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Mercury and other trace metals in lettuce (*Lactuca sativa*) grown with two low-salinity shrimp effluents: Accumulation and human health risk assessment

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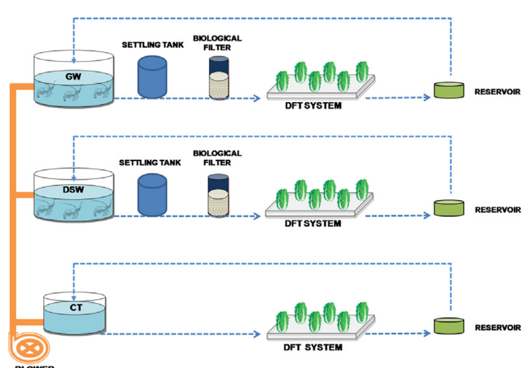
HIGHLIGHTS

- It is feasible to use low-salinity shrimp culture effluents for lettuce production.
- Lettuce production showed a trend using diluted seawater > control > well water.
- Metal levels in lettuce for the treatments showed the same trend Mn > Zn > Cu > Hg.
- Metal levels found did not exceed the safe limits and HRI and THQ indices were < 1.

GRAPHICAL ABSTRACT



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ABSTRACT

Shrimp farming effluents from two sources of low-salinity water, well water (WW) and diluted seawater (DSW) (salinity, 1.7 g L^{-1}; electrical conductivity, 2.7 dS m^{-1}), were used to grow lettuce (*L. sativa*) in order to assimilate the nutrients present in shrimp effluents and produce edible biomass. The two treatments, WW and DSW, were tested in triplicate. Additionally, one hydroponic system in triplicate was constructed to grow lettuce using a nutritive solution as the control treatment (HS). The production variables of lettuce in the two crop varieties (*Parris Island* (VPI) and *Tropicana M1* (VTM1)) showed a general trend of DSW > HS > WW with regards to the size, weight and total foliage, except for the number of leaves, which was higher with HS treatment than with WW and DSW treatments. The accumulation of Cu, Hg, Mn and Zn in edible lettuce tissue and the health risk by the intake of lettuce were evaluated. Heavy metal concentrations in edible lettuce tissue for the three treatments showed the same trend of Mn > Zn > Cu > Hg, with concentration ranges of 47.1 to 188.7, 35.7 to 66.2, 4.1 to 6.4, and 0.01 to 0.02 mg kg^{-1} (dry weight), respectively. Such concentrations did not exceed the safe limits

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Shrimp farming
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(CAC, 1984). The health risk index and target hazard quotient were <1, which indicates that the population exposed to these metals due to intake from lettuce consumption is unlikely to have adverse health effects when shrimp farming effluents are used to grow lettuce plants.

1. Introduction

The current global population has reached 7.2 billion and is expected to reach to 9.7 billion in 2050 (FAO, 2016). This will lead to a 60% increase in global food demand. Fish production (fisheries and aquaculture) contributed 169.2 million tons in 2015, of which aquaculture accounted for 45.3% of the total production to maintain food security. In the last three decades, the aquaculture sector has experienced significant growth, and inland aquaculture is part of this trend, increasing from 29.9 million tons in 2007 to 48.8 million tons produced in 2015. It is worth noting that of the 2.7 million tons of crustaceans (prawns and shrimp) produced, 27% corresponds to inland farming (FAO, 2016). In this context, shrimp farming is associated with several potential negative impacts on the environment by discharge of effluents to the receiving bodies of water, including eutrophication by nutrient excess and contamination by antibiotics as well as other aquaculture additives (Páez-Osuna, 2001; Lyle-Fritch et al., 2006), which includes heavy metals (Lacerda et al., 2006, 2011; León-Cañedo et al., 2017).

Heavy metals such as Cu, Zn, and Mn are referred to as essential micronutrients for humans, animals and plants to regulate and maintain their health. These are required in small quantities, but in excess, they can cause a toxic effect (Salisbury and Ross, 1994; Sparks, 2005). Mercury is not considered an essential element for nutrition; however, it is present in the environment either naturally from volcanic emissions, wildfires and the weathering of the earth's crust or from anthropogenic origins, including association with high temperature processes (smelting, coal combustion and incineration) combined with the commercial uses of Hg (batteries and thermometers) as well as the disposal of Hg–laden wastes (e.g., mining operations) that are converted into volatile forms in the environment (Boyle, 2010).

