International Biodeterioration & Biodegradation 124 (2017) 314–325

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Assessment of heavy metals in aquaculture fishes collected from southwest coast of Taiwan and human consumption risk

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A R T I C L E I N F O

Article history:
Received 7 February 2017
Received in revised form
5 April 2017
Accepted 5 April 2017
Available online 8 April 2017

Keywords:
Metals
Tilapia
Bioaccumulation
Aquaculture
Human health risk

A B S T R A C T

The present study determined the metal levels in aquaculture fish of tilapia and water and sediments in the southwestern Taiwan and estimated the human health risk assessment for consumption of tilapia. Bioconcentration factor (BCF) and biota-sediment accumulation factor (BSAF) were used to assess the metal accumulation ability of biotas, while metal pollution index (MPI) was assessed to compare the pollution level of total eight metals for the different sampling sites and tissues of tilapia. Metal level in tissues revealed a tissue-specific bioaccumulation pattern. Except for Cu, the highest metal burden was found in kidney, showing the significant differences in metal concentration of kidney with the other tissues of tilapia. Muscle accumulated the low concentrations of Hg (0.19 ± 0.21 μg g^{-1} dry wt), Cd (0.05 ± 0.02), As (0.06 ± 0.05), Cu (1.61 ± 1.17), Zn (21.5 ± 10.2), and Ni (1.01 ± 1.03). Results allowed putting the mean MPI of tissues in order from the highest to lowest value, kidney (6.92) > GI tract (2.06) > liver (1.25) > gill (0.80) > muscle (0.59). In addition to Hg and Cd, the estimate of BCF was greater that of BSAF for other metals, demonstrating that the bioaccumulation of Hg and Cd for tilapia collected from aquaculture ponds was from the sediments, as well as the bioaccumulation of other metal was from water. Correlation analysis found that Fulton's condition factor (K) of tilapia had the negative relationship with MPI for muscle, liver, and kidney, meaning decreasing K of tilapia was with the increasing estimates of MPI. For the human health risk assessment, tilapia cultured in the southwest coast of Taiwan was found to be low-risk for consumption and do not surface a potential threat to the health of general human consumers. Results in this effort can assist the government in determining seafood safety and its implementation in Taiwan.

1. Introduction

Metals originally present in the natural environments, yet the anthropogenic sources of metals including mining, industrial, traffic, domestic sewage, and atmospheric deposition vastly elevate the metal concentration in the environments, as well as the aquatic environments (Sapkota et al., 2008; Gu et al., 2015; Saha et al., 2016). With the sharply rapid population growth and economic development, the increase in the discharge of wastes into aquatic environments has led to a significant increase in metal contamination (Dhanakumar et al., 2015). Metals in the environments are non-biodegradable and persistent, and that result in bio-accumulation of metals in organisms (Rajkowska and Protasowucki, 2013; Zhang et al., 2016). Some essential metals are required to play the important roles in physiological metabolisms for organisms, such as Cu, Zn, Ni, and Fe. It also could be toxic for organisms when the overloading essential metals are accumulated in body. For the other non-essential metals, including Hg, Pb, and Cd, those are regarded as uselessness or even hazard for organisms (Ruelas-Inzunza et al., 2011; Gu et al., 2015).

Measuring the metal bioaccumulation in aquatic organisms could assess the possible impacts related to metal pollution in the environments, taking into account bioavailability aspect (Liang et al., 1999; Abdel-Baki et al., 2011; El-Moselhy et al., 2014; De Jonge et al., 2015; Dhanakumar et al., 2015; Abdel-Khalek et al., 2016). For the organisms, the assimilation rate of metals through the surrounding media greater than the rates of elimination and

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http://dx.doi.org/10.1016/j.ibiod.2017.04.003
0964-8305/

physiological metabolism derive the metal bioaccumulation (Farkas et al., 2003). The bioaccumulation pattern of metals in organisms can be linked to the metal-induced adverse responses to consider the concept of bioavailability (Bervoets and Blust, 2003; Neff and Cargnelli, 2004; Couture and Pyle, 2008; Ruelas-Inzunza et al., 2011; Kasimoglu, 2014). Following the linkage, metal bioaccumulation in fish tissue can be used to predict the potential impacts of metal exposure on fish health. In the beginning, no matter for essential or non-essential metals, the adverse effects are not appeared immediately when metals penetrated into the organisms, until the metal burdens accumulated in the organism exceeded the threshold that organisms can afford (Gu et al., 2015; Abdel-Khalek et al., 2016). Investigations of metal bioaccumulation in fish in the aquatic environments have been executed in food safety fields for years (Liang et al., 1999; Lin et al., 2005; Ling et al., 2013; Dhanakumar et al., 2015; Hsi et al., 2016). There are many routes for fish exposure to metals, including direct uptake through gill and biological membranes (waterborne) and digestion of food and sediment matters in the digestive tract (dietary), and metals end up in the body of fish. Rajkowska and Protasowucki (2013) indicated that metal distribution among varied tissues is mainly depended on the metal content in water and food, and therefore it can serve as a pollution indicator of the environments. Generally, liver and kidney were regarded as the organs having high metal accumulation, while muscle and gill have relative low metal burden (Rajkowska and Protasowucki, 2013; Taweel et al., 2013). Farkas et al. (2003) suggested that gill can directly reflect the metal level in water and the storage mechanism will be appeared in hepatic metal content. The patterns of uptake and bioaccumulation depend on metals, species, organs, life stage, diet type, and environmental factors. Consequently, bioaccumulation of metals will be a suitable preliminary assessment for the health of aquaculture fish and human food safety.

