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Short communication

Removal of the off-flavor compounds geosmin and 2-methylisoborneol from recirculating aquaculture system water by ultrasonically induced cavitation

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ABSTRACT

With its high economic impact, off-flavor in fish is still one of the most serious problems in the aquaculture industry worldwide. Until now, the highly cost- and time-intensive, as well as capacity demanding depuration procedure by moving the fish to clean and odor-free water for a certain time prior to harvest is the only reliable way to counteract off-flavors in aquaculture. Alternative strategies and processes for efficient off-flavor prevention are still lacking. Hence, the aim of this study was to investigate the potential of ultrasonic water treatment to decrease the concentration of the relevant off-flavor compounds geosmin (GSM) and 2-methylisoborneol (2-MIB) in aquaculture water. Therefore, different water matrices, varying in their organic and inorganic load and composition (tap water, RAS fresh water, RAS sea water), were spiked with 2-MIB and GSM standard and subsamples of 250 mL were subsequently treated for 15 min using a lab-scale ultrasound transducer at 850 kHz. For verification samples from commercial RAS containing biogenic 2-MIB and GSM were treated equally. The effects of ultrasound frequency and salinity on the removability of 2-MIB and GSM via ultrasonic treatment were investigated by comparing the removal efficiency of high (850 kHz) vs. low (20 kHz) frequency ultrasound and by adding artificial sea salt (10 ppt) to different freshwater samples prior to ultrasound treatment, respectively.

Results have demonstrated that ultrasonically induced cavitation significantly reduces the tested off-flavor compounds GSM and 2-MIB in all tested water types, seemingly irrespective of the (in)organic load. In general, the reduction of GSM was slightly higher compared to that of 2-MIB. Furthermore, the reduction of tested off-flavor compounds was significantly enhanced at high frequency ultrasound (850 kHz) compared to low-frequency ultrasound (20 kHz). The addition of artificial sea salt to fresh water samples caused an additional improvement in removability of both off-flavor compounds.

Our results evidence high frequency ultrasound as a potential treatment process for significant removal of the relevant off-flavor compounds 2-MIB and GSM from RAS process water. In particular, the seemingly low dependency of the ultrasound-induced removal of GSM and 2-MIB on the organic and inorganic process water load predestines ultrasonically induced cavitation as a potential strategy for off-flavor prevention in RAS compared to alternative strategies such as advanced oxidation processes or adsorption processes.

1. Introduction

A great deal of attention has been focused on the negative taste and odor of fish apparently associated with off-flavors encountered in aquaculture systems worldwide. Off-flavor in fish is associated with high levels of 2-methylisoborneol (2-MIB) and geosmin (GSM), which are secondary metabolites, released by different microorganisms, such as cyanobacteria (Izaguirre et al., 1982), actinomycetes (Zaitlin and Watson, 2006) or fungi (Mattheis and Roberts, 1992). These compounds are generally characterized by a slow rate of biodegradation (Ho et al., 2007) and their lipophilic affinity. Furthermore, the relevant concentrations of both compounds in the range from ng/L to μg/L might be too low to compensate the metabolic costs associated to their utilization for biodegradation (Arrieta et al., 2015). Therefore, both compounds

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accumulate in the culture water, where they are directly absorbed through the gills and subsequently stored in the lipid-rich tissue of fish. There are several factors influencing the uptake and depuration rate of these two compounds including the ventilation rate of the gills or fat-content of the tissue (From and Hørlyck, 1984; Martin et al., 1988). Studies have indicated that even very low concentrations of GSM and 2-MIB in the range of ng/L in the surrounding water and a high bio concentration factor (BCF) are sufficient to contribute an earthy-musty smell and taste in fish (Howgate, 2004). Furthermore, the aerobic and organic rich conditions in aquaculture water aggravate the emission of metabolites caused by the stimulation of the growth of off-flavor producing microorganisms (Guttman and van Rijn, 2008). Moreover, off-flavor often appears with extensive seasonal variability or sporadic concentration disparity. As a consequence, the development of strategies to avoid off-flavor events at an early stage proved to be difficult (Tucker, 2000).

The frequent events of off-flavored fish products have adversely affected the economic gains due to a poor product quality (Engle et al., 1995). It has been estimated that in the U.S. catfish production off-flavors add \$15–\$23 million additional production costs annually due to harvest delays or the expensive application of liquid copper products reducing off-flavor occurrences (Hanson, 2003). Currently there hardly exist effective methods or strategies to avoid off-flavor in practice.

Until now, purging off-flavored fish by moving the fish to clean and odor-free water for a certain time prior to harvest is still the only reliable method to counteract off-flavors in aquaculture. However, the weight loss of the fish due to starvation, the extended consumption of resources (e.g. energy, holding site) and the large quantity of clean water required lead to a cost intensive and time consuming process. Moreover, the highly wasteful consumption of clean water for aquaculture is a luxury reserved for countries with sufficient water resources. For this reason there is a growing interest to identify cost-effective alternative technologies that prevent or remove off-flavor compounds efficiently.

