

Correction

Correction: Melaram et al. Microcystin Contamination and Toxicity: Implications for Agriculture and Public Health. *Toxins* 2022, 14, 350

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The authors wish to make the following corrections to their paper [1].

Error in Content

5.1. Biosynthesis

The terms “ecosystem” “agricultural” were mistakenly introduced during the last sentence. The corrected statement is:

“Covalent modifications of amino acid residues may explain the myriad of microcystin variants detected in freshwater sites, some of which present a danger to aquatic and terrestrial plants.”

5.4. Phytotoxicity

The letter “s” was missing after the word “effect” in the first sentence. The corrected statement is:

“Phytotoxicity, a delay in overall seed germination, inhibition of plant growth, or other adverse effects on plant growth and development, has been attributed to the presence of microcystins.”

The concentration of microcystin and names of enzymes were incorrect, and the duration of exposure was missing in the last two sentences. The enzymatic activity is modified. The corrected statements are:

“The metabolism of nitrogen, an essential element for plant growth, shows significant decrease when aquatic and terrestrial plants are placed in concentrations of 9.9–29.8 µg/L of microcystin for 30 days. Enzymatic activity that assists in sequestering nitrogen into tissue, including glutamic-pyruvic transaminase and glutamic-oxaloacetic transaminase, are reduced at this concentration level [76].”

6.2. Tissue Growth

The number of crop species was numerically incorrect in the third sentence. The corrected statement is:

“In a survey of 35 crop species ranging from leafy greens to root vegetables, all reported losses of at least 30% in total leaf surface area [79].”

The second treatment of microcystin concentration was missing. The corrected statement is:

“Anomalies in tissue structure were apparent in crops grown hydroponically, with high concentration of microcystins (10 µg/L and 20 µg/L) [94].”

The word “alternations” was used instead of “alterations.” The corrected statement is:



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“Additional alterations, such as slowing of mitotic and metabolic processes and reduced development, increased with the increase of concentration [82,86].”

6.3. Aquatic Plants

Incorrect reporting of concentrations occurred in the third sentence of the first paragraph and the second-to-last sentence of the second paragraph. The two corrected statements are:

“Submerged species show the highest concentrations present in tissue, with *Elodea canadensis* showing a concentration of 40 µg/g of dry weight [103].”

“Perhaps most impressive, bioaccumulation of microcystin in *Lemna minor* after 5 days of exposure showed resistance to a concentration level (3.0 µg/L) that had earlier been detrimental [106].”

Error in Tables

Several errors were noted in Tables 1 and 2. Major errors in Table 1 included incorrect microcystin congeners and reported concentrations. Minor errors in Table 1 included the misspelling of the genus “*Daucus*”, misclassification of “Stage of Development” and “Route of Exposure” for crop species, and mismatched “Physiological Effects”. Minor errors in Table 2 included misclassification of “Environment” in addition to discrepancies in “Mode of Uptake” and “Plant Response”. The corrections, which were not fully addressed during peer review, are presented below.

Table 1. Physiological effects in agricultural plants from various microcystin exposure routes.

