Chapter 13
Nutritional and Health Benefits of Seafoods

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Abbreviations

ATS	atherosclerosis
BMI	body mass index
BP	blood pressure
CHD	coronary heart disease
CVD	cardiovascular disease
DHA	docosahexaenoic acid
EPA	eicosapentaenoic acid
GLUT4	glucose transporter-4
HDL	high-density lipoprotein
HF	heart failure
Hg	mercury
hs-CRP	high-sensitivity C-reactive protein
LDL	low-density lipoproteins
PC	phosphatidylcholine
PEA	phosphatidylethanolamine

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PL	phospholipids
PS	phosphatidylserine
PUFAs	polyunsaturated fatty acids
ROS	reactive oxygen species
SCD	sudden cardiac death
TG	triglycerides

13.1 Introduction

Metabolic syndrome and the rise in other lifestyle-related illnesses in the elderly have become critical issues for the human health, both in medical terms and financially. Even in high-income countries, more and more patients suffer from obesity, hypertension, diabetes, dyslipidemia and cancer, and the burden of these conditions is growing day by day (Carrion Alvarez and Obregon Perales 2019; Iorga et al. 2019; Gaman et al. 2019a). Metabolic syndrome is associated with several types of cancer, type 2 diabetes mellitus (Cerchietti et al. 2007; Gaman et al. 2019b), nonalcoholic fatty liver disease (Byrne 2010; Epingeac et al. 2019) and cardiovascular disorders (Hwu et al. 2008; Albers et al. 2019). Most probably, the current diabetes and obesity epidemic is due to the increased consumption of dietary sugar and fat (Linseisen et al. 2009; Dobrica et al. 2019; Medina-Gaona et al. 2018). Fast food consumption and soft drinks also have negative effects on the human health. Some of the variables that influence dietary habits in humans include food accessibility, eating preferences, culture, age, and expertise in nutrition and health. A promising novel tactic to tackle unhealthy lifestyle habits is reforming the food milieu (Story et al. 2008; Manea et al. 2019; Vincek et al. 2018).

Annually, fish capture and aquaculture have resulted in 167.2 million tons: 146.3 million tons have been used for human consumption and the remaining 20.6 million tons were destined for other purposes (FAO 2016). There is a remarkable uplift in the demand for seafood products every year mainly due to their nutritional benefits (FAO 1986). The nutritional value of marine foods derives from the considerable amount of proteins, essential micronutrients and lipids contained in seafood. Marine animals, which are considered a supreme source of protein, have the highest content of polyunsaturated fatty acids (PUFAs) and a low caloric density in comparison with terrestrial animals (Tacon and Metian 2013). Seafood is now recognized as an essential human food. In the future, the demand of seafood is expected to increase, taking into consideration its elevated content in high-quality protein, vitamins, trace elements, PUFAs or minerals (FAO 2010).

Seafood possesses of myriad of benefits to the human health. For example, the vital nutrients contained in seafood are important in the development of the brain and nervous system. Apart from this, the nutrients found in seafood are known to have anticancer effects (Liao and Chao 2009). In many developing countries, seafood has helped to alleviate food shortages, offering a valuable complement to a healthy and nutritious diet. The worldwide consumption of seafood has steadily increased in recent years (FAO 2010). Since there is a clear diet-CVD correspondence (Enriquez et al. 2018; Manea et al. 2018), as evidenced both by experimental and epidemiological reports, dietary interventions containing marine food might be of aid in disorders such as atherosclerosis. Moreover, seafood has a great influence on health promotion and maintenance (Mozaffarian and Rimm 2006; Pereira et al. 2004). Seafood is healthy due to its high content of omega-3 PUFAs, mainly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Dyerberg et al. 1978).

Due to the abundance in PUFAs, i.e. EPA and DHA, fish oil is sold as a functional food to encourage healthier dietary habits. Many other bioactive components are also marketed and are being sold as functional foods due to their value in health, with special reference to the reduced risk of ischemic heart disease and inflammatory disorders (e.g. arthritis) and to the possible effect in cancer prevention, as hypothesized in many research papers (Harris 2004; Rudkowska et al. 2009). Fish and other seafood are also a main source of amino acids, such as taurine and choline, but also calcium, phosphorus, iodine, selenium, vitamin D_3 and vitamin B_{12} (Lund 2013).

