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Macroalgae for functional feed development: Applications in aquaculture, ruminant and swine feed industries.

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Abstract

Plant and animal derived products are the main ingredients currently used by the feed industry to produce concentrate feed. There is a need of novel feed ingredients to meet the demand of high quality products by the aquaculture, ruminant and swine production systems, together with the challenge of implementing new sustainable and environmentally friendly processes and ingredients demanded by the modern society. Macroalgae are a large and diverse group of marine organisms that are able to produce a wide range of compounds with unique biological properties. This chapter discusses the incorporation of macroalgae or macroalgal derived ingredients as a source of both macro-nutrients (i.e. proteins, polysaccharides and fatty acids) and micro-nutrients (i.e. minerals and pigments) for animal feed production. The biological health benefits of the macroalgal ingredients beyond basic nutrition for the development of functional feed in the aquaculture, the ruminant and the swine sectors are also discussed together with the industrial challenges of its application.

Keywords: macroalgae and seaweed; nutrition; feed; functional feed; aquaculture; ruminant; swine.

1. Introduction

The global human population is projected to grow to 9.6 billion individuals by 2050 and will continue to grow up to 12 billion by 2100 (Gerland et al., 2014). Within this scenario an increase of 70% in animal production and thus 235% more animal feed will be needed to sustain that growth (Herman & Schmidt, 2016). The animal feed industry faces the challenge to meet the demand of high quality products by the aquaculture, ruminant and swine production systems, and implementing new sustainable and environmentally friendly processes and ingredients demanded by the modern society. There is a need to find new alternatives to traditional animal feed ingredients that could compete in the market in terms of nutritional quality (i.e. macro and micro-nutrient composition) and environmentally sustainable (M Garcia-Vaquero & Hayes, 2016).

Macroalgae are a diverse group of marine organisms with more than 10,000 different species (Collins, Fitzgerald, Stanton, & Ross, 2016). Based on their pigments marine macroalgae are classified as brown (Phaeophyta), red (Rhodophyta) and green macroalgae (Chlorophyta). Marine macroalgae are able to adapt to the changing and extreme marine environmental conditions i.e. salinity, temperature, nutrients, radiation and combination of light and oxygen concentration by producing unique secondary metabolites including proteins, polysaccharides, lipids, pigments and minerals (Collins et al., 2016). Macroalgae are known for their richness in the previously described bioactive molecules with wide variety of biological properties i.e. anti-oxidant, anti-bacterial and anti-tumour amongst others (S. L. Holdt & S. Kraan, 2011). Thus, macroalgae represents great potential for its use in human food and animal feed or for the extraction of biologically active compounds that could be incorporated into the animal's diet.

This chapter discusses the incorporation of macroalgae or macroalgal derived ingredients as a source of both macro-nutrients (i.e. proteins, polysaccharides and polyunsaturated fatty acids) and micro-nutrients (i.e. minerals and pigments) for animal feed production. The nutritional and biological

health benefits of the incorporation of macroalgal ingredients for the development of functional feed in aquaculture, ruminant and swine nutrition were discussed together with the advances and challenges for macroalgal incorporation in animal feed.

2. Macroalgae as source of macro-nutrients

Seaweeds have a highly variable composition, with large differences in the final content of both macro- and micro- nutrients depending on multiple factors such as macroalgae species, date of collection and environmental conditions including pollution, water temperature, light intensity and nutrient concentration in water (Mišurcová, 2011).

2.1. Macroalgal proteins

Macroalgae species and the season of collection are the most common factors affecting both macroalgal protein content and amino acid composition (Joël Fleurence, 1999). The protein content described in brown macroalgae is generally low in comparison with green (10-26%) and red macroalgae species (35-47%) with protein contents comparable to protein-rich foods such as soybean, cereals, eggs and fish (M Garcia-Vaquero & Hayes, 2016). Seasonal variations were appreciated in red macroalgae, with higher protein concentrations in the biomass harvested during the winter season (approximately 22%) when compared to the summer period (~ 12%) (Galland-Irmouli et al., 1999).

