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Nutritional Value of Fish: Lipids, Proteins, Vitamins, and Minerals

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ABSTRACT
The present review aims to give a concise review about important nutrients from fish and their impact on human health. In addition, possible effects of rearing system and feeding on the most vulnerable group of nutrients, the lipids, are summarized.

Fish are considered as nutritionally valuable part of the human diet and consumption two times a week is recommended, mostly due to the content of long chain polyunsaturated n-3 fatty acids. These fatty acids are essential in human nutrition and have proven to be involved in many metabolic functions. Among others, they have anti-inflammatory effects, decrease platelet aggregation and are essential parts in the cell membranes, cardiovascular system, brain, and nervous tissue.

In addition the proteins, peptides and amino acids from fish became more recently known for having positive health effects. Furthermore fish is also a rich source of certain vitamins and minerals as Vitamin D, selenium, phosphorus, and calcium.

It should be highlighted that, when considering nutrition and related health aspects, it is impossible to focus one group of nutrients separately. Most probably the discussed effects of fish on human health are due to the consumption of the fish as a whole and hence the combination of all present nutrients.

KEYWORDS
Calcium; cholecalciferol; n-3 fatty acids; novel feed sources; rearing system

Introduction

Fish and seafood products, have a high nutritional value regarding beneficial amounts of protein, lipids as well as essential micronutrients. Aquatic animal foods are a rich source of protein and have a lower caloric density, and have a high content of omega 3 long chain polyunsaturated fatty acids (n-3 LC PUFA) compared to land living animals (Tacon and Metian, 2013). Strong links between fish and seafood consumption and positive health effects, especially with the decreased risk of coronary heart and cardiovascular diseases, decreased inflammatory disease as arthritis and prevention of cancer have been shown by many researchers (Dyerberg, 1985; Calder, 2004; Rudkowska et al.; 2010; Lund, 2013). Historically the main effects of fish consumption have been attributed to the high content of n-3 LC PUFA. But research is proving more and more, that also other nutrients from fish have positive effects on human health. In addition of being the major source of n-3 LC PUFA, fish and other seafood have also a well-balanced amino acid composition, contain high proportions of taurine and choline, the vitamins D_3 and B_{12} and the minerals calcium, phosphorus, iodine, and selenium. Furthermore, fish and seafood also might provide significant proportions of vitamin A, iron, and zinc to a population if other sources of these nutrients are scarce (Lund, 2013).

Omega-3 fatty acids in fish and lipids in human nutrition

In pre-agricultural times, the foods available to humans were game meat, fish, shellfish, green leafy vegetables, fruits, berries, honey, and nuts (Simopoulos, 2003). This diet, containing higher amounts of n-3 PUFA and lower amounts of n-6 PUFA than modern diets, shaped the genetics of human nutrition. After the agricultural revolution though, intake of cereals increased enormously. Cereals are rich in n-6 PUFA and low in n-3 PUFA and, as a consequence, the n-6/n-3 PUFA balance to which humans are adapted has changed dramatically over the last 10,000 years (Simopoulos, 2002a). Human genetics however could not keep pace with such a fast change in dietary habits, since the spontaneous mutation rate for nuclear DNA is estimated to be 0.5% per million years

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(Simopoulos, 2003). We are therefore (still) adapted to much higher intake of n-3 PUFA in our diet than we actually consume today. In today's Western diets, this ratio is 15 to 20, while it is estimated to have been close to 1 during human evolution (Simopoulos, 2001, 2002b).

A diet rich in PUFA, especially the LC n-3 fatty acids (FA) (≥C20), has been shown to have beneficial effects on human health (Williams, 2000). The n-3 LC PUFA are important for example in the prevention of arteriosclerosis and autoimmune diseases (Kinsella, 1988; Simopoulos, 1999). Eicosanoids synthesized from n-3 PUFA have immunosuppressive properties (Calder, 2001), while the eicosanoids from n-6 PUFA have pro-inflammatory properties and enhance immune reactions like fever and pain (Calder, 2001). A too high intake of n-6 PUFA, is therefore associated with adverse effects on human health, as for example cardiovascular diseases, and diabetes as well as hypertension, depression, neurological dysfunction, and immune disorders (Connor, 2000; Williams, 2000). Also during pregnancy and the neonatal period an optimal diet containing an appropriate amount of the essential LC n-3 PUFA is necessary for neural development of children. The retina and brain of mammals is in general very rich in docosahexaenoic acid, 22:6n-3 (DHA), and the nervous system of newborns has a large demand for it (Lauritzen et al., 2001). It is well established that the maintenance of optimal pre- and postnatal growth and development requires n-3 PUFA (Innis, 1991; Innis et al., 1999).

