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Fish as Source of n-3 Polyunsaturated Fatty Acids (PUFAs), Which One is Better-Farmed or Wild?

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Abstract: Consumption of fish as a source of eicosapentanoic acid (EPA) docosahexenoic acid (DHA) is recommended for preventing cardiovascular and other diseases. Since world's fish stocks are limited, consumers are now being proposed farmed fish as an alternative. However, there is concern that is there any differences between wild-caught and farm- raised fish? Is one type is better than others? The aim of this study was to review the published information on the n-3 PUFAs, n-3/n-6 and DHA/EPA ratios of farmed and wild fishes in order to estimate whether the health benefits of the farmed and wild fish is potentially the same. Further, health benefits of n-3 fatty acids, importance of n-3/n-6 ratios, DHA/EPA ratios, factors affecting n-3 PUFAs, limitations or safety of fish as source of n-3 PUFAs, prospects of aquaculture as potential sources of n-3 PUFAs and optimal intakes of n-3 PUFAs have also been discussed. In general, the lipid content of farmed fish is higher than the wild but the proportion of n-3 PUFAs and DHA/EPA ratios in majority of wild fish are higher than their counterparts although there was a mixed trend for n-3/n-6 ratios. As the fatty acid composition of fish is largely dependent on the fatty acid composition of their feed, it can be customized by adjusting dietary intakes. Since the farmed fish generally have higher total lipid levels than the wild, 100g of farmed fish muscle can provide a similar or higher amount of n-3 PUFA than 100g wild fish. Thus, if they are raised under appropriate conditions and dietary regimes, farmed fish can provide the consumers a nutritional composition that is at least as beneficial as that provided by the wild.

Key words: Docosahexaenoic acid, eicosapentaenoic acid, fish consumption, fatty acids, human health

INTRODUCTION

Fish farming, or aquaculture has been the fastest growing sector of animal food production in the world since 1970. Due to stagnating wild fisheries and a growing human population, aquaculture is expected to fill the gap in supplies of fish as food for humans, as demand continues to increase (Naylor *et al*., 2000; FAO, 2008). It is not fully known, however, whether cultivated or farmed fish and shellfish have nutrient composition similar to their wild counterparts. Few earlier studies suggest that nutrient contents of farmed fish is more uniform than wild and that fat content of farmed fish exceeds that of wild (Jahncke *et al*., 1988; Suzuki *et al*., 1986; Chanmugam *et al*., 1986; Mustafa and Medeiros, 1985; Nettleton and Exler, 1992). The nutritional properties of fish and fish products render them valuable foodstuffs that are beneficial for human health. The nutritional benefits of fish stems for the most part, from its exceptionally advantageous fatty acid profile. In recent years increasing attention has been focused on significance of n-3 polyunsaturated fatty acids (PUFAs) in human nutrition, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Although PUFA composition vary among different fish species of both freshwater and marine origins, it is important for human health to increase the consumption of fish and its products, which are rich in n-3 PUFA and poor in n-6 PUFA series (Burr, 1989; Sargent, 1997). The composition of fish and fish derived product is recommended as a means of preventing cardiovascular and other diseases, and has considerably increased over recent decades.

The lipid content and fatty acid profile of fish vary between and with species even in dark and white muscle, which are affected by many factors such as the temperature, salinity, season, size, age, species habitat, life stage, and the type and abundance of food, especially whether a species is herbivorous, omnivorous or carnivorous (Ackman, 1989; Sargent *et al*., 1995; Saito *et al*., 1999). As the world's fish stocks are limited, consumers are now being proposed farmed fish as an alternative. However, there is concern that- is there any nutritional differences between wild-caught and farm raised fish? Is one type is better than others? In the present review a comparison has been made between the n-3 PUFA profiles of farmed and wild fishes in order to estimate whether the health benefits of the formers is potentially the same as those of the latter. Further, health benefits of n-3 fatty acids, importance of n-3/n-6 ratios, DHA/EPA ratios, factors affecting n-3 PUFAs and prospects of aquaculture as sources of n-3 PUFAs have also been discussed.

Polyunsaturated fatty acids: Fatty acids consists of a hydrocarbon chain (CH_2) or with an acid or carboxyl group (COOH) at one end and a methyl group at the other. Fatty acids are classified as saturated or unsaturated, depending on the number of hydrogen atoms present. Saturated fats have the maximum number of hydrogen atoms and therefore no double bonds, while polyunsaturated fatty acids contain two or more double bonds. The group of polyunsaturated fatty acids termed as omega-3 (abbreviated as *w*3 or n-3) fatty acids are distinguished by having the first double bond positioned on the third carbon atom from the methyl or N terminal end of fatty acid chain (Nettleton, 1995). The major varieties of PUFAs are n-3 PUFAs such as DHA (C22: 6 n-3), EPA (C20: 5 n-3) and n-6 PUFAs such as arachidonic acid (AA, C20: 4n-6).

