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# Fish as a functional food: some issues and outcomes

**Ronan Gormley, UCD Institute of Food and Health, University College Dublin, Belfield, Dublin 4 (ronan.gormley@ucd.ie)**

## Introduction

Seafoods are inherently functional and possess many components that are good for human health. Seafoods and their by-products are an excellent source of nutraceuticals and bioactives, and these can be extracted/isolated and added to a range of foods thereby enhancing functionality of the foods in terms of human health (Shahidi, 2003; Alasalvar and Taylor, 2002). These aspects are addressed under nine headings: (1) inherent functionality; (2) nutrient intake of different populations from fish; (3) health benefits of fish products; (4) improving functional profiles of fish and fish products; (5) upgrading fish waste; (6) safety implications of functional seafoods; (7) ethical and sustainability issues; (8) health claims; (9) promoting fish and fish products to consumers. Most of the coverage given is brief; comprehensive coverage would require a book rather than this 33 page article.

## 1. Inherent functionality

Functional foods are broadly defined as those that offer 'something extra' in terms of health benefits than the basic food item, e.g. probiotic-enriched yoghurt versus ordinary yoghurt (Gormley, 2006). The term functional food, by its very nature, suggests that other foods are not functional and have less health benefit relative to functional foods. This is far from fact as many animal and plant foods are highly beneficial for health 'as consumed' and possess inherent functionality (Gormley, 2010a). The term *inherent functionality* is stronger than the term *naturally present* used to describe health-promoting constituents occurring naturally in foods such as taurine in fish and conjugated linoleic acid in dairy or meat products. Inherent functionality is, therefore, a term needed for consumer information in that foods of the same type may differ in their inherent functionality and scientists/technologists/consumers should be aware of this.

### 1.1 Natural complexity

Natural complexity is a close relative of inherent functionality and suggests that nature does things best and that whole foods should preferably be eaten for at least two reasons, (a) key nutrients are retained, and (b) nutrients are 'diluted' i.e. bioactive compounds are contained in a cellular/muscle fibre matrix and as such are slow-released in the gastrointestinal tract (Gormley et al., 1987). This favours *inherently functional* foods over conventional (i.e. man made) functional foods in that the concentration of the key compound/agent in the latter may be too high, and there is also the possibility that the key compound/agent may also be obtained from other functional foods thereby leading to an intake overload. Consuming bioactives in concentrations higher than supplied by nature could have safety implications (see section 6).

## 2. Nutrient intake of populations from fish

Fish is often referred to as 'rich food for poor people' and provides quality proteins, fats, vitamins and minerals. The nutrient intake of populations from fish is directly proportional to the amount of fish consumed. This varies considerably from country to country and from region to region within countries, i.e. coastal communities are likely to have higher fish intakes than inland dwellers although there are many exceptions. Despite fluctuations in supply and demand, fisheries, including aquaculture, have traditionally been, and remain an important source of food, employment and revenue in many countries and communities (Anon., 2002). The total food fish supply, and hence consumption, has been growing by 3.6% per annum since 1961 with the world's population increasing by 1.8% per annum. Proteins from fish and shellfish represent 13.8 and 16.5% of animal protein intake of populations and the per capita availability of seafoods has almost doubled in 40 years thereby outpacing population growth (Anon. 2002).

The annual per capita consumption of fish and shellfish for human food by region is presented in Table 1 together with standard deviation, range (highest-lowest), and also the countries showing this range. The data are for the period 1999-2002 and fish consumption may have dropped since then because of shortage of fish due to over-fishing and other stock depleting situations. The order of fish consumption (Table 1) is North America > Oceania > Far East > Caribbean. The data are based on live-weight equivalent which means only 40-60% (depending on fish type, size, and other factors) of this weight is eaten after removal of heads, guts and bones. Intake of nutrients can be approximated by referring the edible amounts to standard food composition tables for the species concerned being careful to distinguish between white and fatty species.

**Table 1:** Annual per capita consumption (estimated live weight equivalent in kg)[1] of fish and shellfish for human food by region together with ranges (lowest-highest consumption and the corresponding countries) 1999-2001 averages

| **Region** | **Mean** | **SD** | **Range** | **Countries** |
|---|---|---|---|---|
| N America | 50.5 | 32.6 (4)[2] | 2-84 | USA - Greenland |
| Oceania | 44.4 | 43.2 (23) | 2–200 | Amer. Somoa-Tokelau |
| Far East | 31.4 | 37.6 (25) | 0.2-187 | Mongolia-Maldives |
| Caribbean | 20.1 | 12.4 (24) | 1–43 | Puerto Rico-Aruba |
| Europe | 17.9 | 20.7 (46) | 0.1-92 | Tajikistan- Iceland |
| Africa | 12.5 | 15.1 (51) | 0.2-85 | Ethiopa– Saint Helena |
| L America | 11.9 | 12.0 (21) | 2–52 | Guatemala - Guyana |
| Near East | 10.4 | 8.7 (19) | 0.1-26 | Afghanistan-UAE |

[1]Source: Food and Agriculture Organisation of the United Nations (FAO)
[2]Number of countries contributing to the mean and standard deviation (SD)

## 3. Health benefits of seafood

The market for seafood products worldwide has grown significantly in recent years largely fuelled by the image of fish as a healthy component of the diet (Kinsella, 1986; Anon., 2001). Fish and fish products are increasingly promoted as functional foods (Gormley, 2006), and Alasalvar and Taylor (2002) have reviewed applications of marine nutraceuticals to food and health. Many health benefits have, and are, being attributed to fish and include risk reduction/alleviation in relation to a number of diseases/conditions: cardiovascular health and blood pressure; blood clotting; cancer; arthritis; vitamin and mineral deficiencies (Gormley, 2006). Fig. 1 illustrates some of the many potential effects of fish components on human health and some of these are discussed in sections 3.1 to 3.4. There are also many pathways by which seafoods and their products/extracts can act both as inherently functional and as functional agents in seafoods and other foods consumed in the human diet (Fig. 2).