Mammals are not able to synthesize n-3 or n-6 PUFA in the body (Innis, 1991) but can to a minor amount metabolize the longer chain PUFA from the parental FA α-linolenic acid, 18:3 n-3 (ALA), and linoleic acid, 18:2 n-6 (LA), (Gerster, 1998; Arts et al., 2001). The desaturase and elongase systems for the metabolism of the parental n-3 and n-6 PUFA ALA and LA are the same for both n-3 and n-6 PUFA (De Henauw et al., 2007; Palmquist, 2009). Even if delta 6 desaturase has a higher affinity for ALA than to LA, due to the much higher dietary intake LA has been suggested to limit the conversion of ALA to EPA and DHA (Palmquist, 2009). Considering the metabolic competition between n-6 and n-3 PUFA (Palmquist, 2009) and their opposing properties (Schmitz and Ecker, 2008), it is generally assumed that the intake of n-6 FA is too high in the present diet. An intake ratio of 1 to 4 is generally recommended (Simopoulos, 2001, 2002b). For this reason, a more balanced intake of n-6 and n-3 PUFA is important. Due to this, a daily intake of eicosapentaenoic acid (EPA, 20:5 n-3) and DHA of at least 0.22g each has been suggested as adequate for adults (Simopoulos, 2002b) and many countries have set up their own recommendations for the daily intake of EPA and DHA (Givens and Gibbs, 2008). This makes it important to include sources rich in n-3 PUFA in the daily diet. Oily fish for example, contain high amounts of n-3 LC PUFA, and are therefore a good source for these. Besides, the European Food Safety Authority (EFSA) approved several health claims related to the consumption of fish or EPA and DHA, as for example the maintenance of normal level of blood triacylglycerols, normal brain function and vision, cardiac function and blood pressure (EFSA Panel on Dietetic Products, 2010). European Food Safety Authority has also proposed FA reference labeling intake values for the general population: 250 mg EPA+DHA; 2 g ALA and 10 g of LA per day (EFSA, 2009). Furthermore it was concluded, that a fish consumption of 1 to 2 servings per week could be protective against coronary hearth diseases and ischemic stroke (FAO & WHO, 2011), to reverse the increase in the western world.

Proteins in fish

Fish protein has since long been considered having a high nutritional value (Sargent, 1997). Aquatic animal foods have a higher protein content than most terrestrial meats. In addition aquatic protein is highly digestible and rich in several peptides and essential amino acids that are limited in terrestrial meat proteins, as for example methionine and lysine as suggested by Tacon and Metian (2013).

Nonetheless, only in the last decade, research has also focused on the beneficial health effects of fish protein in human nutrition (Rudkowska et al., 2010; Pilon et al., 2011). Even if this research is still in its beginning, studies related to inflammation, metabolic syndrome, osteoporosis, insulin resistance, obesity-related comorbidity and development of cancer have been executed and fish protein, peptides or hydrolysates have shown of importance in nearly as many areas as fish lipids. For example, a sardine protein diet showed to lower insulin resistance, leptin and TNFα, improved hyperglycemia and decreased adipose tissue oxidative stress in rats with induced metabolic syndrome (Madani et al., 2012). The authors suggested dietary sardine protein as a possible prophylaxis against insulin resistance.

