

LD – detection limit;

MC – microcystins. MC-RR, MC-LR, MC-YR are all variants of microcystin.

* unless otherwise specified

Top photo credit - Blue green algae in irrigation drain at Griffith, NSW. 1989. © CSIRO Land and Water used under the Creative Commons Attribution 3.0 Unported license.

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