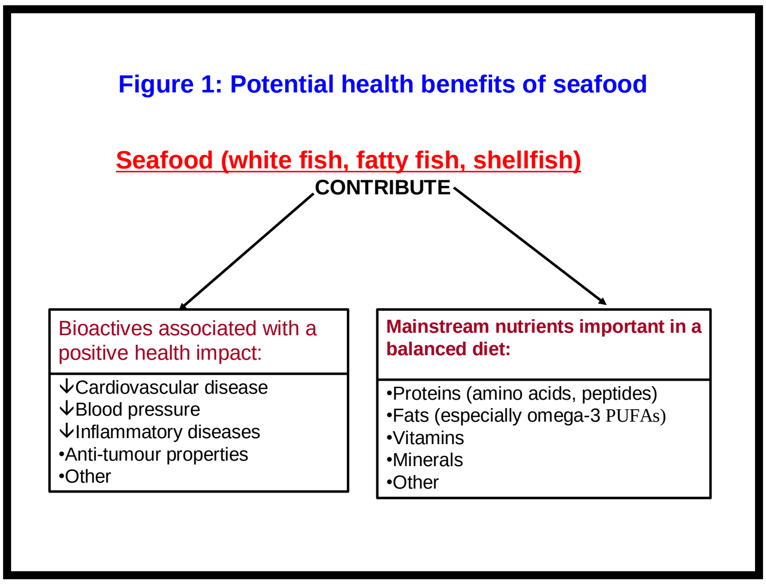
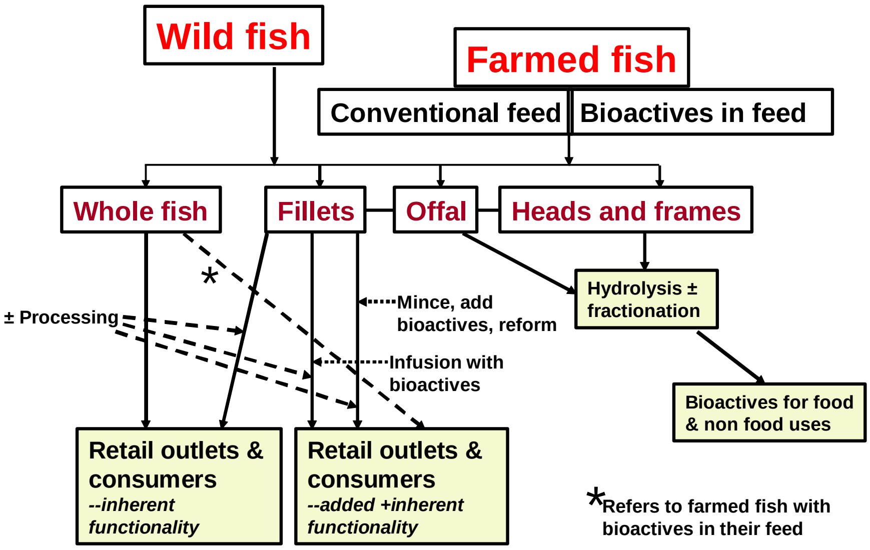


Figure 1: Potential health benefits of seafood

**Figure 2 : Pathways to functional fish (inherent + added functionality)**




## 3.1 Polyunsaturated fatty acids (PUFAs): intakes and supply

In evidence-based guidelines, the dietary intake of at least two fatty fish dishes per week is recommended by international and national associations to guarantee an adequate dietary supply of ω-3 PUFAs (Singer & Wirth, 2003). The recommended minimum daily intake of EPA/DHA varies from 250mg (EU dietary reference value) to 1250mg (British Nutrition Foundation). An average serving of salmon or mackerel will easily supply these amounts. Most white fish also contain oil and EPA/DHA but the amounts are small relative to oily fish. However, organs of some white fish, e.g. cod liver, are major sources of oil and EPA/DHA, and have been recognised as such by our forefathers. However, a word of caution on intakes of ω-3 PUFAs was raised in a recent study which showed a link between high blood concentrations of a single ω-3 fatty acid and a doubling of the risk of developing high-grade prostate cancer (Brasky et al., 2013). The outcomes of this study suggest that consumers who follow the recommended diet of eating oily fish twice a week are doing the right thing. As for taking supplements, the latest research does not prove that ω-3 supplements cause prostate cancer, but it does suggest that a surfeit of fish oils in the diet may not be desirable. Another recent study suggests that EPA, even in low doses, may help to kill off squamous-cell carcinoma (SCC) which is responsible for many skin cancers. SCC can also occur in the lining of the digestive tract, lungs and other areas of the body (Nikolakopoulou et al., 2013).

A recent Irish study indicated oil contents in the range farmed salmon (10-18), mackerel (14-19) and farmed sea bass (4.5-7%) (Slattery and Gormley, 2013a). In wild fish the higher the oil content the higher the content of EPA/DHA. However, for farmed fish this may not always be the case as vegetable oil, in addition to marine oil, is increasingly used in fish feed for sustainability reasons. For example, Atlantic salmon reared on diets based on marine oil contain about 2.5g of EPA/DHA per 100g of flesh while those on a diet with 75% vegetable oil contain 0.8—1.0g. However, some farmed salmon darnes currently on retail sale in Ireland contain more than 3g of EPA/DHA per 100g. EPA and DHA are relatively stable to heat and hence survive heat processes such as canning and hot smoking. For example, some smoked mackerel contain up to 8g of EPA/DHA per 100g flesh (Gormley, 2012a).

The supply of marine fish containing ω-3 PUFAs is being diminished by over-fishing and pollution and this area must be addressed as a matter of urgency. Conservation should be based on the importance of species for their oil rather than as just another fish species that needs to be conserved (Gormley, 2013). Anchovies and sardines are two of the main species harvested for the production of oil needed for salmon farming; however, about 2-4kg of anchovies is required for the production of 1kg of farmed salmon. This is not sustainable and anchovy and sardine stocks will be exploited to extinction as the requirements for more fish oil increase. These small species are also an essential feedstock for larger wild fish. Potential ways forward towards a sustainable supply of fish oils include: (i) increase the use of krill as a source of EPA & DHA; Antarctic krill biomass is estimated at 200-400 million tonnes; yet current catches are only about 200k tonnes per annum; (ii) novel sources of EPA & DHA are expected to yield <50k tonnes of extra oil by 2017 – most of this coming from algae; (iii) integrated production systems embracing farming of fish, molluscs and macro-algae side-by-side where the molluscs use waste from the cages and macro-algae utilise some of the other by-products; (iv) vegetable oil seeds which have been genetically modified to produce EPA & DHA in quantity also have potential; currently there is no commercial production of plant based EPA & DHA but the two species closest to market are soy and rapeseed (canola) (Gormley, 2013).

