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Seaweed-based Functional Foods

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14 Seaweed-based Functional Foods

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14.1 INTRODUCTION

Functional foods are foods that provide health benefits in addition to basic nutrition. They are categorized through identification, characterization, and evaluation of the health-promoting properties they present. New high-value nutrition and wellness products, manufactured by reformulation of existing products through development of nutraceutical or functional foods, present an exciting opportunity for the food industry worldwide. Many bioactive constituents to which a beneficial physiological function has been directly or indirectly attributed, originating mainly from plant extracts, have been incorporated in already existing food products or have been commercialized in the form of pharmaceutical products such as pills, capsules, solutions, and gels (Espín *et al.* 2007). The global market for nutraceuticals is expected to reach €200 billion (USD264.4 billion) in 2013, with a compound growth rate of 7.4%. There have been a number of key drivers for this unprecedented growth rate, including the increase in world population and changes in the demographics of that population (particularly the increase in the aging population), advances in the understanding of the relationship between diet and health, increase in diet-related diseases, and the demand for health and wellness food products across the life course, from childhood to old age (Espín *et al.* 2007).

This situation has created a surge of research activity in identifying new ingredients and raw materials with beneficial health properties for the development of functional foods from both terrestrial and marine sources. Marine algae have been identified as a major potential source for growth in the functional food sector. The world seaweed industry is estimated to be worth €4.2–4.5 billion (USD5.5–5.9 billion) annually, with €3.8 billion (USD5 billion) being generated from products destined for human consumption and the remainder from hydrocolloids and miscellaneous products (Walsh & Watson 2011).

Seaweeds (macroalgae) are still considered an underexploited plant resource despite being used in diets and traditional remedies for centuries (Heo *et al*. 2009). Seaweeds are often referred to as being a treasure house of novel healthy food ingredients and biologically active compounds, due to their phenomenal biodiversity (Kadam & Prabhasankar 2010; Gupta & Abu-Ghannam 2011a). Green, brown, and red seaweeds are an outstanding source of biologically active phytochemicals such as carotenoids, phycobilins, fatty acids, polysaccharides, vitamins, sterols, tocopherol, and phycocyanin, all of which are associated with a number of biological activities, such as antimicrobial, antifungal, antiviral, and antioxidant effects, in addition to potential benefits in the control of hyperlipidemia, thrombosis, tumor, and obesity (Vairappan *et al.* 2001; Duan *et al.* 2006; Cox *et al.* 2010). Moreover, seaweeds are a rich source of dietary fiber (DF), with a content ranging from 33 to 50 g/100 g dry basis (d.b.), placing them as an important candidate in the development of new functional foods

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characterized by a low glycemic index (GI) or in the supplementation and enrichment of already existing foods indentified as being low in DF content.

The environment in which seaweeds grow is harsh, as they are exposed to a combination of light and high oxygen concentrations. These factors can lead to the formation of free radicals and other strong oxidizing agents but seaweeds seldom suffer any serious photodynamic damage during metabolism. This fact implies that their cells possess some protective antioxidative mechanisms and compounds (Matsukawa *et al.* 1997). Motivated by these observations, many researchers have focused in recent years on marine algae and their constituents as sources of nutraceuticals and functional foods for potential health promotion, mostly attributed to their omega-3 fatty acids, antioxidants, and other bioactive components (Shahidi 2009).

14.2 OVERVIEW OF SEAWEED BIOACTIVE COMPONENTS FOR THE DEVELOPMENT OF FUNCTIONAL FOODS

An increasing number of scientific reports are highlighting the diverse biological properties of seaweeds and their potential in health promotion. This has led to increased interest in identifying methodologies and approaches for the utilization of seaweeds or their extracts in the development of seaweed-based functional foods. This section provides an overview of some of the main bioactive components in seaweeds and their potential utilization in the development of functional foods.

14.2.1 Dietary fiber

DF in seaweeds is mainly composed of four families of polysaccharides: laminarans, alginates, fucans, and cellulose. Laminarans are reserve polysaccharides found in brown algae and are composed of (1,3)-β-D-glucose with some (1,6)-linkages in which some of the reducing ends are replaced with mannitol. The major matrix component of brown seaweeds is the gelling polyuronide alginate, which consists of alternating sequences of β-(1,4)-D-mannuronic acid, its C5 epimer α-(1,4)-L-guluronic acid, and 20–30 units of uronic acids (Jiménez-Escrig & Sanchez-Muniz 2000). Fucans can be classified into three major groups: fucoidans, xylofucoglycuronans, and glycorunogalactofucans (Jiménez-Escrig & Sanchez-Muniz 2000). Cellulose makes up the cell walls of brown and red algae and is mainly composed of sulfated galactans (carrageenans and agar), xylans, and mannans (Lahaye 1991). Green seaweeds contain starch, cellulose, xylans, mannans, and ionic polysaccharides, which contain sulfate groups and uronic acids. Lahaye (1991) reported that rhamnose, xylose, galactose, and arabinose are also found in green algae.

Polysaccharides also contribute to the antioxidant activity of marine algae, as reported by a number of authors (Xue *et al.* 2001; Rupérez *et al.* 2002; Zhang *et al.* 2003). Consumption of seaweeds and their incorporation in low-dietary-fiber foods can therefore increase the intake of DF and lower the occurrence of some chronic diseases, such as diabetes, obesity, heart diseases, and cancer, associated with low-fiber diets, particularly in Western countries (Southgate 1990).

DF can be divided into soluble and insoluble fractions. The viscosity of soluble fiber is responsible for slower digestion and the absorption of nutrients, and lower levels of blood cholesterol and glucose. Insoluble DF is characterized by its ability to increase fecal bulk and decrease intestinal transit time (Baghurst *et al.* 1996; Potty 1996).

As seaweeds are a rich source of fiber (33–50 g/100 g d.b.)—particularly soluble fractions (50–85% of total DF content)—they can be exploited to enrich the fiber contents of foods that are generally low in this component (Jiménez-Escrig & Goni 1999; Jiménez-Escrig & Sánchez-Muniz 2000; Rupérez & Saura-Calixto 2001). For example, fishery and meat products, which otherwise possess high nutritional properties, are poor in fiber content and would benefit significantly from the incorporation of seaweeds. This would also allow the seaweed functional properties, including water-binding, gelling, and emulsifying capacities, to be exploited in the final products (Borderías *et al.* 2005; Venugopal 2009).

14.2.2 Phenolic content and antioxidant capacity

Research has shown seaweeds to be rich sources of natural antioxidant compounds (Cox *et al*. 2010; Duan *et al.* 2006; Kuda *et al.* 2007; Lim *et al.* 2002). This leads to the suggestion that algae have developed a protective mechanism consisting of antioxidant compounds. Such compounds are able to minimize the concentration of reactive oxygen species (ROS) generated by ultraviolet (UV) radiation or heat from the sun (Matsukawa *et al.* 1997).

The antioxidant activity of marine algae can arise from pigments such as chlorophyll, carotenoids, phenolics, and hydroquinones, as well as from flavonoids, phospholipids, and other antioxidative substances, which directly or indirectly contribute to the inhibition or suppression of oxidation processes (Shahidi 2009).