Species	Experimental Design	Concentration of Microcystin *	Duration of Exposure (Days)	Stage of Development	Physiological Effects	Reference
<i>Brassica juncea</i> (mustard green)	Pot study	150 µg/kg MC-LR	10 d	Mature plants	Reduced plant height and weight	[56]
<i>Brassica napus</i> (rape seed)	Germination	600–3000 µg/L MC-LR	10 d	Seeds	Reduced germination	[81]
<i>Daucus carota</i> (carrot)	Independent exposure experiment	50 µg/L MC-LR	28 d	Mature plants	Reduced root growth Increased photosynthetic efficiency	[82]
<i>Ipomoea batatas</i> (sweet potato)	Pot study	150 µg/kg MC-LR	10 d	Mature plants	Reduced plant height and weight	[56]
<i>Lactuca sativa</i> (lettuce)	Hydroponics	50 µg/L MCs	21 d	Mature plants	Reduced leaf growth and mineral content	[77,78]
	Hydroponics	100 µg/L MC-LR	10 d	Mature plants	Reduced biomass of leaves and mineral content	
					Increased GST activity in roots	
<i>Lepidium sativum</i> (watercress)	Germination	10 µg/L MC-LR	6 d	Seeds	Reduced radicle length and shoot weight	[83]
<i>Medicago sativa</i> (alfalfa)	Germination	5 µg/L MCs	7 d	Seedlings	Inhibition of germination and root growth	[84]
					Increased lipid peroxidation	
<i>Oryza sativa</i> (rice)	Hydroponics	1–3000 µg/L MC	7 d	Seedlings	Reduced biomass of leaves, stems, and roots	[26]
	Hydroponics	500 µg/L MCs	30 d		Reduced root weight, length, surface area and volume	[85]
					Increased levels of tartaric acid and malic acid	
<i>Phaseolus vulgaris</i> (green bean)	Germination	3500 µg/L MC-LR	30 d	Seeds	Reduced chlorophyll content, delayed development	[86]
					Reduced conductivity and phototropic response	
<i>Solanum lycopersicum</i> (tomato)	Soil	5 µg/L MC-LR	90 d	Seeds	Stimulation of inflorescence and blooming of flower	[87]

Table 1. Cont.

Species	Experimental Design	Concentration of Microcystin *	Duration of Exposure (Days)	Stage of Development	Physiological Effects	Reference
<i>Spinacia oleracea</i> (spinach)	Hydroponics	50 µg/L MCs	21 d	Mature plants	Reduced leaf growth and mineral content	[77]
<i>Triticum aestivum</i> (wheat)	Germination	0.5 µg/L MC-LR	3 d	Seeds	Reduced germination	[88]
	Soil		14 d		Reduced photosynthesis and root and shoot development	
					Increased GST activity	
<i>Zea mays</i> (corn)	Germination	100,000–800,000 µg/L	1 d	Seeds	Reduced plant height and weight	[89]
* Concentration of microcystin exposure on crop species is expressed as µg/L or µg/kg. MCs = total concentration of microcystin (variants not available) MC-LR = microcystin-leucine arginine; GST = glutathione-S-transferase.						

Table 2. Accumulation of microcystins in aquatic plants.

Species	Environment	Mode of Uptake	* Microcystin Toxins	** Concentration of Microcystin	*** Plant Response	Reference
<i>Alternanthera philoxeroides</i> (alligator weed)	Submerged	Root absorption	Total MCs	169–3945 ng/g	--	[107]
		Diffusion				
<i>Ceratophyllum demersum</i> (hornwort)	Submerged	Root absorption	MC-LR	71 µg/g	--	[103]
		Diffusion				
<i>Elodea canadensis</i> (American waterweed)	Submerged	Root absorption	MC-LR	40 µg/g	--	[103]
		Leaf contact with water surface				
		Diffusion				

Table 2. Cont.

Species	Environment	Mode of Uptake	* Microcystin Toxins	** Concentration of Microcystin	*** Plant Response	Reference
<i>Hydrilla verticillata</i> (water thyme)	Submerged	Root absorption Diffusion	Total MCs	>1000 µg/kg	Biotransformation of MCs	[108]
			MC-LR	>1000 µg/kg		
			MC-RR	<500 µg/kg		
			MC-YR	<500 µg/kg		
<i>Lemna gibba</i> (duckweed)	Floating	Root absorption	MC-LR	2.44 µg/g	Reduction in plant growth and chlorophyll content	[109]
		Leaf contact with water surface			Biotransformation of MCs	
<i>Phragmites australis</i> (common reed)	Floating	Root absorption	MC-LR	5–40 µg/L	Inhibition of growth and development	[110]
		Leaf contact with water surface				
<i>Polygonum portoricensis</i> (smooth smartweed)	Submerged	Root absorption Diffusion	Total MCs	>400 µg/kg	Biotransformation of MCs	[108]
			MC-LR	>400 µg/kg		
			MC-RR	<200 µg/kg		
			MC-YR	<200 µg/kg		
<i>Trapa natans</i> (water chestnut)	Floating	Root absorption	Total MCs	1.68 ng/g	--	[111]
		Leaf contact with water surface				
<i>Typha</i> sp. (cattail)	Floating	Root absorption Leaf contact with water surface	Total MCs	>1500 µg/kg	Biotransformation of MCs	[108]
			MC-LR	>1500 µg/kg		
			MC-RR	<500 µg/kg		
			MC-YR	<500 µg/kg		
<i>Vallisneria natans</i> (eelgrass)	Submerged	Root absorption	MC-RR	10 mg/L	Reduction in root and leaf numbers	[105]
		Diffusion				

* Total MCs = concentration of analyzed MC congeners; MC-LR = microcystin-leucine arginine; MC-RR = microcystin-arginine arginine; MC-YR = microcystin-tyrosine arginine.