Furthermore, fish protein hydrolysates are considered as superior from a nutritional point of view due to the excellent amino acid composition and easily digestible proteins. But, due to the undesirable fishy odor and flavor they have been earlier mostly used in animal nutrition (Kristinsson and Rasco, 2000; Chalamaiah et al., 2012). It has been shown in human macrophages that fish protein hydrolysates decreased tumor necrosis factor α (TNFα) compared to casein hydrolysates. In the same study the combination of n-3 PUFA with fish protein hydrolysates synergistically decreased expression levels of (TNFα) compared to fish protein hydrolysates or n-3 treatment only (Rudkowska et al., 2010). The same authors suggested that part of the beneficial effect of fish protein hydrolysates compared to casein hydrolysates could be due to the higher content of arginine in fish protein. Arginine has shown to limit the production of superoxide anions by nitric oxide synthase (iNOS). In addition, the higher content of glycine in the fish protein hydrolysates could be beneficial, as glycine has shown to repress the expression of TNFα and the pro-inflammatory interleukin-6 (IL6) in various cell cultures (Rudkowska et al., 2010). The exact mechanisms are yet unclear, however the authors suggested, it might be by activation of the peroxisome proliferator-activated factor γ (PPAR γ), which is also important in lipid metabolism. The third factor could be taurine, which is an amino acid by-product also highly found in fish, which has shown to also suppress production of TNFα, IL6, interleukin-1β (IL-1β) and iNOS (Rudkowska et al., 2010; Lund, 2013).

In general it seems that these above mentioned amino acids and taurine in fish have similar anti-inflammatory effects as the long chain n-3 PUFA. Moreover, some other amino acids and particularly taurine, may play an important role in the beneficial effects of fish protein especially of oily fish including sardines, by for example, limiting the complications of type 2 diabetes and decreasing glucose, insulin and insulin resistance (Madani et al., 2012). On the other hand, Balfego et al. (2016) showed inclusion of 100 g of sardines 5 days a week into the standard diet for type 2 diabetes in a period of 6 months, did not have effect on glycemic control but had lowering effects on cardiovascular risk.

Furthermore proteins from various fish as bonito, salmon, mackerel, herring and cod have shown anti-inflammatory properties while salmon and cod protein in addition improved insulin sensitivity in rats (Lavigne et al., 2001; Ouellet et al., 2007; Pilon et al., 2011). Dort et al. (2012) found cod protein to better promote growth and regeneration of skeletal muscle after trauma compared to peanut protein and casein and suggested this also to be partly because of the improved resolution of inflammation by cod protein. Salmon calcitonin, a 32-amino acid peptide with blood calcium lowering functions has been used for medical purposes for more than 30 years (Chesnut et al., 2008). Calcitonin preserves bone quality and has been used in the treatment of metabolic bone diseases as osteoporosis and Paget's disease and has also shown potentials for the treatment of osteoarthritis and to reduce postmenopausal osteoporosis (Chesnut et al., 2008). Salmon calcitonin has shown to be 40 to 50 times more potent than human calcitonin (Azria et al., 1995).

In the more recent research, a decreased risk of metabolic syndrome in adults has been attributed to the consumption of lean fish (Torris et al., 2016). Drotningsvik et al. (2015) indicated that already a low dietary intake of cod protein (25%) compared to a casein only diet, improved lipid metabolism and glucose regulation in obese rats. For humans, Aadland et al. (2015) showed that already 4 weeks of a diet with 60% of proteins from lean-seafood reduced serum triacylglycerol concentrations and prevented elevation in VLDL particle number in comparison to a diet without seafood-proteins. In a follow up study, the lean-seafood intake showed to reduce postprandial C-peptide and lactate concentrations as well as the TG/HDL-cholesterol ratio (Aadland et al., 2016). The authors concluded that the diet with 60% lean seafood protein had an effect on long-term development of insulin resistance, type 2 diabetes, and cardiovascular disease. Furthermore Schmedes et al. (2016) observed higher lipid catabolism after the lean-seafood intake. The results regarding type 2 diabetes are in line with earlier research that has shown that fish protein improved insulin sensitivity and subsequently increased capacity to store glucose as glycogen (FAO & WHO, 2011, Pilon et al., 2011).

These results indicate that fish consumption has a positive effect on human health due to both the lipid and the protein/peptide composition. Many of the mechanisms are not fully explored and more research is still needed to completely understand the effects of fish proteins as well as the synergistic effects from the combined uptake of fish lipids and proteins.

In addition, some amines, such as spermine and spermidine are highly relevant in the newest health discussions and anti-cancer research (Prester 2011; Wang et al. 2017). As these findings are only very premature, we only make this remark.