Cox *et al*. (2010) examined six species of edible Irish seaweed (*Laminaria digitata*, *Laminaria saccharina*, *Himanthalia elongata*, *Palmaria palmata*, *Chondrus crispus*, and *Enteromorpha spirulina*) for phenolic content and antioxidant activity. A significant difference ($P < 0.05$) was observed in the total phenolic contents of the different seaweeds studied, with extracts from *H. elongata* exhibiting the highest total phenolic content—expressed as gallic acid equivalents (GAEs) at 151.3 mg GAE/g seaweed extract—and the highest 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity ($P < 0.05$), with a 50% inhibition (EC_{50}) level at 0.125 μg/ml of extract. *H. elongata* showed significantly more activity than the ascorbic acid control ($P < 0.05$) at the EC_{50} level, indicating a possible role in reducing typical oxidation reactions associated with the deterioration of food quality and shelf life. The ability of seaweed extracts to quench free radicals is known to take place over longer period of time than rapid-acting synthetic antioxidants such as butylated hydroxyanisole (BHA). This may have benefits for extending the shelf life of food products during distribution and storage, and it opens up possibilities for a reduction in the usage of synthetic antioxidants, due to decreased consumer appeal and substitution with natural antioxidants that provide both health benefits and food preservation effects. Such properties and applications are necessary to the development of functional foods and will be examined further later in this chapter

14.2.3 Omega-3 fatty acids

Seaweeds are also known to contain omega-3 and omega-6 essential fatty acids. Omega fatty acids have potential applications in health promotion that include prevention of atherosclerosis, protection against arrhythmias, reduction of blood pressure, benefits for diabetic patients, prevention against various cancers, promotion of bone health, and improvement in brain function in children. Omega-3 oils have been incorporated into bakery products, pastas, dairy products (e.g. milk, yogurt, juice), and nutrition bars (Kadam & Prabhasankar 2010). Dawczynski *et al.* (2007) have reported that seaweed products show high levels of omega-3 fatty acids and demonstrate a nutritionally ideal omega-3–omega-6 free fatty acid (FFA) ratio. Wong & Cheung (2001) also found the seaweed species *Undaria pinnatifida* and *Hijikia fusiforme* to be rich sources of omega-3 fatty acids.

14.2.4 Fucoidans

Recently, fucoidans from seaweeds have gained attention as sources of bioactive ingredients for functional foods. Fucoidans are a complex series of sulfated polysaccharides found in the cell walls of brown seaweeds and have been reported to have antioxidant, antiviral, anticoagulant, and antiobesity effects (Li *et al.* 2008). These properties have supported the application of fucoidan as an ingredient in functional foods to provide disease prevention and health promotion (Vo & Kim 2013). Park *et al.* (2011) reported that fucoidan showed high lipid inhibition activity at 200 μg/ml concentration and suggested that this carbohydrate could be useful in the prevention or treatment of obesity, due to its reduction in the accumulation of lipid caused by stimulatory lipolysis.

It has also been reported that alginates from seaweeds increase satiety effects, since their physical characteristics—such as viscosity and gel strength—can reduce hunger. Solah *et al.* (2010) tested the impact of alginate on hunger by feeding subjects high-alginate drinks, finding these subjects were less hungry than those fed a low-viscosity drink. Fucoidans provide a strong opportunity for the development of functional-based beverages that tackle the ever-growing worldwide obesity endemic.

14.3 SEAWEED PRETREATMENT PRIOR TO INCORPORATION IN FUNCTIONAL FOODS

Due to their compositional and textural characteristics, seaweeds have traditionally been subjected to some form of processing, mainly drying, in order to render them palatable for human consumption or for preservation purposes. However, very little has been reported on the effects of such processes on seaweeds' bioactive components. This section provides an overview of work conducted by the authors regarding optimized drying methodologies and complementary processing techniques designed to overcome textural issues while maximizing the retention of biological activities for utilization in functional foods.

14.3.1 Drying and rehydration

Fresh seaweeds, which are collected from coastlines worldwide, are generally washed and dried to reduce their water activity (a_w) and minimize deterioration from chemical reactions and microbial activities before they are used as food source. Being marine in nature, seaweeds contain a large amount of water: up to 85% on a fresh basis (Gupta *et al*. 2011c). Because of their high levels of unsaturated fatty acids, seaweeds tend to deteriorate within a few days after harvest if they are not properly preserved.

The traditional process for preserving seaweeds is to sun dry them (Lim & Murtijaya 2007). This is generally carried out by spreading the harvested wet seaweed over a net or a tarpaulin on the ground. On an industrial scale, the bulk of the seaweed industry utilizes mechanical drying, but little investment in required training or the purchase of high-tech equipment has been made in this sector (Walsh & Watson 2011). Drying has the advantages of reducing bulk handling and transportation costs and allowing for product use out of season. On consumption, seaweeds are usually rehydrated to restore their original structure. In addition to preservation and shelf-life extension, drying is also considered an important step in rendering many seaweed species palatable; they are rarely consumed in their fresh raw state due to the extreme toughness of their texture (Gupta *et al.* 2011c).

While drying is the most common method of processing seaweeds, there is very little information in the literature on the effects of drying on their nutritional composition. Wong & Cheung (2001) studied the effects of oven drying and freeze drying on the protein extractability of three subtropical brown seaweeds and reported that oven drying significantly improved protein extractability and quality. However, the long drying times at relatively high temperatures during the falling rate periods often lead to undesirable thermal degradation in vegetable products, and similar effects would be expected in the drying of seaweeds (Mousa & Farid 2002).

The concept of incorporating seaweeds—as a whole material rather than just bioactive extracts—in traditional food products in order to develop new functional foods will therefore require that seaweeds have a maximum level of bioactive components in addition to an acceptable sensory texture. Seaweed drying is essential to the development of a palatable texture, which is critical for consumer acceptance of functional foods. However, bioactivity losses are to be expected.

The Irish edible brown seaweed *H. elongata* has been selected as an example of the utilization of seaweeds in the development of functional foods because of its high bioactivity (Cox *et al*. 2010). In this section, the effects of drying and hydrothermal processing on the physicochemical properties of

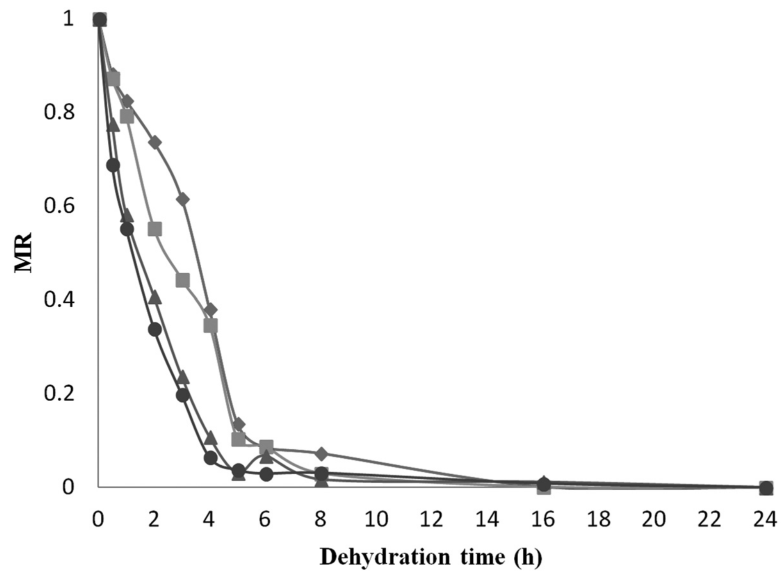

Figure 14.1 Drying time of *H. elongata* at different temperatures (◆: 25 °C; ■: 30 °C; ▲: 35 °C; ●: 40 °C). (For a color version of this figure, please see the color plate section.)