## 3.2 Polyunsaturated fatty acids (PUFAs): role in cardiovascular health and brain development/cognitive function

*3.2.1 Cardiovascular health:* PUFAs, notably EPA (eicosapentaenoic acid; C20:5) and DHA (docosahexaenoic acid; C22:6), are among the most researched group of compounds in seafoods with over 5000 scientific publications on their health-promoting effects (Bahri et al., 2002). ω-3 PUFAs have been cited as beneficial in alleviating, preventing, or reducing the incidence/severity of a number of diseases including: cardiovascular disease (Burr et al., 1989; Ness et al., 2002), high blood pressure (Morris et al., 1993); blood clotting (Murphy et al., 1999); cancer (Wolk et al., 2006; English et al., 2004), and improved cognitive function (Kalmijn et al., 2004). The ω-3/6 ratio of modern western man is circa 20-fold lower than that of primitive man and indicates massive changes in eating patterns (Block & Pearson, 2006). A second factor is the higher content of ω-6 acids in seafood, and especially farmed fish, which is due to their lower marine and higher vegetable oil diet (see section 7). Castro-Gonzalez et al. (2007) analysed 18 Mexican marine fish for their ω-3 PUFA content in relation to their use as an inherently functional food. Twenty seven percent of the fish showed low (4 to 40), 66% intermediate (7 to 170) and 7% (two species; picuda and sargo) high values (200-300 mg/100 g) for ω-3 PUFAs. These two species are recommended as inherently functional fish. The beneficial effects of ω-3-PUFAs from fish and fish oil on human health is derived from their role in modulating membrane lipid composition and affecting metabolic and signal-transduction pathways (Huang et al., 2009). These authors working with rats demonstrated that EPA and DHA from tuna and salmon oils can be effectively incorporated into tissue membranes.

*3.2.2 Brain development/cognitive function:* Neurodevelopment relates to the growth and development of the brain and central nervous system and embraces brain function, emotion, learning ability, memory and long-term cognition. DHA is essential for this development and expectant mothers have an increased need for DHA which they can get from a combination of supplementation (e.g. capsules) and eating oily fish (Nys and Debruyne, 2011). For pre-term infants DHA supplementation has a beneficial effect early in life on cognitive development at greater than 12 months of age. However, for term infants or for healthy children older than two there is no evidence for beneficial effects on cognitive performance following DHA supplementation (Eilander et al., 2007). However, some inconsistencies between studies may be due to genetic effects which are not yet fully understood. For example, some breast fed children attain higher IQ scores than those not fed breast milk, presumably because of PUFAs uniquely available in breast milk. However, in those with a quite common genetic variant (*FADS2*) involved in fat metabolism, the beneficial effect of breast feeding was not observed (Caspi et al., 2007).

Current evidence suggests a protective effect of ω-3 PUFAs against dementia and over 100 clinical trials are running globally on cognitive health and nutrition. A study in the Nehru Science Centre, Mumbai has shown that DHA decreases progression of neurodegenerative disorders in older age. In contrast, a recent UK study on young adults (18-29 years) showed that DHA supplementation increased blood flow to the brain but was not accompanied by consistent improved cognitive performance in solving computerised cognitive tasks relative to a control group (Jackson et al., 2012). The so-called EPOCH trial is investigating the effect of ω-3 PUFAs on cognitive ageing and wellbeing in cognitively healthy older adults (391 individuals; 54% females). It includes persons with an alternative form of a particular gene which is thought to modify the effect of DHA supplementation (Danthiir et al., 2011). Tan et al. in 2012 confirmed that an EPA/DHA rich diet protects against brain ageing. Over 1500 dementia free patients (average age 67) underwent brain scans and were tested for mental function, body mass, and EPA/DHA content of their red blood cells. The group was divided in four; the bottom quartile having the lowest EPA/DHA levels in their blood and the top quartile the highest, with the two middle quartiles having intermediate levels. Those in the bottom quartile had lower brain volumes than those in the other three quartiles and also scored lower on visual memory tests and executive function, such as problem solving and multi-tasking. A further study by Virtanen et al. (2013) suggests that the level of circulating ω-3 PUFAs (a biomarker of regular fish consumption) may be beneficial for the prevention of certain sub-clinical brain abnormalities that are commonly observed in the elderly.

### 3.3 Bioactive proteins and peptides

Elevated blood pressure is a significant risk factor for CVD. Moderately elevated blood pressure is a very attractive target for the functional food/natural health product and nutraceutical industries as it is one of a relatively small group of health conditions where the consumer can readily assess the effect of alternative therapies (Muir, 2005). Fish in common with other foods contain anti-hypertensive peptides known as angiotensin I-converting enzyme (ACE) inhibitors (Gormley, 2006). Many of the active compounds are contained in hydrolysates from fish waste; (see section 5) and Kitts and Weiler (2003) have outlined some of the bioprocesses needed to isolate and recover the key compounds. ACE inhibitory peptides lower blood pressure by limiting the vasoconstrictory effects of Angiotensin II and potentiating the vasodilatory effects of bradykinin (De Leo et al., 2009). Matsufuji et al. (1994) isolated 13 ACE inhibitors from sardine mussel and most were competitive inhibitors of ACE with the potential to lower blood pressure. Vercruysse et al. (2005) reviewed the topic of ACE inhibitors derived from enzymatic hydrolysates of fish muscle and concluded that these peptides offer great potential as anti-hypertensive agents in functional foods. Enzyme-treated fish protein hydrolysates (FPHs) can also be used as cardio-protective (anti-atherogenic) agents in the form of a functional food or pharmaceutical (Berge, 2005). Je et al. (2008) produced bioactive peptides by enzymatic hydrolysis of big-eye tuna dark muscle. They followed this with further purification and mass spectrometry, and identified the potent peptide as H-Leu-Asn-Leu-Pro-Thr-Ala-Val-Tyr-Met-Val-Thr-OH (MW 1222Da). This peptide scavenged cellular free radicals and enhanced the viability of ter-butylhydroperoxide-induced cytotoxicity. It also inhibited PUFA peroxidation.

*3.3.1 PEP inhibitors*: PEP inhibitors block the action of the enzyme prolyl endopeptidase (PEP). High levels of this enzyme in the blood are associated with neuro-degeneration, disturbance in memory and cognition (Husain & Nemeroff, 1990), and with disorders such as depression, schizophrenia and autism. Altered blood PEP activity is related to psychiatric disorders and Alzheimer's patients have abnormally high levels of PEP activity. The presence of PEP inhibitors is, therefore, important and they have been isolated from cod, salmon and trout flesh (Sorensen, et al., 2004). PEP inhibitors are also found in other foods and plant materials including red wine, green tea and herbal extracts. While PEP inhibitors have not received the level of attention given to EPA/DHA for brain health/function, nevertheless in time they may be proven to be important.

*3.3.2 Taurine:* The effect of taurine on cardiovascular health has been demonstrated by a number of authors (Hayes et al., 1989; Liu and Li, 2000). Fennessy et al. (2003) have shown that taurine modifies endothelial dysfunction in young smokers and restores normal flow-mediated dilation in the brachial artery. The extensive data on the physiological effects of taurine are not matched by corresponding data on the taurine content of foods. However, papers have been published on the taurine content of seafoods and other products (Gormley et al., 2007; Murata et al., 1998).

Tests on fish samples purchased from the ice-counter on eight occasions in supermarkets showed taurine contents in the order plaice > cod > mackerel > farmed salmon (fresh weight basis) (Table 2**).** While values varied from test date to test date the order for the species was the same each time. Selected studies (Gillum et al., 1996) have shown that white and fatty fish consumption is beneficial for human health and this could be due, in-part, to their taurine content and to other similar compounds.