The nutritional and health aspects of functional foods reduce the risk of lifestyle-associated diseases (Gheorghe et al. 2019; Tica et al. 2018). The bioactive moieties of seafood are essential in improving unbalanced diets and in preventing lifestyle-associated diseases. Thus, the aim of this chapter is to summarize the available evidence regarding the beneficial effects of micronutrients obtained from seafood (Fig. 13.1).

13.1.1 Major Biochemical Constituents of Seafood

In this section, we detailed the major biochemical components reported in seafoods. Table 13.1 presents summaries of these various components and their effects in human system.

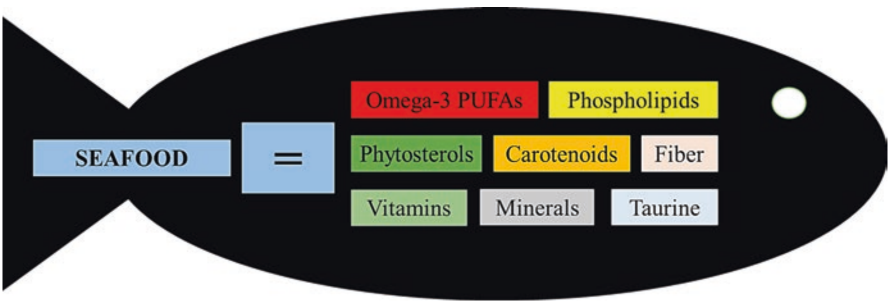

Fig. 13.1 Nutrients available in seafood. *PUFAs* polyunsaturated fatty acids

Table 13.1 Nutrients found in seafood: sources and effects in preclinical and clinical studies

Nutrient	Sources	Effects	References
Omega-3 PUFAs	Phytoplankton Mackerel Salmon Herring	Primary/secondary CVD prevention	Shahidi (2011) and Lavie et al. (2009)
		Stabilization of ATS plaques	Thies et al. (2003)
		↓ Obesity ↓ Inflammation ↑ Insulin sensitivity	Ramel et al. (2010)
		↑ Expression, affinity, membrane fluidity, protein content of GLUT4 in the adipose tissue	Peyron-Caso et al. (2002)
		↓ BMI ↓ Lipid oxidation	Couet et al. (1997)
		↑ Satiety control, improve the cytokine profile	Abete et al. (2010)
		Antiarrhythmic ↓ Inflammation ↓ Risk of congestive HF ↓ Risk of CHD and SCD ↓ Risk of ischemic stroke	Rimm et al. (2018)
		Cardio-protective and antithrombotic ↓ BP and blood lipids ↑ blood vessel function ↑ heart function ↓ inflammation and oxidative stress	Mori (2017)
		Anti-Alzheimer's disease Anti-prostate cancer	Morris et al. (2003)
Phospholipids	Krill oil Squid mantle	PC ↓ blood lipids PC ↑ brain function	Mastellone et al. (2000) and Chung et al. (1995)
		PEA and PS ↓ cholesterol PEA and PS ↑ brain function	McDaniel et al. (2003)
		↑ EPA and DHA in the plasma and cell membrane	Wang et al. (2011) and Maki et al. (2009)
		PL + omega-3 PUFAs ↓ obesity	Shirouchi et al. (2007)
		Antioxidant	Hiratsuka et al. (2008)
		↓ Inflammation	Ikemoto et al. (2001)
		Antineoplastic	Hosokawa et al. (2001)
		PL + omega-3 PUFAs ↓ TG	Hosomi et al. (2010)
Proteins	Fish oil Whole fish Fish sausages Japanese surimi Cod	Omega-3 PUFAs ↓ TG	Balk et al. (2006)

(continued)

Table 13.1 (continued)