The PUFAs are considered as the physiologically active factor in many species. PUFAs actively participate in gonad maturation, egg quality (Izquierdo *et al*., 2001) and larval growth of fish (Tulli and Tibaldi, 1997). PUFAs can enhance membrane fluidity and flexibility of spermatozoa membrane, and are believed to be actively involved in the regulation of cellular movement, gonadal metabolism of lipids and fusion capacity in common octopus, *Octopus vulgaris* (Miliou *et al*., 2006). PUFAs also regulate the production of eicosanoid (prostaglandins) and steroid hormones and gonad development (ovulation) (Izquierdo *et al*., 2001). In invertebrates especially crustaceans and mollusks, the PUFAs not only determine hatching and growth (Xu *et al*., 1994), but also play an important role in metabolism processes like production of prostaglandins and hormones and regulate ionic fluxes (Stanly-Samuelson, 1987).

n-3 PUFAs and health benefits: The first element of n-3 fatty acids is the essential fatty acid alpha-linolenic acid (ALA, C18: n-3); other members of this family are derivatives of ALA with longer, more unsaturated hydrocarbon chains. The main ones are EPA (C20:5 n-3) and DHA (C22:6 n-3). Recently there has been an increased interest in the medical and public health communities concerning the role of highly unsaturated n-3 PUFAs in human health and well beings. This dietary requirement is almost certainly due to the fact that humans (like most animals) have a very limited capacity to synthesize these fatty acids from the essential precursors alpha-linolenic acid (Riediger *et al*., 2009), therefore dietary intake of these fatty acids is a key aspects of human nutrition (Cunnane, 2003). Danish research on Eskimo food in Greenland suggests that there must be a connection between the large amounts of fish eaten there and low incidence of heart attacks among inhabitants (Bang and Dyerberg, 1972; Dyerberg *et al*., 1975). Various studies suggest that societies with high fish intake such as Inuits and the Japanese, have considerably lower rates of acute myocardial infractions, other ischemic heart diseases, and atherosclerosis (Bang and Dyerberg, 1980; Blanchet *et al*., 2000). This was confirmed by exhaustive investigations in Japan. In consequence of the high intake of fish in families of fishermen living along the coast, their mortality rate owning to ischemic heart disease and cerebrovascular diseases is manifestly lower than in farmers families (Hirai *et al*., 1987). Furthermore, intake of highly unsaturated n-3 PUFAs was inversely related to the risk of impaired cognitive function (Lie, 2004). Highly unsaturated PUFAs are critical for normal neural and visual development in the human fetus (Innis and Elias, 2003). Beneficial health effects of n-3 PUFAs are well demonstrated and include the prevention of number of diseases, such as coronary heart diseases, inflammation, hypotriglyceridemic effect, allergies, hypertension, arthritis, autoimmune disorders, and cancer (Von Sckacky, 2003; Mozaffarian *et al*., 2005; Mnari *et al*., 2007). It has been reported that a high dietary consumption of marine n-3 fatty acids may prevent the development of atherosclerosis and thrombosis (Calder, 2004). Studies with newborns indicate that DHA is essential for the normal functional development of the retina and brain, particularly in premature infants (Connor, 2000).

Numerous clinical and epidemiological studies have correlated the long term consumption of PUFAs of the n-3 series with a reduced incidence of wide range of common degenerative diseases in humans, as well as the alleviation of some symptoms (Harris, 2004; Stansby, 1990). Sea food is known to contain PUFAs that can help regulate prostaglandin synthesis and hence induce wound healing (Gibson, 1983; Zuraini *et al*., 2006). Epidemiological data indicated that there was a decrease in the number of deaths caused by coronary heart diseases in people who consumed fish or fish oil containing small amount (0.4g) of n-3 PUFAs on a regular daily basis and consumption of as little as one or two fish dishes per week may be of preventive value in relation to coronary heart diseases (Kromhout *et al*., 1985). Numerous studies explained the mechanism how EPA and DHA are involved in cardiovascular disease pathways. For example, they decrease plasma very low-density-lipoprotein (LDL) and triglyceride levels, and reduce postprandial lipidemia and lead to antithrombotic changes (Schmidt, 1997), decreases platelet aggregation (Knap, 1997) and inflammation (Calder, 2001). n-3 PUFAs have antiarrhythmic action in the heart, link to a fall in the risk of sudden death (Kang and Leaf, 1996; Albert *et al*., 2002). Research has demonstrated that there are considerable health benefits to be gained from having a diet rich in highly unsaturated

Table 1: Muscle total lipid, PUFA, n-3 and n-6 fatty acids, n-3/n-6 ratios, DHA , EPA and DHA/EPA ratios of some important farmed and wild fishes*