H. elongata and optimization of conditions for bioactive retention and development of an acceptable sensory texture will be examined. In addition, the rehydration characteristics of dried *H. elongata* will be presented.

The initial moisture content of the fresh seaweed was approximately 4.05 ± 0.05 kg water/kg dry matter. Drying was carried out at 25, 30, 35, and 40 °C. The variation in moisture content as a function of time at the four dehydration temperatures can be seen in Figure 14.1. The dehydration temperatures examined were on the lower side of typical food product drying temperatures, in order to simulate the air-drying conditions typically employed in the seaweed drying industry. Figure 14.1 shows a clear exponential tendency; as expected, an increase in the drying temperature accelerated the drying process. At 25 °C, the drying rate became minimal and approached equilibrium after 8 hours, whereas equilibrium at 40 °C was attained after 5 hours, representing a 37.5% reduction in the total drying time.

The effect of different drying temperatures on the phytochemical content was also investigated, as presented in Figure 14.2. Overall, regardless of temperature, drying resulted in a reduction in total phenolic content, although the contents were still higher than those reported for dried seaweeds (Kuda *et al*. 2005). Drying at the lower temperatures of 25 and 30 °C resulted in a continuous reduction of total phenolic content, although a small increase was observed after 4 hours of drying when the moisture content was reduced by up to 50%. When dried at 40 °C for 2 hours, there was a maximum increase of 41% in the total phenolic content over the low drying temperatures of 25 and 30 °C for the same period of time. Dixon & Paiva (1995) have reported that plants respond to wounds by increasing phenolic compound production in order to repair the damage, which in this case could have resulted from the effects of drying. However, at the end of the 24-hour drying period a reduction of 29–51% in the total phenolic content was seen for *H. elongata* dried at the different drying temperatures investigated. This can be attributed mainly to the extended applied drying time and perhaps to permanent damage in the wound-repair mechanism. While drying is mainly applied in order to extend the shelf life of seaweeds, other observed effects include an increase in the total phenolic content under certain conditions of drying time and temperature. Phenols have been directly correlated to antioxidant capacity. Accordingly, semidried seaweeds with higher phenolic contents and an acceptable sensory texture offer

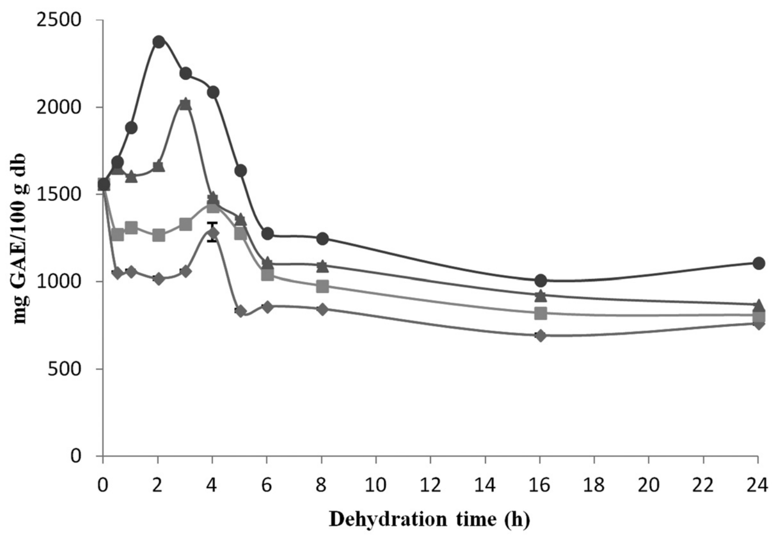

Figure 14.2 Effect of drying temperatures on the total phenolic content of *H. elongata* (◆: 25 °C; ■: 30 °C; ▲: 35 °C; ●: 40 °C). (For a color version of this figure, please see the color plate section.)

a valuable element which can be exploited in the development of a range of functional foods. Due to the somewhat higher water activity compared to fully dried seaweeds, packaging options such as modified atmosphere packaging (MAP) will need to be considered.

Higher losses of total phenolic content were observed at lower drying temperatures with maximum reductions of up to 51% for *H. elongata* when dried at 25 °C, whereas a reduction of only 29% was seen when drying was carried out at 40 °C for the same period, as compared to fresh seaweeds. It is possible then to speculate that drying at low temperatures causes higher losses of phenolic content because of changes in seaweed composition and content (Guan *et al*. 2005).

The lower dehydration temperatures reported here may not have inactivated the oxidative enzymes completely, causing some oxidation of the phenolic substances and thus resulting in a relatively lower phenolic content. Decreases in total phenolic content during drying can also be attributed to the binding of polyphenols with other compounds such as proteins or to alterations in the chemical structure of polyphenols that cannot be extracted or determined by currently available analytical methods (Martín-Cabrejas *et al*. 2009; Qu *et al*. 2010).

Dehydration resulted in a decrease in antioxidant activity, as exhibited by a reduction in the DPPH free radical-scavenging activity, tested at an extract concentration of 50 μg/ml. Fresh *H. elongata* had a DPPH radical scavenging activity of 78.9%. However, by the end of 24 hours' dehydration at 25 and 30 °C, reductions of the magnitude of 17.3 and 12.8% were observed, respectively, as compared to fresh seaweeds, while at 35 and 40 °C, reductions were 7.3 and 4.5%, respectively—significantly less than those obtained at the lower temperatures.

The rehydration capacities of seaweeds dried at 40 °C for 24 hours were studied at 20, 40, 60, 80, and 100 °C until the moisture content reached equilibrium, which was mostly within 80 minutes (Cox *et al*. 2012). The initial moisture content of the dried seaweed was 4.07 ± 0.02 g water/g d.b., which represented a 98.1% reduction in water content/g d.b. Figure 14.3 depicts moisture content variations as a function of time for the five rehydration temperatures studied, showing a decrease in rehydration time as temperature increased until a uniform equilibrium moisture content was attained. For all of the rehydration temperatures studied (20, 40, 60, 80, and 100 °C) the DPPH radical scavenging activity initially increased in the range of 13.2–24.3% for up to 20 minutes of treatment, after which it declined.