In addition, most seaweed species are considered a rich source of essential amino acids (M. Garcia-Vaquero, Lopez-Alonso, & Hayes) and acidic amino acids such as aspartic acid and glutamic acid (J. Fleurence, 2004). The macroalgae contents of amino acids such as threonine, lysine, tryptophan, cysteine, methionine and histidine in macroalgal proteins are higher than those found in terrestrial plants (Joël Fleurence, 1999).

Together with protein, macroalgae also contains large amounts of non-protein nitrogen (i.e. nitrates), resulting in an overestimation of their protein content when analyzed by traditional laboratory methods. Nitrogen to protein conversion factors of 5.38, 4.92 and 5.13 have been proposed for brown, red and green algae respectively as alternatives to the traditional factor of 6.25 (Makkar et al., 2016).

Protein is regarded as the most expensive nutrient in animal feed (Rezaei et al., 2013). Thus, the high protein levels described in macroalgae (see **table 1**) together with its amino acid profile could suggest its incorporation in animal feed as an alternative source of high quality protein.

Table 1. Protein contents (% dry weight) in selected macroalgae described in the literature.

Algal species	Protein content (% DW)	Reference
Phaeophyta (Brown macroalgae)		
<i>Laminaria spp.</i>	7	Dawczynski, Schubert, and Jahreis (2007)
	4-8	Schiener, Black, Stanley, and Green (2015)
<i>Sargassum spp.</i>	17	Rodrigues et al. (2015)
	12-14	Yu, Zhu, Jiang, Luo, and Hu (2014)
<i>Undaria pinnatifida</i>	17	Taboada, Millan, and Miguez (2013)
	20	Dawczynski et al. (2007)
<i>Himanthalia elongata</i>	5	Cofrades et al. (2010)
	5	Sánchez-Machado, López-Cervantes, López-Hernández, and Paseiro-Losada (2004)
Rhodophyta (Red macroalgae)		
<i>Porphyra spp.</i>	39	Cofrades et al. (2010)
	33	Taboada et al. (2013)
<i>Gracilaria spp.</i>	19	Rohani-Ghadikolaei, Abdulalian, and Ng (2012)
	10	Tabarsa, Rezaei, Ramezanpour, and Waaland (2012)
Chlorophyta (Green macroalgae)		
<i>Ulva spp.</i>	25	Lee, Chang, and Lee (2014)
	7	Satpati and Pal (2011)
<i>Ulva lactula</i>	11	Tabarsa et al. (2012)
	17	Rohani-Ghadikolaei et al. (2012)

2.2. Macroalgal polysaccharides

The total polysaccharide concentrations in macroalgae range from 4% to 76% of dry weight with the highest contents described in *Ascophyllum*, *Porphyra* and *Palmaria* spp., in comparison with green macroalgae (S. L. Holdt & S. Kraan, 2011). Differences in polysaccharide content and composition could be appreciated depending on the macroalgae species, parts of the macroalgae sampled and seasonal variations (Kim, 2012; Men'shova et al., 2012; Skriptsova, Shevchenko, Tarbeeva, & Zvyagintseva, 2011).

Macroalgae contain a number of complex carbohydrates and polysaccharides in variable amounts depending on the macroalgae species. Brown algae contain alginates, sulphated fucose-containing polymers and laminarin; red macroalgae is a rich source of agars, carrageenans, xylans, sulphated galactans and porphyrans; and green algae contain xylans and sulphated galactans (Makkar et al., 2016).

Marine polysaccharides from seaweeds are an integral part of a globally thriving marine-bio industry. Seaweeds are the most abundant source of polysaccharides including (1) alginate, agar, agarose and carrageenan with commercial applications in the biomedical and pharmaceutical industries (Venkatesan et al., 2015) and (2) laminarin and fucoidan with promising potential in food and animal feed. Fucoidan and laminarin, showed a wide range of biological activities such as anti-inflammatory, anti-microbial, anti-coagulant, anti-adhesive, anti-oxidant, anti-viral, anti-peptic, anti-tumour, anti-apoptosis, anti-proliferative and immunostimulatory, in both *in vitro* and *in vivo* model systems (Hahn, Lang, Ulber, & Muffler, 2012; Kadam, Tiwari, & O'Donnell, 2015).