Nutrient	Sources	Effects	References
	Sardine Jumbo squid	↓ Serum cholesterol ↑ Cholesterol catabolism ↓ Cholesterol and bile acids absorption	Hosomi et al. (2009)
		↑ Fibrinolysis	Murata et al. (2004)
		Antihypertensive	Boukortt et al. (2004)
		↓ Obesity	Oishi and Dohmoto (2009)
		Cod proteins ↓ hs-CRP	Ouellet et al. (2008)
		Cod proteins ↑ insulin sensitivity	Ouellet et al. (2007)
		↓ Cholesterol	Wergedahl et al. (2004)
		Antimicrobial	Tincu and Taylor (2004)
		↓ Lipid peroxidation	Mendis et al. (2005)
		Immunomodulation	Duarte et al. (2006)
		Valyl-tyrosine ↓ BP	Kawasaki et al. (2000)
Vitamin D	Fish Salmon	↓ risk of hip fractures Bone health	Fan et al. (2013)
Selenium	Tilapia fish Seafood	Seleno-proteins Thyroid gland activity	Holben and Smith (1999)
		↓ Hg toxicity	Ralston and Raymond (2010)
Calcium	Mollusks Crustaceans Salmon Cod bones	Bone metabolism Skeleton rigidity	Ghosh and Joshi (2008), Tacon and Metian (2013) and Malde et al. (2010)
Phosphorus	Mollusks Fish	Bone health Cell membranes Nucleoproteins Nucleic acids Organic phosphates	Martınez-Valverde et al. (2000) and Tacon and Metian (2013)
Taurine	Oysters	Regulates the actions of antioxidants Regulates Ca^{2+} levels Regulates bile acids' conjugation Immunity Membrane stability	Huxtable (1992) and Schuller-Levis and Park (2004)
		Taurine + omega-3 PUFAs ↓ ATS and dyslipidemia	Elvevoll et al. (2008)
		↓ BMI ↓ Atherogenic index ↓ TG	Zhang et al. (2004)
		Anti-hypertensive ↓ Cholesterol ↓ Inflammation	Matsushima et al. (2003) and Schaffer et al. (2010)

(continued)

Table 13.1 (continued)

Nutrient	Sources	Effects	References
Fibers	Edible seaweed	↓ Cholesterol ↓ LDL ↓ TG Interfere with micelle development ↓ Lipids and bile acids' absorption	Jimenez-Escrig and Sanchez-Muniz (2000) and Amano et al. (2005)
		Antioxidant	Heo et al. (2005)
		Antiviral	Artan et al. (2008)
		↓ Inflammation	Kim et al. (2009)
		Anticoagulant	Matsubara et al. (2000)
Phytosterols	Edible microalgae	↓ LDL-cholesterol ↓ Cholesterol	Kanazawa (2001), Malinowski and Gehret (2010) and Plaza et al. (2009)
		↓ Cholesterol uptake (gut) Bind to micelles (small intestine) ↑ luminal cholesterol excretion	Marangoni and Poli (2010)
		Antioxidant	Mannarino et al. (2009)
		↓ Inflammation	Houweling et al. (2009)
		Anticancer	Bouic (2001)
Carotenoids	Lobster Salmon Crustaceans *Hijiki afusiformis* *Laminaria japonica* *Sargassum fulvelum* *Undaria pinnatif*	Convert light into chemical energy Antioxidant ↓ ROS-induced damage	Lesser (2006) and Maeda et al. (2007)
		↓ Inflammation ↓ Dyslipidemia ↓ Oxidative stress	Cicero et al. (2007) and Woo et al. (2010)
		↓ TG ↑ HDL-cholesterol	Yoshida et al. (2010)
		↓ Fat tissue ↓ Abdominal fat ↓ Inflammation ↓ Risk of cancer and stroke	Maeda et al. (2008)