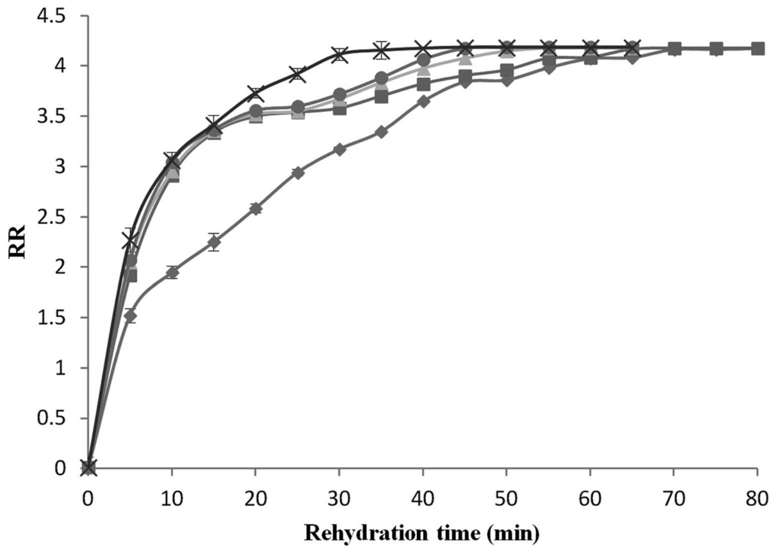

Figure 14.3 Rehydration of *H. elongata* at different temperatures (◆: 20 °C; ■: 40 °C; ■: 60 °C; ●: 80 °C; ×: 100 °C). (For a color version of this figure, please see the color plate section.)

However, the overall antioxidant activities of rehydrated seaweeds were up to 18% higher than those of dried seaweeds, regardless of the rehydration temperature applied.

It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruptions that took place during drying. There can often be irreversible cellular rupture and dislocation, resulting in a loss of integrity and, therefore, a dense structure of collapsed, greatly shrunken capillaries with reduced hydrophilic properties. This often results in an inability to imbibe sufficient water and rehydrate fully (Krokida & Marinos-Kouris 2003). Seaweeds grow in distinct vertical bands on the seashore and it is well known that their ability to recover from physiological processes following desiccation is correlated to their shore position. Despite this, little is known of the cellular mechanisms by which intertidal seaweeds limit membrane damage during desiccation and subsequent rehydration. The ability to tolerate desiccation is therefore a prerequisite for their survival (Burritt *et al*. 2002). The dried seaweed studied by Cox *et al*. (2012) had the ability to rehydrate with a final moisture content equal to or higher than that of the fresh seaweed. Based on these findings, it is suggested that the hydrophilic properties of seaweeds give them the ability to imbibe sufficient water at all working temperatures, which is of great benefit. Not all plants have the ability to be dried and rehydrated to their original capacity. For example, Vega-Gálvez *et al*. (2009) found that aloe vera could achieve a maximum rehydration capacity only 38% that of the original product.

14.3.2 Hydrothermal processing

Hydrothermal processing, sometimes referred to as boiling if carried out at close to 100 °C, is a typical unit operation that is applied to vegetables mainly to render them edible. Due to the high temperatures employed in such processes (80–100 °C), significant losses in valuable bioactive components and sensory properties can occur if time and temperature parameters are not adequately controlled and optimized.

As indicated earlier, seaweeds' tough texture is one of the main obstacles to their wider utilization as a food component and some form of heat is typically applied to overcome this. Therefore, it is relevant to examine the extent of the effects hydrothermal processing can have on the sensory and nutritional acceptability of seaweeds.

H. elongata was heat-treated (using water as the medium) at both 80 and 100 °C in order to examine the effects of the low- and high-end temperatures of hydrothermal processing; changes in texture were measured both instrumentally and sensorially every 5 minutes until an acceptable texture was obtained, as judged by a tasting panel (Cox *et al.* 2011a, 2011b). An acceptable palatable texture was obtained within 40 minutes for both 80 and 100 °C. This corresponded to losses of up to 85% in the total phenolic content as compared to fresh *H. elongata*. However, the former study also showed that if a drying step was applied prior to hydrothermal processing then losses in total phenolic content could be significantly reduced. Cox *et al.* (2011a) reported that drying at 25 °C for 12 hours followed by hydrothermal processing at 100 °C reduced the time required to achieve an acceptable texture from 40 to 25 minutes and most importantly resulted in only about 9% losses in total phenolic content as compared to fresh seaweeds. It is worth noting that the drying time and temperature in Cox *et al*. (2011a) did not produce a totally dried product, and it would be interesting to investigate further submissions to other forms of heating. It seems that air drying seals seaweeds from more losses in bioactive components upon further processing while progressively acting on the texture toughness. Considering the low water temperatures under which seaweeds typically survive and grow, a drying temperature of 25 °C will have more substantial effects on their physiochemical properties than a similar temperature range applied to terrestrial plants. Cox *et al.*'s (2011a, 2011b) studies also indicated that the DPPH free radical scavenging ability, which is one of the methods applied to measure the extent of antioxidant activity, had doubled as compared to fresh samples when seaweeds were dried initially at 25 °C for 12 hours and then submitted to a hydrothermal processing step for 25 minutes at 100 °C. These findings, which typically are not observed if similar processes are applied to terrestrial plants, provide significant opportunities for the exploitation of seaweeds in the development of functional foods.

Pretreatment of seaweeds prior to further utilization in functional food development is critical to a successful outcome. The proposed methodologies presented in this section have been implemented in the development of two functional food products that incorporated seaweeds pretreated as described here.

14.4 INCORPORATION OF SEAWEEDS IN THE DEVELOPMENT OF FUNCTIONAL FOODS

A number of research reports can be cited where seaweeds were added to food products as a whole component in order to exert certain functional or structural properties. Fernández-Martín *et al*. (2009) incorporated *H. elongata* into pork sausages to replace animal fat and studied the effects on meat batter gelation. López-López *et al*. (2009) added *U. pinnatifida* to beef patties in order to reduce salt and fat levels. Prabhasankar *et al*. (2009a, 2009b) added *U. pinnatifida* and *Sargassum marginatum* to pasta to increase antioxidant levels. The green seaweed *Monostroma nitidum* was incorporated into noodles to develop a new product; the resulting cooking yields were improved by up to one-third (Chang & Wu 2008). Choi *et al*. (2012) incorporated the brown seaweed *Laminaria japonica* into pork patties in order to reduce fat content and increase DF levels; the resulting product had better sensory scores on overall acceptability when compared to the control. Cofrades *et al*. (2011) reported that *H. elongata* added to restructured poultry was found acceptable by a sensory panel. The use of seaweeds as food ingredients is thus of indubitable interest from the standpoints of nutrition and technology (Cofrades *et al*. 2008; Gupta & Abu-Ghannam 2011b). When developing functional foods it is important to minimize losses in the nutraceutical properties, particularly during processing, in order to ensure retention of high levels of bioactivity in the final product. In addition, functional foods should have an acceptable sensory profile and consumer appeal, as in some cases the incorporation of bioactive components can influence the product flavor, aroma, or texture. This aspect was also considered and evaluated in the examples presented here.