2.3. Macroalgal fatty acids

Brown macroalgae typically have the highest total lipid content, followed by green and red macroalgae (Gosch, Magnusson, Paul, & Nys, 2012). However, there is considerable variation in total lipid between species and also season. I.e. levels of 68.9 mg / g dry weight (DW) and 57.5 mg / g DW

were described in different species of green macroalgae within the Bryopsidales order (Gosch et al., 2012). Also high lipid contents were described in winter and spring in *Ulva lobate*, *Egremia menziesii* and *Chondracanthus canaliculatus* (Nelson, Phleger, & Nichols, 2002).

In recent years, lipid composition in marine algae has raised considerable interest due to their high content of polyunsaturated fatty acids (PUFA). PUFA contents varied from 34% of the total fatty acids content in *Porphyra* spp. to 74% in *Undaria pinnatifida* (Dawczynski et al., 2007). Macroalgal PUFA include α -linolenic (18:3 n-3), octadecatetraenoic (18:4 n-3), arachidonic (20:4 n-6) and eicosapentaenoic acids (20:5 n-3) (Kendel et al., 2015). I.e. *Ulva* spp. is unique in comparison with plant and fish derived oils due to high levels of octadecatetraenoic acid, as well as offering essential dietary eicosapentaenoic and docosahexaenoic acids, which are generally absent in terrestrial plants (McCauley, Meyer, Winberg, & Skropeta, 2016). PUFA are considered essential nutritional components in humans and animals, playing an important role in the prevention of cardiovascular diseases, osteoarthritis and diabetes. Additional beneficial health properties include anti-microbial, anti-viral, anti-inflammatory and anti-tumour properties (Kendel et al., 2015).

Recent studies showed the future potential of the controlled cultivation of *Ulva* spp. biomass to generate an algal-based oil for human and/or animal nutrition, as part of a biorefinery process for high value products (McCauley et al., 2016).

3. Macroalgae as source of micro-nutrients

3.1. Minerals

The capacity of macroalgae to accumulate metals depends on multiple factors, but it is mainly related to the bioavailability of the metals in the surrounding water, the uptake capacity of the macroalgae (Besada, Andrade, Schultze, & Gonzalez, 2009) and the efficient adsorption of metal/organometallic species from seawater (Besada et al., 2009; Romaris-Hortas et al., 2010).

Important essential minerals for human health, such as iodine, copper, selenium and zinc were found in high proportions in macroalgae. *Laminaria* spp. are known to be the best iodine accumulators among all living systems and the accumulation of iodine can be up to 30,000 times larger than in the surrounding environment (S. Holdt & S. Kraan, 2011). Copper, selenium and zinc levels described in macroalgae in Norway showed to be safe when applied the macroalgae as food and feed, with higher levels of zinc described in red and brown macroalgae (Duinker et al., 2016). Reported accumulation of heavy metals in seaweed includes arsenic, cadmium, chromium, nickel, vanadium, mercury, lead, cesium-137, and radium-226 (van der Spiegel, Noordam, & van der Fels-Klerx, 2013). Large amounts of arsenic in its inorganic form were found in *Sargassum* spp., while the organic arsenic contents ranged from 38 to 75% (Almela et al., 2002). However, in a recent study the health risk due to the toxic elements in seaweed was estimated and the contribution to total element intake of arsenic, cadmium and lead of macroalgae does not appear to pose any threat to the consumers, although the concentrations of these heavy metals should be controlled to protect the consumers' health (Desideri et al., 2016).

3.2. Pigments

There are three different groups of light harvesting and photoprotective pigments in macroalgae named chlorophylls, carotenoids and phycobiliproteins present in different proportions depending on the macroalgae species (Hallerud, 2014).

Chlorophylls are green lipid-soluble photosynthetic pigments found in all macroalgae species, terrestrial plants and cyanobacteria (S. L. Holdt & S. Kraan, 2011). Chlorophyll a is found in all photosynthetic macroalgae, while chlorophyll b and c are found in green and brown macroalgae respectively (Hallerud, 2014). The increasingly restrictive legislation concerning the origin of food preservatives (anti-oxidants and anti-microbials) and the growing demand for natural compounds, has renewed the interest in anti-oxidants such as chlorophylls from natural sources, instead of chemically synthesised molecules (Guedes et al., 2013).