**Table 2:** Taurine content (mg/100g raw) in portions of four fish species purchased in a supermarket [1]

| **Fish species** | **Taurine content[2,3]** |
|---|---|
| Plaice | 146 |
| Cod | 108 |
| Mackerel | 78 |
| Farmed salmon | 60 |
| *F-test (LSD)[4]* | *P< 0.001 (7.78)* |

[1]Source: Gormley, et al., 2007. *European Food Res. & Technol.* 225, 837-842
[2]Values are means for 8 test dates
[3]Samples purchased bi-weekly over a 16 week period
[4]Least significant difference

Data for the taurine content of 14 other species (spot samples) indicated a wide range in taurine contents (Gormley et al., 2007). Albacore tuna and ray wing had the highest contents while some of the deep water species had virtually none. Wild salmon had a taurine content of 60 mg/100 g fresh weight. The taurine contents reported above are generally towards the lower end of the ranges reported for fish species in the literature. For example, Sakaguchi et al. (1982) reported taurine levels of 973 and 26 mg/100 g in dark and white muscle, respectively, of mackerel (*Scomber japonicus*), and corresponding values of 1040 and 11 mg/100 g in yellowtail (*Seriola quinqueradiata*). Zhao et al. (1998) reported a range in taurine content from 41 to 851 mg/100 g edible portion in 29 aquatic products. Contents were relatively high in flatfish and ray, and relatively low in silver pomfret, yellow croaker and baby croaker. Therefore, consumers eating 150-200 g portions of fish per day would fall short of the level of taurine supplement (1.5 g/d) given by Fennessy et al. (2003) in a clinical trial with smokers. However, these workers did not test if lower levels of taurine intake would also be beneficial in alleviating endothelial dysfunction. Taurine intakes (from seafood and meat) by Chinese men from different regions in China ranged from 33.5 to 79.7 mg/d (Zhao et al. (1998) while British males averaged 76 mg/d (Rana and Sanders, 1986).

### 3.4 Antioxidants

Antioxidants in fish have the potential to influence human health positively (Gormley, 2006). For example, *Anguilla japonica* and *Conger myriaster* are popular eel species in the Chinese food industry, and eel is also used in traditional Chinese medicine with reported potential as a functional food. Antioxidants protect the body against oxidation by scavenging biologically toxic reactive-oxygen species. Ekanayake *et al.* (2005) screened potential antioxidant compounds in the skin and flesh extracts of the two eel species above and all extracts of *Anguilla japonica* showed dose-dependent DPPH (2,4-dipicrylhydrazine) free-radical scavenging, and also significant hydroxyl radical-scavenging activities. The diethyl ether extract of this species showed high superoxide-scavenging activity. The authors concluded that *Anguilla japonica* is rich in heat-stable and non-polar antioxidants. In another study, Noguchi (2003) examined the biological activity in halibut skin and found that an alkaline extract showed inhibition of proliferation of some tumour cells *in-vitro*. It was concluded that fish skin components have significant biological activity and are valuable for functional foods and drugs.

### 3.5 Selenium

Selenium is an important trace element for human health and is linked to protection against cancer (Careche et al., 2008; Ip et al., 2000; Finley, 2003). The concentration of selenium in fish is not influenced by cooking, or by cooking method (Fox et al., 2004). The Recommended Dietary Amount (RDA) for selenium is 55 µg (EC Directive 90/496/EC). A number of selenium-containing compounds are associated with being protective, including the easily absorbed glutamyl-Se-methylselenocysteine and Se-methyl-selenocysteine. Blood selenium concentrations in humans were inversely related to the risk of colon (Jacobs et al., 2004), prostate, and lung cancers (Clark et.al., 1996; Finley, 2003). Many soils are deficient in selenium and consumers in these regions are, therefore, likely to be deficient in selenium. This can be overcome to an extent by enriching the soil with selenium-containing compounds, and by growing plants known for their ability to readily absorb selenium such as garlic (Larsen et al., 2006) and feeding these to fish (Schram et al., 2008; Cotter et al., 2008).

## 4. Improving functional profiles of fish, fish products, and other food products/diets

While fish are inherently functional, there are many examples of fish being enriched with functional ingredients thereby attempting to increase further the health benefits, i.e. inherent functionality plus added functionality. This is shown schematically in Fig. 2 (see page 4) where a number of options are detailed. The EU SEAFOODplus project was a major provider of novel product concepts in this area (Careche et.al., 2008). Some examples of enhancing the functional food properties of fish are as follows:

### 4.1 Enriching fish with taurine

The potential benefits of taurine for cardiovascular health have been cited above (section 3.3.2) so it may be beneficial to enrich fish to a level of circa 1% with additional taurine. This was achieved by vacuum tumbling yellowfin tuna (*Thunnus albacares*) cubes in an aqueous solution of taurine and sodium tripolyphosphate (STPP) (Gormley et al., 2007). The tumbled samples were subjected to five post-tumbling treatments to study the level of retention of the added taurine. The results showed that tumbling in a taurine/phosphate solution was a suitable procedure for adding taurine to tuna cubes and contents ranged from 710 (tumble only) to 917 mg/100 g (wet weight) for tumbling + chilling (Table 3) (target concentration circa 1%) indicating a good level of uptake and retention.

**Table 3:** Taurine content (mg/100g raw) of vacuum tumbled and processed tuna cubes [uncooked (UC) and microwaved (MW)][1]

| Treatment | UC[2] | MW[3] |
|---|---|---|
| Tumbled [taurine (7.5% w/v)] + STTP (5% w/v)[4] | 710 | 741 |
| Tumbled+ frozen (-20ºC/4 d) | 917 | 850 |
| Tumbled+chilled (2-4ºC/6 d) | 856 | 941 |
| Tumbled+freeze-chilled (-20ºC/5d+2-4ºC/6 d) | 751 | 856 |
| Tumbled+*sous vide* cooked (core:90ºC/4 min) | 767 | 714 |
| *F-test (LSD)[5]: Treatments* | *P<0.01 (75.4)* | |
| *F-test (LSD): Uncooked vs microwaved* | *NS (47.6)* | |

[1]Source: Gormley, et al., 2007. *European Food Res. & Technology* 225, 837-842
[2]Except for *sous vide* samples
[3]3.5 min/850 W
[4]Sodium tripolyphosphate
[5]Least significant difference

**Table 4:** Sensory tests[1,2] on taurine-enriched microwave heated tuna cubes[3]

| Comparison | Preference ratio | Acceptability score |
|---|---|---|
| Not tumbled vs tumbled taurine-phosphate | 10/10 (NS)[4] | 3.3 vs 3.1 (NS) |
| Not tumbled vs tumbled phosphate | 14/6 (NS) | 3.7 vs 3.6 (NS) |
| Tumb.taurine-phosphate vs tumb. phosphate | 8/12 (NS) | 3.4 vs 3.6 (NS) |

[1]Paired comparison taste panel; 20 tasters
[2]6 cm line with end-points of 0 (unacceptable) and 6 (very acceptable)
[3]Taurine content = 800 mg/100 g
[4]Not significant

Added taurine/STPP did not affect product sensory acceptability and scores were above the mid-point of the 6-cm acceptability scale (Table 4). Of three cooking methods, grilling gave the best retention of added taurine followed by microwaving and steaming. This may be due to the high temperature of grilling which led to a coagulated protein skin on the fish surface thus minimising weeping of taurine-containing drip (Gormley et al., 2007).

