State of the Aqua Feed Industry in Asia

Key to Indonesian Shrimp Farming

Aqua Feeds 2.0: From Farm to Plate

DHA in Seafood for Human Health

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DHA in seafood for human health

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As a major source of DHA for human health, farmed fish need alternative and sustainable sources of dietary DHA to replace fish oil.

Scientific studies emphasise the importance of long chain omega-3 polyunsaturated fatty acids (LC-PUFA) in human health and in particular the benefits of docosahexaenoic acid (DHA, 22:6 n-3). The minimum FAO recommendation is 250 mg DHA/day/person. However, supplies of fish oil, the most common natural source of DHA are only 100,000 tonnes DHA/year, very far from the demand of 821,000 tonnes to keep the global population of 9 billion healthy. The shortage of DHA has triggered a search for new and alternative sources of DHA including heterotrophic algae, krill oil and transgenic plants.

DHA in human health

Studies demonstrate that DHA is essential for brain and retina development. It is an important structural and functional component of retina photoreceptors, neurons and signalling synapses. Moreover, consumption of DHA and other n-3 LC-PUFAs reduces the risk of coronary heart disease (CHD), lowers the levels of triglycerides (TG), and reduces blood pressure (Kris-Etherton et al. 2002; Iso et al. 2006). Besides, there is evidence that DHA can be a precursor of potent anti-inflammatory Resovin D which, together with n-3 LC-PUFAs, can be used in the control of rheumatoid arthritis (Kremer 2000; Duffield et al. 2006, Kohli and Levy 2009).

Seafood and DHA

The consumption of fishery products, principal sources of DHA, varies considerably among countries. Figure 1 shows that the consumption of seafood in some populous countries such as India (5.5 kg/capita/year) and Brazil (8.3 kg/capita/year) is less than half of the world average of 18.5 kg/capita/year (FAO 2009).
The dietary intake of n-3 LC-PUFAs in these countries is lower than the minimum recommended by FAO (250 mg DHA + EPA (eicosapentaenoic acid, 20:5 n-3) per day).

As a comparison, the consumption of fishery products in USA is 2.8 times higher (24.1 kg/capita/year) than that in Brazil (FAO), but, according to USDA dietary guidelines 2010, Americans are consuming only 44% of the desirable quantity of seafood in order to achieve the minimum daily intake of 250 mg DHA + EPA. Countries in Africa and South America have the lowest average consumption of fishery products (10 kg/capita/year) which is less than half of the European and North American consumption.

Even with several regions recording a low consumption of seafood, there is still a huge demand for this food resource. As production from capture fisheries plateaued two decades ago at around 90 million tonnes/year, the increase in demand has been met by aquaculture to reach a combined annual production in 2011 of 154 million tonnes (SOFIA 2012).

Dietary DHA in fish oil is important to meet the fish nutrition requirements and to improve meat nutritional value. However, the production of farmed fish is facing a crisis with low supplies of fish oil. The total replacement of fish oil by vegetable oil is not possible for several marine species and a partial replacement decreases significantly the DHA content in the fillet because vegetable oils do not contain LC-PUFAs (NRC, 2011).

DHA pathways

In humans, DHA can be converted from dietary α-linolenic acid (ALA 18:3 n-3), EPA and docosapentaenoic acid (DPA 22:5 n-3) (Jumpsen and Clandinin 1995). ALA, an essential fatty acid is present in vegetable oils such as flaxseed oil, while EPA, DPA and DHA are especially found in fish and in chicken eggs. The conversion of ALA to DHA in humans is very limited, estimated at only 1% for new born babies. This capacity tends to decrease during the aging process (FAO 2010, EFSA 2010). Therefore eating n-3 supplements based on flax seed oil will not bring a lot of benefit.

On the other hand, a direct consumption of DHA sources such as salmon, fish oil or algae oil is able to increase DHA levels in plasma phospholipids and erythrocytes (Barrow et al 2009; Raatz et al. 2013; Arteburn et al. 2008). Clearly, it is much more efficient to consume DHA directly rather than ALA which may also require the control of linoleic acid (LA: 18:2 n-6) intake. LA, found in common vegetable oils, competes for the same enzymes required to elongate and desaturate ALA during the metabolic pathway of DHA synthesis (Holub 2002, Arterburn et al. 2006).

DHA recommendations

In adults, there is a considerable variation in the daily DHA intake recommendations suggested by national and international institutions. Most of them are based on the risk reduction of cardiovascular diseases (CVDs). The recommendation for DHA + EPA in adults ranges from 90 to 1,000 mg/day (Figure 2). The highest is from the Japanese Ministry of Health Labour and Welfare (MHLW) which recommends 1 g DHA + EPA per day or at least 90 g of fish per day (MHLW 2010). In 2011, the average Japanese consumption of seafood was 72.7 g/day (which is high compared to most countries, although the current consumption has decreased 26% compared to the historical peak of 98.2 g in 1997 (MHLW 2010)).