Vitamin D, selenium, calcium and phosphorus in fish

In addition to its valuable lipid and protein composition, fish is also a significant source of vitamin D (Holick, 2008b). Deficiency of vitamin D leads among others to rickets, osteomalacia, a low bone mineral density (BMD) and thereby to osteoporosis. Also an increased occurrence of cases of falling has been found in people with low vitamin D levels (Cranney et al., 2007). Furthermore, a significant correlation between higher fish intake and a lower risk of hip fractures was found in Chinese elderly (Fan et al., 2013). Beside bone connected issues deficiency of vitamin D has been connected with diabetes (Holick, 2008a), increased aggressiveness of certain cancers and increased occurrence of autoimmune diseases as well as cardiovascular diseases (Holick, 2008b; Norman, 2008). Norman (2008) found in addition the vitamin D receptor either present or involved in many other body systems, as the adaptive and innate immune system, pancreas and brain. Usually vitamin D can be photochemical produced in the skin by mediation of sunlight. Due to concerns about skin cancer (Norman, 2008) or other reasons for low exposure to the sun, as living on northern altitudes, high rates of vitamin D deficiency have been reported from children and adults all around the world (Holick, 2008b; Norman, 2008). The general recommendation is to ingest at least 1000 IU vitamin D per day, which corresponds to 25 μg (Lu et al., 2007; Holick, 2008b). The form of vitamin D found in fish is vitamin D_3 (cholecalciferol), which is also the form being produced in the skin from 7-dehydrocholesterol when exposed to ultraviolet light and which has recently shown to have more than 3 times higher potency compared to the vitamin D_2 (ergocalciferol) which is found for example in mushrooms (Holick, 2008b; Norman, 2008). The two forms differ by ergocalciferol having one double bond and a methyl group more than cholecalciferol.

Mattila et al. (1995) found a variation of vitamin D content between 0.5 and 30 μg/100 g fish muscle in various species. In addition it was also shown that farmed salmon had a much lower vitamin D content compared with wild salmon and also that the way of preparation might have an influence on the final content (Lu et al., 2007). In the mentioned study, only 50% of the original vitamin D was recovered after frying of salmon (Lu et al., 2007). So clearly these factors have to be considered when predicting the nutritional value of fish.

Selenium is toxic in large doses; but it is essential as a micronutrient in animals and humans. In humans, selenium functions in the form of selenoproteins as cofactor for reduction of diverse antioxidant enzymes, such as glutathione peroxidases and is also responsible for the function of the thyroid gland as a cofactor for the three of the four known types of thyroid hormone deiodinases (Holben and Smith, 1999). Low levels of selenium have been associated with myocardial infarcts and increased death rate from cardiovascular disease. Beside this, low levels of selenium have been correlated with increased risk of cancer and renal disease (Holben and Smith, 1999). Selenium has also shown to decrease the toxicity of methyl mercury (Ralston and Raymond, 2010). Seafood is a good source of selenium and was ranked on place 17 of 25 by the USDA National Nutrient Database according to (Ralston, 2008). In addition, it was found that selenium and selenite from fish was highly bioavailable and had a higher bioavailability than selenium from yeast (Fox et al., 2004). Kehrig et al. (2013) analyzed various fish and seafood from the South Atlantic Ocean and found beside beneficial selenium values also selenium to mercury ratios above the critical value 1:1 which is sufficient to give protection against methyl mercury toxicity. Furthermore, there have been studies on successful supplementations of tilapia with selenium in order to increase selenium content in fish (Molnar et al., 2012). Already earlier Kaneko and Ralston (2007) suggested a so called selenium health benefit value (Se-HBV) based on the absolute amounts and relative proportions of selenium and mercury in seafood as a criteria for seafood safety. More recently, the group updated the Se-HBV value to not only take in account the availability of selenium from fish but also if the selenium status is improved or diminished. This new value is abbreviated HBV_{Se} to distinguish it from the earlier Se-HBV (Ralston et al., 2016).

