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Impacts of aeration management and polylactic acid addition on dissolved organic matter characteristics in intensified aquaponic systems

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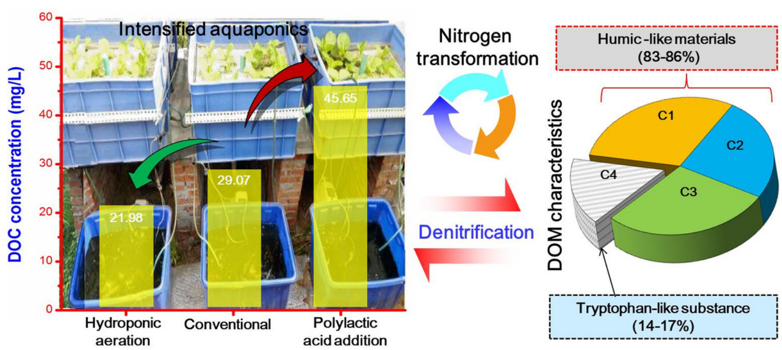
HIGHLIGHTS

- Hydroponic aeration and PLA addition cleary altered the DOM quality in aquaponics.
- Humic-like and tryptophan-like substances were identified by EEM-PARAFAC analysis.
- Humic acid-like fluorescence could be affected more than other fluorophores.
- DOM reduction was mainly connected to the denitrification pathway in aquaponics.

GRAPHICAL ABSTRACT



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ABSTRACT

Aquaponics as a potential alternative for conventional aquaculture industry has increasingly attracted worldwide attention in recent years. However, the sustainable application of aquaponics is facing a growing challenge. In particular, there is a pressing need to better understand and control the accumulation of dissolved organic matter (DOM) in aquaponics with the aim of optimizing nitrogen utilization efficiency. This study was aiming for assessing the characteristics of DOM in the culture water and the relationship with the nitrogen transformations in different intensified aquaponic systems with hydroponic aeration supplement and polylactic acid (PLA) addition. Two enhancing attempts altered the quantity of DOM in aquaponic systems significantly with a varying DOM content of 21.98–45.65 mg/L. The DOM could be represented by four identified fluorescence components including three humic -like materials (83–86%) and one tryptophan-like substance (14–17%). The fluorescence intensities of humic acid-like components were decreased significantly after the application of intensifying strategies, which indicating that two enhancing attempts possibly affected humic acid-like fluorescence. Variation of optical indices also suggested the reductions of water DOM which could be impacted by the enhancing

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nitrogen treatment processes. These findings will benefit the potential applications and sustainable operation of these strategies in aquaponics.

1. Introduction

Aquaponics, as a typical recirculation aquaponic system (RAS) with better environmental and economic benefits, has been attracting considerable attention and was applied in many countries (Love et al., 2015; Hambly et al., 2015; Buric et al., 2016; Chakravartty et al., 2017). Aquaponics is a soilless and closed-loop agriculture system which synergistically combines conventional aquaculture with hydroponics, and these systems could achieve a sustainable production of fish and plants simultaneously (Wongkiew et al., 2017). However, the rapid development of aquaponics has several challenges including investment, operation and other environmental concerns. Moreover, an operational failure may emerge due to the bad water quality conditions and the accumulation of potentially toxic compounds such as ammonia generated in the system (Pedersen et al., 2009; Hambly et al., 2015; Yamin et al., 2017; Fang et al., 2017a).

Many attempts at solving such problems are typically carried out by regulating operation parameters, adjusting treatment processes and applying new technologies (Müller-Belecke et al., 2013; Zhu et al., 2015; Fang et al., 2017a; Fang et al., 2017b; Zou et al., 2016a; b). In these years, the promotion of aquaponics has been commonly focused on improving nitrogen utilization efficiency particularly (Zou et al., 2016a; b; Wongkiew et al., 2017; Zou et al., 2017). Generally, nitrogen transformations in aquaponics could be affected by several factors including pH, dissolved oxygen, hydraulic loading rate, carbon to nitrogen ratios, as well as ammonia and nitrite concentrations (Wongkiew et al., 2017). In particular, it has been demonstrated that the dissolved organic matter (DOM) concentration is of great importance to the effectiveness of treatment processes such as particle/solids and nitrogen removal (Summerfelt and Vinci, 2008; Timmons and Ebeling, 2010; Guerdat et al., 2011). Ling and Chen (2005) observed that nitrification performance decreased significantly with the addition of dissolved organic carbon (DOC) into the water matrix. Negative impacts on nitrification efficiency with increases in C:N ratios was also observed by Hu et al. (2009), and high C:N ratios should be avoided by other studies (Michaud et al., 2014). Moreover, it is suggested that the efficient and successful management of aquaponics is heavily dependent on controlling the accumulation and quality of DOM in the system (Yamin et al., 2017). Monitoring and controlling DOM content in aquaponics could also be beneficial to the prevention and prediction for aquaponics failure (Hambly et al., 2015). Given the importance of DOM in aquaponic systems, it is of great interest to characterize and evaluate the quantity and quality of DOM in these systems.