In order to provide enough nutrition to rapid growth population in the 20th century, the demand for seafood products is increasing (Sapkota et al., 2008). Aquaculture production is also steadily expanding year by year. Larsen and Roney (2013) analyzed the global demand for animal protein and found global farmed fish production exceeded beef production in 2011. Moreover, fish is a main source of nutrition and is widely consumed in coastal regions (Saha et al., 2016). As if aquaculture fish farmed in the metal-contaminated environments, fish could accumulate metals through water, sediment, and feeds; consequently, human who has high consumption rate of fish could be exposed to the higher health risk. For vulnerable population, such as the old, children, and pregnant woman, the limitation of metal daily uptake for them should be more stringent than the general population to prevent them from having the metal-induced adverse effects. (Oken et al., 2012). As far as we know, the potential non-carcinogenic risks can be assessed by the hazard quotient (HQ) and total hazard quotient (THQ) proposed by the US EPA to quantify the health risk for fish consumption (Cheung et al., 2008; Gu et al., 2015; Abdel-Khalek et al., 2016; Zhang et al., 2016).

Aquaculture is commonly positioned in the coast area of Taiwan, ascribing its geographic environment and close to the water source (Ling et al., 2013). Aquaculture industries play a vital role in the economy of Taiwan's agriculture. About 0.7% of total global fish production was from Taiwan recorded by the United Nations Food and Agriculture Organization (FAO) (Sapkota et al., 2008). However, coastal areas always have high population density and intense economic activity (Martínez et al., 2007). For this study area, it is needed to pay the attention for the metal bioaccumulation of aquaculture organisms because fish farms are located near the naphtha cracker plant, which may release metal into air by burning activity. Moreover, in the aquaculture environments, the Cu-based antifoulants and formulated fish feeds could be also the extra sources of metals (Sapkota et al., 2008).

Tilapia is a commercially major fish and is stocked traditionally in Taiwan. Tilapia, an omnivorous filter feeder, was introduced into Taiwan in 1946. The Fisheries Statistical Yearbook in Taiwan for 2015 reported that the fish production and value of tilapia were respectively about 70,472 metric tons and NT$ 3.53 billion per year, with the rank of fourth in the major seafood species in recent years (Fisheries Agency, 2016). Straus (2003) indicated that tilapia is the most tolerant fish to exist on the poor water quality than that most commonly farmed freshwater fish. Tilapia have been reported by many studies as a suitable vertebral organism for being used extensively to research in biological, physiological, and toxicological (Nussey et al., 1995; Pelgrom et al., 1995; Wong and Wong, 2000).

Under certain conditions, human accumulate metals through consumption of aquaculture organisms and could have adverse effects on body (Saha et al., 2016). Previous studies have investigated the metal contents of farmed fish (tilapia and milkfish) in Taiwan, indicating tilapia might own tendency to accumulate metals from the aquaculture environments and then pose health risk to consumers (Ling et al., 2009, 2013; Gu et al., 2015). Therefore, for clarifying aforementioned doubt, the objectives of the present study were carried out as following: (i) to discriminate the bioaccumulation and distribution of metals (Hg, Pb, Cd, Cr, As, Cu, Zn, and Ni) in the selected tissues (muscle, gill, liver, kidney, and gastrointestinal tract) of tilapia from aquaculture in the southwestern coast of Taiwan, and (ii) to estimate the daily metal intake ascribing from the consumption of cultured tilapia and then conduct a human health risk assessment of metals for Taiwanese.

2. Materials and methods

2.1. Study area and collection

In this study, fish samples (tilapia) were collected from the aquaculture ponds distribute the area of southwestern Taiwan in 2015 and 2016 (Fig. 1). The locations of sampling site are shown in Table 1. Sampling sites are close to the naphtha cracker plant, which is located at the southwestern coast line of Taiwan. The distances from each sampling site to the naphtha cracker plant are measured to investigate the effect of them on the metal accumulation in tilapia (Table 1). Water and sediments samples from each site were respectively collected in polyethylene bottles of one liter and polyethylene plastic bags and transported to the laboratory and preserved in a freezer for further analysis. A total of 26 tilapias were held in polyethylene bags with ice, labeled and transported to the laboratory in 24 h. The mean body weight and length of collected tilapias were measured before they were dissected. Tilapias were dissected and five tissues of muscle, gill, liver, kidney, and gastrointestinal (GI) tract were obtained and ready to freeze-dry.

2.2. Determination of heavy metals

The tissues of fish samples were freeze-dried for 1 day until the sample was constant weight. Each dried tissue sample was ground by a set of porcelain mortar and pestle. Tissue sample was weighted (0.5–1.0 dry weight), and digested with hydrogen peroxide (>35% H_2O_2, SHOWA) and nitric acid (67–70% HNO_3, Fisher Scientific) in glass beaker at 95 °C until the solution become clear. At the end of the digestion and after cooling, the samples were diluted to 25 mL with deionized distilled water and then analyzed for metal content.

The sediment samples were first sieved and particles with diameter >63 μm were discarded. The sieved sediment samples were dried naturally at room temperature and gently homogenized