## 4.2 Enriching catfish with selenium

Schram et al. (2008) reported the enrichment of African catfish with functional selenium originating from garlic. The dietary total selenium concentration of 8.5 mg/kg resulted in a total selenium concentration of 9 mg/kg in the fillet (wet weight). The main compound recovered in an extract made from the fillet was selenomethionine which is considered important from a nutritional point of view. Seleno-methyl-selenocysteine, which has anti-carcinogenic properties, was also detected in the fillets but could not be quantified. Similarly, Cotter et al. (2008) fed hybrid striped bass with diets containing either organically or inorganically derived selenium. A 100 g portion of the enriched fish flesh contained between 33 and 109 µg/kg Se depending on the level of Se in the feed which, in turn, amounted to a dietary intake of 25 - 80 µg/kg; this level satisfies daily intake recommendations. The trials were deemed highly successful for raising fillet selenium content to nutritionally meaningful levels.

## 4.3 Enriching fish products with dietary fibres, antioxidant dietary fibres or prebiotics

There are increasing demands for healthy convenience fish products and this gives scope for enriching fish products with dietary fibres (DFs), antioxidant dietary fibres (AODFs) or with prebiotics thereby making the products doubly functional, i.e. the inherent functionality of the fish and the added functionality of the DF, AODF or prebiotic. Designing functional foods has become a key area and is the subject of many articles (McClements and Decker, 2009). AODF is plant derived material with a DF content of at least 50% (dry matter basis), an inhibitory lipid oxidation potential (per g AODF) >200 mg of vitamin E, and free radical scavenging capacity >50 mg vitamin E. Examples of some products containing DF, AODF or a prebiotic are cited below.

*4.3.1 Apple pomace in mackerel products*: Apple pomace is a cheap product with minimal commercial value and is produced in volume in many countries but especially in Poland where there is a large production of apples and a significant fruit juice industry. Pomace from the apple cultivar Shampion is white and, is therefore, conducive to adding to products. Pomace is largely cell wall material with significant pectin content, and is known to reduce cholesterol and low density lipoprotein (LDL) cholesterol in addition to its other properties as an AODF (Dragsted and Gormley, 2010). Keilen et al. (2007) added pomace (0, 2, 4% w/w) to minced mackerel tissue (*Scomber scombrus*) and this was formed into burgers. The pomace had a DF content of 50%; total phenols were 569 mg gallic acid equivalents /100 g dw, but the anti radical power of 0.312 [1/IC 50 (g/$L^{-1}$)] was low. Sensory acceptability scores were >3 (mid-point of scale) with the exception of the sample with 4% apple pomace on day 7 (Fig. 3). Thiobarbituric acid substances (TBARS) values were high (Fig. 4) suggesting oxidation of the fish lipid but the analysis was influenced by the apple pomace itself and by other constituents in the burgers as indicated by increasing TBARS values with rising inclusions of apple pomace.  In addition, TBARS values rose over time indicating increasing oxidation and that the pomace was not performing efficiently as an antioxidant under the conditions prevailing in the trial.

**Figure 3: Sensory acceptability (ACC) scores (0-6) for mackerel burgers (+ apple pomace) stored at 2-4ºC for 7 days**

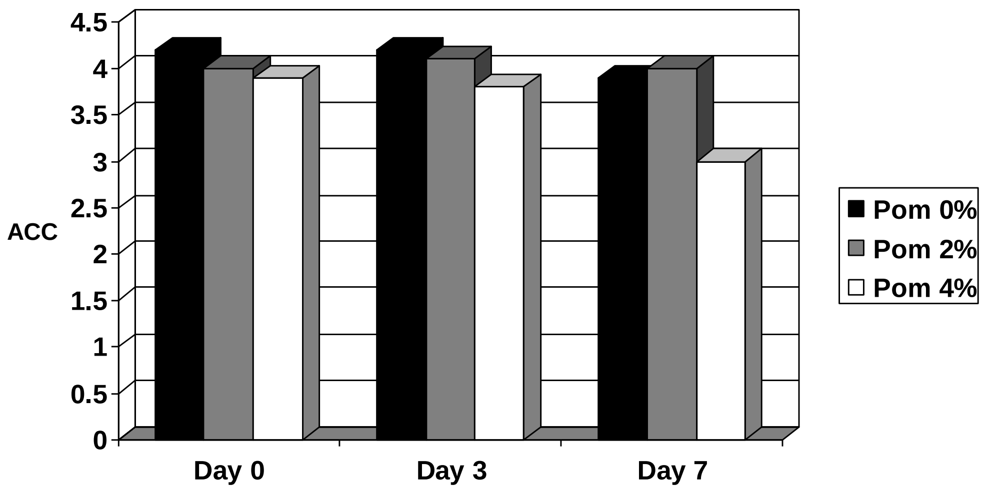
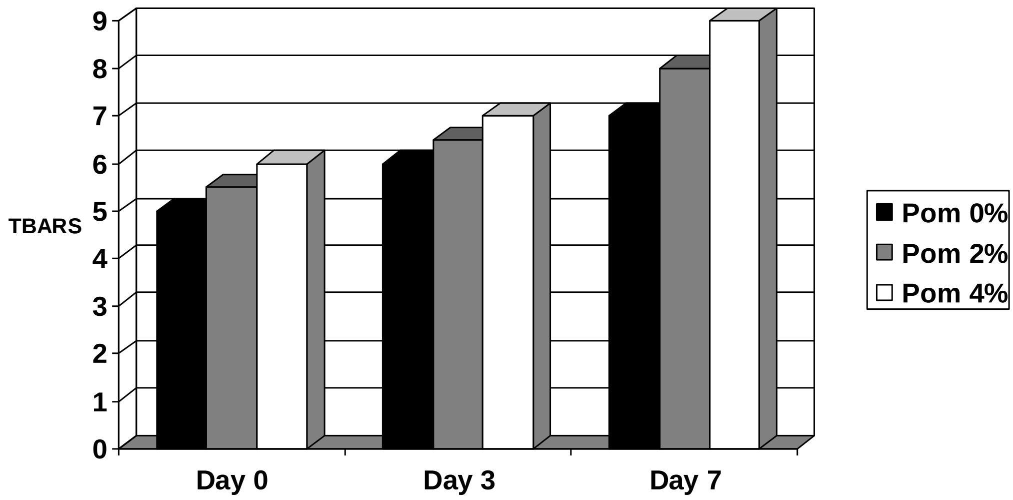