A Japan Public Health Center study on fish consumption of 41,758 middle-aged adults was partly used to derive the national recommendation (Iso et al. 2006). This study also showed that the group consuming 180 g/day had the highest reduction of CHD risk events. The same study showed that the risk decreases significantly at a daily consumption rate of 51 g compared to the lowest intake of 23 g/day (Figure 3).

The government of Japan is probably concerned as it needs to reduce the cost of CVDs treatments. It has an aging population and a need to reduce the risk of CVDs. The recommendation by the MHLW is 1 g DHA + EPA per day or at least 90 g of fish per day (MHLW 2010). The Japanese government has also embarked on a campaign to increase the consumption of seafood in Japan.

Figure 2. Daily recommendations of DHA and EPA for humans of different ages (mg/day)

Legends:
USDA, United States Department of Agriculture; NIH, National Institute of Health (US); EFSA, European Food Safety Agency; NHMRC, National Health and Medical Research Council (AU); ISSFAL, International Society for the Study of Fatty Acids and Lipids; MHLW, Japan Ministry of Health, Labor and Welfare

Figure 3. Japanese DHA + EPA intake 2005 (mg/day)
population and is using the culture of seafood consumption to support recommending such a high intake level. In 2010, the demographics of its population was: 18% young people (≤19 years old), 59% adults (20-64 years old) and 22% elders (>65 years old, HGW).

In contrast, international institutions such as FAO or the European Food Safety Authority (EFSA) have more conservative daily minimum intake recommendations of DHA + EPA at 250 mg and 250-500 mg respectively. Daily consumption of 250-500 mg of DHA + EPA appears generally accepted as a level which decreases the risk of CVDs. This range is recommended by EFSA, International Society for the Study of Fatty Acids and Lipids (ISSFAL) and the American Heart Association (AHA), although consumption of DHA + EPA up to 2,000 mg is considered safe and can be part of a healthy diet (FAO 2010).

Such high recommendations imply a huge impact on the fish oil market since many countries do not have fish-eating habits like Japan. Higher doses of DHA + EPA may be recommended in some specific cases such as for patients with documented CHD (1~ g) or hypertriglyceridemia (2~4 g) under medical supervision (Lichtenstein et al. 2006).

The importance of DHA in fetus and new born development received attention after high levels of DHA were reported in breast

Figure 4. DHA and EPA (mg/100g) content in marine and freshwater fish ranked by DHA concentration (MEXT 2005; USDA 2012).

“...species rich in DHA/EPA include mackerel, Atlantic salmon, Japanese yellowtail, Pacific saury and sardines, having more than 2,000 mg/100 g. ”

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When used in aquaculture feeds, fish oil and fish meal provide finfish and crustaceans with the essential nutrients they need for optimum growth and development.
milk; these levels are higher compared to common dairy milk used for human nutrition and in some infant formulas. DHA is an essential nutrient for infants because it improves the visual acuity and learning capacity when comparing supplemented to non-supplemented infant formulas. This observation further indicates that the capacity of conversion of ALA to DHA is insufficient for good development of the brain and retina of infants.

There is a positive correlation between dietary DHA and the breast milk DHA content implying that DHA consumption is preferred instead of a high intake of ALA. The FAO (2010) DHA recommendation is 0.1-0.18% of total energy intake for 0-6 month infants, while the recommendation for infants of 6-24 months varies from 10 mg/kg/day DHA (FAO, 2008) to 100 mg/day DHA (EFSA, 2010). The minimum recommendation for pregnant and lactating mothers is 100-200 mg DHA/day. The depletion of the mother’s DHA levels is possible due to the DHA being re-directed to the fetus development (Van Gool et al. 2004). Perinatal depression and postpartum depressive symptoms seem to be related to low DHA intakes (Hibbeln 2002; Rees et al. 2009), although according to Leung and Kaplan (2009), the perinatal depression may be associated with the deficiency of other nutrients as well. The intake of DHA will not only improve the concentration of this essential fatty acid in the breast milk during the lactating period, but also help to keep adequate levels for the mother’s general health. Recent studies also show that supplementing the diet of children with DHA reduces attention deficit disorder.