13.1.2 Omega-3 Fatty Acids

The importance of seafood in the human diet is due to the presence of naturally occurring fatty acids such as omega-3 PUFAs (EPA and DHA), which possess multiple beneficial health effects. The highest ratio of fatty acids, such as EPA and DHA, in the food chain is found in the marine phytoplankton. The overall content in EPA and DHA of fish is influenced by several factors, e.g. species or environment. According to Shahidi (2011), fatty fish such as mackerel, salmon or herring, have a higher concentration of omega-3 PUFAs as compared to halibut haddock or cod that are categorized in lean fish category. Shellfish such as crab, lobster or shrimp, contain low levels of omega-3 PUFAs. The most well-known metabolites of EPA are thromboxanes, 5-series leukotrienes, 3-series prostaglandins and prostacyclin (Calder 1998). Pro-thrombotic and pro-inflammatory eicosanoids resulted from arachidonic acid are not as active as EPA-derived eicosanoids. In humans, omega-3 and omega-6 levels are dependent on the dietary consumption (Lands et al. 1992). In cardiovascular health, PUFAs supplementation therapy remains a highly effective method in the prevention of cardiovascular disorders (Lavie et al. 2009).

The American Heart Association suggests that patients with ischemic heart disease should include approximately 1 g/day of EPA and DHA in their diet. This dietary intervention is helpful in the general prevention of CVD (Kris-Etherton et al. 2002). Similarly, AHA recommends that healthy people should consume fatty fish at least 2 times/week or have a dietary intake of about 500 mg EPA and DHA/day. In addition, ≥3–20 EPA and DHA g/day has effects on serum triglycerides (TG), blood vessel flexibility, endothelial function, platelet aggregation, blood pressure and inflammation (Kris-Etherton et al. 2003). In their study published in *The Lancet*, Thies et al. have demonstrated that the consumption of (n-3) PUFAs enhances the stability of atherosclerotic plaques affecting the carotid arteries (Thies et al. 2003). Moreover, Ramel et al. have shown that omega-3 PUFAs present anti-obesity effects, reduce inflammation and insulin sensitivity (Ramel et al. 2010). In obese and insulin resistant murine models, the incorporation of dietary omega-3 PUFAs into the phospholipids of the cell membrane stimulated the expression, affinity, membrane fluidity, protein content of glucose transporter-4 in the fat tissue (Peyron-Caso et al. 2002) as well as the expression of some insulin receptors (Das 1999), sensitizing tissues in the body to the action of insulin. Furthermore, in obese subjects, omega-3 PUFAs can reduce the oxidation of lipids and the body mass (Couet et al. 1997). The potential health benefits of PUFAs have also been studied in rheumatologic disorders (rheumatoid arthritis or lupus), immunoglobulin A nephropathy or gastrointestinal disorders (ulcerative colitis, Crohn's disease) (Volker et al. 2000; Walton et al. 1991; Belluzzi et al. 1996; Das 2005; Stenson et al. 1992; Donadio et al. 1994). Omega-3 PUFAs improve the control of satiety and the cytokine profile (Abete et al. 2010). Moreover, omega-3 PUFAs have antiarrhythmic effects, counteract oxidative stress and reduce the risk of heart failure and sudden cardiac death (Rimm et al. 2018; Mori 2017).

13.1.3 Phospholipids

Approximately 10% of the fat from seafood comes in the form of TG and phospholipids (PLs). Several animal studies have concluded that dietary PLs could be beneficial to the human health. Phosphatidylcholine, the major component of phospholipids (PLs), reduces the total lipids in the blood (Mastellone et al. 2000) and enhances the activity of the brain (Chung et al. 1995). Phosphatidylethanolamine and phosphatidylserine are also able to reduce lipid levels and improve the function of the brain (McDaniel et al. 2003). The abundance of effective and potential seafood derived PLs like EPA and DHA has also been included in foods as a valuable ingredient.

The administration of omega-3 PUFAs seems more effective if omega-3 PUFAs were given as PL- rather TG-formulations (Wijendran et al. 2002). The beneficial effects of dietary krill oil supplementation have also been examined in several clinical studies. Supplementation with krill oil has proven beneficial effects on the human health, mainly by increasing the EPA and DHA levels in the plasma and the cell membrane (Wang et al. 2011; Maki et al. 2009). In addition, obesity-related metabolic disorders are ameliorated under the administration of PL-containing omega-3 PUFAs (Shirouchi et al. 2007). Moreover, in several studies conducted on animals, these agents were explored for their antioxidant (Hiratsuka et al. 2008), anti-inflammatory (Ikemoto et al. 2001) and antineoplastic properties (Hosokawa et al. 2001). Previous studies have reported a decrease in serum and liver TG following the addition of PL-containing omega-3 PUFAs derived from squid mantle muscle or from soybeans to the diet (Hosomi et al. 2010).