Carotenoids include carotenes and xanthophylls with relative abundance variable depending on the macroalgae species. Green macroalgae species include β -carotene, lutein, violaxanthin, neoxanthin and zeaxanthin, red macroalgae contain mainly α - and β -carotene, lutein and zeaxanthin and brown macroalgae are a rich source of β -carotene, violaxanthin and fucoxanthin (S. L. Holdt & S. Kraan, 2011). Due to their potential health benefits, the incorporation of carotenoids into functional foods or dietary supplements is a major interest of both consumers and the food industry (Salvia-Trujillo, Qian, Martín-Belloso, & McClements, 2013). The beneficial effects of carotenoids are thought to be due to their role as anti-oxidants. Other activities include the pro-vitamin A ability of β -carotene (S. L. Holdt & S. Kraan, 2011), the protective role against eye disease showed by lutein and zeaxanthin (Johnson, 2002) and the promising anti-tumour activities of fucoxanthin (S. L. Holdt & S. Kraan, 2011).

Phycobiliproteins include phycoerythrin, phycocyanin, allophycocyanin, and phycoerythrocyanin. Phycoerythrin levels of 12% DW in *Palmaria palmata* and 0.5% in *Gracilaria tikvahiae* (J. Fleurence, 2004). Phycobiliproteins showed spontaneous fluorescence, property that is used by the biomedical industries in the development of diagnostic techniques such as fluorescent immunoassays (Harnedy & FitzGerald, 2013). Also, phycobiliproteins showed multiple biological activities i.e. anti-oxidant, anti-inflammatory, anti-viral and anti-tumour (Sekar & Chandramohan, 2008) that could be used in the development of functional foods (Langellotti, Buono, Vargas, Martello, & Fogliano, 2013).

4. Macroalgae as functional feed

There is an increased interest in the scientific community to discover new functional foods or functional food ingredients. Functional foods were described as foods or dietary components that may provide a health benefit beyond basic nutrition (Wildman, Wildman, & Wallace, 2016). Several functional food ingredients of different chemical nature have been reported to possess anti-oxidant, anti-bacterial, anti-hypertensive, anti-inflammatory and anti-tumour activities (Wildman et al., 2016). Functional foods could help in the prevention or reduce the progression of many chronic

diseases, such as cardiovascular disease, cancer and degenerative diseases (Olaiya, Soetan, & Esan, 2016).

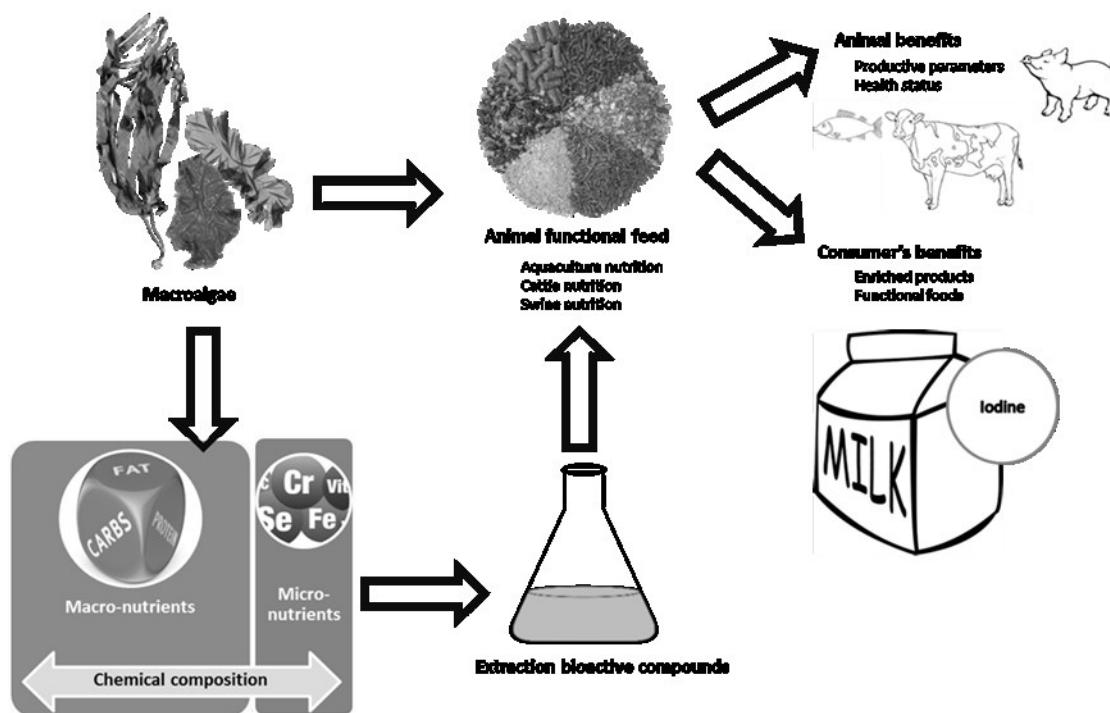
Animal nutrition (i.e. aquaculture, ruminant and swine) has been traditionally evaluated in terms of productive parameters such as animal weight gain or feed utilization (France, Theodorou, Lowman, & Beever, 2000). Recently, animal nutrition has gained attention as an effective way to produce functional food ingredients with beneficial health effects that could increase the price of animal products in the market (Siró, Kápolna, Kápolna, & Lugasi, 2008). I.e. the use of supplements in cattle (Rey-Crespo, López-Alonso, & Miranda, 2014; López-Alonso et al., 2016) or swine feeds (Dierick, Ovyn, & De Smet, 2009) to increase the contents of essential trace elements in milk or meat.