**DHA in natural sources**

Marine fish is the main natural source of EPA/DHA for human nutrition (Figure 4) but variation in concentration within the marine fish is very high (yellowtail: 3 g/100 g, Atlantic salmon: 2-3 g/100g, but cod: 100 mg/100g). The reason for this is that DHA is a part of the fat. Low fat fillet fish have therefore low concentrations of DHA and vice versa. Some freshwater fishes contain relative high amounts of DHA (carp: 300 mg/100 g) while others are very low (tilapia: 50 mg/100 g)

Terrestrial plant oils from vegetables, fruits, fungus, potatoes, seeds and cereals do not contain LC-PUFAs (MEXT 2005). Plants can synthesise LA and ALA and most common plant oils used in human nutrition have high n-6:n-3 ratio (LA:ALA), except canola oil and flaxseed. FAO (2010) does not recommend a specific n-6:n-3 ratio in the human diet if all the essential fatty acids are provided by the food. However, vegetarians who do not consume fish or eggs may be exposed to a high LA:ALA ratio and may require DHA supplementation despite a high ALA intake.

The highest content of DHA/EPA in marine fish is found in the belly meat of bluefin tuna (4,600 mg/100 g) which is the most expensive fish in the Japanese market (Figure 4). Other species rich in DHA/EPA include mackerel, Atlantic salmon, Japanese yellowtail, Pacific saury and sardines, having more than 2,000 mg/100 g. However, these species do not necessarily provide a best ratio of n-3 LC PUFA: total fat.

Crustaceans generally have a low content of LC-PUFAs compared to marine fish. Krill is an exception and can contain more than 500 mg of DHA/EPA per 100 g. On the other hand, shrimp have less than 100 mg of DHA/EPA per 100 g. Among molluscs, squids have DHA/EPA concentrations about 200-300 mg per 100 g and can be used as a complementary source of DHA. The small firefly squid (whole body) can provide 760 mg of DHA/EPA per 100 g but its availability is limited.

Aquaculture products such as salmon and Japanese yellowtail are excellent sources of n-3 LC PUFAs. However, recent increases in the price of fish oil used in fish feed is forcing the industry to partially replace the fish oil with vegetable oils (NRC, 2011). However, this tends to decrease the levels of DHA and EPA in the flesh of fish because the profile of the fillet is similar to the profile of the diet (NRC, 2011) hence leading to a decrease in the nutritional value for humans. Figure 5) shows that there has been a decrease in the DHA content in commercial Atlantic salmon in recent years, while the price of fish oil limits or makes impracticable its use in diets for some fish species.

**DHA enriched products**

Recent research on the importance of DHA in human health and the relatively low intake in some populations such as vegetarians, encouraged many companies to develop DHA enriched products and supplements in the market. Among these are dietary supplements made wholly from fish oil or krill oil with DHA concentrations ranging from 8 to 170 mg DHA and EPA/pill (Japan) depending on the fish oil source or fish oil processing technology. However, it is important to emphasise that while fish oil supplements are a good source of fat, DHA, EPA and added antioxidants, they do not contain other important nutrients for the maintenance of good health.

**Future demand**

The demand of LC-PUFA products is increasing due to their health benefits. In the case of aquaculture, an estimated increase by 2 billion people in the global population by 2050 and basing on an FAO recommended daily dose of 250 mg of EPA/DHA per person means a salmon aquaculture production of more than 8.1 million tonnes or 6.8 million tonnes of Japanese yellowtail per year will be required. Fish oil, as a DHA source, is already scarce and to meet future demand, it will be necessary to find alternative and sustainable sources of DHA.

Some alternatives include krill oil, genetically modified yeast and DHA produced by heterotrophic fermentation of marine algae. The use of krill oil is controversial because harvesting is energy intensive, trawling of small zooplankton is technically difficult and there is a catch quota to conserve resources (NRC...
2011, Sæther 1986). A second possibility is DHA extracted from transgenic plants. Research on enzymatic elongation and desaturation of the natural fatty acids contained in oil seeds and transgenic technology studies are undergoing, but better yields of LC-PUFAs are still to be reached (Walsh and Metz 2013; Jiao and Zhang 2013). Besides, transgenic plants need to pass through a rigorous environmental and human health safety assessment before approval and commercialisation.

A more natural, more sustainable and more environment friendly approach is to produce natural strains of algae high in DHA content. DHA produced by heterotrophic microalgae in a controlled industrial process is available in the market and this constitutes a more sustainable production with lower levels of contaminants compared to fish oil. Alltech has shown that these algae are potential supplies of large amounts of DHA. Alltech’s Algae factory can produce more than 10,000 tonnes of dry weight of algae per year with fat levels of over 50%. Many studies have shown that these algae can be used to produce DHA enriched eggs, broiler meat, pork meat, fish as well as to completely replace fish oil in fish diets.

References are available on request.

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