Recently, the fluorescence excitation-emission (EEM) spectrophotometry and parallel factor analysis (PARAFAC), as a rapid and precise tool, provides an alternative to the traditional methods for determination of DOM concentration and characteristics in regard to aquaponics systems (Hambly et al., 2015; Yamin et al., 2017). Hambly et al. (2015) firstly applied EEM-PAFAFAC analysis to characterize and understand the accumulated DOM. Furthermore, EEM-PAFAFAC approach was used to characterize changes in DOM composition of the culture water during long-term operation of a zero-discharge aquaculture system (Yamin et al., 2017). Nevertheless, these studies were only aim to test if the EEM-PAFAFAC technique can identify characteristic organic matter fractions in aquaculture system and can be used as a sensitive monitoring parameter of system water quality. In our previous studies, two types of optimization methods including aeration in hydroponic bed and addition of polylactic acid (PLA) were applied successfully to promoting nitrogen transformations and nitrogen utilization in aquaponics, and a better environmental and economic benefits were also obtained (Zou et al., 2017). However, compared to previous conventional aquaponics, there is still limited information on the characteristics and biodegradability of DOM and its impact on nitrogen transformations in these intensified aquaponic systems with the aim of the sustainable operation.

Thus, the primary purpose of this study was to investigate DOM characteristics in two types of intensified aquaponic systems (hydroponic aeration supplement and PLA addition) by exploiting EEM-PARAFAC technique. The content of water DOM in different intensified aquaponic systems was quantified, and the composition and properties of water DOM were identified. Moreover, the relationship between water DOM variation and nitrogen transformations was analyzed to elucidate the mechanisms of intensifying methods in optimizing nitrogen transformation and benefits of aquaponic systems.

2. Material and methods

2.1. Experimental aquaponic system

Experiments were carried out in the greenhouse at central campus of Shandong University in Jinan, China (36°40′36″N, 117°03′42″E). Different experimental aquaponic systems, i.e., hydroponic aeration aquaponics (System 1, HAA), conventional aquaponics (System 2, CA) and PLA added aquaponics (System 3, PLAA), were setup with three parallels. All systems used in this study comprised a fish tank ($85 \times 55 \times 45$ cm) with an effective volume of total 100 L and a media-based hydroponic bed ($70 \times 50 \times 45$ cm), which were equipped with air compressor for supplying air and peristaltic pump for circulating water (Fig. 1). The more detailed description for each system can be found in our previous study by Zou et al. (2017) and Zou et al. (2016a, b). Particularly in this study, a 10 cm bottom layer of gravel (3–5 mm in diameter) and a 20 cm top layer of perlite (1–2 mm in diameter) were served as the supporting fillers in the hydroponic bed of HAA and CA systems. While for PLAA system, the gravel layer in the hydroponic bed was replaced with a mixing layer of gravel and PLA at the volume ratio of 1:1 (Zou et al., 2017). In the HAA system, a concentric-circle aeration diffusor was installed at the bottom of hydroponic bed for achieving uniform aeration. Common carp (Cyprinus carpio) and Chinese cabbage (Brassica chinensis), which are very popular in northern China, were selected in the present study. The cabbage (with similar size and weight of 0.8 g) and carps (weighting about 45–70 g) were cultured at an initial density of 25 plants/m^2 and 12 kg/m^3. During the experimental period, there was no death and disease for fish and plants, and at the end of the experiment, the increased biomass of fish and plants in different aquaponic systems were 2.54–3.22 kg/m^3 and 3.04–4.87 kg/m^2, respectively (Zou et al., 2017).