Species	Farmed/ Wild	Total lipid	∑PUFA	∑n–3 fatty acids	∑n–6fatty acids	n-3/n-6 ratio	DHA	EPA	DHA/ EPA ratio	References
Red porgy	Farmed	3.0	36.9	29.8	7.1	4.2	17.8	7.5	2.4	Rueda *et al*.(1997)
(*Pagrus pagrus*)	Wild	0.7	51.2	36.7	14.5	2.5	25.7	7.1	3.6	
Gilthead sea bream	Farmed	-	34.7	22.8	11.9	1.9	7.0	5.7	1.2	Grigorakis *et al*.(2002)
(*Sparus aurata*)	Wild	-	38.0	28.7	9.3	3.1	17.6	12.7	1.4	
Gilthead sea bream	Farmed	11.1	30.7	24.1	6.6	3.7	10.9	7.5	1.5	Orban *et al*(2003)
(*S. aurata*)	Wild	7.4	16.5	12.1	4.4	2.8	3.3	5.0	0.7	
Gilthead sea bream	Farmed	0.8	32.1	24.4	7.7	3.1	18.0	5.1	3.5	Saglik *et al*. (2003)
(*S. aurata*)	Wild	0.5	41.3	32.6	13.0	2.5	28.3	4.3	6.5	
Gilthead sea bream	Farmed	0.2	40.3	35.5	7.8	4.2	23.0	7.7	3.0	Mnari *et al*(2007)
(*S. aurata*)	Wild	0.1	38.6	19.4	19.3	1.0	9.2	7.6	1.2	
White sea bream	Farmed	5.8	42.3	36.3	6.0	6.1	25.2	6.0	4.2	Cejas *et al*(2004)
(*Diplodus sargus*)	Wild	4.0	47.2	36.3	10.9	3.3	28.4	3.9	7.3	
Black sea bream	Farmed	9.2	26.8	23.4	35.5	6.7	11.8	7.3	1.6	Rodriguez *et al*.(2004)
(*Spondyliosoma canthrus*)	Wild	3.5	44.9	36.6	8.4	4.4	28.8	6.2	4.6	
Blue fin sea bream	Farmed	3.5	27.4	17.2	10.1	1.7	1.9	4.9	2.2	Hossain *et al* (2012)
(*Sparidentex hasta*)	Wild	4.6	16.6	12.5	4.1	3.0	6.5	5.3	1.2	
Yellow fin bream	Farmed	4.4	29.1	18.4	10.6	1.7	12.6	5.3	2.4	Hossain *et al* (2012)
(*Acanthopagrus hasta)*	Wild	4.1	19.6	15.6	4.1	3.8	10.3	4.6	2.2	
Sea bass	Farmed	5.2	36.1	26.8	9.3	2.9	18.1	6.0	3.0	Alasalvar *et al*. (2002)
(*Dicentrarchus labrax*)	Wild	1.4	47.4	35.6	11.8	3.0	19.5	10.6	1.8	
Sea bass	Farmed	9.4	30.9	22.7	8.2	2.8	10.8	7.7	1.4	Orban *et al*. (2003)
(*D. labrax*)	Wild	2.2	31.5	23.7	7.8	3.0	12.1	7.1	1.7	
Sea bass	Farmed	2.9	31.5	16.8	14.7	1.1	9.6	6.2	1.5	Saglik *et al.* (2003)
(*D. labrax*)	Wild	0.6	23.3	18.3	5.0	3.7	11.7	6.7	1.7	
Sea bass	Farmed	4.6	30.3	17.8	12.5	1.4	7.4	9.3	0.8	Fuentes *et al.* (2010)
(*D. labrax*)	Wild	1.0	39.1	29.9	9.2	3.3	16.6	12.2	1.4	
Silver pomfret	Farmed	2.5	27.5	21.1	6.3	3.4	16.3	4.9	3.3	Zhao *et al*.(2010)
(*Pampus argenteus*)	Wild	1.1	34.5	26.7	7.8	3.4	17.8	8.9	2.0	
Silver pomfret	Farmed	9.6	20.8	10.4	10.5	1.00	5.1	3.8	1.3	Hossain *et al*.(2012)
(*P. argenteus*)	Wild	8.6	14.3	13.9	1.0	14.6	7.2	1.5	4.8	
Trout (*Salmo gaidneri*	Farmed	6.0	29.0	20.0	9.0	2.2	13.0	4.0	3.2	van Vliet and Katan (1990)
and *S. trutta fario*))	Wild	5.0	35.0	30.0	5.0	6.0	15.0	7.0	2.1	
Rainbow trout	Farmed	1.3	28.4	19.4	9.0	2.2	14.9	3.0	5.0	Aslan *et al*. (2007)
(*Onchorhynchus mykiss)*	Wild	1.2	40.5	24.8	15.7	1.6	11.6	7.4	1.6	
Salmon (*Salmo salar*)	Farmed	16.0	20.0	17.0	3.0	5.7	7.0	5.0	1.4	van Vliet and Katan (1990)
	Wild	10.0	22.0	20.0	2.0	10.0	10.0	5.0	2.0	
Halibut (*Hippoglossus*	Farmed	-	30.3	21.2	9.1	2.3	11.1	5.7	2.0	Cahu *et al*. (2004)
hippoglossus)	Wild	-	43.9	40.4	3.5	11.5	25.4	12.2	2.2	
Turbot (*Scaophthalmus*	Farmed	1.1	47.3	38.5	8.8	4.4	24.5	8.2	3.0	Serot *et al*.(1998)
maximus)	Wild	0.6	49.3	44.3	5.0	8.9	28.3	9.3	3.0	
Macquarie perch	Farmed	9.2	32.5	18.2	14.3	1.3	1.0	3.5	3.1	Sheikh-Eldin *et al.* (1996)
(*Macquaria australasica*)	Wild	8.2	33.3	16.8	16.5	1.01	8.2	4.2	2.0	
Perch	Farmed	-	35.0	27.1	6.01	4.5	16.8	7.2	2.3	Jankowska *et al*.(2010)
(*Perca fluviatilis*)	Wild	-	43.0	29.2	3.1	2.2	16.7	7.3	2.3	
Grouper (*Epinephelus*	Farmed	3.8	25.6	9.2	16.4	0.6	4.7	3.4	1.4	Hossain *et al*. (2012)
coioides)	Wild	4.4	21.6	11.3	10.3	1.1	7.6	2.4	3.2	
Red drum	Farmed	2.1	35.6	14.0	21.6	0.6	6.9	4.4	1.6	Jahncke *et al*.(1988)
(*Sciaenops ocellatus*)	Wild	0.56	37.3	29.5	7.8	3.8	21.1	3.6	5.9	
Northern pike	Farmed	2.4	42.0	32.4	6.5	5.0	18.9	9.4	2.0	Jankowska *et al.* (2008)
(*Esox lucius*)	Wild	0.2	58.3	41.3	15.8	2.6	28.0	6.7	4.2	
Gulf sturgeon	Farmed	-	31.3	24.3	7.1	3.4	12.2	8.3	1.5	Chen *et al.* (1995)
(*Acipenser oxyrinchus desotoi*)	Wild	-	15.9	11.3	4.6	2.5	6.1	1.8	3.4	
Rohu (*Labeo rohita*)	Farmed	4.3	25.0	12.6	12.4	1.0	5.1	2.6	2.0	Sharma *et al.* (2010)
	Wild	1.6	41.5	19.0	22.5	0.8	9.9	3.2	3.1	