Calcium is another important mineral in human nutrition being important for bone density. Calcium salts provide rigidity to the skeleton and calcium ions play a role in many if not most metabolic processes (FAO Agriculture and Consumer Protection department, 2002). Nearly 99% of the calcium in the human body is found in the bones (Ghosh and Joshi, 2008). The recommended daily intake of calcium by WHO/FAO is 400 to 500 mg/d for adults. Compared with other minerals, calcium absorbance to the body is relatively inefficient. In general, only about 25% to 30% of dietary calcium is effectively absorbed (FAO Agriculture and Consumer Protection department, 2002). Beside milk and milk products, fish and fish bones are good sources of calcium and it was also shown earlier that calcium absorption from fish is comparable to for example skimmed milk (Hansen et al., 1998). Fish and other aquatic animal food products are rich source of calcium (Martínez-Valverde et al., 2000). An average of 68 to 26 mg/100 g of calcium in crustaceans, molluscs and fish, was documented compared to around 14 mg/100 g in terrestrial meats (Tacon and Metian, 2013). In addition also salmon and cod bones were evaluated as a good source for well absorbable calcium (Malde et al., 2010). The authors suggested these fish bones as a valuable by-product to be used as a natural calcium source in functional foods or food supplements.

Also phosphorus plays an important role in the bones as well as in the cellular membranes as a component of the phospholipids building the membrane lipid bilayer. In addition it is also a component of many intracellular compounds as nucleic acids, nucleoproteins and organic phosphates as for example creatine phosphate and adenosine triphosphate. The total content of phosphorus in the human body is about 700 g of which 80% are bound in the bones, 10.9% in viscera and 9% in the skeletal muscle tissue (Martínez-Valverde et al., 2000; Ghosh and Joshi, 2008). Deficiency of phosphorus in the body leads to muscle disorder, metabolic acidosis, encephalopathy and alteration in bone mineralization as well as in cardiac, respiratory, neurological and metabolic disorders (Ghosh and Joshi, 2008). In several publications fish and seafood are suggested to be a better source of phosphorus with an average between 204 and 230 mg/100 g phosphorus in fish, mollusks and crustaceans, compared to 176 mg/100 g in terrestrial meats (Martínez-Valverde et al., 2000; Tacon and Metian, 2013).

Factors influencing nutritional value in fish

A number of factors influence the composition of fish flesh. Every step in the history of the fish, for example the way of production and processing influences the quality of the final product. Under intensive culture conditions feed composition and feeding regimen have a major influence (Lie, 2001). Especially the lipid content and the FA composition are easily influenced by feed composition also in addition to feeding regimen and rearing system (Morris, 2001; Shearer, 2001). In contrary, as long as fish are fed adequate diets containing all needed nutrients in sufficient amounts, the protein content and composition seem to be predetermined for each species of fish regardless of the content in the diet or the feeding regimen (Morris, 2001; Shearer, 2001). Ash content and mineral composition are similarly predetermined in fish as the proteins; but some other micronutrients can be influenced and can have some effect on flesh quality (Baker, 2001). Regarding wild fish, the composition cannot be manipulated by the diet, however quality of the fish and later products will be affected by handling and processing (Erikson, 2001). In aquaculture, besides the feeding, handling after the harvest, as transport, possible storage or purging of the fish and the slaughter methods (Erikson, 2001; Robb, 2001) are important for the final product quality. All these steps can have an effect on lipid content and composition.

During processing, FA will be affected due to possible oxidation but especially due to the addition of oils or fat to the products. Last but not least the way of culinary preparation has a significant influence on the FA composition of the finally consumed product. The later aspects have recently been reviewed in separate articles (Sampels, 2015a, 2015b) and will hence be not repeated here.

Effects of feed and rearing system

The FA composition of the feed will be mirrored in the flesh (Robin et al., 2003). Especially in aquaculture, the rearing system and type of feed will have a significant influence as the fish have to feed what they get. This is true for both marine and freshwater intensive aquaculture. In marine aquaculture traditionally fish oil is used in feeds to provide the fish with a sufficient proportion of n-3 PUFA (Watanabe, 1982) and to produce fish with a nutritional valuable FA composition (Steffens, 1997; Torstensen et al., 2005; Steffens and Wirth, 2007). Due to an increasing demand of fish and subsequently an increased aquaculture production, fish oil is getting scarce and since many years, research on good and sustainable substitutes which at the same time preserve the natural, nutritional valuable FA composition of fish (Gatlin et al., 2007; Pickova and Morkore, 2007; Torstensen et al., 2008; Naylor et al., 2009; Thanuthong et al., 2011) is ongoing. Various sources as vegetable oils, algae, krill, insects, single cell oils, plankton, mesopelagic fish, and fungal biomass have been investigated as possible replacers for fish oil (Harel et al., 2002; Pickova and Morkore, 2007; Miller et al., 2010; Olsen et al., 2010; Tocher et al., 2010; Turchini and Mailer, 2010; Berge et al., 2013, Henry et al., 2015; Kousoulaki et al., 2015).