** Concentration of microcystin is expressed as ng/g, µg/g, µg/kg, or mg/L. Reported concentrations should be interpreted with caution. *** -- = no information available.

Error in References

Numerous inconsistencies were evident in the original publication, such as missing, incorrect, or out-of-order citations. All citations have now been corrected. With this correction, the order of some references has been adjusted accordingly.

References Citation Changes in Maintext (Reordered Labeled)

Section 1: Introduction

“A study examined the effects of microcystin buildup in agricultural crops, finding cabbage, dill, and parsley plants accumulated threefold greater amounts of microcystins compared to fruiting crops [27].”

“Microcystin variants have been detected in all these water reservoirs [29], increasing the potential likelihood of biotoxin transport into crop and drinking water systems. Microcystins have also been found in groundwater samples [30], which account for half of the drinking water available on Earth [31,32].”

“Agricultural water use from eutrophic sources has significantly impacted 160 terrestrial food crop species [34].”

Section 4.1: Irrigation with Polluted Water

“Two studies indicated that contaminated irrigation water with microcystins threatens crop quality and yield [52,53].”

Section 4.2: Application of Cyanobacterial Manure

“Cyanobacterial fertilizer, which contains living cyanobacteria cultures that aid in harnessing solar energy, nutrients, and water resources essential to plant growth have become popular in recent years [54,55]. The application of cyanobacterial fertilizer in tandem with manure has the potential to improve soil quality and plant growth and reduce crop production costs in agriculture [55]. However, its use in soils affected by cyanobacterial blooms is not recommended due to higher bioaccumulation capacity in edible plants from polluted soil [50].”

“Furthermore, the co-existence of microcystin congeners in manure is considered a human health risk [56].”

Section 4.3: Compost

“The agricultural use of compost has risen in the past decade to foster improved soil ecosystem health for greater crop outputs with less dependence on chemical inputs [58]. While the negative influence of microcystin contamination is well documented for marine invertebrates, few studies have indicated its effect on soil-dwelling species [47,59]. Soil nematodes were shown to have a reduction in overall lifespan and a decrease in reproduction and were less motile in the presence of a mere 1.0 µg/kg MC-LR concentration, with any higher dose largely obliterating nematode existence [59].”

“Compost used for crop production has increased interest in the likelihood of unintentional contamination [61].”

“Higher mean concentrations of MCs, in the 12.3–22.8 µg/kg were found in lettuce and cabbage, as compared to root vegetables such as carrot (10.5–12.6 µg/kg) that were grown in compost-rich soil [28].”

Section 5.2: Mechanism of Action

“Microcystins exert a strong affinity toward protein phosphatase 1 (PP1) and 2A (PP2A) and, to a lesser extent, protein phosphatase 2B (PP2B) [65].”

Section 5.4: Phytotoxicity

“This directly impacts photosynthesis activity, with overall chlorophyll concentration decreasing as much as 0.80 mg/g [73]. Stomatal integrity is similarly impacted by the weakening cytoskeletal elements and can lead to oxidative stress including less leaf transpiration and poor gas exchange [74].”

“Microcystin concentrations above 250 µg/L caused total inhibition of assemblage of nutrients at the root level [75].”

Section 6: Agricultural Plants

“Plant growth, whether in terrestrial or aquatic form, has shown sensitivities to microcystins [62,77–79]. The two are distinguished from each other by the traditional definition of true aquatic plant, meaning it must be submersed in water for most of its life cycle [74]. Terrestrial plants, in contrast, spend their life cycle on land and root directly into the soil [80]. Those that can withstand periods of standing water are still classified as terrestrial, land-dwelling plants [80]. Of the two, terrestrial plants have received significant attention where crops are concerned, as those are directly consumed [25,26]. The effects on tissue and seedling growth are presented below (Table 1).”