*: Expressed as % of total fatty acids, PUFA-Polyunsaturated fatty acids, DHA-Docosahexaenoic acid, EPA-Eicosapentaenoic acid

PUFAs, and in particular EPA and DHA. For example, the highly unsaturated PUFAs ARA and DHA play an important role in neonatal health and development (Horrocks and Yeo, 1999; Innis, 2000), in particular the acquisition of ocular vision and brain development: it is for this reason that both these fatty acids are recommended for inclusion in infant formula milks (Agostoni, 2008).

Although refined fish oils can provide nutrients of high biological value, crude fish oil has potential hazards. Highly unsaturated fatty acids are easily oxidized. Also pollutants and impurities accumulate in fish (Racine and Deckelbaum, 2007). Since EPA and DHA are highly unsaturated long chain PUFAs, they are susceptible to lipid peroxidation (Yagi, 1987). Under conditions of higher dietary intakes of EPA and DHA, the excretion of urinary malondialdehyde (MDA), a principal end product of lipid per oxidation, is elevated (Wahle and Brown, 1990), probably reflecting an amplification of cellular hydroperoxide production. Thus, ingestion of excess n-3 PUFAs may contribute to an overall enhancement of prooxidant stress in the body resulting lower concentration of endogenous antioxidants, such as vitamin E (Harmon *et al*., 1966). A recent study also showed that daily intake of fish oil supplements reduces the plasma concentration of vitamin E to below normal range (Nair *et al*., 1993).

In most Western societies, the diets are dominated by vegetable oils and processed foods which contain excessive levels of n-6 fatty acids such as linoleic acids, and are generally under-represented in levels of n-3 PUFAs (Cordain *et al*., 2005). It has been estimated that our ancestral dietary fat composition showed a n-6/n-3 ratios of 2:1, this same ratio is today in excess of 10:1 (Simopoulos, 1999). To address the imbalance, some researchers have proposed an inclusion of a fish component in the diet (Lovegrove *et al*., 1997), daily supplements of fish oil (Howe, 1996) or incorporation of stabilized fish oil in food products, such as margarine (Saldeen *et al*., 1998) and liquid foods (Kolanowski *et al*., 1999). Marine fish, specially marine carnivores, have a natural diet rich in highly unsaturated n-3 fatty acids. As a consequence, the level of n-6 fatty acids as well as those of short chain n-3 PUFAs are rich in freshwater than in marine fish, the latter having higher concentrations of long-chain n-3 PUFAs (Ackman, 1967). Therefore, the foods of marine origin and their enrichment in artificial diets might be desirable from human nutritional point of view.

Fish as source of n-3 PUFA-
farmed vs wild: There is a nutritional deficit of n-3 PUFA in the human diet; therefore, a high consumption of food containing these fatty acids is recommended. Modification of human diet such as fish, that form part of our diet, is another alternative for increasing the consumption of these fatty acids in our food (Valenzuela, 1999). To increase the intake of n-3 PUFA, researchers have proposed the inclusion of a fish or shell fish or incorporation of stabilized marine oil in food products (Osman *et al*., 2001). Consequently, n-3 concentrated oils, salmon oil and cod liver oil are readily available as supplements in the liquid or capsule form in pharmacies and health stores. However, some research suggest that the bioavailability of n-3 PUFA and thus the health benefits are enhanced when fatty fish are consumed compared with supplementation of the diet with fish oils in the form of capsules (Elvevoll *et al*., 2006). Although when fish is suggested as a means of improving health, both fat content and the PUFA composition must be considered (Savage, 2009). Comparing different types of fish, lower risk of coronary heart disease (CHD) appears more strongly related to intake of oily fish (e.g. salmon, herring, sardine), rather than lean fish (e.g. cod, catfish, halibut) (Oomen *et al*., 2000; Mozaffarian *et al*., 2003). Farmed fish have the advantage of being reared and harvested under control conditions so hazards associated with fish consumption can more easily be controlled (Fuentes *et al*., 2010). It is of considerable interest for the farming industry and consumers to be aware of the compositional and nutritive differences between farmed and wild fish. Table 1 shows the known composition of n-3 PUFAs, total n-3 and n-6 fatty acids, DHA, EPA, n-3/n-6 and DHA/EPA ratios of some farmed and wild fishes in order to estimate whether the expected health benefits of former are potentially the same as those of the later. The fat content in fish varies from 1% in white fish e.g. cod, coley, plaice and haddock to 25% in oily fish e.g. trout, salmon, mackerel, herring, pilchard and sardine (Gibson, 1988). With few minor exceptions most of the farmed fish as shown in Table 1 have been found to contain higher lipid than wild fishes. This observation is also in agreement with data previously published on different species (Otwell and Rickards, 1981; Chanmugam *et al*., 1986; Haard, 1992). Grigorakis (2007) also reported that cultured gilthead bream had significantly higher muscle fat than their wild counterparts. Farmed fish accumulate more intracellular lipid than wild ones, mainly in the form of neutral fats (Haard, 1992).

