Review:

Essential fatty acids: importance of fish oils and aquaculture

Summary

The fatty acids (EFAs) omega-3 and omega-6 are absolutely essential lipids and should always be present in both fish and human diets. The enormous and harmful imbalance in the consumption of the families n-3 and n-6 clearly shows the lack of long chain polyunsaturated fatty acids n-3 (PUFA-LC), whose main sources are from fishing and aquaculture, as well as the excessive World consumption of the n-6 series, present in the grains most consumed in the last few centuries. In the context of aquaculture, important research has been done evaluating the capacity of fish to elongate and desaturate the fatty acid precursors. Studies concerning the lipid nutrition of fish, selection of microorganisms, breeding of micro algae and multidisciplinary actions are essential to revert the present process.

Key words: Aquaculture; Fish Oils; Omega-3 polyunsaturated fatty acids; EFAs; PUFA-LC and health.

Resumo

Os ácidos graxos (AGEs) omega-3 e omega-6 são lipídios absolutamente essenciais. Eles devem estar sempre presentes tanto nas dietas para os peixes como nas dietas para os humanos. O imenso e perigoso desbalanço no consumo das famílias n-3 e n-6 estabelecem claramente a falta dos ácidos graxos poliinsaturados de cadeia longa n-3 (AGEP-CL), cujas principais fontes são a pesca e a aquacultura, tanto quanto o exessivo consumo mundial da série n-6 presentes nos grãos mais consumidos nos últimos séculos. No contexto da aquacultura, existem importantes pesquisas avaliando a capacidade dos peixes em alongar e dessaturar os ácidos graxos precursors. Os estudos relativos à nutrição lipídica de peixes, seleção de microrganismos, como o cultivo de microalgas e ações multidisciplinares são essenciais para reverter o presente processo.

Palavras-chave: Aquacultura; Óleos de peixe; Omega-3, Ácidos Graxos Poliinsaturados (AGEP) e saúde.
Review: Essential fatty acids: importance of fish oils and aquaculture
SOUZA, S. M. G.

1 Introduction

For many decades, fish has been referred to as an excellent source of high biological value protein for man. More recently, however, it has been considered as an almost irreplaceable source of polyunsaturated fatty acids, especially the long chain ones.

The essential fatty acids (EFAs), both omega-3 and omega-6, are lipids absolutely essential for life, i.e., they must be a part of both animal and human diets.

The lack of omega-3 fatty acids, whose main sources are the long chain polyunsaturated fatty acids (n-3 PUFA-LC) found in the fish supplied by fisheries and aquaculture, is notable in the human diet. At the same time, the aquaculture sector, which increased considerably over the past three decades, is still highly dependent on marine caught fish as a source of this key dietary nutrient in the form of fish meal, fish oil and trash fish (TACON, 2004). This fact illustrates the competing dietary needs between fishes and humans. On the other hand, some studies can be found that used filleting residues from Nile Tilapia Oreochromis niloticus from aquaculture, to feed native Brazilian fish such as the Astyanax altipananae (ARAÚJO et al., 2007) and the Rhamdia quelen (OLIVEIRA FILHO et al., 2006). The latter authors commented that the value of the coefficient of digestibility of the dry matter (DM) was low, 58.6%, due to the great amount of ash (25.2%) in the residue.

Table 1 shows the multiple abbreviation forms used in this review for the different fatty acids and the ratio between the two families.

The use of PUFA-LC, abbreviation for polyunsaturated long chain fatty acid, and HUFA-LC, for highly long chain polyunsaturated fatty acid is used indiscriminately. In this work, the first abbreviation will be adopted, i.e., PUFA-LC.

With respect to human nutrition, Fagundes (2002) mentioned that human physiology remains adequate to operate with a diet appropriate for the Stone Age. However the changes in food consumption over the last 10 thousand years have been radical, mainly regarding fats. The drastic reduction in the consumption of n-3 EFAs from food of aquatic origin, the excessive consumption of n-6 from meat of domestic animals and cultivated land plants, and, more recently, the use of trans fatty acids, are factors currently associated with many diseases such as cardiac diseases, psychiatric disorders (depression, bipolarity, senile dementia), rheumatoid arthritis, cancer, obesity, asthma and many others (KOLLER et al., 2003; MAMALAKIS et al., 2006). Many authors refer to this situation as being a public health problem (SHAPIRO, 2008; CUNNANE, 2000).