In animal nutrition, functional feed has not a clear definition to date (see **figure 1**). Functional feed for pet animals adopt the definition previously described for functional foods, focusing on the additional health benefits that the functional ingredients could provide to the pets such as reduction of risk of obesity, osteoporosis, colon cancer and inflammatory bowel disease (<http://www.petfoodindustry.com/articles/2926-advances-in-functional-petfood-ingredients>).

However, functional feed in production animals such as aquaculture have been modify to incorporate the important economic benefits of the incorporation of the ingredients in animal production. In this sense, functional feeds were described as dietary ingredients that provide growth, health, environmental and economic benefits beyond traditional feeds (Olmos Soto, Paniagua-Michel, Lopez, & Ochoa, 2015).

Due to the wide variety and biological properties of the compounds discovered in macroalgae, the incorporation of algal biomass or isolated molecules in functional feed formulation could represents a great opportunity in animal nutrition.

Figure 1. Scheme showing the possibilities for incorporation of macroalgae or macroalgal derived ingredients for the development of functional feeds for animals.



4.1. Aquaculture nutrition

Aquaculture is the fastest growing sector of the food economy, increasing by more than 10% per year and currently accounts for more than 50% of all shrimp/fish consumed (Olmos Soto et al., 2015). Feeding represents 40-60% of the total production costs in shrimp/fish farming (Olmos Soto et al., 2015) thus, the development of new ingredients or novel feed formulations that could help to reduce the production cost and improved animal health represents a promising field from both scientific and industrial points of view. The use of animal protein sources, such as fish meal in aquaculture feeds is expected to be reduced or completely eliminated as a consequence of increasing economic, environmental and sanitary regulations (Olmos Soto et al., 2015). Macroalgae species with elevated protein content and production rates could be considered as potential novel feed ingredients in aquaculture (L. M. P. Valente et al., 2006).

The partial substitution or inclusion of different percentages of macroalgae into the diet of fish showed promising results improving productive parameters in fish (i.e. growth rates), enhancing animal health (i.e. metabolic rates or response to stress) and increasing certain beneficial