Section 6.1: Plant Seedling Growth

“In the past decade, studies have measured the effects of varying concentrations of microcystins on the growth of agriculturally important crops, including leafy greens, herbs, root vegetables, and squash [34,53,62,90,91]. Height, biomass, leaf surface area, seedling diameter, and root development were significantly reduced across all crops (root vegetables, herbs, leafy greens, and squash) tested, with leafy greens holding the highest risk to exposure [77].”

“*Rhizobia* nodules, which are essential for many growing seedlings to successfully fix and uptake nitrogen, are reduced or non-existent when grown in high concentrations of microcystins [92]. As a result, root surface area, length, number of roots present, and total biomass are reduced by upward of 60% in leafy green vegetables [79].”

Section 6.2: Tissue Growth

“Irrigating mature crops with microcystin-contaminated water also leads to poor nitrogen fixation, reduced height, and reduction in total biomass in tissue development [77–79]. As seen with seedlings, the higher the concentration of microcystins present in irrigation water, the more at-risk tissues are for reduced photosynthesis, decreased leaf and root production, and an overall reduction in biomass [74,77–80]. In a survey of 35 crop species ranging from leafy greens to root vegetables, all reported losses of at least 30% in total leaf surface area [79]. Further analysis suggests that microcystins play a direct role in the inhibition of photosynthetic activities and can cause tissue death, increase oxidative stress, reduce membrane integrity, and impair the ability of roots to absorb nutrients [85,88,93]. Anomalies in tissue structure were apparent in crops grown hydroponically, with high concentration of microcystins (10 µg/L and 20 µg/L) [94].”

“Despite the effects of microcystins on seedling and tissue growth, they are not the sole contributing factor in plant developmental changes [25]. The impacts of microcystins are greatest at higher concentrations, with the greatest effect on the seedling stage [77,78,81,84]. Due to the structure, surface area, and gas exchange exhibited by leafy greens, microcystins can readily diffuse through stomata into plant tissue and cause negative impacts [79,93,95,96]. Hydroponically grown species of leafy greens including watercress, lettuce, and spinach, over those grown in soil-based cultures, were 30% more likely to have hinderance of growth [97,98].”

Section 6.3: Aquatic Plants

“Microcystins can readily enter many aquatic plant species through simple diffusion, stomata of leaves in contact with water, and absorption via the root system [87]. Several cases have documented accumulated microcystin uptake in both field and laboratory settings [101,102]. Submerged species show the highest concentrations present in tissue, with *Elodea canadensis* showing a concentration of 40 µg/g of dry weight [103].”

“While microcystin accumulation proves harmful to essential processes such as photosynthesis, overall height, and weight of the mature plant, aquatic species can detoxify the bacteria through the action of a natural antioxidant, glutathione S-transferases (GSTs) (Table 1). High levels of GSTs found in contaminated plant tissue suggests that microcystin presence may trigger their production [104]. Laboratory studies of several different species show similar results, signaling the likelihood of microcystins contributing to the enhancement of GST concentrations in exposed aquatic plants [38,105].”

Section 7: Human Health Risks

“Epidemiological research has indicated potential health effects of microcystins from human consumption of contaminated drinking water and aquatic foods [15–18]. A recent work posits environmental microcystins as an emergent risk factor in endemic regions plagued by hepatocellular carcinoma [112].”

“Given the discussed high levels of microcystin accumulation in leafy vegetables, including lettuces and spinach when grown through use of contaminated irrigation, the possibility of health risk is present [50,53,74,77–79,91,93,98,99,104].”

“This also raises questions and concerns regarding the potential health risks to agricultural workers who are directly in contact with irrigation water and thus exposed to high microcystin concentrations [77,78].”

Adjusted References (Reordered Labeled)

Switch Original Refs 16 and 17

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The authors sincerely apologize for the errors in the original publication. The changes do not affect the original meaning of the work. This correction was approved by the Academic Editor. The original publication has also been updated.

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