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Tracking pollutants in dietary fish oil: From ocean to table☆

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ABSTRACT

Dietary fish oil used in aquafeed transfers marine pollutants to farmed fish. However, the entire transfer route of marine pollutants in dietary fish oil from ocean to table fish has not been tracked quantitatively. To track the entire transfer route of marine pollutants from wild fish to farmed fish through dietary fish oil and evaluate the related human health risks, we obtained crude and refined fish oils originating from the same batch of wild ocean anchovy and prepared fish oil-containing purified aquafeeds to feed omnivorous lean Nile tilapia and carnivorous fatty yellow catfish for eight weeks. The potential human health risk of consumption of these fish was evaluated. Marine persistent organic pollutants (POPs) were concentrated in fish oil, but were largely removed by the refining process, particularly dioxins and polychlorinated biphenyls (PCBs). The differences in the POP concentrations between crude and refined fish oils were retained in the fillets of the farmed fish. Fillets fat content and fish growth were positively and negatively correlated to the final POPs deposition in fillets, respectively. The retention rates of marine POPs in the final fillets through fish oil-contained aquafeeds were 1.3%–5.2%, and were correlated with the POPs concentrations in feeds and fillets, feed utilization and carcass ratios. The dietary crude fish oil-contained aquafeeds are a higher hazard ratio to consumers. Prohibiting the use of crude fish oil in aquafeed and improving growth and feed efficiency in farmed fish are promising strategies to reduce health risks originating from marine POPs.

1. Introduction

Fish are an important food, as they provide abundant nutrients, particularly n-3 polyunsaturated fatty acids (PUFAs), such as eicosapentaenoic acid and docosahexaenoic acid, which reduce the risks for cardiovascular diseases and alleviate the inflammation process (Bucher et al., 2002; Iso et al., 2006; König et al., 2005; Kris-Etherton et al., 2002). However, fish are main vectors transferring environmental pollutants to humans through food intake (Alcock et al., 1998; Harrison et al., 1998; Llobet et al., 2003). For example, fish contain the highest concentrations of polychlorinated biphenyls (PCBs) of almost all daily foods in Belgium accounting for about 50% of total daily PCB intake (Voorspoels et al., 2008). Moreover, Kiviranta et al. (2004) reported that fish are the major source of dioxins in Sweden, Norway, and Italy. Therefore, the benefits and risks of consuming fish have caught the attentions of scientists and administrators.

Notably, direct consumption of wild captured fish is decreasing and a large proportion of daily fish intake is sourced from aquaculture. Hence, the food safety of farmed fish has become particularly important health topic. Some studies indicate higher

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concentrations of pollutants, particularly persistent organic pollutants (POPs), including polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCPs), and PCBs are found in farmed than those in wild-caught fish (Hites et al., 2004; Rodríguez-Hernández et al., 2017). However, other studies show that farmed fish contain fewer contaminants than the corresponding wild species (Lundebye et al., 2017). The contradictory results could be explained by the fact that the pollutant concentrations in farmed fish are closely related to contaminated aquafeeds which vary depending on pollution status of different aquaculture regions (Berntssen et al., 2005; Blanco et al., 2007; Friesen et al., 2015; Hites et al., 2004; Karl et al., 2003; Lundebye et al., 2004). It has been clearly indicated that increasing dietary exposure of dioxin and dioxin-like PCB in salmon would significantly increase the concentrations of these pollutants in both salmon fillets and whole fish (Lundebye et al., 2004). Therefore, the content of pollutants in aquafeeds is an important factor affecting the safety of farmed fish.

Fish meal and fish oil, which are mainly sourced from wild-caught ocean fish, are the two main dietary ingredients in the aquafeed industry. A number of studies have demonstrated that including fish meal and fish oil in aquafeed positively correlate with the pollutants in farmed fish (Berntssen et al 2010, Berntssen et al 2005; Hamilton et al., 2005; Jacobs et al., 2002; Tacon and Metian, 2008). marine POPs tend to accumulate in the lipids of wild ocean fish because of their lipophilic characteristics and ultimately are transferred to fish oil, which is extracted from wild-caught ocean fish (Martí et al., 2010). Thus, fish oil accumulates 30-fold and 9-fold greater coplanar PCBs than bone meal, fish meat and fish meal (Guruge et al., 2005). In addition, fish oil also contains a large number of heavy metals, but the concentrations of heavy metals in fish oil are much less than those in fish meal (van de Ven, 1978). Therefore, fish oil has been identified as one of the major vectors to deliver pollutants, mainly POPs, from ocean to farmed fish through aquafeeds.