Regarding the fatty acid differences, in general, most of the studies reported in Table 1 observed higher content of total PUFAs and n-3 PUFAs in wild than those of the farmed ones. However, these results are in contrast to what has been found by other authors (Chen *et al*., 1995; Orban *et al.*, 2003; Mnari *et al*., 2007; Hossain *et al.*, 2012), who found higher proportion of total PUFAs and n-3 PUFAs in farmed fish than in wild specimen of different fish species. However, in case of n-6 PUFAs, the trend was mixed between farmed and wild fishes. The difference in n-3 PUFA composition of lipids between farmed and wild fishes observed in different studies can be explained by the fatty acid composition of the diet of both wild and farmed fishes. Most of the marine fishes are carnivores and eat small fish and crustaceans in which the PUFAs are nearly n-3 PUFAs

Table 2: EPA and DHA content in several common fish oils*

Oil sources	% Total fatty acids EPA	DHA
Anchovy	9.0-18.2	8.7-13.0
Sardine	12.4-14.5	9.8-12.5
Mackerl	6.1 5.7	7.0-8.7
Herring	7.4-7.4	6.7-8.7
Salmon	12.7-13.4	10.0-10.2
Halibut (wild)	12.2	25.4
Sand eel	10.9	9.7
Menhaden	10.6	6.4-9.2
Capelin	9.9	7.9
Tuna	4.6	18.3

*: Adapted from Racine and Deckelbaum (2007)

and n-6 PUFAs proportion is very low. In contrast, the commercial feeds usually use cereal and vegetable oils that contain more of the n-6 fatty acids and less n-3 PUFAs. However, commercial feeds which use high proportion of fish meal and fish oil usually contains higher proportion of n-3 PUFAs and less of n-6 PUFAs. So, feeding such commercial diets will lead to the deposition of higher n-3 PUFAs in the fish muscle. Ackman and Takeuchi (1986) reported that the percentage of n-3 fatty acids in cultured marine fish is usually lower than their wild counterparts, presumably because of the lack of lipids originating from marine phytoplankton and other marine organisms.

The n-3/n-6 ratio has been suggested to be a better index for comparing the relative nutritional value of different species (Piggot and Tucker, 1990). However, this index is of limited value without consideration of which fatty acids are present. Generally, C20 and C22 fatty acids are more nutritionally valuable than C18 fatty acids (Arts *et al*., 2001). Owning to their predominating quantity, two fatty acids namely DHA and EPA are responsible to the greatest extent for changes in the n-3/n-6 ratios, a reliable indicator that enables a comparison of relative nutritive value of lipids. The n-3/n-6 ratios observed in different marine fishes as shown in Table 1 were found to vary between 0.6 to 11.5. According to Sargent (1997) the optimum ratio of n-3/ n-6 PUFA should be 1:5 (0.2). The higher the n-3/n-6 ratios, the more able the body is to use the n-3 fats. A lower ratio means the enzymes that convert these fats into the forms in which they are active in the body are more likely to be used up by the n-6 PUFAs. All the fish in Table 1 showed a much higher ratios of n-3/n-6 PUFAs. In most cases, the cultured sea bream showed a higher n-3/n-6 in contrast to those reported by Grigorakis *et al*. (2002) and Hossain *et al*., 2012. On the other hand, all the studies with sea bass showed higher n-3/n-6 values for wild compared to those of the farmed ones. Likewise, wild silver pomfret, trout, salmon, halibut, turbot, perch and red drum showed higher n-3/n-6 ratios (Table 1) values than those of their counterparts. As mentioned earlier, diet is the main factor affecting the n-3 and n-6 PUFA content in fish, but location, species, season and environmental conditions may also play a role. Whether the diet is natural or compounded, the fatty acid composition of fish muscle is clearly influenced by their diet (Justi *et al*., 2003). Young (2009) in his review article reported that the ratio of n-3:n-6 PUFA in farmed tilapia did not exceed 1. According the same author, the ratio of these acids in wild tilapia differs due to the fact that the diet of wild fish contains higher contents of n-3/n-6. Generally, fish lipids and fish products have much higher n-3/n-6 ratio than is recommended (1:5), and from nutritional standpoint this is highly beneficial and desirable for the daily human diet. The n-3/n-6 ratios in other foodstuffs is considerably lower than recommended. For example, this ratio ranges from 1:10 to 1:2 in animal lipids, while in vegetable oil that are used widely in households, these ratios ranges from 1:15 to 1:200 (Usydus *et al*., 2011).