Recently, Hg, Cu and Zn have been associated with shrimp aquaculture. Lacerda et al. (2006, 2011) and León-Cañedo et al. (2017) have showed that these three metals and Mn are associated to enrichment of sediments and waters from shrimp farms; which is due to the use of chemical products (soil and water treatment compounds, fertilizers, feed additives (copper sulfate, manganese sulfate, zinc sulfate, zinc oxide), and fungicides (copper sulfate)) which are widely used. For example, in Mexico the 91–100% of all shrimp farms applies chemical products containing such metals (Lyle-Fritch et al., 2006). Therefore, the continuous application of these chemical products in shrimp farms can constitute a problem in the use of the effluent produced for the cultivation of lettuce and other vegetables. In intensive shrimp farming, these metals can also originate from the addition of feed (Hg as impurities), followed by incoming water, while organic sludge and output water are the main routes of removal (Tacon and Forster, 2003; Lacerda et al., 2006; Tacon and Hasan, 2007). Although the described metal levels are relatively reduced, these are of concern due to the metal emissions into the adjacent receiving bodies of water (Lacerda et al., 2011; León-Cañedo et al., 2017).

In diverse countries of North America, Europe, Asia and Latin America, industrial and municipal wastewater (treated or untreated) is eventually used for the irrigation of trees, forests and some fodder, mainly in suburban ecosystems, due to its easy availability, disposal problems and scarcity of fresh water (Arora et al., 2008). It is estimated that at least 20 million hectares of land in 50 countries are irrigated with raw or partially treated wastewater (Emenyonu et al., 2010). Several studies have been carried out to evaluate the growth of different vegetables with irrigation using wastewater from different sources, such as lettuce (Cuba et al., 2015), tomatoes (Cirelli et al., 2012), and strawberries (Villarroel et al., 2011). In recent years, effluents and water from aquaculture have been used to irrigate plants. In fact, various studies have been developed to evaluate the potential effect of irrigation using this type of water through traditional technology (Seawright et al., 1998; Palada et al., 1999), aquaponics technology (Rakocy et al., 2004, 2007; Endut et al., 2016) or recirculation systems (Naegel, 1977; Mariscal-Lagarda et al., 2012, 2014; Fierro-Sañudo et al., 2015).

The use of wastewater and/or effluents as an irrigation source for plants provides benefits such as increased production, optimization of water use and a reduction of the fertilizer dosage. However, such use of wastewater also exhibits disadvantages in terms of crops such as the salinization of soils, adverse effects due to the salinity, excess nutrients, and the presence of coliforms (Urbano et al., 2017). In this context, a serious concern has been that heavy metals are easily accumulated in the edible parts of leafy vegetables compared to grain or fruits crops (Mapanda et al., 2005). Our hypothesis is that unlike municipal and industrial waste water, the low-salinity effluents of shrimp aquaculture have lower levels of heavy metals, which makes them viable and acceptable to grow plants such as lettuce.

Lettuce (*Lactuca sativa* L.) is widely consumed around the world, and its production exceeded 24 million tons in 2014 (FAO, 2014). Lettuce is an annual plant of the *Asteraceae* family that normally is cultivated in tropical climates, and it has also been used as bioindicator to evaluate the contamination of soil and water (Wolf et al., 2017). The present study was performed with the aim of evaluating the concentrations of four heavy metals (Cu, Mn, Zn and Hg) in two lettuce varieties, *Lactuca sativa* (*Parris Island* (VPI) and *Tropicana M1* (VTM1)) grown in a deep flow technique (DFT) hydroponic system with shrimp culture effluent. The effect of using shrimp culture effluent is evaluated by examining the accumulation of Cu, Zn, Mn and Hg in lettuce (leafs and roots). Additionally, the human health risk by heavy metal intake associated with lettuce consumption was estimated through the daily intake (EDI) of metals as well as the health risk index (HRI) and the target hazard quotient (THQ).

2. Materials and methods

2.1. Description of the experiment

The study was conducted in the YK Experimental Module located in Mazatlan, Sinaloa, Mexico (23° 12′ 11.9″ N; 106° 25′ 41.29″ W). The experimental system for the shrimp culture consisted of six tanks (2-m diameter × 1.2-m height; 3.14 m^3 capacity per tank), which were coupled to a DFT hydroponic system; the tanks were used for the shrimp culture, and the DFT system was used for the lettuce crop (Fig. 1). Three tanks were filled with well water (WW) with an electrical conductivity (CE) of 2.7 dS m^{-1} (1.7 g L^{-1} of salinity) from a shrimp farm located in southern Sinaloa, and three tanks were filled with diluted seawater (DSW) with the same electrical conductivity (2.7 dS m^{-1}) prepared with seawater (34 g L^{-1}) and fresh water (0.2 g L^{-1}) from the domestic supply. The coupling of the lettuce with the shrimp tanks was performed just after the shrimp were harvested (7 weeks of growing). The shrimp culture effluent used in both treatments (WW and DSW) is defined here as the water remaining at the end of a culture cycle, which normally shrimp farmers discharge during the harvest.