A refining process is necessary to produce fish oil for human consumption, and it can largely reduce the concentrations of environmental pollutants in the final fish oil products (Berntssen et al., 2010). However, a large number of aquafeed producers continue to use crude fish oil as a dietary oil source, especially in developing countries. One reason is that using crude fish oil decreases costs. Another more important reason is that the influence of a crude fish oil-contained diet and refined fish oil-contained diet on the potential health risks of the final farmed aquatic products have not been compared. Subsequently the use of crude fish oil in aquafeeds has been overlooked by aquafeed producers and administrators. Moreover, the transfer efficiency of the dietary fish oil-containing pollutants from ocean to farmed fish has not been precisely evaluated through the whole transmission process, including industrial and aquaculture processes. As different farmed fish species have different growth performances and biochemical compositions, whether the transfer efficiency of fish oil-containing pollutants from ocean to farmed fish varies from fish species also remains unknown. All these have caused severe difficulty to assess reliably the final health risks caused by supplementing fish oil in aquafeeds.

In the present study, we obtained crude and refined fish oils originating from the same batch of wild-caught ocean anchovy from the Chinese Yellow Sea and Bohai Sea, and performed a tracking study to investigate transfer of environmental pollutants from wild fish to farmed fish through fish oil-contained aquafeed. To distinguish the possible different transfer efficiencies among different farmed fish species, we chose Nile tilapia (*Oreochromis niloticus*) and yellow catfish (*Pelteobagrus fulvidraco*), which are omnivorous lean fish and carnivorous fatty fish, respectively, as the farmed fish. The concentrations of dioxins, PCBs, dichlorodiphenyltrichloroethane (DDTs) and heavy metals (lead, Pb and arsenic, As) in anchovy, crude and refined fish oils, dietary ingredients, fish culture water and the fillets of farmed fish were measured. We also calculated the transfer efficiencies of fish oil-containing pollutants in the two farmed fish species. The potential human health risks were assessed if the fillets of the farmed fish were consumed. The whole study design is presented in Fig. 1.

The main results of the present study indicate that: 1) differences in POPs concentrations between crude and refined fish oil were retained in the fillets of the farmed fish fed with the corresponding fish oils; 2) the deposition rates of marine POPs in fillets of farmed fish were 1.3%–5.2%, and varied slightly between fish species; 3) the use of crude fish oil in aquafeeds produces final aquatic products with a higher health risk to consumers.

2. Methods

2.1. Collection of wild anchovy and industrial fish oil preparation

In the present study, the anchovy (*Engraulis mordax*) as the raw material for fish oil were caught by using a seine net with 8 mm mesh size in Bohai Sea and Yellow Sea of China during November 2014 to January 2015. A total of 10 tons of anchovies were transported in ice cold containers to two different factories for crude fish oil (CFO) extraction in Shandong province, China, to make crude fish oil 1 (CFO1) and crude fish oil 2 (CFO2). The industrial processing protocols of both factories were the same, mainly included stewing, squeezing, alkaline neutralization and vacuum drying, and the oil extraction rate was around 2% (final fish oil/total anchovies). The obtained CFOs from two factories (around 200 kg) were reprocessed to refined fish oil (RFO) in another oil refining factory in Guangdong province, China, mainly through degumming, alkaline neutralization, vacuum drying, bleaching and winterization. Finally, 180 kg RFO was obtained. The processing protocols of crude fish oil extraction and refining used by these factories are common in the majority of crude fish oil extraction factories in China. The CFO1, CFO2 and RFO were then used as dietary lipid sources to make three purified fish diets. The study design for the whole tracking study is shown in Fig. 1. During the study, the concentrations of pollutants were detected in all components used including anchovy, crude and refined fish oils, dietary ingredients, fish culture water, and the fillets of farmed fish.

2.2. Fish, diet preparation, feeding trial and sampling

In order to evaluate the effects of fish species and body chemical composition on the pollutants accumulation, two widely cultured species, juvenile Nile tilapia (*Oreochromis niloticus*) as an omnivorous lean fish and yellow catfish (*Pelteobagrus fulvidraco*) as a carnivorous oily fish, were chosen. Fish were obtained from the Fishery Genetic Resources Experiment Station of Shanghai Ocean University (Shanghai, China). Three purified diets were formulated and prepared by using pure casein and gelatin as protein sources, pure corn starch as carbohydrate source and the processed fish oils as the unique lipid sources. Purified diets were necessary in order to avoid possible contaminations from exogenous pollutants sources. The fish oil content in the diets was set as 10%, a dietary lipid level that is commonly used in experimental or practical diets for Nile tilapia (Ng et al., 2013) and yellow catfish (Wang et al., 2014). The diets were prepared as previously described (He et al., 2015). The formulation (g/kg) and proximate analysis of the trial diets (%) are presented in the Supplementary Table S3.

Before the formal experiment, about 600 fish from each species were acclimated for one week, during which they were fed with a commercial diet (Dajiang, China). After acclimation, 180 visually