In all cases, with the exception of Fuentes *et al*. (2010) the percentage share of DHA in the lipid exceeded that of EPA. The ratios of DHA/EPA ranged between 0.7 and 7.3. The majority of the wild fish showed higher DHA/EPA ratios than their counterparts. However, the lowest of DHA/EPA ratio of 0.7 was noted in wild gilthead sea bream (Orban *et al*., 2003). In contrast, some cultured fish showed higher DHA/EPA ratios than the wild; the reason could be related to their dietary regime as has been discussed previously. Whalen (2009) reported that high ratio of DHA/EPA has an advantageous impact on consumer health and that DHA is more efficient than EPA in reducing the risk of coronary heart diseases. The biological significance of dietary DHA/EPA can be viewed in terms of competitive interactions between fatty acids for incorporation into phospholipids, especially competition for the enzymes that esterifies fatty acids into the phospholipids structures (Sargent *et al*., 1999). A positive correlation between dietary DHA/EPA and fish larval growth and survival has been reported (Rodriguez *et al*., 1997). Wu *et al*. (2002) also reported that DHA is superior to EPA in promoting fish growth.

Table 2 shows the EPA and DHA content of several common fish oils. Among them halibut, tuna, herring and mackerel oils showed higher DHA levels than their EPA levels. On the other hand, anchovy, sardine, salmon, sand eel, menhaden and capelin oil showed higher EPA levels than their DHA levels. The highest level of DHA (25%) and EPA (9.0 - 18.2%) were recorded in halibut and anchovy respectively. Currently fish oil is mainly a byproduct of fish meal and species used for fish oil production are not necessarily the richest in n-3 PUFAs. Most often oil is extracted from three categories of fish: species caught primarily for fish meal production (such as sand eel, menhaden or Norway pout), surplus of fish caught primarily for human consumption, and non-food-grade fish (Racine and Deckelbaum, 2007). The manufacturers of fish oil supplements usually blend different sources of fish oil together to get a desired ratio of DHA and EPA. Fish oil capsules may contain 20 to 80% of EPA and DHA by weight, little or no mercury and variable levels of polychlorinated biphenyls (PCBs) and dioxins (Jimenez *et al*., 1996). People who do not eat fish, a fish oil supplement may be considered. The most common fish oil capsules in the United States provide 180 mg of EPA and 120mg of DHA per capsule. So, depending upon preparation up to three 1 g fish oil capsule per day may be necessary to provide ≈ 1g/d of n-3 PUFAs. However, compared with oil supplement, fish intake also provides potentially beneficial protein, vitamin D and selenium.

Factors relating to n-3 PUFA in fish: The biochemical composition of fish is strongly affected by the composition of their food (Henderson and Tocher, 1987; Orban *et al*., 2007). In addition to food, other factors such as species, genetics, size, reproductive status as well as the environmental characteristics can also influence the proximate composition of fish (Piggot and Tucker, 1990). Dietary lipids may affect the fatty acid composition of fish, which (mostly marine fish) find it difficult to desaturate and elongate fatty acid chains consisting of more than 18 carbon atoms (Watanabe, 1982). Dietary intakes are therefore responsible for the high DHA and EPA content in fish. As mentioned the acquisition and accumulation of n-3 PUFA in fish largely depends on what the fish eats. Atlantic menhaden (*Brevoortia tyrannus*), which is extensively used for fish oil production, is a good example of direct transfer of fatty acids from primary producers to fish since adult fish are filter feeders (Arts *et al*., 2001). In addition to dietary niche and variability of component dietary sources, seasonal variation in food availability has also been noted to influence the total lipid content and n-3 PUFA content of fish (Jensen *et al*., 2007). Pelagic fishes living in cold water usually have the highest content of EPA and DHA. The content of n-3 PUFA can vary considerably even in a single species depending on the season and area of fishing as well as the age and gender of the fish (Ackman, 1982).

Significant differences were found between the two sexes of tilapia in the n-3 PUFA, resulting in a higher n-3-/n-6 ratios in the males (Biro *et al*., 2009). The higher levels of n-3 PUFA in the muscle of male fish than that of females also found in *Salmo trutta macrostigma* (Akpinar *et al*., 2009), in *Onchorhynchus mykiss* (Gorun and Akpinar, 2007). The fatty acid profile exhibited many differences between the two fish groups, with the spawning herring having significantly higher PUFA content in the gonads, with DHA representing the greatest proportion at more than twice than that found in the flesh (Huynh *et al*., 2007). However, the total content of n-3 PUFA was low, due to the fact that herring eggs and milt contain a low amount of lipid. Moreover, due to the significant lipid loss during spawning, the absolute amounts of n-3 PUFA in the flesh of spawning fish will decrease even further. Thus, non-spawning herring are a better nutritional food source than spawning herring (Huynh *et al*., 2007).