14.4.1 Incorporation of seaweeds in bakery products

Bakery products are consumed regularly and in considerable amounts by many population groups worldwide, and are therefore considered excellent candidates for the incorporation of marine functional ingredients. One of the latest enrichments to bakery products is the addition of omega-3 polyunsaturated fatty acids (PUFAs) to bread in order to improve essential fatty acid intake. In Europe, consumption of bread enriched with omega-3 PUFAs is steadily increasing, due to a recognition of the health benefits of such supplementation. Therefore, the future for nutrition might potentially include using breads as vehicles for various micronutrients (Kadam & Prabhasankar 2010).

The consumption of DFs in many Western diets is very low compared to the recommended intake, and it is generally believed that three out of four people do not get their recommended daily allowance (RDA). Bakery products present a substantial opportunity for the enhancement of DF intake and for making a positive contribution to the alleviation of diseases related to low DF consumption.

In this section we will propose the supplementation of breadsticks with seaweed functional ingredients, due to their popularity and appeal. To this end, *H. elongata* was fully dried under optimized conditions (with respect to maximum antioxidant capacities as described in Section 14.3.1), then ground into a fine powder and incorporated in the breadstick base mix, which consisted of whole meal and white flour. The nutritional content, sensory evaluation, and consumer appeal of the final product were then evaluated. A response surface methodology (RSM) study was applied to help determine the optimum concentrations of seaweed and flour blends required to maximise the phytochemical and DF levels in breadsticks.

The addition of seaweed to the base mix significantly increased the total phenolic content of the resulting breadsticks ($P < 0.05$), with an up to 80% increase recorded when the overall flour concentration was substituted with 17% dried seaweeds. This level of dried seaweed replacement increased the DPPH activity by up to 47% ($P < 0.05$) compared with controls. These results are higher than those reported Prabhasankar *et al*. (2009a) for other cereal-based food products incorporated with seaweed. The same authors studied the influence of the addition of the brown seaweed *Sargassum marginatum* to pasta. The total phenolic content in the cooked pasta increased from 9 to 13 mg GAE/100 g with 5% addition of seaweed. Prabhasankar *et al*. (2009b) also reported that an addition of 30% *Undaria pinnatifida* seaweed increased the total phenolic content of pasta from 9 to 27 mg GAE/100 g. The variations in these results can be attributed to the seaweed species utilized. The dried seaweeds used in the development of breadsticks were thus optimized with respect to the drying conditions in order to maximize their phenolic content. Hence, pretreatment processing of seaweeds is critical to maintaining their bioactive components.

In view of the therapeutic potential of DF, the addition of fiber in current food product development is on the rise. In the breadstick study, the incorporation of up to 17% dried seaweed into the base mix represented an up to 44% increase in the total DF, which is a considerable increase over controls. These results are higher than those reported in the literature for other products containing seaweed. Prabhasankar *et al*. (2009a) reported that the addition of 2.5% dried seaweeds to pasta resulted in a fiber content improvement of only 4%. As that is considerably less seaweed than was initially applied in the development of the breadsticks, it is to be expected that the fiber enhancement would also be low. This sheds light on the need to recognize the final sensory properties of the functional food product developed. While the main aim in developing functional foods is to maximize bioactive components, it is also important to manufacture products with acceptable consumer appeal. There is a significant difference in acceptable texture parameters in breadsticks versus pasta from a consumer perspective, and hence there are variations in the acceptable maximum levels of dried seaweed that can be incorporated. It is thus important to recognize the physicochemical properties of a seaweed (in this example, mainly the high hydration potential) and their consequences for the texture of the final product.

A sensory panel of 20 judges considered the incorporation of up to 10% seaweed in the breadstick base mix to produce a highly acceptable product, scoring 3.75 out of 5 on the sensory scale. The incorporation of more than 15% dried seaweeds, although giving significant improvements in antioxidant and fiber content, produced a harder texture and a level of aroma that was not sensorially acceptable.

As seaweeds are a rich source of fiber (up to 60% of their composition), a reduction in the rheological properties of the breadstick mix is expected with high levels of seaweed incorporation, causing the final product to show less textural acceptability. This emphasizes the importance for product composition optimization of using approaches such as RSM to maximize resources and ultimately develop functional foods with a modified nutritional content and consumer appeal.

14.4.2 Incorporation of seaweeds in meat-based products

Over the past few decades, meat products have come under increasing scrutiny by medical, nutritional, and consumer groups because of the associations established between their consumption (or that of a number of their constituents, such as fat and cholesterol) and the risk of some of the major degenerative and chronic diseases, including heart disease, cancer, hypertension, and obesity. Therefore, meat-based functional foods are being seen as an opportunity to improve the "image" of meat and address consumer nutritional and dietary needs (Jiménez-Colmenero 2007). Meat is one of the most commonly consumed foods worldwide and its supplementation with functional ingredients offers an excellent means of promoting their intake without requiring any radical changes in eating habits (Cofrades *et al*. 2008). The introduction of functional ingredients with probable biological activity, such as botanicals, plant extracts, and seaweeds, into processed meat products is thus the subject of much attention (Calvo *et al*. 2008; Cofrades *et al*. 2008; Hayes *et al*. 2005; Hernández-Hernández *et al*. 2009; Valencia *et al*. 2008).

Meat is low in DF, so the addition of ingredients containing fiber would be beneficial. Plant biomass and its derived bioactive compounds have been considered as possible functional components by which to alleviate the colorectal cancer risk associated with the consumption of processed meats (Demeyer *et al*. 2008). Seaweeds are also high in phytochemicals, such as phenolic compounds (Cox *et al*. 2011a). Therefore incorporation of seaweed into beef patties has potential as a way of developing healthier meat products. At the same time, exploitation of the technological benefits of the hydrocolloids in the seaweeds would also increase DF and reduce processing losses, resulting in improvements in cooking yields.

The use of DF in cooked meat products generally improves hydration properties and fat-holding capacity, reducing fat and water loss during cooking and increasing emulsion stability (Cofrades *et al*. 2000; Jiménez-Colmenero *et al*. 2005; Thebaudin *et al*. 1997). Traditional beef patties are high in fat (about 14%) and there are often issues with the low fat content of finely ground meat products, which can have difficulties in terms of appearance, flavor, and texture. Such products may be less acceptable to consumers than unmodified versions (García *et al*. 2002; Keeton 1994; Tokusoglu & Ünal 2003). Manufacturers have introduced several modifications to try to offset the detrimental effects of reducing the fat content, including the use of non-meat ingredients to help convey desirable texture and, more importantly, enhance water-holding capacity (Ako 1998; Keeton 1994). In this regard, the incorporation of carbohydrates and fiber has been successful in improving cooking yield, reducing formulation cost, and enhancing texture (Jiménez-Colmenero 1996; Keeton 1994; Mendoza *et al*. 1998).

Semidried seaweeds (40 °C, 2 hours) were submitted to hydrothermal boiling at 80.5 °C for 20 minutes (as optimized by RSM) by Gupta *et al*. (2011c) and Cox *et al*. (2011b). The semidrying treatment enhanced the antioxidant levels in the seaweeds, avoiding the losses observed in complete drying. However, semidrying did not produce a palatable texture suitable for incorporation in meat. As a result, the seaweeds were submitted to a further heating step, optimized at 80.5 °C for 20 minutes. The optimization was based on a time and temperature combination that tenderized the seaweed texture while at the same time minimizing losses in antioxidant capacity. By following this approach, a higher percentage of seaweed (up to 40%) could be incorporated in the meat. Trials aimed at incorporating fully dried seaweeds proved to be unsuccessful due to their lack of rehydration capacity in meat.