compounds in derived animal products (i.e. pigmentation or iodine concentration). *Eucheuma denticulatum* can be efficiently utilized by Japanese flounder juvenile (*Paralichthys olivaceus*) and promote best growth and feed utilization at a level of 3% (Ragaza et al., 2015). The addition of 5% of *Ascophyllum nodosum*, *Porphyra yezoensis* or *Ulva pertusa* to the feed of fingerling red sea bream (*Pagrus major*) increased body weight, feed utilization and muscle protein deposition in comparison with the fish fed a normal diet (Mustafa, Wakamatsu, Takeda, Umino, & Nakagawa, 1995). *Porphyra dioica* at levels of 10% in rainbow trout's feed showed no negative effects on the growth performance and increased the flesh pigmentation of the fish (Soler-Vila, Coughlan, Guiry, & Kraan, 2009). The inclusion of 5% *Gracilaria* or *Alaria* spp. into the feed of meagre (*Argyrosomus regius*) modulated the metabolic rates and enzymatic responses during a bacterial infection without affecting the growth performance of the fish (Peixoto, Salas-Leitón, Brito, et al., 2016). Similarly dietary macroalgae supplementation (*Ulva*, *Gracilaria* and *Fucus* spp.) improved the immune and antioxidant responses in European seabass (*Dicentrarchus labrax*) without compromising growth performance of the fish (Peixoto, Salas-Leitón, Pereira, et al., 2016). The inclusion of up to 5% of *Gracilaria vermiculophylla* in diets for rainbow trout (*Oncorhynchus mykiss*) did not affect the growth of the fish. The supplemented fish showed improved flesh quality traits (higher colour intensity and juiciness) and the flesh iodine content on the flesh doubled in comparison with the fish of the control diet (Luísa M. P. Valente et al., 2015).

Similarly, recent studies used macroalgae in the diet of important aquaculture production systems such as shrimps and molluscs. Commercial feed of marine shrimp (*Litopenaeus vannamei*) could be replaced up to 50 % with *Ulva lactuca* as source of protein and lipids without negative effects on the growth performance of shrimps (Pallaoro, do Nascimento Vieira, & Hayashi, 2016). The co-culture of juvenile shrimp and green macroalgae *Ulva clathrata* showed increased growth rates, diminished lipids in shrimp carcass and also and higher body carotenoids content in comparison with the animals without co-cultured macroalgae (Cruz-Suárez et al., 2010). In mollusc culture, the culture of macroalgae *Hynea spinella*, *Hynea musciformis* and *Gracilaria cornea* in a biofiltration unit with

fishpond waste water effluents was successfully used as feed in juvenile abalone (*Haliotis tuberculata coccinea* R.). The survival and growth rates of juvenile abalone were similar to those raised commercial conditions (Viera et al., 2005).

4.2. Ruminant nutrition

There is growing interest and evidence of the benefits of using macroalgal biomass in livestock production systems, particularly for ruminants (Machado, Kinley, Magnusson, de Nys, & Tomkins, 2015).

The use of extracts from macroalgae *Ascophyllum nodosum* was extensively reported in feed-lot steers (Evans & Critchley, 2014). The potential benefits of the macroalgae extracts include improved carcass characteristics and meat quality (K. Braden et al., 2007), ruminal organic matter and total tract crude protein digestibility in cattle (Leupp, Caton, Soto-Navarro, & Lardy, 2005) and color stability and extend beef shelf-life of meat products (Montgomery et al., 2001). Also, the inclusion of 2% of *Ascophyllum nodosum* extract in feedlot cattle diets showed a reduction in *Escherichia coli* in fecal samples (K. W. Braden, Blanton, Allen, Pond, & Miller, 2004)

In small ruminants the macroalgae *Laminaria digitata* and *Laminaria hyperborea* biomass could be used as an alternative feed source due to the high organic matter content, digestibility, and rumen dry matter degradability of these macroalgae species (Hansen, Hector, & Feldmann, 2003). The addition of 1% of macroalgal meal to the forage of lambs had no significant influence on relative growth of body components, but it influenced hot carcass weight (Al-Shorepy, Alhadrami, & Jamali, 2001). Furthermore, the addition of *Ascophyllum nodosum* extract at 2% in the diet of goats improved the anti-oxidant status of the animals exposed to simulated pre-slaughter stress (Kannan et al., 2007).

The use of seaweed to increase mineral content in animal products is currently of interest, especially in relation to increasing the iodine content of foods (Rey-Crespo, López-Alonso, & Miranda, 2014;

López-Alonso et al., 2016). A mixture of three macroalgal species *Ulva rigida*, *Sargassum muticum* and *Sachorhiza polyschides* at 0.5% of the total daily feed intake in organic dairy cattle significantly improved the animals and milk mineral (mainly iodine and selenium) status (Rey-Crespo, López-Alonso, & Miranda, 2014; López-Alonso et al., 2016). Similarly, the dietary inclusion of *Ascophyllum nodosum* in dairy cows led to an improvement of the iodine content in milk, and to a modification of its microbiota with a positive effect on milk hygiene and transformation (Chaves Lopez et al., 2016).