**Figure 4 : TBARS values (µg malonaldehyde/g) for mackerel burgers (+ pomace) stored at 2-4ºC for 7 days**




*4.3.2 Wheat, grape and seaweed dietary fibre (DF) inclusions in seafood products:* Careche et al. (2008) incorporated wheat DF (WDF) into minced fish at levels up to 6% (w/w) and/or to surimi gels and non-gelled products (3-6% w/w inclusions). In many of the trials 3% WDF was the upper level of inclusion in terms of product sensory acceptability. Grape and seaweed AODFs were also tested in-product. The former was included in restructured products made from horse mackerel (Sanchez-Alonso et al., 2007). Tests indicated that inclusions of 2% in-product were well accepted sensorically, but that 4% gave a less acceptable texture but did not impact on product flavour. Tests were also conducted on including seaweed AODF extracted from *fucus vesiculosus* into restructured seafood products. However, the inclusions imparted an undesirable green colour to the product and also an over-strong flavour (Careche et al., 2008).

*4.3.3 Fish ready-meals and fish-fruit combination products:* While fish is an excellent and nutritious product in its own right, its use in combination with other food types also provides major commercial opportunities. For example, Braida and Gormley (2008) produced a gluten-free salmon lasagne ready-meal containing an oligosaccharide (a prebiotic and sweetener), taurine, pectin or algal calcium, or a combination of all four. The potential health benefits from taurine and pectin (cell wall material) were outlined above, while Aquamin is a readily-absorbable form of algal calcium (O'Leary, 2010). Gluten-free is also a requirement for an increasing number of consumers. The meal comprised salmon sauce, (50% salmon pieces), Bėchamel sauce, gluten-free pasta sheets and mozzarella cheese and was based on conventional salmon lasagne. The nutraceuticals were included in the Bėchamel sauce at a range of concentrations. Each of the inclusions reduced sauce acceptability score for the Bėchamel sauce, and the all-inclusions combined treatment (pectin content 2.5%) got the lowest sensory score. The Bėchamel sauce with a prebiotic (3.1) got a similar rating to the control (3.3) on a 6-cm line scale with end-points 0 (unacceptable) and 6 (very acceptable) and these data transferred to the acceptability of the lasagne ready-meals. The conclusion was that the gluten-free lasagne ready-meals with prebiotic, taurine or pectin can be classed as new-generation products targeted at the health market.

Tests conducted as part of the EU ISAFRUIT project (Gormley, 2009) included fish-fruit chilled combination/convenience products embracing steamed/grilled white or fatty fish portions together with heat-processed apple puree (cultivar Bramley's Seedling) containing a prebiotic. These functional products were presented in compartmented trays with a modified atmosphere and were stored at 2-4ºC (Gormley, 2008).

*4.3.4 Conjugated linoleic acid inclusions in seafoods*: Conjugated linoleic acid (CLA) has been linked to reduction of body fat without substantially reducing body weight. *In-vitro* studies have shown that CLA may have anti-carcinogenic activity, protect against atherosclerosis, and have other positive physiological effects (Pariza et al., 2001; Belury, 2002; Noone et al., 2002). There has, therefore, been extensive interest in the last five years in enriching fish fillets with CLA thereby giving additional functionality. Manning et al. (2006), enriched catfish (*Ictalurus punctatus*) with CLA and ω-3 PUFAs by dietary manipulation. Fish muscle showed an increase in both CLA and ω-3 PUFAs compared to controls and the content of CLA was 6.4 % of total lipid indicating successful enrichment. Valente et al. (2007a) studied the effect of CLA (diets contained up to 2%) on growth, lipid composition and hepatic lipogenesis in juvenile European sea bass (*Dicentrarchus labrax*). The total accumulation of CLA was 5.6% in the muscle thereby giving the product functional food status. Similarly, Valente et al. (2007b) studied CLA accumulation in rainbow trout (*Oncorhynchus mykiss*). Levels of 4.2% were achieved in the flesh. Ramos et al. (2008) studied the time course deposition of CLA in market size rainbow trout (*Oncorhynchus mykiss*). Feeding the trout with 1% CLA during an 8-week period was sufficient to attain muscle CLA levels similar to those obtained after 12 weeks. A fast accumulation was registered reaching 1.3% of total fatty acids after just 2 weeks supplementation.

*4.3.5 Supplementing foods and diets with seafood-derived bioactives*: The EPA and DHA content of daily diets in the USA can be increased significantly and cost effectively using nutraceuticals, functional and whole foods, and in this way meet the strategies of the American Heart Association in relation to secondary CHD prevention (Patterson and Stark, 2008). A good way to raise the ω-3 PUFA content of the diet, without radical changes in eating habits, is to enrich commonly consumed food products with ω-3 PUFAs using fish oil preparations (30% EPA+DHA) and/or powder encapsulated forms (10% EPA+DHA) without significant flavour deterioration (Kolanowski et al., 1999). ω-3 PUFAs are being added to a plethora of diets and foods including eggs, breads, sausages, milk, reduced-fat spreads and others (Kolanowski and Laufenberg, 2006). However, the long-term supply of marine oil, the high energy cost of obtaining it (e.g. diesel for trawlers), and the lack of non-marine, synthetic or biosynthetic sources of ω-3 PUFAs raises serious sustainability issues and a likely shortage even in the short term (Gormley, 2010b). Picone et al. (2009) commented on the strong mediatic pressure for supplementing diets of pregnant women with ω-3 PUFAs and suggest that apart from a positive effect on cerebral development, the overall evidence for supplementation is not yet strong.

Rose and Holub (2006) found that consuming a breakfast containing liquid egg supplied 1.3 g/d of EPA+DHA, decreased plasma triglycerides by 32%, and the triglyceride:HDL-cholesterol ratio by 37% compared with a control breakfast. They concluded that this egg product could serve as a dietary intervention for supporting CHD risk management. Dry fermented sausages were developed by Valencia et al. (2006) supplying 0.64 g EPA/100 g and 0.46 g DHA/100 g using de-odourised oils. The sausages showed no oxidation during storage and can be considered a technologically viable functional food. Lock and Bauman (2004) reported the enrichment of milk with CLA, EPA and DHA. Transfer of EPA and DHA was low (<4%) largely due to biohydrogenation in the rumen. However, diet formulation for dairy cows is central to achieving even a modest uptake. Kolanowski et al. (2004) reported the preparation of a reduced-fat spread containing unhydrogenated fish oil. The spread could be stored for 3 mo without quality deterioration and a daily portion of 30 g provided 0.25 g of

EPA+DHA thereby significantly raising the ω-3 PUFA content of the average diet. However, a cautionary note is added (see page 18) that too high intakes of ω-3 PUFAs may be in fact harmful.