The effect on the physical, chemical, microbial, and sensory traits of vacuum-packed cooked beef patties of adding up to 40% *H. elongata* seaweed as a source of antioxidants and DF was studied throughout chilled storage (30 days at 4 °C). Those patties with seaweed showed a 7% reduction in cooking losses and had an up to 50% increase in their texture tenderness as compared to those without

($P < 0.05$). The control sample contained no detectable polyphenols at tested levels, while the total phenolic content increased significantly ($P < 0.05$) with increasing seaweed concentrations from 10 to 40%. By storage day 30, the DPPH radical scavenging activity levels were in the range of 26.65–40.69% for the various different concentrations of seaweeds incorporated, which ranged from 10 to 40%. Such an improved initial antioxidant capacity in the seaweed patties clearly points to an enhancement in their nutritional quality, as meat products generally lack antioxidant capacity. Antioxidant capacity can improve both their nutritional properties and their shelf life.

The safety and quality of the seaweed-incorporated patties were also examined. Total viable counts (TVCs) and lipid oxidation were significantly lower in patties containing seaweed ($P < 0.05$). By day 30 of storage there was no bacterial growth recorded on the samples with $\geq$20% seaweed and calculated lipid oxidation was at low levels (0.61 mg malondialdehyde/kg sample). Control samples without seaweed incorporation showed 5.41 log colony forming units (CFUs)/g TVC and 1.12 mg malondialdehyde/kg sample lipid oxidation levels, which were significantly higher than those in the samples containing seaweed. The incorporation of seaweed significantly increased the total DF of the seaweed patties as compared to controls (1.64 g/100 g fresh weight (f.w.) in 40% seaweed patties). The DF results are in line with Choi *et al*. (2012), who reported that pork patties with dried *Laminaria japonica* incorporated in the range of 1–5% contained 1.23–3.14% DF. López-López *et al*. (2010) reported the total DF in pork patties containing dried seaweed to be up to 1.36%.

One of the most important findings was that as seaweed levels increased, the patties became tenderer. An addition of 40% seaweed represented a 46.98% difference in tenderness levels compared to controls. DFs from different sources have been studied for the formulation of different meat products, with a view to improving texture, among other things. It has generally been found that addition of such fibers to meat augments firmness (Cofrades *et al*. 2008; Fernández-Martín *et al*. 2009; Sánchez-Zapata *et al*. 2011). However, while some authors have observed increases in firmness with the addition of fibers to meat, others have found no difference or the production of tenderer products (Chun *et al*. 1999; Cofrades *et al*. 2000; Jiménez-Colmenero *et al*. 2005; Selgas & Cáceres, 2005). López-López *et al.* (2010) also reported that beef patties containing seaweed were tenderer than controls. The effect of seaweed addition on the tenderness of the meat patties was mainly due to the role played by fiber, as the protein contents of the control and the seaweed patties were similar. In this case, the seaweed fiber absorbed the moisture loss from the meat during cooking (typically referred to as "cooking loss") such that the moisture content was retained within the meat and was not lost externally. In addition, the incorporation of "wet" seaweed rather than a dry type contributed to this enhanced tenderness. Meat tenderness is recognized as one of the major attributes of high eating quality, and there have been many attempts to enhance it, including the application of chemical, mechanical, and physical methodologies. In this example, the incorporation of seaweeds in meat offers an enhancement not just of its nutritional properties but of its functional and keeping qualities too.

The results of sensory analysis indicated that the meat patties incorporated with seaweeds were accepted by consumers in terms of aroma, appearance, texture, and taste. Patties containing up to 40% seaweed were rated highest in terms of overall acceptability, most likely due to the improvement in texture and mouthfeel. In addition, the sensory panel rated the addition of seaweeds to meat patties as a positive approach and considered it better than the control samples. In this regard, seaweeds provide an exciting ingredient for many meat-based products, mainly within the sphere of producing meat-based functional foods.

14.5 CONCLUSION

Seaweeds offer a considerable opportunity for the functional food industry in terms of the wealth of their bioactive components. However, seaweeds require pretreatments before they can be utilized in order to minimize losses in their initial levels of bioactive material and to attain sensory acceptability. This chapter presented examples of such treatments and their applications. Future research is necessary to identify approaches to controlling or reducing the aroma and flavor issues with seaweed-based functional foods so that they are considered acceptable by consumers.

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REFERENCES

Ako, C. (1998) Fat replacers. *Food Technology* **52**, 47–53.

Baghurst, P. A., Baghurst, K. I. & Record, S. J. (1996) Dietary fibre, non-starch polysaccharides and resistant starch—a review. *Food Australia* **48**, S3–S35.

Borderías, A. J., Sánchez-Alonson, I. & Pérez-Mateos, M. (2005) New applications of fibres in foods: addition to fishery products. *Trends in Food Science and Technology* **16**, 458–465.

Burritt, D. J., Larkindal, J. & Hurd, C. L. (2002) Antioxidant metabolism in the intertidal red seaweed *Stictosiphonia arbuscula* following desiccation. *Planta* **215**, 829–838.

Calvo, M. Garcia, M. & Selgas, M. (2008) Dry fermented sausages enriched with lycopene from tomato peel. *Meat Science* **80**, 167–172.

Chang, H. C. & Wu, L. C. (2008) Texture and quality properties of Chinese fresh egg noodle formulated with green seaweed (*Monostroma nitidum*). *Journal of food Science* **73**(8), 398–404.

Choi, Y. S., Choi, J. J., Han, D. J., Kim, H. Y., Kim, H. W., Lee, M. A., Chung, H. J. & Kim, C. J. (2012) Effects of *Laminaria japonica* on the physico-chemical and sensory characteristics of reduced-fat pork patties. *Meat Science* **91**, 1–7.

Chun, S. S. Park, J. R Park, J. C., Suh, J. S. & Ahn, C. B. (1999) Quality characteristics of hamburger patties added with seaweed powder. *Journal of the Korean Society of Food Science and Nutrition* **28**, 140–144.

Cofrades, S., Guerra, M. A., Carballo, J., Fernández-Martín, F. & Jiménez-Colmenero, F. (2000) Plasma protein and soy fibre content effect on bologna sausage properties as influenced by fat level contents of processed edible seaweeds. *Food Chemistry* **85**, 439–444.

Cofrades, S., López-López, I., Solas, M. T., Bravo, L. & Jiménez-Colmenero, F. (2008) Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emustion meat systems. *Meat Science* **79**, 767–776.

Cofrades, S., López-López, I., Ruiz-Capillas, C., Triki, M. & Jiménez-Colmenero, F. (2011) Quality characteristics of low-salt restructured poultry with microbial transglutaminase and seaweed. *Meat Science* **87**, 373–380.