A number of strategies have been investigated to prevent the growth of cyanobacteria, as one of the main off-flavor producing organisms, e.g. manipulating nutrient availability by phosphorus removal (Wu and Boyd, 1990), biomanipulation by planktivorous fishes (Perin et al., 1996) or algaecides (Schrader et al., 1998). However, the wide range of off-flavor producing and often unknown microorganisms reduces the chance for a selective removal or avoidance of these organisms. Additionally, these strategies restrict biological cleaning applications often used in RAS like bio filtration or result in the lysis of off-flavor producing cells and the release of GSM and 2-MIB into the water.

Accordingly, common methods for treatment of drinking water were conducted with the focus on the reduction of off-flavor compounds in aquaculture water. The biodegradation of GSM or 2-MIB with a biological sand filtration (Ho et al., 2007) or anaerobic sludge digestion treatment (Guttman and van Rijn, 2009) offered some good results but did not reveal an efficient solution to remove 2-MIB and GSM in an aquaculture system. The adsorption with granular (GAC) or powdered activated carbon (PAC) is restricted by natural organic matter (NOM) due to clogging or competitive adsorption, so that a high economic ineffective dose of activated carbon is required to remove off-flavor compounds to an acceptable concentration (Chen et al., 1997; Cook et al., 2001). Experiments with conventional chemical oxidizing agents showed encouraging removal rates but with regard to further implementation in an aquaculture system, the occurring side effects exclude the applicability of these methods. For example, the applied doses of chlorine or chlorine dioxide to reduce off-flavor substances could produce disinfection by products (DBPs) like trihalomethanes (THMs) or haloacetic acids which are highly toxic to aquatic animals (von Sonntag and von Gunten, 2012). The application of "low-dose" ozone to improve certain water quality parameters did not significantly reduce off-flavor compounds. The addition of higher dosages of O_3 might remove 2-MIB and GSM in RAS water but required ozone-reducing strategies to avoid the risk of ozone toxicity (Schrader et al., 2010). To improve the oxidation efficiency, advanced oxidation processes (AOPs) like UV/O_3 or UV/H_2O_2 have received considerable attention due to the specific enhanced generation of the more powerful hydroxyl radical ($OH^•$). However, these methods are limited by dissolved or non-dissolved substances of aquaculture water caused by competitive oxidation processes with other organic matter or inorganic radical scavengers (Klausen and Grønborg, 2010) and the production of fish toxic DBPs (Tango and Gagnon, 2003).

In recent years ultrasound has received attention in view of several applications in water treatment. The advantage of this technique is the occurrence of cavitation caused by ultrasonically induced pressure waves. Cavitation is the formation and the sudden implosion of vapor cavities in a local hot spot under extreme conditions ($p > 100$ atm, T °C to 5200 K) (Suslick et al., 1986). Whereas in the stable cavitation the microbubbles oscillate around a certain radius, in the transient cavitation the bubble radius increases in a couple of acoustic cycles until the bubble implodes. This implosion causes mechanical as well as sonochemical effects. The mechanical effects are a combination of turbulences, liquid circulation currents and shear forces via shock waves (Piyasena et al., 2003). The sonochemical effects include the thermal dissociation (pyrolysis) inside of the hot spot and the generation of free radicals or secondary oxidants. For example, hydrogen atoms and hydroxyl radicals were generated by the thermal dissociation of water vapor. The formation of secondary oxidants such as hydrogen peroxide derived from the recombination of two hydroxyl radicals (Riesz, 1992). The quantity and the effects of cavitation depend on the intensity (W/m^2), irradiation time and frequency (kHz) of ultrasound as well as from the reactor configuration. High-frequency ultrasound produces more small cavities than low-frequency ultrasound due to the shorter wave length and less time for bubble growth, respectively. Therefore low-frequency ultrasound gives more time for growth, so that bigger cavities collapse more violently by achieving larger maximum sizes. As a consequence, higher shear forces in combination with sonochemical effects are expected at low frequencies while at higher frequencies only sonochemical effects are present (Portenlänger and Heusinger, 1997).

Song and O'Shea (2007) have demonstrated a high potential of high-frequency ultrasound water treatment (640 kHz) for the removal of GSM and 2-MIB in demineralized water. Experiments with radical scavengers have revealed the ultrasound-induced pyrolysis as the dominant degradation process rather than the radical reaction pathway. Furthermore, the ultrasound treatment at 200 kHz has shown higher removal rates of off-flavor compounds than at lower frequencies in pond water (Srisuksomwong et al., 2011).

In RAS the application of ultrasound has hardly been carried out. Hence, the aim of the present study was to investigate the ultrasound-induced degradation of GSM and 2-MIB in different RAS water matrices. Optimization capabilities were examined by investigating the influences of salinity and frequency of the off-flavor degradation.

2. Material and methods

2.1. Experimental setup

2.1.1. Experiment with standard solution in different water matrices

In order to investigate the ultrasonically induced degradation of off-flavor in aquaculture water, samples from RAS were