## 5. Upgrading Fish Waste

By-products from seafood processing may account for up to 80% of the weight of the harvest depending on the species, and include a variety of constituents with potential use as nutraceuticals and bioactives (Shahidi, 2003). These include ω-3 PUFAs from the livers of white lean fish, waste flesh parts of fatty fish, blubber of marine animals, hydrolysates from fish guts/cleanings, peptides, and products from crustaceans such as chitosan, chitosan oligomers, and glucosamines. For example, antioxidative peptides with up to 16 amino acids in chain length have been isolated from pollock skin. Many of the above constituents may render benefits above their nutritional value. Hence, by-products processed from seafoods could serve as important value-added nutraceuticals and functional food ingredients (Fig. 2, see page 4). A comprehensive book on advances in seafood by-products has been compiled by Bechtel, (2002). Extensive work is also ongoing in Ireland on bioactives from fish waste as part of the ongoing NutraMara project (http://www.nutramara.ie/).

Ogawa et al. (2004) isolated acid-soluble collagen and pepsin-solubilized collagen from bones and scales of black drum (*Pogonia cromis*) and sheepshead seabream (*Archosargus probatocephalus*). These are typical type-I collagens with potential applications in functional foods, cosmetics, biomedical, and pharmaceutical industries. Ohba et al., (2003) also studied the properties of collagens and keratin derived from fish waste and found strong ACE inhibition indicating potential for treating high blood pressure.

Rademacher et al. (2004) investigated the potential of fish bones/crab shell waste as calcium nutraceuticals for inclusion in food products. Bones from plaice (*Pleuronectes platessa*), cod (*Gadus morhua*) and farmed salmon (*Salmo salar*) together with crab shell waste were washed/steamed, dried and de-fatted. Bone/shell samples were (i) canned, (ii) hydrolysed, or (iii) high-pressure treated to study the effect on bone softening and calcium release. Dialysable/available calcium was measured by an *in-vitro* dialysis sac method and a sample of cheddar cheese was tested for comparison. The results indicated that fish bone and crab shell powders were of limited value as calcium nutraceuticals for inclusion in food products based on the *in-vitro* test used.

Chitin is the second most abundant natural biopolymer after cellulose, and both it and chitosan have many food applications (Shahidi et al., 1999); shells of crustaceans are a major source. Nutritional/health properties include antioxidant potential, reduction of cholesterol in animals (Hirano et al., 1990), activity as a dietary fibre (Muzzarelli, 1996), and anti-tumour activity (Suzuki, 1996).

The functional properties of fish protein hydrolysates (FPH) have been studied by a number of authors. Matsui et al. (1993) found that sardine protein hydrolysates acted as ACE inhibitors. Wasswa et al. (2007) used enzymatic hydrolysis (Alcalase ®) to obtain protein hydrolysates from grass carp skin. The FPHs had desirable essential amino acid profiles and had good oil holding, emulsifying capacity, and binding properties. Hatchery waste products were utilised as functional food material via preparation of FPH from fish scraps of three marine species by protease treatment (Khan et al., 2004). The peptides produced stabilized the hydrate water surrounding myofibrils and suppressed dehydration-induced denaturation. This property was also studied by Hossain et al. (2003) in FPH from four species of shrimp. The amount of unfrozen water in myofibrillar protein and shrimp FPH increased significantly suggesting that the peptides of the hydolysate stabilised water molecules thereby maintaining structural stability and suppressing dehydration-induced denaturation. Zhang et al. (2002) produced FPHs from Antarctic krill and found that they stabilized the bonding of water molecules leading to suppressed denaturation of lizard fish and shrimp myofibrils during dehydration. .

## 6. Safety implications of functional seafoods

The microbiological or residue aspects of seafoods are taken as read and are not addressed here. However, there are safety considerations associated with the ingestion of bioactives from seafood. For example, ω-3 PUFAs occur naturally in fatty fish and food technologists are now adding PUFAs and other bioactives to many foods so there is a danger that consumers could get an overload; this may or may not be harmful. Several models have been developed to calculate safe maximum amounts of vitamins and minerals for the purpose of food fortification. However, none of the models include the adding of bioactive ingredients to foods. At present, the number and variety of bioactive substances used as functional food ingredients is growing rapidly (Niemann, 2010); they are a diverse group of chemicals including complex mixtures and microbes. All these substances are normal constituents of our daily diet in low and/or trace amounts but we run the risk of obtaining oversupply because they have been added to a range of foods.

A simple strategy to derive reasonable amounts of functional food ingredients could be the follows: (i) the substance has to be characterised and all traditional foods containing it have to be determined; (ii) the population with the highest habitual intake of these foods has to be selected for calculating the intake of the substance; (iii) the highest identified habitual intake could be divided by a factor of 10 to consider the multiple exposure by all the other food commodities containing the same ingredient. The resulting amount could be added to one serving size of a given food product. However, this approach cannot be used for functional foods claiming dose-related effects that require amounts beyond all nutritional experience (Niemann, 2010).

## 7. Ethical and sustainability issues

Many consumers are aware of ethical and sustainability issues relating to the foods they purchase. This applies equally to whether they are buying unprocessed fish (inherently functional) or fish products which may have added functionality as well. The major fishing sustainability requirement is an eco-systems approach to fishing and the Marine Stewardship Council's (MSC) (www.msc.org) fishery certification programme and seafood eco-label recognise and reward sustainable fishing. The MSC is a global organisation working with fisheries, seafood companies, scientists, conservation groups and the public to promote the best environmental choice in seafood. Fisheries around the world have been assessed against MSC environmental standards for sustainable fishing and currently at least 63 fisheries are certified in the MSC program with many of these clustered in the Atlantic stretching from Norway to southern Spain. Many supermarket chains now use the blue MSC eco-label and consumers are slowly becoming aware of this label (Gormley 2010b).