Cox, S., Abu-Ghannam, N. & Gupta, S. (2010) An assessment of the antioxidant and antimicrobial activity of six species of edible Irish seaweeds. *International Food Research Journal* **17**, 205–220.

Cox, S., Abu-Ghannam, N. & Gupta, S. (2011a) Effect of processing conditions on phytochemical constituents of edible Irish seaweed *Himanthalia elongata*. *Journal of Food Processing and Preservation* **36**, 348–363.

Cox, S., Gupta, S. & Abu-Ghannam, N. (2011b). Application of response surface methodology for studying the influence of hydrothermal processing on the phytochemical constituents of Irish edible brown seaweed *Himanthalia elongata*. *Botanica Marina* **54**, 417–480.

Cox, S., Gupta, S. & Abu-Ghannam, N. (2012) Effect of different rehydration temperatures on the moisture and phytochemical constituents of dried edible Irish Brown seaweed. *LWT—Food Science and Technology* **47**, 300–307.

Dawczynski, C., Schubert, R. & Jahreis, G. (2007) Amino acids, fatty acids, and dietary fibre in edible seaweed products. *Food Chemistry* **103**, 891–899.

Demeyer, D., Honikel, K. & De Smet, S. (2008) The World Cancer Research Fund report 2007: a challenge for the meat processing industry. *Meat Science* **80**, 953–959.

Dixon, R. A. & Paiva, N. L. (1995). Stress-induced phenylpropanoid metabolism. *Plant Cell* **7**, 1085–1097.

Duan, X. J., Zhang, W. W., Li, X. M. & Wang, B. G. (2006) Evaluation of antioxidant property of extract and fractions obtained from a red alga, *Polysiphonia urceolata*. *Food Chemistry* **95**, 37–43.

Espín, J. C., García-Conesa, M. T. & Thomás-Barberán, F. A. (2007). Nutraceuticals: facts and fiction. *Phytochemistry* **68**, 2986–3008.

Fernández-Martín, F., López- López, I., Cofrades, S. & Jiménez Colmenero. (2009) Influence of adding Sea Spaghetti seaweed and replacing the animal fat with olive oil or konjac gel on pork meat batter gelation. Potential protein/alginate association. *Meat Science* **83**, 209–217.

García, M., Dominguez, R., Galvez, M., Casas, C. & Selgas, M. (2002) Utilization of cereal and fruit fibres in low fat dry fermented sausages. *Meat Science* **60**, 227–236.

Guan, T. T. Y., Cenkowski, S. & Hydamaka, A. (2005) Effect of drying on the nutraceutical quality of sea buckthorn leaves. *Journal of Food Science* **70**, E514–E518.

Gupta, S. & Abu-Ghannam, N. (2011a) Bioactive potential and possible health effects of edible brown seaweeds. *Trends in Food Science and Technology* **22**, 315–326.

Gupta, S. & Abu-Ghannam, N. (2011b) Recent developments in the application of seaweeds or seaweed extracts as a means for enhancing the safety and quality attributes of foods. *Innovative Food Science and Emerging Technologies* **12**, 600–609.

Gupta, S., Cox, S. & Abu-Ghannam, N. (2011c) Effect of different drying temperatures on the moisture and phytochemical constituents of edible Irish brown seaweed. *LWT—Food Science and Technology* **44**, 1266–1272.

Hayes, J. E., Desmond, E. M., Troy, D. J. Buckley, D. J. & Mehra, R. (2005) The effect of whey protein enriched fractions on the sensory properties of frankfurters. *Meat Science* **71**, 238–243.

Heo, S. J., Hwang, J. Y., Choi, J. I., Han, J. S., Kim, H. J. & Jeon, Y. J. (2009) Diphlorethohydroxycarmalol isolated from *Ishige okamurae*, a brown algae, a potent α-amalyse inhibitor, alleviates postprandial hyperglycemia in diabetic mice. *European Journal of Pharmacology* **615**, 252–256.

Hernández-Hernández, E. Ponce-Alquicira, E. Jaramillo-Flores, M. E. & Guerrero Legarreta, I. (2009) Antioxidant effect rosemary (*Rosmarinus officinalis* L.) and oregano (*Origanum vulgare* L.) extracts on TBARS and colour of model raw pork batters. *Meat Science* **81**, 410–417.

Jiménez-Colmenero, F. (1996) Technologies for developing low-fat meat products *Trends in Food Science and Technology* **7**, 41–48.

Jiménez-Colmenero. F. (2007) Healthier lipid formulation approaches in meat based functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends in Food Science and Technology* **18**, 567–578.

Jiménez-Colmenero, F., Ayo, M. J. & Carballo, J. (2005) Physicochemical properties of low sodium frankfurter with added walnut: effect of transglutaminase combined with caseinate, KCl and dietary fibre as salt replacers. *Meat Science* **69**, 781–788.

Jiménez-Escrig, A. & Goni, C. I. (1999) Nutritional evaluation and physiological effects of edible seaweeds. *Archivos Latinoamericanos de Nutricion* **49**, 114–120.

Jiménez-Escrig, A. & Sanchez-Muniz. F. J. (2000) Dietary fibre from edible seaweeds: Chemical structure, physiochemical properties and effects on cholesterol metabolism. *Nutrition Research* **20**, 585–598.

Kadam, S. U. & Prabhasankar, P. (2010) Marine foods as functional ingredients in bakery and pasta products. *Food Research International* **43**, 1975–1980.

Keeton, J. T. (1994) Low-fat meats products technological problems with processing. *Meat Science* **36**, 261–276.

Krokida, M. K. & Marinos-Kouris, D. (2003) Rehydration kinetics of dehydrated products. *Journal of Food Engineering* **57**, 1–7.

Kuda, T., Tsunekawa, M., Goto, H. & Araki, Y. (2005) Antioxidant properties of four edible algae harvested in the Noto Peninsula, Japan. *Journal of Food Composition and Analysis* **18**, 7, 625–633.

Kuda, T., Kunii, T., Goto, H., Suzuki, T. & Yano, T. (2007) Varieties of antioxidant and antibacterial properties of *Ecklonia stolonifera* and *Ecklonia kurome* products harvested and processed in the Noto peninsula, Japan. *Food Chemistry* **103**, 900–905.

Lahaye, M. (1991) Marine algae as sources of fibres. Determination of soluble and insoluble dietary fibre contents in some sea vegetables. *Journal of Science Food Agriculture* **54**, 587–594.

Li, B., Lu, F., Wei, X. & Zhao, R. (2008) Fucoidan: structure and bioactivity. *Molecules* **13**, 1671–1695.

Lim, S. N., Cheung, P. C. K., Ooi, V. E. C. & Ang, P. O. (2002) Evaluation of antioxidative activity of extracts from a brown seaweed, *Sargassum siliquastrum*. *Journal of Agricultural and Food Chemistry* **50**, 3862–3866.

Lim, Y. Y. & Murtijaya, J. (2007) Antioxidant properties of *Phyllanthus amarus* extracts as affected by different drying methods. *LWT—Food Science and Technology* **40**, 1664–1669.