Farmed fish show more constant rates of EPA and DHA synthesis because of their feed is controlled and balanced throughout the farming period (Cahu *et al*., 2004). There are also differences in terms of fatty acid composition between fresh water and marine water fishes. Fresh water fish is generally recognized to contain lower levels of n-3 PUFA than marine fish (Akpinar *et al*., 2009). However, chain elongation and desaturation processes are more efficient in fresh water fish than in marine fish. Thus, fresh water fish can be converted to a food of having higher nutritional value with proper feed (Steffens, 1997). Environmental factors including salinity and temperature have been shown to influence the fatty acid composition (Cordier *et al*., 2002; Ibarz *et al*., 2005). In gilthead bream increase of unsaturation in muscle polar lipids (EPA and DHA in particular) has been related to cold acclimation from 18 to 8^{o}C irrespective of temperature drop rates (Ibarz *et al*., 2005). In cultured sea bass, increase of salinity was negatively correlated with DHA concentration in muscle polar lipids (Cordier *et al*., 2002). Dunstan *et al*. (1999) also reported that with increased latitude there was a concomitant increase in n-3 PUFA, with DHA being particularly high in fish from cooler waters. Thus, in general, cold-water fish present higher n-3 PUFA concentration than those of tropical water fishes.

Limitations or safety of fish as a source of n-3 PUFAs: Some species of fish may contain significant levels of methyl mercury, polychlorinated biphenyls (PCBs), dioxin and other environmental pollutants. Although refined fish oils can provide nutrients of high biological value, crude fish oil has potential hazards. Highly unsaturated fatty acids are easily oxidized. Also pollutants such as methyl mercury, PCBs and pesticides can accumulate in fish (Racine and Deckelbaum, 2007). Oxidation affects color and taste of fish oil and impair its nutritional value. Oxidation can be increased by exposure to temperature, light, trace metals and certain enzymes. Generally antioxidants are added to fish oils. The oils are often encapsulated which protects against light, oxygen and other oxidant stimulants (Genot *et al*., 2004). Fish are usually deep frozen after catch to prevent the oxidation.

Mercury is a heavy metal which is usually converted into organic methyl mercury by microbial activity. Inorganic mercury is poorly absorbed following ingestion, while methyl mercury is readily absorbed and transported into tissues. Methyl mercury bioaccumulates in the aquatic food chains and has greater potential toxicity than inorganic mercury. Methyl mercury has long life in humans and bioaccumulates in lager, long-living predators e.g. sword fish, shark, king mackerel have higher tissue concentrations, while smaller or shorter-lived species such as shellfish, salmon etc. have very low concentrations (Risher *et al*., 2002). Other species either wild or farmed are also exposed to methyl pollutions especially in coastal waters. Health effects of very high mercury exposure following occupational or industrial accidents are well documented but health effects of chronic low level mercury exposure i.e. that seen with fish consumption are less well established (Mozaffarian and Rimm, 2006). Very high levels of methyl mercury mainly affect neural development, leading to mental retardation, visual loss, and can cause neuromuscular symptoms such as poor coordination and abnormal muscle reflexes (Risher *et al*., 2002). Mozaffarian and Rimm (2006) concluded that potential risks of fish intake must be considered in the context of potential benefits. Based on strength of evidence and potential magnitudes of effect, the benefits of modest fish consumption (1- 2 serving per week) outweigh the risks.

Organochlorine pesticides, PCBs and dioxins are resulting from human activities. Dioxin and PCBs are fat soluble and persistent chemicals found in many foods. Oily fish and fish oil supplements have large fat deposits. Levels are usually high in fish liver oil than in fish body oils (MAAF, 1999). Because of dioxin and PCBs accumulate in fat over time it is possible that exposure levels over a life time are more important to health than individual high dose. Fish from industrialized coasts are more contaminated, especially if they do not migrate. Several studies found significant amounts of PCBs and other organochlorine residues in fish oils (Jimenez *et al*., 1996; Jacob *et al*., 2004) even though bleaching and deodorization steps removed about half of the contents of these pollutants from crude fish oil. These compounds have been linked to abnormalities in neural and cognitive development, fertility and thyroid functions and to birth defects, immunosuppression and increased risk of some malignancies (Mozaffarian and Rimm, 2006). Hopper (1999) recommended that people with cardiovascular disease should consume 200-400g of oily fish per week as there is good evidence that it is protective, despite the levels of dioxins and PCBs it contains. For those who cannot tolerate oily fish, fish body oil supplements (not fish liver oil) should be recommended at a level of 0.5 - 1.0g of n-3 fats per day. However, the consumers need to be aware of both the benefits and risks of fish consumption for their particular stages of life. Children and pregnant and lactating women may be at increased risk for mercury intoxication from fish consumption but also are at low risk for coronary heart diseases. Thus, avoidance of potentially contaminated fish is a higher priority for this group. For middle-aged and older men and postmenopausal women, the benefits of fish consumption far overweigh the risks with the guidelines established by the FDA and Environmental Protection Agency (Kris-Etherton *et al*., 2002).