13.1.4 Protein, Peptide, and Non-protein Nitrogen Compounds

The human diet usually includes fish oil and whole fish. Dietary omega-3 PUFAs reduce serum TG even if serum cholesterol is not reduced (Balk et al. 2006). The main micronutrients found in fish are fish proteins. Around the globe, fish proteins are essential elements in human nutrition and have been included as main ingredients in processed fish products such as fish sausages or the Japanese surimi (FAO 2010). The impressive levels of amino acids in seafood proteins can make up between 10% and 25% of their content. Seafood proteins can be classified as sarcoplasmic, myofibrillar or stromal proteins. In terms of amino acid composition and bioavailability, animal proteins are more acceptable *versus* vegetable proteins.

The potential impact of fish proteins on the lipid metabolism is another dimension of the role of fish proteins in health. In this context, researchers have shown that the administration of fish proteins in laboratory animals influenced serum cholesterol levels (Wergedahl et al. 2009). The reduction in serum cholesterol was due to the properties of fish protein to inhibit the absorption of cholesterol and bile acids. Thereby, the catabolism of cholesterol in the liver increased (Hosomi et al. 2009). Additionally, other beneficial effects of these substances include the enhancement of fibrinolysis (Murata et al. 2004), as well as their antihypertensive (Boukortt et al. 2004) and anti-obesity properties (Oishi and Dohmoto 2009). Furthermore, animal and human studies have concluded that dietary cod proteins reduce the levels of high-sensitivity C-reactive protein in the serum (Ouellet et al. 2008) and increase insulin sensitivity in subjects resistant to insulin (Ouellet et al. 2007).

Biopeptides extracted from seafood proteins have an immense influence on the promotion of healthy eating. In a placebo-controlled trial, the administration of valyl-tyrosine, a peptide extracted from sardines, has resulted in a decrease of 9.3 mmHg in the systolic blood pressure and a decrease of 5.2 mmHg in the diastolic blood pressure (Kawasaki et al. 2000). Moreover, marine bioactive peptides isolated from the jumbo squid were seen to inhibit lipid peroxidation. Their activity was similar to butylated hydroxytoluene (BHT), but much lower in comparison with α-tocopherol (Mendis et al. 2005). According to previously stated work by several authors, marine bioactive peptides have ameliorated hypocholesterolemia (Wergedahl et al. 2004) and have displayed immunomodulatory (Duarte et al. 2006) and antimicrobial effects (Tincu and Taylor 2004), both in animals and in vitro. However, the health benefits of marine proteins need further investigation in studies conducted on humans.

13.1.5 Vitamin D

In addition to its valuable protein and lipid composition, seafood also comprises considerable amounts of vitamin D (Holick 2008). Rickets, low bone density, osteomalacia and osteoporosis are health conditions associated with vitamin D deficiency (Cranney et al. 2007). Fan and his coworkers (2013) reported an inverse relation among fish consumption and chances of hip fracture in the Chinese elderly. Alongside to bone-related disorders, vitamin D deficiency seems to be also involved in the development of diabetes, autoimmune disorders, aggressive cancers, as well as CVD (Holick 2008). Sunlight exposure is a key element in vitamin D homeostasis. Limited sun exposure has been linked to vitamin D deficiency (Norman 2008). Overall, the average dietary intake of vitamin D is of at least 1000 international units (IU) or equivalent to 25 mg per day (Lu et al. 2007; Holick 2008). Vitamin D_2 (ergocalciferol) is found in plants such as mushrooms, whereas vitamin D_3 (cholecalciferol) is found in fish and is also produced in the skin *via* exposure to ultraviolet B rays (Holick 2008; Norman 2008). Ergocalciferol slightly differs in structure from cholecalciferol, as it contains one additional double bond along with methyl group. In various species of fish muscle, the vitamin D content ranges from 5 to 30 mg/100 g (Mattila et al. 1995). It was observed that wild salmon has a higher content of vitamin D as compared to farmed salmon. Moreover, the methods of preparation also affect the final quantity of vitamin D. After frying, 50% of the vitamin D is retained in the salmon (Lu et al. 2007).