Consumers eat farmed salmon because they are aware of the health benefits of ω-3 PUFAs. However, feeding vegetable oil rather than marine oil in the feed to salmon and trout leads to fish with a vegetable rather than a marine fat profile. The fish are then 'converted' to marine oil near time of harvest to improve their fat profile. This is deceiving for consumers and highlights the major requirement of finding alternative sources of marine oils containing ω-3 PUFAs. For this reason it may be beneficial to label the EPA/DHA content of farmed oily fish (Gormley, 2012b). Utilisation of seaweeds and microalgae may be an alternative source of ω-3 PUFAs (Soler-Vila et al., 2009), as may single-cell oils (Ward and Singh, 2005). Cronin et al. (1991) indicated big differences between the fat status of wild versus farmed salmon (Table 5). Despite relatively similar PUFA contents in the flesh oil of both types, the wild salmon had a much higher ratio of ω-3/ω-6 PUFAs than farmed; this is a reflection of the formulated feed used for the latter.

**Table 5:** ω-3/6 PUFA ratios of wild and farmed salmon[1]

| Sample | Linoleic acid (%) (LA) | ω-3 PUFAs in flesh oil (%) | $\frac{EPA^2 + DHA^3}{LA}$ |
|---|---|---|---|
| **Wild** (n=12) | | | |
| Mean | 1.1 | 18.4 | 17.5 |
| CV (%) | 22.5 | 16.6 | 30.9 |
| **Farmed** (n=17) | | | |
| Mean | 6.1 | 16.1 | 2.7 |
| CV (%) | 10.5 | 9.1 | 17.8 |

[1]Source: Cronin et al., 1991. *Irish J. Food Science and Technology,* 15**,** 53-62
[2]EPA=Eicosapentaenoic acid
[3]DHA=Docosahexaenoic acid

A second related issue is the selling of production grade farmed salmon in retail outlets. These fish have poor condition (low condition factor) manifested by little body curvature behind the head/on the back, and poor belly condition, and in some cases gill bronzing (Schallich and Gormley, 1996). These fish have elevated water content and reduced fat content, i.e. fat trades with water (Table 6). This deceives consumers as in effect they are buying low fat fish with less ω-3 PUFAs.

**Table 6:** Composition versus condition factor of ungutted fresh farmed salmon[1]

| Condition factor[2] | Moisture (%) | Protein (%) | Fat (%) |
|---|---|---|---|
| 1.21-1.30 | 66.7 | 20.1 | 13.2 |
| 1.11-1.20 | 68.7 | 20.0 | 11.3 |
| 1.01-1.10 | 68.1 | 19.4 | 12.5 |
| 0.90-1.00 | 71.5 | 18.9 | 9.6 |
| <0.80[3] | 77.9 | 19.0 | 3.1 |

[1]Source: Schallich, E. and Gormley, T.R. 1996. *Farm and Food,* 6(3), 28-31
[2]Condition factor (CF) = [fish weight (g) x100] ÷ [fish length (cm)]$^3$; CF for farmed salmon >1.1 (gut-in) and >0.9 (gutted); [3]reconditioned fish

## 8. Health Claims

Health claims are a highly emotive issue with the food industry and there is frequent criticism of the EU and the European Food Safety Authority (EFSA) that their approach is too stringent and that they are stifling innovation in functional foods, and putting the European functional food and related industries at a disadvantage relative to the US industry. EFSA requires good scientific proof of efficacy before a new health claim is allowed. This requires very expensive human trials and these may also be supported by trials with laboratory animals and by *in-vitro* procedures. Even when efficacy for a particular bioactive is proven for a given food (e.g. stannols in yogurt), the proven efficacy may or may not be accepted for a different carrier, e.g. the stannol at the correct concentration but now in pureed apple rather in yogurt. The requirement for proof of efficacy puts SMEs at a considerable disadvantage relative to large companies as the former don't have sufficient money for the expensive human trials. Currently the EU is permitting this situation to prevail while at the same time offering R&D support funding for food SMEs, i.e. one policy seems to oppose the other. Hopefully, some form of compromise will emerge which will ease the claims procedure while maintaining safety for the consumer. Common sense must prevail and SMEs must be well represented at committee level where decisions on health claims are being made that may militate against them. The situation on these issues has been published by the Irish Food Safety Authority (Anon., 2010) in a publication entitled '*Information on Nutrition and Health Claims*'. Obviously all the seafood bioactives mentioned in this chapter must go through the expensive health claims process before an actual health claim can be made for them. The position regarding nutrition claims is less stringent (Anon., 2010).

## 9. Promoting Fish and Fish Products to Consumers

There is a wide range in fish consumption from country to country and among populations (Table 1, see page 3). These differences may be due to necessity, i.e. that fish is the only available protein-containing food in a particular region, or to other factors including availability, price, social status, and likes and dislikes of consumers. Social status is a barrier to fish consumption in many countries as fish is now an expensive commodity for the consumer. Most developed countries have proactive programmes/organisations which promote fish to consumers in terms of health benefit, sensory quality and value for money; for example, the Irish Sea Fisheries Board (BIM) in Ireland and its equivalents in other countries. These organisations have fish cooking recipes for consumers and it is essential that these are drawn-up with good nutrition in mind. Factors militating against this include: (i) many fish are heavily breaded and are then French fried; (ii) fish are often served with high-fat sauces in hotels and restaurants, and are seasoned heavily with salt. However, the wet fish counter in stores offers fish that are untreated, and high quality frozen fillets/portions are also available that are untreated except for a light glaze.

In 2013 study face to face interviews were held with 371 consumers (classified in seven age categories) chosen at random who were shopping in three major retail stores in Dublin in February/March 2013 to assess their knowledge of the health properties of fish

(Slattery and Gormley, 2013b). This number was interviewed in order to get 100 consumers in each outlet who purchased and ate fish. Store 1 was in a working class area and stores 2 and 3 in middle class areas. The main outcomes from the study were:

- 19% of the 371 consumers interviewed did not purchase or eat fish while 74% of the 300 consumers who did buy fish did so at least once per week. Fish from the ice counter was by far the most popular form purchased and cod and salmon were by far the most popular species. Overall, fish was considered expensive.

- Health was cited by 56% of the consumers as the reason they bought fish and when prompted 100% said that fish was good for health. Consumer knowledge of why fish is good for health was only reasonable with 'contains fish oils' and 'is low calorie/fat' the main responses. Relatively few consumers responded 'good source of protein or of minerals/vitamins' and none were aware of beneficial bio-actives such as peptides and amino acids.

- Most (98%) consumers interviewed had heard of omega-3 fish oils but 35% did not know why they were good for health. Heart and brain health were the two most cited reasons as to why the oils are good for health. Only 30% of the 300 consumers had heard of EPA and DHA and of these only 12% classified them correctly as PUFAs or constituents of fish oils. Knowledge of oil containing fish species was good.

- Female consumers were more knowledgeable of the health aspects of fish than males as were middle class consumers compared with working class.

- Results from this survey indicate the need for continued promotion of the health properties of fish by the seafood sector, retailers and health professionals as a route to increased fish sales/consumption and to better population health.

- It is stressed that this is a survey of 300 consumers and the results may or may not reflect the overall position in Dublin or nationwide.

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