Prospect of aquaculture as a sustainable source of n-3 PUFAs: Concerns exists about sustainability of aquaculture and commercial fishing practices (Naylor *et al*., 2000; Pauly *et al*., 2005). The lipid content and fatty acid composition of fish and shellfish are affected by various factors including genetic, seasonal and environmental factors, and the nutritional quality of dietary components. This can cause variation in the nutritional quality of seafood caught from different areas and times of the year. Farming marine fish specially for high n-3 PUFA content can overcome the problem of variation in the fatty acid composition of fish due to dietary variance (Savage, 2009). Moreover, in aquaculture, one has greater control during the production and processing of the organisms to optimize n-3 PUFA content. As consumer, we take wild fish as they come, but the body composition of farmed fish can be altered. Fish feed can be supplemented with protein and lipids to make the body composition more favorable for human health and nutrition. Justi *et al*. (2003) reported that *Oreochromis niloticus*, which received a diet with addition of flaxseed oil (high in n-3 fatty acids) showed highest index for n-3 PUFA and the best n-3/n-6 ratio. Thus, it shows that it is possible to favorably change the body composition of fish through changes in diets (Steffens, 1997). Sargent *et al*. (1989) also agreed that it is technically possible to produce a fish with a ratio of n-3/n-6 PUFA that is optimal for human nutrition. Proper choice of dietary lipid sources would allow the fatty acid composition of cultured fish to be tailored to address the beneficial health aspects and consumer's demand (Alasalvar *et al*., 2002).

A further advantage of farming fish and shellfish for n-3 PUFA content as opposed to harvesting wild stock is the potential better control of environmental contaminants. However, as mentioned earlier, one of the most important reason for farming marine fish organism for n-3 PUFA as opposed to capture fisheries is to ensure sustainable resources. Fish oil remains as the main source of n-3 PUFA for human health supplements. However, diminishing wild fish stocks are forcing the industry to look at more sustainable alternatives to capture fisheries for food and related products. Some progress have been made such as changes in feed to reduce dependence on fish meal or oil (Naylor *et al*., 2000). Aquaculture has started to replace fish oil with vegetable oils, incorporating soybean, corn and canola into aquafeeds. However, given the importance of n-3 PUFAs for health, balance must be achieved between environmental and economic concerns to allow sustainable financially viable aquaculture and commercial fishing (Naylor *et al*., 2000; Pauly *et al*., 2005).

Optimal intakes of n-3 PUFA: Optimal intake of n-3 PUFA may vary depending on population and outcome of interest (Mozaffarian and Rimm, 2006). A number of countries (Canada, Sweden, United kingdom, Australia, Japan) as well as the World Health Organization and North Atlantic Treaty Organization have made formal population-based dietary recommendations for n-3 PUFAs. Typical recommendations are 0.3 to 0.5 g/d of EPA +DHA and 0.8 to 1.1g of α-linolenic acid (Kris-Etherton *et al*., 2002). These recommendations can easily be met by following the AHA Guidelines to consume two servings per week, with an emphasis on fatty fish (i.e. salmon, herring, and mackerel, and by using vegetable oil containing α-linolenic acid. Commercially prepared fried fish (e.g. from restaurants and fast food establishments), as well as many frozen convenience-type fried fish products should be avoided because they are low in n-3 PUFAs and high in trans-fatty acids (Kris-Etherton *et al*., 2002).

For individuals with coronary heart disease, 1 g/d of EPA +DHA is recommended to reduce coronary heart disease mortality (Kris-Etherton *et al*., 2002; Van de Werf *et al*., 2003). This could be achieved by consuming approximately 6 ounce (≈ 170 g) serving/week of fish richest in n-3 PUFAs (e.g., farmed salmon, anchovies, herring), more frequent consumption of other fish or supplements (Mozaffarian and Rimm, 2006). On the other hand, Gebauer *et al*. (2006) reported that according to the Dietary Guidelines for American 2005, consuming approximately two servings of fish per week (8 ounce ≈ 227g) may reduce the risk of mortality from coronary heart disease and that consuming EPA and DHA may reduce the risk of mortality from cardiovascular disease in people who have already experienced a cardiac event. For those individuals do not eat fish, have limited access to variety of fish, or cannot afford to purchase fish, a fish oil supplement may be considered.

CONCLUSION

Increase in consumption of fish in general with the hope of increasing the n-3 PUFA concentration may not be the answer as they may cause a concomitant increase in the n-6 concentration as well-especially in fish where n-3 to n-6 ratios are very small. Therefore, fish with higher n-3/n-6 ratios should be recommended for consumption. However, allowing a direct comparison of the lipid quality of fish from different sources, an estimation of the absolute content of total n-3 and n-6 PUFAs in fish flesh has more importance in view of human consumption. Farmed fish generally have higher total lipid levels than the wild fish, 100g of farmed fish fillet can provide a higher amount of n-3 PUFAs (especially EPA and DHA) than 100g of wild fish. This observation has more important nutritional implication considering that now-a-days an increasing proportion of fish in the markets are coming from aquaculture sources.

Although today's fish oil production meets demand, it is likely that it will not be possible to increase the oil production without adversely affecting the world's wild stock of fish. Neither wild nor the farmed fish constitute a sustainable sources of n-3 fatty acids for supplementation. Solution must be found through the evolution of current aquaculture system or finding alternative sources like marine microalgae (Racine and Deckelbaum, 2007). However, the microalgae industry faces high production costs at the moment and still needs to improve its cost-effectiveness. So, multiple sources of n-3 fatty acids will likely be needed to meet the demand for n-3 PUFAs specially EPA and DHA intakes as their impact on health are increasingly recognized. Finally it is concluded that provided that they are raised under appropriate conditions and dietary regime, farmed fish can provide the consumers a nutritional composition that is at least as beneficial as that provided by wild fish.

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