HYFFI Report Summary
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Final Report Summary - HYFFI (Hydrocolloids as functional food ingredients for gut health)

Executive summary:

Batch culture screening of 19 novel low molecular weight polysaccharide (LMWP) derivatives of seaweed derived polysaccharides revealed that several of such compounds had potential prebiotic properties. Two LMWPs (one agar- and one alginate-derived) were selected on the basis of technological and organoleptic suitability for more detailed assessment. In an in vitro gut model and in a human intervention study, small changes in gut microflora profile were seen with both LMWP products. In some cases changes were observed in groups with potentially beneficial effects, e.g. the increase in Faecalibacterium prausnitzii associated with agar intake in the human volunteer study. Although statistically significant, the results however are unlikely to be of biological importance due to the small magnitude of the changes. Similarly, only small changes in short chain fatty acid (SCFA) profile were seen which probably reflect the minor changes in gut bacterial numbers. We conclude therefore that the agar and alginate LMWPs have no prebiotic effects in human volunteers. There were however potentially beneficial changes in gut function characteristic of dietary fibre in the volunteers consuming the agar or alginate LMWP derivatives. During consumption of the LMWPs there were significant increases in stool weight by comparison with the placebo group and the agar LMWP reduced faecal pH. Furthermore, post prandial glucose absorption was decreased in subjects consuming modest amounts (8 g / day) of alginate LMWP. Such effects indicate that despite the considerable reduction in molecular weight of the polysaccharides and the associated decrease in viscosity, fibre-related properties in the gut were maintained.

Project context and objectives:

From a global perspective, the European seaweed industry is small and predominantly services the traditional low-value sectors of the hydrocolloids, horticulture and animal feed industries. Small amounts are harvested for human consumption, cosmetics and biotechnology. Globally, in excess of 11 million tonnes of raw seaweed are harvested or aquacultured on a yearly basis and approximately 90 % comes from south East Asia. Within Europe, Norway is the only country that contributes to greater than 1 % of the global total (Hurtado & Salayo 2006). In most European countries, Norway being an exception, seaweed is still harvested from wild stocks by hand and processing is basic. The hydrocolloids industry, in particular alginate production, is by far the major market for this resource (approximately 90 %, CyberColloids, see http://pers.com online for further details) but recent years have seen a decline and closure in processing facilities as cheaper raw materials are made available from China, Australia and South America.

Traditionally, seaweed derived polysaccharides (also known as hydrocolloids) have been used to provide thickening and gelling functionality to food stuffs and other industrial applications however there is emerging evidence to show that lower polysaccharides and oligosaccharides derived from these hydrocolloids can act as a source of soluble fibre and may also have prebiotic activity (Warrand 2006). Recent developments in Japan and Korea have seen products containing low molecular weight (LMW) seaweed derived fibre hitting the market. There is also some evidence for the beneficial effects of seaweed...
derived fibre in other key health areas such as cardiovascular health, cancer, diabetes and obesity (Ito & Hori 1989, Smit 2004, Warrand 2006). However, relatively little is known about the chemical, physiochemical and fermentation characteristics of seaweed fibre in the human gut.

Some hydrocolloids, notably guar gum, have also been employed for their health promoting properties in the areas of glucose tolerance and cholesterol lowering. However, the use of hydrocolloids as functional food ingredients with health benefits for consumers has been rather limited and has focused more on uses in products for diabetics.

The scientific evidence points to the significant scope for improving health in Europe by nutritional means. One strategy to improve public health is to change the nature of the food supply through new ‘health / functional foods’. The term ‘functional food’ can be defined as a food material that provides specific functional benefit (health or physiological) additional to its basic nutritional value. Segmenting by health benefit, the functional food market remains dominated by gut health products, ahead of heart health which is growing strongly and products to boost the immune function. In the United States of America (USA), the gut health market is estimated at USD 4 billion whereas Datamonitor report 3.7 million regular European functional food users for gut health products.

It is particularly in the area of gut health that small and medium-sized enterprises (SMEs), involved in hydrocolloids production and processing, can enter the functional food ingredients market by using innovative processing technology. The total dietary fibre content of seaweed can be as high as 75 % of the total dry weight and much of this is soluble (Jimenez-Escrig & Sanchez-Muniz 2000). The fibre component essentially comprises the structural polysaccharides i.e. alginate and fucoidan in brown seaweeds, carrageenan, agar and porphyran in red seaweeds and ulvan in green seaweeds. As these fibres are primarily soluble, they form viscous gels as they pass through the gastrointestinal tract. Some of the fibre is fermented in the lower intestine but in general, soluble and insoluble seaweed fibre tends to pass through the gut without being digested. (Warrand 2006). In its natural form as part of the seaweed plant, this fibre is typically high in molecular weight and passes through the gut too rapidly for the gut microflora to utilise to any great extent. There is therefore a necessity to develop lower molecular weight forms that are more soluble and can be added at higher concentrations to food products without affecting the sensory properties of the product.