An understanding of the complexity of the broad process of fat imbalance requires multidisciplinary integration, as seen in the review of Broadhurst et al. (2002), involving scientists from environmental chemistry, agriculture, nutrition and archeology. There is now robust evidence for the absolute requirement of the omega three fatty acids, PUFA-LC and especially DHA for brain growth. Current nutritional evidence considers land ecology as an improbable basis for human evolution. Instead, the advantages of littoral and lacustrine habitats are clearly supportive.

Concomitantly and not less important than the reduction in consumption of food rich in omega-3 such as LnA, EPA and DHA, the worldwide increase in the consumption of omega-6 LA over the past century may be considered as an extensive and uncontrolled experiment that may have contributed to the increased societal burdens of aggression, depression and cardiovascular mortality. Conversely, actively lowering LA intake must be carefully considered because of the potentially large effects on agricultural economies. The limited worldwide fisheries and aquaculture production would more likely be able to meet world needs. Since LA constitutes such a large percentage of the calories in the diet, it seems prudent to carry out large-scale intervention trials to determine whether lowering its intakes will reduce cardiovascular risk and psychiatric morbidity (HIBBELN et al., 2006).

Lipid nutrition based on cultivated fish represents an important field of investigation, in the search for food production beneficial to the health, the so called nutraceuticals (VARGAS et al., 2008a; MANNING et al., 2006).

Table 1. Multiple abbreviations observed in this review.

<table>
<thead>
<tr>
<th>Fatty acids and ratio</th>
<th>Abbreviation found in papers about fish</th>
<th>Abbreviation found in papers about humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>18:2n-6 linoleic acid</td>
<td>LA</td>
<td>LA</td>
</tr>
<tr>
<td>20:4n-6 arachidonic acid</td>
<td>ARA</td>
<td>AA</td>
</tr>
<tr>
<td>18:3n-3 α-linolenic acid</td>
<td>LnA</td>
<td>α-LNA</td>
</tr>
<tr>
<td>20:5n-3 eicosapentaenoic acid</td>
<td>EPA</td>
<td>EPA</td>
</tr>
<tr>
<td>22:6n-3 docosahexaenoic acid</td>
<td>DHA</td>
<td>DHA</td>
</tr>
<tr>
<td>Ratio</td>
<td>n-3/n-6</td>
<td>n-6/n-3</td>
</tr>
</tbody>
</table>
However, the question remains of how to associate, or link, knowledge of the main animal nutrition to human nutrition as well as to the medical specialties and many other areas of knowledge, taking into account progress made as a result of the application of appropriate strategies to revert the processes outlined above.

2 What are the EFAs and where can they be found?

The fatty acids found in biological matters are grouped according to their chemical or biological properties. From the perspective of nutrition, fatty acids (FAs) may be grouped into those that cannot be re-synthesized although being essential for growth and development (EFAs), and those that can be synthesized (non-essential). The EFAs belong to two families: the linoleic acid family, n-6 - 18:2n-6 linoleic acid, and the linolenic acid family, n-3 - 18:3n-3 alpha linolenic acid. The EFAs must be supplied in the food. Both animals and plants can catabolize, elongate and desaturate (dehydrogenate) fatty acids via successive steps (OLSEN, 1998).

Fish and other aquatic animals are the most important sources of polyunsaturated long chain fatty acids PUFA-LC, but there are differences between marine and fresh water species. A typical \( \sum n\text{-}3 : \sum n\text{-}6 \) ratio for freshwater fish ranges from 0.5 to 3.8, and for marine fish the ratio varies from 4.7 to 14.4 (HENDERSON and TOCHER, 1987). Marine fish are characterized by low levels of LA and LnA, but with high levels of DHA, EPA and ARA i.e. long chain n-3 and n-6 PUFA-LC when compared to freshwater fish (SOUZA et al., 2007). Thus carnivorous marine fish such as salmon depend on a diet rich in n-3 PUFA-LC fatty acids, particularly EPA and DHA, for rapid growth (SARGENT et al., 2002).

High contents of long-chain n-3 PUFA-LC e.g. eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are only found in marine plants, whereas the shorter linoleic acid (18:2n-6), and to a lesser extent alpha linolenic acid (\( \alpha 18:3n\text{-}3 \)) are more abundant in terrestrial animals, domestic animals (HIBBELN et al., 2006) and plants. This difference is also found in animals in marine and terrestrial systems, because the fatty acid distribution of animals is primarily determined by the composition of their dietary fatty acids. The n-3 fatty acids generally dominate the n-6 fatty acids by a factor of 5-20 in marine food webs (OLSEN, 1998).