López-López, I., Bastida, S., Ruiz-Capillas, C., Bravo, L., Larrea, M. T., Sánchez-Muniz, F., Cofrades, S. & Jiménez-Colmenero, F. (2009) Composition and antioxidant capacity of low-salt meat emulsion model systems containing edible seaweeds. *Meat Science* **83**, 492–498.

López-López, I., Cofrades, S., Yakan, A., Solas. M. T. & Jiménez-Colmenero, F. (2010) Frozen storage characteristics of low-salt and low-fat beef patties as affected by wakame addition and replacing pork backfat with olive oil-in-water emulstion. *Food Research International* **43**, 1244–1254.

Martín-Cabrejas, M. A., Aguilera, Y., Pedrosa, M., Cuadrado, C., Hernández, T., Díaz, S. & Esteban, R. (2009) The impact of dehydration process on antinutrients and protein digestibility of some legume flours. *Food Chemistry* **114**, 1063–1068.

Matsukawa, R., Dubinsky, Z., Kishimoto, E., Masak, K., Masuda, Y., Takeuchi, T., Chihara, M., Yamamoto, Y., Niki, E. & Karube, I. (1997) A comparison of screening methods for antioxidant activity in seaweeds. *Journal of Applied Phycology* **9**, 29–35.

Mendoza, E., M. L. García, C. Casas, M. F. & Fernández, M. D. (1998) Selgas. Utilización de proteínas como sustitutos de grasa en productos carnicos. *Alimentación: Equipos y Tecnología* **7**, 87–92.

Mousa, N. & Farid, M. (2002) Microwave vacuum drying of banana slices. *Drying Technology* **20**, 2055–2066.

Park, M. K., Jung, U. & Roh, C. (2011) Fucoidan from marine brown algae inhibits lipid accumulation. *Marine Drugs* **9**, 1359–1367.

Potty, V. H. (1996) Physio-chemical aspects, physiological functions, nutritional importance and technological significance of dietary fibres—a critical appraisal. *Journal of Food Science and Technology* **33**, 1–18.

Prabhasankar, P., Ganesan, P. & Bhaskar, N. (2009a) Influence of Indian brown seaweed (*Sargassum marginatum*) as an ingredient on quality, biofunctional and microstructure characteristics of pasta. *Food Science and Technology International* **15**, 471–479.

Prabhasankar, P., Ganesan, P., Bhaskar, N. Hirose, A., Stephen, N., Gowda, L. R., Hosokawa, M. & Miyashita, K. (2009b) Edible Japanese seaweed, wakame (*Undaraia pinnatifida*) as an ingredient in pasta: chemical, functional and structural evaluation. *Food Chemistry* **115**, 501–508.

Qu, W., Pan, Z. & Ma, H. (2010) Extraction modeling and activities of antioxidants from pomegranate marc. *Journal of Food Engineering* **99**, 16–23.

Rupérez, P. & F. Saura-Calixto. (2001) Dietary fibre and physicochemical properties of edible Spanish seaweeds. *European Food Research and Technology* **212**, 349–354.

Rupérez, P., Ahrazem, O. & Leal, J. A. (2002) Potential antioxidant capacity of sulfated polysaccharides from the edible marine brown seaweed *Fucus vesiculosus*. *Journal of Agricultural and Food Chemistry* **50**, 840–845.

Sánchez-Zapata, E., Fernández-López, J., Peňaranda, M., Fuentes-Zaragoza, Sendra, E., Sayas, E. & Pérez-Alverez, A. (2011) Technological properties of date paste obtained from date by-products and its effect on the quality of a cooked meat product. *Food Research International* **44**, 2401–2407.

Selgas, M. D. E. & Cáceres, M. L. (2005). García Long-chain soluble dietary fibre as functional ingredient in cooked meat sausages. *Food Science and Technology International* **11**, 41–47.

Shahidi, F. (2009) Nutraceuticals and functional foods: whole versus processed foods. *Trends in Food Science and Technology* **20**, 376–387.

Solah, V. A., Kerr, D. A., Adikara, C. D., Meng, X., Binns, C. W., Zhu, K., Devine, A. & Prince, R. L. (2010) Differences in satiety effects of alginate and whey protein-based foods. *Appetite* **54**, 485–491.

Southgate, D. A. T. (1990) Dietary fibre and health. In: *Dietary Fibre: Chemical and Biological Aspects* (eds D. A. T. Southgate, K. Waldron, I. T. Johnson & G. R. Fenwick), The Royal Society of Chemistry: Cambridge, UK; pp. 10–19.

Thebaudin, J. Y., Lefebvre, A. C. & Harrington, C. M. (1997) Bourgeois dietary fibres: nutritional and technological interest. *Trends in Food Science and Technology* **8**, 41–48.

Tokusoglu, Ö. & Ünal, K. (2003) Fat replacers in meat products. *Pakistan Journal of Nutrition* **2**, 196–203.

Vairappan, C. S., Daitoh, M., Suzuki, M., Abe, T. & Masuda, M. (2001) Antibacterial halogenated metabolites from the Malaysian *Laurencia* species. *Phytochemistry* **58**, 291–297.

Valencia, I., O'Grady, M. N., Ansorena, D., Astiasarán, I. & Kerry, J. P. (2008) Enhancement of the nutritional status and quality of fresh pork sausages following the addition of linseed oil, fish oil and natural antioxidants. *Meat Science* **80**, 1046–1054.

Vega-Gálvez, A., Notte-Cuello, E., Lemus-Mondaca, R., Zura, L. & Miranda, M. (2009) Mathematical modelling of mass transfer during rehydration process of aloe vera (*Aloe barbadensis* Miller). *Food and Bioproducts Processing* **87**, 254–260.

Venugopal, V. (2009) *Marine Products for Healthcare: Functional and Bioactive Nutritional Compounds from the Ocean*, CRC Press: Boca Raton, FL.

Vo, T. S. & Kim, S. K. (2013) Fucoidans as a natural bioactive ingredient for functional foods. *Journal of Functional Foods* **5**(1), 16–27.

Walsh, M. & Watson, L. (2011) A market analysis towards the further development of seaweed aquaculture in Ireland. Bord Iascaigh Mhara, Available: http://www.bim.ie/media/bim/content/publications/corporate-other-publications/A%20Market%20Analysis%20towards%20the%20Further%20Development%20of%20Seaweed%20Aquaculture%20in%20Ireland.pdf [last accessed June 17, 2013].

Wong, K. & Cheung, P. C. (2001) Influence of drying treatment on three *Sargassum* species 2. Protein extractability, *in vitro* protein digestibility and amino acid profile of protein concentrates. *Journal of Applied Phycology* **13**, 51–58.

Xue, C., Fang, Y., Lin, H., Chen, L., Li, Z., Deng, D. & Lu, C. X. (2001) Chemical characters and antioxidative properties of sulfated polysaccharides from *Laminaria japonica*. *Journal of Applied Phycology* **13**, 67–70.

Zhang, Q., Yu, P., Li, Z., Zhang, H., Xu, Z. & Li, P. (2003) Antioxidant activities of sulfated polysaccharide fractions from Porphyra haitanesis. *Journal of Applied Phycology* **15**, 305–310.