4.3. Swine nutrition

Moderate to high amounts of brown macroalgae in the diet may be detrimental to pigs (Makkar et al., 2016) i.e. the inclusion of *Ascophyllum nodosum* at 10% in pigs diets produced weight loss in the animals after several weeks (Jones, Blunden, & Probert, 1979). However, the incorporation of macroalgal derived polysaccharides, such as laminarin and fucoidan showed promising results used as prebiotics in pigs diets to modulate the microbiota in the digestive tract and immunomodulating properties in pigs (Sweeney et al., 2012; Walsh, Sweeney, O'Shea, Doyle, & O'Doherty, 2013). *In vivo* studies incorporating laminarin from brown macroalgae in the diet of pigs showed a down-regulation of the expression of inflammatory cytokines in the colon (Sweeney et al., 2012) and mucin gene expression in the ileum and colon (Ryan et al., 2010; Smith et al., 2010). A down-regulation of pro- and anti-inflammatory cytokines was appreciated in the colon of post-weaning pigs supplemented with laminarin and a reduction in *Enterobacteriaceae* counts was appreciated in the animals supplemented with fucoidan (Walsh et al., 2013).

As in the case of ruminants, the use of macroalgae in pigs feed has been proposed to increase iodine concentration in pig meat that could be beneficial for its consumption by deficient population. The organic iodine found in *Laminaria* or *Ascophyllum* spp. is readily metabolized and stored in the muscle, unlike inorganic iodine (Banoch, Fajt, Drabek, & Svoboda, 2010). The addition of 2% of *Ascophyllum nodosum* to the diet of pigs increased the concentration of iodine by 2.7-6.8 in different animal derived products. The consumption of these iodine enriched products could be one safe

strategy to help deficient population (Dierick, Obyn, & De Smet, 2009). Similarly, the inclusion of *Enteromorpha* sp. to the diet of pigs did not affect the growth and productive parameters of the animals in comparison with animals supplemented with inorganic salts of copper and zinc. The meat of the animals supplemented with macroalgae showed higher manganese (49%), but also slight increases in iron (13%), copper (12%) and zinc (4%) when compared to the meat of the piglets supplemented with inorganic salts (Michalak, Chojnacka, & Korniewicz, 2015).

5. Future prospects

Crop cultivation induces a significantly high carbon debt and high water consumption, thus, terrestrial biomass seems not to be sustainable at present due to environmental as well as economic impacts (Jung, Lim, Kim, & Park, 2013). Macroalgae could be a good alternative as a novel ingredient in both human and animal feed. Overharvesting of wild macroalgae could lead to negative environmental impacts and problems in the sustainability of the supply in the market. Despite this, growth rates of marine macroalgae far exceed those of terrestrial biomass (Kraan, 2013). Also, widely marketed species such as *Ascophyllum nodosum* have shown quick re-generation and growth after being hand harvested in portion only on the top of the fronds allowing annual harvesting from the same beds (Ugarte, Sharp, & Moore, 2007).

Mariculture could provide a solution for sustainable supply of macroalgae. Cultivation systems include rope farms, tidal flat farms and floating cultivation systems that are currently used successfully in the production of *Laminaria* spp. (offshore), *Ulva* spp. (tidal flat farm) and *Sargassum* spp. (floating cultivation) (Kraan, 2013). Also, the combination of macroalgal culture with other production animals such as fish and molluscs could be a viable commercial alternative (Burg et al., 2013).

As previously commented, the incorporation of macroalgae biomass in animal feed as source of macro-nutrients (i.e. protein) in substitution of traditional ingredients or as a source of micro-

nutrients (i.e. mineral or pigments) could be a viable alternative for the development of both functional animal feed and for the fortification of the derived animal products that could be used in the market of functional foods (see **figure 1**). Also, the extraction of macroalgal compounds (i.e. polysaccharides) for their incorporation into animal feed has shown promising results as pre-biotics improving animal's health.

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