13.1.6 Minerals

Selenium is an essential mineral in humans and animals. However, in high levels, it is toxic. In humans, selenium is responsible for the synthesis of seleno-proteins, as well as in the normal activity of the thyroid where it acts as a cofactor in the metabolism of thyroid hormones (Holben and Smith 1999). Selenium deficiency is associated with cardiovascular events (e.g. myocardial infarction) and a higher rate of CVD-related deaths. Likewise, selenium deficiency is also linked with a higher risk of kidney disorders and cancer (Holben and Smith 1999). Selenium also partakes in the process of reducing methylmercury toxicity (Ralston and Raymond 2010). According to the United States Department of Agriculture (USDA), seafood is an excellent source of selenium (Ralston 2008). In comparison with yeast-derived selenium, selenium obtained from fish has a higher bioavailability (Fox et al. 2004). During the analysis of seafood obtained from the South Atlantic Ocean, a beneficial selenium-to-mercury ratio (> critical level of 1:1) was observed and held responsible for the protection against methylmercury toxicity (Kehrig et al. 2013). Moreover, the selenium content of seafood can be increased by supplementing the diet of fish with selenium, as seen in studies conducted on tilapia (Molnar et al. 2012). For seafood safety, the selenium health benefit value (Se-HBV) was proposed. It takes into consideration the exposure to methylmercury and the selenium intake (Kaneko and Ralston 2007). Recently, the Se-HBV has been updated to consider its availability from fish. In order to differentiate between the two, Se-HBV is now abbreviated as HBVSe (Ralston et al. 2016). Mercury-induced toxicity seems to be related, in avid seafood consumers, to an increase in oxidative stress levels (Karimi et al. 2016).

Calcium is an essential macro-mineral in human nutrition for its role in bone metabolism. Calcium ions play a significant role in maintaining the rigidity of the skeleton. In the human body, 99% of calcium is stored in of bones (Ghosh and Joshi 2008). The average intake of calcium differs based on age groups. However, in adults, the WHO/FAO recommends a daily intake of 400–500 mg/day. In comparison with other nutrients, the absorbance of calcium in body is inadequate. Generally, the bioavailability of the total dietary calcium is estimated at 25–30% (FAO Agriculture and Consumer Protection Department 2002). Besides milk and dairy products, fish and other marine animals also contain calcium (Martınez-Valverde et al. 2000). In comparison with terrestrial meat which contains 14 mg calcium/100 g, mollusks, crustaceans and fish contain 26–68 mg calcium/100 g (Tacon and Metian 2013). Moreover, calcium from salmon and cod bones has a better absorption (Malde et al. 2010).

Phosphorus is also a key factor in bone health and the composition of cell membranes. Moreover, phosphorous is also an important component of nucleoproteins, nucleic acids, as well as organic phosphates i.e. adenosine triphosphate and creatine phosphate. Martınez-Valverde et al. (2000) reported that 700 g of phosphorous are found in the body, of which 80% is found in bones, 10% in viscera and 9% in the skeletal muscles (Ghosh and Joshi 2008). Phosphorus deficiency is related to a myriad of health disorders: metabolic acidosis, muscle disorders, variation in bone mineralization, and respiratory, cardiac or neurological disorders (Ghosh and Joshi 2008). In various studies, seafood are proposed as excellent sources of phosphorus, since 204–230 mg phosphorus/100 g are found in mollusks and fish, in comparison with terrestrial meat which only contains 176 mg phosphorus/100 g (Tacon and Metian 2013).