In humans, DHA occurs naturally in the cell membrane of the brain, retina, testicle and sperm, and has been reported as essential to the development of these organs and cells (KROES et al., 2003). According to Levant et al. (2006) there is a great demand for DHA during fetal formation. Thus an inadequate supply of n-3 PUFA can reduce the maternal brain DHA content after a single productive cycle. This depletion may affect neuronal function and hence the sensitivity of the postpartum organism to stress.

3 The importance of fish oils in the diet of marine and freshwater fish

The oil and fishmeal made from fish captured in the oceans are the basis of the diet for carnivorous fish cultivated in both sea and fresh water. Naylor et al. (2000) has already pointed out the risk inherent in this question and suggested solutions, for example, the use of fish species from the first trophic levels, i.e. herbivorous and filtering ones. Tacon (2004) confirmed the situation showing the growth in the production of soybean and consequently of soy oil in the world. He underlined that this could be used as an important ingredient in the diet of herbivorous fish, but would not totally fulfill the needs of carnivorous fish. On the other hand, one cannot ignore the fact that fish is a functional food and the production of fish rich in EPA and DHA presupposes a diet with good sources of the precursor LnA, not adequately present in soybean. The studies must therefore be directed at the various lipid sources, their precursors, and the capacity of each species to bioconvert the precursors into PUFA–LC. Some vegetable oils, such as linseed and canola oils, are excellent LnA sources and, when introduced into fish diet, may produce good results (TURCHINI et al., 2006; SOUZA et al., 2007).

Knowledge of the desaturating and elongating activities of the enzymes involved in the biosynthesis of long chain fatty acids in fish has been the object of much interest (SARGENT et al., 2002). A diet with an excess of n-6 PUFA may inhibit the metabolism of 18:3n-3 \( \alpha \)-linolenic acid. Although the n-3 PUFA are more efficient in inhibiting the metabolism of the n-6 PUFA, the reverse process occurs due to a preference of the desaturating enzymes (\( \Delta 5 \) and \( \Delta 6 \)) for the series n-3 in all higher animals (ZHENG et al., 2004). Thus it is possible to determine the effectiveness with which vegetable oil, rich in precursors of PUFA, but with a lack of n-3 PUFA, can replace fish oils in the diets (SARGENT et al., 2002) (Figure 1).

The fatty acids present in the fillets and/or carcasses of marine and freshwater fish, such as in the roe, have been widely analysed in the search for species and/or products that present aggregated value for the fishing industry and aquaculture (VARGAS, 2008a; BHUIYAN et al., 2006).

Research in aquaculture has indicated five important issues: (i) determination of the lipid requirements of species of commercial interest; (ii) evaluation of the capacity of the species to elongate and desaturate the EFAs; (iii) establish the determination of the dynamic balance of fatty acids by the body mass method in vivo; (iv) evaluate the zootecnical and sanitary performances (v) consider...
Review: Essential fatty acids: importance of fish oils and aquaculture

SOUZA, S. M. G.

In the past, the idea of “nutritional requirements” was linked to the concept of essentiality. This means there are nutrients that must be compulsory in the diet since man is not able to produce them, enabling man to avoid the appearance of the signs and symptoms of deficiencies. Nowadays, the trend is for the scientific pursuit of nutraceutical food production in order to reduce the risk of degenerative and chronic diseases (HIBBELN et al., 2006).

It is evident that several worldwide health agencies recognize the importance of increasing the EPA and DHA intake from fish in order to decrease the risk of cardiovascular diseases. Since the n-3 fatty acid intake in the United States is appreciably lower than the recommended value, it is important that strategies be implemented to increase its consumption (Table 2 - modified from GEBAUER et al., 2006).

Considering the globalization of food habits and personal choices, such as the adoption of vegetarian habits, it is possible that these factors could induce health problems. Davis and Kris-Etherton (2003) and Kornsteiner et al. (2008) mentioned that a vegetarian diet with an average n-6/n-3 ratio of 10/1, promotes biochemical n-3 tissue decline. To ensure physical, mental and neurological health, vegetarians should reduce the n-6/n-3 ratio by including an additional intake of direct sources of EPA and DHA, regardless of age and gender.

Figure 1. The elongation and desaturation pathway of linoleic (18:2n−6) and α-linolenic (18:3n−3) acids (modified from SARGENT et al., 2002 and NAKAMURA and NARA, 2004).

the final product taking into account the compatibility of the n-3/n-6 ratio with that recommended for nutraceutical feed (TURCHINI et al., 2006; VARGAS et al., 2008a; RICHARD et al., 2006; LEE et al., 2003).