A restricting factor is, that for example vegetable oils do not contain the essential n-3 LC-PUFA EPA and DHA but only the shorter chain precursor ALA. Hence the fish must be able to convert the precursor to the longer metabolites if the diet is only prepared with vegetable oils. Most fish, as mammals including human, are not able to synthesize the n-3 LC PUFA in a sufficient proportion and the change from fish-oil to vegetable oil, in general leads to a decrease in LC PUFA (Steffens, 1997; Trattner et al., 2008b; Turchini et al., 2009). Nevertheless, there are differences between species. Already earlier it has been shown that, fresh water species like carp in contrast to marine fish seem to be able to convert ALA towards the longer chain metabolites in a greater amount (Farkas, 1984; Henderson, 1996; Turchini et al., 2006). It was also discussed that the ability of fish to synthetize n-3 LC-PUFA depends on their particular metabolic and life-history adaptations to varied environments (Leaver et al., 2008). We suggest that predatory species have a lower capacity for the synthetization of n-3 LC-PUFA as these species have these FA available in the diet compared to herbivorous or omnivorous fish, which naturally have less n-3 LC-PUFA in the diet.

There has also been some research to increase the metabolism in fish towards the LC derivatives by adding bioactive compounds to the feed. A promising compound is for example sesamin, that showed to increase n-3 LC PUFA synthesis in rainbow trout (*Oncorhynchus mykiss*) (Trattner et al., 2008a), Atlantic salmon (*Salmo salar*) hepatocytes (Trattner et al., 2008b) and in juvenile barramundi (*Lates calcarifer*) (Alhazzaa et al., 2012). Also Lipoic acid has shown to increase metabolism from

ALA to EPA in South American pacu (*Piaractus mesopotamicus*) (Trattner et al., 2007).

More recently even n-3 LC PUFA rich vegetable oil plants (genetically modified) have been suggested as a sustainable source for n-3 (Kitessa et al., 2014; Napier et al., 2015; Robert, 2006). For example a transgenic *Camelina sativa* has successfully been tested in feeds for Gilthead Sea Bream (*Sparus aurata* L.) (Betancor et al., 2016). In addition, a transgenic canola (*Brassica napus* L.) line has been suggested (Napier et al., 2015) but due to the best of our knowledge until now no results of practical applications have been published. Another example is transgenic *Arabidopsis* producing oil rich in EPA and DHA (Robert et al., 2005; Ruiz-Lopez et al., 2013). Also, a genetically modified yeast (*Yarrowia lipolytica*) has been shown to be applicable for fish oil replacement in fish feeds (Berge et al., 2013).

In addition to novel oil and FA sources also new feeding techniques have been investigated as for example a finishing feeding technique or circadian alteration feeding (Brown et al., 2010; Thanuthong et al., 2011). Other strategies aim to increase the bioavailability of the n-3 FA in the used feed source by different treatments. Berge et al. (2013) for example showed, that the application of a disruption process to yeast cells, increased the digestibility coefficients of EPA and DPA from the yeast biomass for Atlantic salmon significantly.

Another part of the rearing system for some species is the so-called purging. For certain species it is necessary to be starved for some time prior consumption in order to empty the entrails and eliminate rearing odor in the flesh. A very good example for freshwater fish that have to be starved before slaughter, are carp, which are mainly starved to eliminate bad odors and taste (Zajic et al., 2013). From the marine species, salmon are often starved for some time to reduce fat content or to decrease metabolic rate before transport (Erikson, 2001). Another reason to starve fish is to reduce the amount and activity of digestive enzymes in fish that are sold whole without prior evisceration (Rørå et al., 2001). Purging however, if pursued for a longer period also leads to weight loss and storage fat mobilization and hence influences the FA composition (Zajic et al., 2013).