13.1.7 Taurine

Seafood contains taurine (2-aminoethanesulfonic acid). Taurine is abundantly found in the blood, the developing brain, the retina and the heart (Wójcik et al. 2010). Guinea-pigs and rats' diets are highly dependent on taurine. As compared to humans, the synthesis of taurine is higher in animals (e.g. Guinea-pigs and rats). Taurine (a nonessential amino acid) has a significant impact in many biological processes which regulate the actions of antioxidants, the calcium level, and the conjugation of bile acids, immunity and membrane stability (Huxtable 1992; Schuller-Levis and Park 2004). Seafood contains high amounts of taurine and a high percentage of the taurine in the human diet comes from seafood (Tsuji and Yano 1984). Marine invertebrates such as oysters contain higher amounts of taurine (>1/100 g) in comparison with plants, in which the taurine content is lower or even absent (Kataoka and Onishi 1986). Taurine decreases the risk of lifestyle-related diseases and acts as anti-hypertensive, anti-hypercholesterolemic and anti-inflammatory agent (Matsushima et al. 2003; Schaffer et al. 2010). Studies have reported that the association between taurine and omega-3 PUFAs exerts more pronounced anti-atherogenic and hypolipidemic effects in humans as compared to omega-3 PUFAs supplements alone (Elvevoll et al. 2008). Zhang et al. concluded that a 7-week taurine supplementation in a dosage of 3 g/day significantly reduced the body weight, atherogenic index and serum TG of non-diabetic obese human subjects. According to their research, an adequate amount of taurine might be helpful to decrease the risk of lifestyle-associated disorders such as stroke or atherosclerosis (Zhang et al. 2004).

13.1.8 Fiber

Carbohydrates and fibers are present in a very little amount in seafood. Edible seaweed comprises of 25–75% of dry weight of dietary fiber and also contains approximately 50–80% of water soluble fiber constituents (Jimenez-Escrig and Sanchez-Muniz 2000). Seaweeds are divided into three groups based on pigmentation: brown seaweeds, green seaweeds and red seaweeds. Brown seaweeds owe their color to the pigment known as fucoxanthin and consist of primary polysaccharides (alginates, cellulose, fucans and laminarins) (Goni et al. 2002). In green seaweed, chlorophyll and ulvan are the major polysaccharide components responsible for its color (Robic et al. 2009). Red seaweeds owe their color to phycoerythrin and phycocyanin (McHugh 2003). In terms of health, the consumption of polysaccharides extracted from edible seaweeds has been linked to a significant reduction in total cholesterol, low-density lipoproteins and plasma TG (Amano et al. 2005). Polysaccharides extracted from seaweeds showed hypo-cholesterolemic effects due to their increased interference with micelle development and absorption of lipids and biliary acids. Moreover, sulfated polysaccharides (carrageenans and fucoidan) have several important biological functions: antioxidant (Heo et al. 2005), antiviral (Artan et al. 2008), anti-inflammatory (Kim et al. 2009) and anticoagulant (Matsubara et al. 2000). Thus, their potential has been employed in cosmetics, functional foods and pharmaceuticals (d'Ayala et al. 2008).

13.1.9 Phytosterols

The structure of phytosterols and cholesterol is similar. The only difference between them is the relative positioning of the methyl and ethyl groups. In plants, phytosterols exist in the form of beta-sitosterols, campesterol and stigmasterol, while in marine invertebrates these phytosterols exist in the form of stanols, sterols and sterol esters (Kanazawa 2001). Phytosterols play an important role in the production of healthy food products like milk, fat free or low-fat yogurt, spreads, juice, bread and cereals (Demonty et al. 2009). In clinical trials, an intake of 2–3 g/day of phytosterols has significantly reduced LDL-cholesterol (Malinowski and Gehret 2010). Moreover, edible microalgae containing phytosterols have proven hypocholesterolemic effects (Plaza et al. 2009). Phytosterols reduce the uptake of cholesterol in the gut since they bind to micelles in the small intestine. Also, phytosterols enhance the action of the ATP-binding cassette G-proteins in the enterocytes *via* excretion of cholesterol in the lumen (Marangoni and Poli 2010). Other biochemical actions of phytosterols include their antioxidant (Mannarino et al. 2009), anti-inflammatory (Houweling et al. 2009) and anticancer activities (Bouic 2001). Musa-Veloso et al. (2011) have hypothesized the cardio-protective effects of phytosterols against coronary heart disease and have reported that an intake of ≥2 g/day of phytosterols significantly lowers LDL-cholesterol.