4 The importance of fish oils in the human diet

Our human ancestors consumed the animals they hunted and fished, which certainly had a different fatty acid balance from the domestic animals or reared fish available nowadays (CRAWFORD et al., 1970). More recently Broadhurst et al. (2002) noted that a fish rich diet was decisive for brain development. The brain has tripled in size during the last three million years, resulting in the birth of Homo sapiens most probably around the Rift Valley lakes and up the Nile corridor into the Middle East. Current studies show a great discrepancy between the present diet and that of our ancestors, primarily with respect to the excess of omega-6 fatty acids and the deficit of omega-3 fatty acids, reaching a value of from 14 to 20 times more omega-6 in relation to omega-3 (FAGUNDES, 2002).

The brain is unique in comparison to other tissues because it does not use LnA and LA, but only their desaturated and elongated forms. The human brain contains more than 90% DHA and ARA. Yet humans and other mammals are inefficient at synthesizing them from their respective 18-carbon precursors. The biosynthetic processes for PUFA-LC are complex and rate limited, particularly in humans (greater in women than men) and guinea pigs (WEISINGER et al., 1995; BURDGE, 2006).

In opposition to this assumption, based on a controlled feeding study, Welch et al. (2008) suggests that the status of n-3 PUFA is feasible from plant sources of LnA, which could have implications in the requirements for fish intake.

In the past, the idea of “nutritional requirements” was linked to the concept of essentiality. This means there are nutrients that must be compulsory in the diet since man is not able to produce them, enabling man to avoid the appearance of the signs and symptoms of deficiencies. Nowadays, the trend is for the scientific pursuit of nutraceutical food production in order to reduce the risk of degenerative and chronic diseases (HIBBELN et al., 2006).

It is evident that several worldwide health agencies recognize the importance of increasing the EPA and DHA intake from fish in order to decrease the risk of cardiovascular diseases. Since the n-3 fatty acid intake in the United States is appreciably lower than the recommended value, it is important that strategies be implemented to increase its consumption (Table 2 - modified from GEBAUER et al., 2006).

Considering the globalization of food habits and personal choices, such as the adoption of vegetarian habits, it is possible that these factors could induce health problems. Davis and Kris-Etherton (2003) and Kornsteiner et al. (2008) mentioned that a vegetarian diet with an average n-6/n-3 ratio of 10/1, promotes biochemical n-3 tissue decline. To ensure physical, mental and neurological health, vegetarians should reduce the n-6/n-3 ratio by including an additional intake of direct sources of EPA and DHA, regardless of age and gender.
The increasing presence of Japanese food in the Western diet has greatly increased the consumption of raw fish, which presents higher DHA and EPA contents as compared to cooked or roasted fish. Studies have shown that the consumption of fried fish is not correlated with beneficial levels of plasma phospholipids (MOZAFFARIAN et al., 2003). A significant influence of the lipid sources, fish oil or vegetable oil rich in precursory n-3 LnA, was noted in ex vivo, in vivo experiments with animal models and studies in human feeding control, and most of the studies confirmed the requirement for their consumption (KOLLER et al., 2003; BOURRE and PAQUOTTE, 2008) and others.

### 5 Possible immuno-modulator activity in fish

Diet rich in fish oil contain a large amount of fatty acids of the n-3 family, EPA and DHA, which are precursors of leukotrienes and prostaglandin. These eicosanoids have a smaller pro-inflammatory effect than the arachidonic acid of the n-6 family (MAPLE et al., 1998). The polyunsaturated fatty acids present in a fish diet can lead to an immuno-modulating activity that depends on the species as well as on the dose/response ratio of the PUFAs. For the first time the results of experiments with cat fish (Rhamdia quelen) showed that different lipid sources produced various physiological responses, and this may represent an alternative for the treatment of the protozoa Ichthyophthirius multifiliis. The highest survival rates were detected in treatments where the fingerlings were fed with high levels of the n-3 family, while the lowest survival rate was recorded in the treatment with corn oil, where the fish consumed high levels of the n-6 series fatty acids (VARGAS et al., 2008b). In the same line of research, Wu et al. (2002) and Lin and Shiau (2003) observed the existence of a direct correlation between the content of DHA in the fish tissue and both the proliferation of leukocytes as well as the increase in activity of the phagocytes (Epinephelus malabaricus).

### 6 Contamination of caught fish

Many researchers and also public and private institutions have been putting out warnings about high levels of contaminants such as dioxins and PCBs (derived from biphenyl polychlorinated) in the liver and muscle of fishes of commercial interest (SKARE et al., 2007). The contamination varies greatly depending on where and in which period of the year the fish was caught and the warnings emphasis the consumption by fertile and pregnant women (SKARE et al., 2007; VILLENEUVE et al. 2000).