Effects of water temperature and salinity

Besides the feed and rearing system also other factors as water salinity and temperature have shown to influence the FA composition in fish (Farkas, 1984; Fonseca-Madrigal et al., 2012). In many poikilotherms, the content of unsaturated FA decreases with increasing temperature (Farkas, 1984) and vice versa. Also Jobling and Bendiksen, 2003 summarized that lower water temperatures in general result in lower accumulation of SFA and increased proportions of unsaturated FA. More recently, Norambuena et al. (2016) showed that water temperature clearly affected FA composition in salmon reared at 10 °C versus 20°C, where fish kept at 10°C showed higher contents of n-6 FA in fillets. In line with this, also Mellery et al. (2016) found a higher accumulation of C18 n-6 PUFA content in rainbow trout raised at 15°C versus 19°C. The same authors also reported a decreased bioconversion from ALA to EPA and DHA at increased temperatures.

Regarding salinity, Roche et al. (1983) found a lower lipid content in sea dace (*Icentrarchus labrax pisces*) at a salinity of 4 ppt compared to higher values (18, 36, and 40 ppt, respectively). Fish also showed a lower content of MUFA and higher proportion of PUFA at the lowest salinity in this study. In the brackish Baltic Sea, herring (*Clupeus harrengus*) is less fatty compared to the saltier North Sea (National Food Agency Sweden, 2017). In line with this Liu et al. (2017) found a lower fat content at lower salinity in juvenile American shad (*Alosa sapidissima*), but in opposite to sea dace and herring, American shad showed a higher MUFA at the lowest salinity and increasing proportions of PUFA with increasing salinity (Liu et al. 2017). Similar results have been shown earlier for silverside (*Chirostoma estor*), where an increased biosynthetis of long chain n-3 PUFA was found in fish raised at higher salinities (Fonseca-Madrigal et al., 2012). On the other hand resulted a lower salinity in higher biosynthesis of EPA and DHA in red sea bream (*Pagrus major*) (Sarker et al. 2011). Changes in lipid metabolism have also been observed in species that undergo a transfer from freshwater to seawater (anadromous), for example during smoltification in salmonids (Bell et al., 1997; Sargent et al., 1989). During smoltification of juvenile salmonids an increased activity of the long chain PUFA synthesis was found until seawater transfer and a decreased activity during the sea water phase (Bell et al., 1997). In general it is assumed that freshwater fish have a higher ability to elongate and desaturate ALA to DHA compared to marine fish, and it seems that increasing salinity or lower temperatures sometimes can have a stimulating effect in some species (Kheriji et al 2003, Fonseca-Madrigal et al., 2012; Liu et al. 2017). In general, when considering salinity effects, species with a large span of environmental adaptations, have a higher fat content (most likely because of better growth) in their environment of origin. For example herring, being a marine fish species, has a higher fat content in higher salinities, compared to brackish environment (National Food Agency, Sweden, 2017). Salmonids (most species) have a higher fat content when they are on feeding migration in saltwater compared to the environment where they hatch and smoltify.

Conclusions

When considering fish as food and the nutritional value connected with these products, first of all the n-3 PUFA are in focus. Furthermore, it gets obvious that also the proteins and peptides in fish have not only a high nutritional value but also impact on human health issues. In addition fish can be considered as a good source of several minerals, vitamins and micronutrients.

The most vulnerable nutrients from fish are the FA, as they are significantly influenced by the feed and the processing of the fish, while protein and the minor nutrients seem to be less affected as long as the fish was not starved or wrongly fed or exposed to abusive storage or processing conditions.

In general, it should be highlighted that, when considering human nutrition and related health aspects, it is impossible to focus one group of nutrients separated from all others. Most probably the discussed effects of fish on human health are due to the consumption of the fish as a whole and hence the combination of all present nutrients.

Future work regarding effects of fish consumption on human health should therefore focus on both, a holistic and metabolomic approach, investigating the effects of fish consumption via techniques as NMR, MALDI-TOF, MALDI imaging MS, and HPLC-MS in order to get a more complete picture. When it comes to nutrition studies, metabolomics are developing fast as a powerful tool, enabling a direct insight into metabolism of the diverse nutrients, possible regulation pathways as well as finding markers for disorders (Cornett et al., 2007; Wagner et al., 2014; Cheng et al., 2016; Schmedes et al., 2016).

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