13.1.10 Carotenoids

Carotenoids (fat-soluble) contain orange and yellow pigments and have the ability to convert light into chemical energy. Carotenoids comprise antioxidants that prevent reactive oxygen species-induced damage in fungi, plankton and other photosynthetic organisms (Lesser 2006). Carotenoids (e.g. β-carotene) play important roles in many biological processes, such as the formation of vitamin A in the body (García-González et al. 2005). Other examples of carotenoids include lycopene, fucoxanthin and astaxanthin (Gaman et al. 2019c). Seafood carotenoids (e.g. astaxanthin, fucoxanthin) have many commercial applications. The xanthophyll carotenoid astaxanthin can be found in lobsters, salmon and marine crustaceans and presents anti-inflammatory, anti-hyperlipidemic and anti-oxidative stress actions (Cicero et al. 2007). Oxidative stress has emerged as a putative mechanism in the development of many health issues, including myeloid and lymphoid malignancies (Moisa et al. 2018a, b, 2019; Gaman et al. 2014, 2019d; Pascu et al. 2019). Yoshida et al. (2010) reported a significant reduction in TG and an increase in high-density lipoprotein (HDL) cholesterol in non-obese individuals after the intake of astaxanthin for 12 weeks (Yoshida et al. 2010). However, there is limited data on the effect of astaxanthin on the human health. Edible seaweeds contain the orange-colored pigment fucoxanthin (Maeda et al. 2007). Fucoxanthin decreases abdominal fat and inflammation. Also, it can be useful to reduce the risk of malignancy and stroke (Maeda et al. 2008). Furthermore, HDL-cholesterol in the plasma of mice can increase following fucoxanthin consumption (Woo et al. 2010).

13.2 Factors Affecting the Nutritional Status of Seafood

Several factors such as the production methods and the processing conditions usually influences the composition and quality of seafood. The diet of marine creatures can also influence the nutritional status of seafood (Lie 2001; Morris 2001). There are some other factors such as the ash content, the mineral composition, the protein content and other micronutrients which can alter the quality of fish (Baker 2001). Feeding, handling, transportation, storage and slaughtering methods can also interfere with the quality of fish and fish products (Robb 2001). The lipid content and configuration is affected by the aforementioned steps. The way of processing also alters the fatty acid composition of seafood *via* possible oxidation (Sampels 2015a, b).

13.3 Risk Associated with Fish Consumption

The reported increase in fish consumption might be due to their beneficial effects on health, such as their role in CVD prevention (FAO 2010). On the other hand, fish consumption might pose health risks as well. Edible marine products contain methylmercury which is metabolized by microorganisms and causes damage to the central nervous system. This effect can also occur in the fetus and in infants. It has been reported that the severity of central nervous system damage depends on the quantity of methylmercury consumed (Clarkson et al. 2003). The Food and Drug Administration (FDA) has already published several dietary guidelines addressing the type and quantity of fish which can be consumed by pregnant women and children. Additionally, some other environmental toxins found in seafood, such as dioxins and polychlorinated biphenyls, have negative effects on the human health (Arisawa et al. 2005). The health benefits of fish and fish products are only present if consumed in appropriate amounts (He 2009). The reported benefits of seafood consumption outweigh their risks, with the exception of some sea animals (sharks, swordfish) and edible plants which contain severe environmental toxins (Dewailly et al. 2007). However, the benefits and risks of seafood and other natural products require further preclinical investigation (Islam et al. 2018; Luis Gomes et al. 2018). Eventually, the evidence should be incorporated into more clinical studies and randomized controlled trials to test these findings.

13.4 Conclusion

The nutritional content of seafood (proteins, fats, minerals, vitamins etc.) has helped us recognize the value of these products in our diet. Unfortunately, the health benefits of seafood have been acknowledged only after many years. Taking into consideration the epidemic of lifestyle-related disorders worldwide, dietary interventions based on seafood might be of aid in the near future.

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