Other studies indicate possible risks to health due to the presence of the heavy metals, arsenic, lead, cadmium and mercury in marine and freshwater fish (SKARE et al., 2007; MÖLLERKE et al., 2003).

### 7 Outlets for the supply

For centuries, open access was the rule in fishing. Fishermen considered they could catch whatever they could or wished as a right available to everyone. However it is now widely recognized that some limits and strict control in the capture of wild fish are essential for sustainability. Similarly, in aquaculture, a shift is occurring towards more area-based management, particularly with respect to water management and disease control (FAO, 2008).

Aquaculture, as in all types of animal production, moves according to determined social, environmental and...
economic aspects related to man and the planet. Thus the outlets for providing the supply of n-3 PUFA-LC are affected by multiple interventions. Bourre and Paquette (2008) suggested the possibility of increasing the level of polyunsaturated fatty acids in foodstuffs of animal origin by the appropriate management of the feed of domestic animals. They show the importance of underlining the role of fish, whose nutritional value is almost indispensable in the prevention of cardiovascular diseases and other possible pathologies. They emphasize, however, the direct link with the nature of the fats these fish were fed on. Therefore in cultivating fish, the lipid food sources are the key to solving this impasse. The inclusion not only of vegetable oils, but also of 0.5 to 1.0% of conjugated linoleic acid (CLA) in the feed of catfish (Ictalurus punctatus), offers a unique opportunity in the production of this fish and its derivatives as a new and wholesome food product (MANNING et al., 2006). Sea phytoplankton effectively produces EPA, DPA and DHA from LnA. This marine food chain, from phytoplankton via zooplankton to fish, causes the accumulation of significant amounts of EPA and DHA (SKARE et al., 2007). For fresh water however, much controversy remains.

Eleven years ago, Milstein (2007) referred to the polyculture of fish with first level trophic habits as presenting peculiar conditions in Israel, differing not only in its total dependence on the inert diet of the West, but also on the use of manure in Southeast Asia. In a review on the sources of omega n-3 for fish, Souza et al. (2007) considers that the cultivation of fish in green water, rich in phytoplankton, might be a good source of PUFA-LC precursors. In this sense, Tadesse et al. (2003) suggests that the use of certain groups of algae, including the diatoms and flagellum, could result in benefic levels of LC-PUFA in tilapia (Oreochromis niloticus). For other fish species from the first trophic levels, Domajzon et al. (2000) claims that the influence of zooplankton on the levels of DHA is greater than that of phytoplankton in silver carp (Hypophthalmichthys molitrix), and the influence of the intestinal micro fauna of the fish in the process should not be ignored.

As outlets for the supply of essential fatty acids, Drenner (2006) mentions the immense biodiversity of microorganisms such as microalgae, some fungi and bacteria, combined or not with the use of genetic improvement and the establishment of cultivation technology on a large scale, both for animal and human consumption, due to their richness in the fatty acid families of the n-3 type PUFA-LC. Other authors commented that there are a few species of microalgae, for example diatoms, which have been employed effectively in aquaculture. Lebeau and Robert (2003) commented that despite their abundance and diversity, few diatom species have been employed in aquaculture or for the production of products of commercial interest.

Of the multiple interventions and strategies, intensive work and multidisciplinary research continues in the areas of public health, fishing, aquaculture, agriculture, food engineering and education, fundamental links leading to a more conscious way to increase the production and consumption of n-3 PUFA-LC and decrease the consumption of n-6 PUFA-LC. This will probably have an effect on the food production matrix and cause changes in food consumption habits.

8 Conclusion

As an alternative to the supply of fish oils, it is possible to rely on the production of cultivated fish from the first trophic level, fed on an adjusted lipid diet such as vegetable oils rich in alpha linolenic acid and massive microalgal cultures selected for their profiles of both short and long chain fatty acids. This will most probably represent a major change in the food production matrix over the next few decades.

Acknowledgements

The author is grateful to the students Diego de Oliveira, Kyrie Lucas Isnardi and Renata Facchin Fioravanzo for their collaboration in the edition of tables, figures and references, and also to Dr. Renata M. Rosat for her attention in reviewing the English of the manuscript.

References


Review: Essential fatty acids: importance of fish oils and aquaculture
SOUZA, S. M. G.


 Souza, S. M. G.; Vargas, R. J.; Tognon, F. C. Fatty acids Omega-3 and Omega-6 in fish nutrition - Sources and relations. Revista de Ciências Agroveterinárias, Lages, v. 6, n. 1, p. 63-71, 2007.