LMW forms may have a further benefit by acting as potential prebiotics. The particular focus of the proposed research is to develop, from agar and alginate polymers, novel prebiotics. A prebiotic is defined as ‘a non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and / or activity of one or a limited number of bacteria in the colon and thus improves host health’. (Gibson and Roberfroid, 1995) Most are oligosaccharides of various sugar moieties with degrees of polymerisation up to 60, although more commonly ranging between 2 and 10, and are derived from inulin (fructooligosaccharides). The European prebiotic market is relatively developmental, with a few companies (Beghin-Meiji, Cosucra, Orafti and Sensus) dominating in the supply of fructan ingredients (inulin and fructooligosaccharides), both claiming to stimulate the growth of bifidobacteria and lactobacilli and as a consequence prevent the growth of harmful bacteria. The European fructan market valued at EUR 87 million in 2004, is predicted to rise by a compound annual growth rate of 10.2 % until 2010. There are great opportunities however to develop a wider variety of prebiotic applications and to exploit other properties of prebiotics.

Fructan ingredients are in the market growth stage, whilst other prebiotic ingredients such as resistant starch, galactooligosaccharides and isomaltooligosaccharides are more developmental. Examples of other prebiotic ingredients include gum arabic from Colloides Naturals Inc (CNI), larch gum from Larex Inc. and LMW guar from Novartis. Recent market developments in France include an apple pomace derived pectin oligosaccharide from a cider company Val de Vire and a LMW konjac or glucomannan flour from Kalys, a konjac gum supplier. An example of multifunctionality stimulating wider applications is demonstrated by MSC, a Korean company, which is selling a LMW alginate as a cholesterol reducing agent as well as a prebiotic.
The current project is framed around the realisation of a commercial opportunity to produce LMWPs from alginate and agar bearing seaweeds for application in food and health and wellness products. It addresses the requirements of a consortium of three SMEs from traditional harvesting and processing sectors of the European seaweed industry that are seeking the technological know-how and scientific validation to develop novel higher value products from their basic resources. Acquisition of this knowledge will render significant competitive and commercial gain through the development of innovative processing technology, novel higher value LMWP products and access to premium markets. As none of the SME participants have the research and development (R&D) capacity required to develop a commercially viable prebiotic fibre three research and technological development (RTD) providers with appropriate expertise in hydrocolloid chemistry, nutrition and health have been identified to carry out the research.

Objectives

From the above it is clear that there is a large and growing market for gut health products, particularly prebiotics. In order to exploit the use of agars and alginates in this area a number of technological and scientific problems need to be solved and these are addressed within the current proposal. The scientific and technical objectives may be summarised as follows:

(1) To develop novel LMWP derivatives of agar and alginates This will be delivered by CyberColloids Ltd. using raw materials and seaweed meal supplied the Hebridean Seaweed Company and Roko. CyberColloids will deliver eight LMWP derivatives for evaluation. These will be based on pure extracts of alginate and agar and also cruder preparations of alginate rich and agar rich seaweed fibre.

(2) To screen the novel products for potential beneficial effects on gut microflora composition (bifidogenic activity) and bacterial metabolism (SCFA) and to provide evidence for potential to increase calcium absorption in the gut.

Having isolated a variety of the LMWP derivatives, it will be necessary to identify the ones with the greatest potential for prebiotic activity. One of the RTD providers, the University of Reading will screen the candidate products for bifidogenic activity and production of SCFAs. This will enable the remainder of the project to focus on the agar and alginate LMWP with the greatest potential to be effective in humans.

(3) To provide evidence of efficacy of selected LMWP in human volunteers in terms of bifidogenic activity, gut health, blood glucose and plasma lipids; to generate additional evidence for production of a beneficial SCFA profile within the colon using a novel gut model system.

This objective of the project is to provide definitive evidence that the selected LMWP(s) exert prebiotic effects when consumed at a reasonable level (15 g per day) in human volunteers. The proposed study under this objective is designed not only to provide information on bifidogenic activity (a prime property of prebiotics) but also to generate data on other potential health benefits in the gut such as improvements in stool formation (laxation) beneficial effects on plasma lipid profiles and blood glucose levels. Concomitant with the human study, a detailed in vitro investigation of the effects of the selected agar and alginate LMWPs in an in vitro model of the human colon will be conducted to provide further supporting evidence of beneficial effects on bacterial types and activities in the colon. Due to the inaccessibility of the human colon, such models are the only way of addressing this issue.

(4) LMWP technology transfer and scale up

The main objective is to optimise the LWMP process in the laboratory to produce a robust and reproducible process and to validate optimised process at pilot plant scale. Furthermore, to identify the scale-up requirements and the suitable equipment to match production criteria.
Potential Impact:

HYFFI potential impact statement

The overall aim of the HYFFI project was to provide the SME partners with information, knowledge and capacity to produce alginate and agar LMWP fractions of various molecular weights and structures from seaweed and seaweed derived powders, with valuable prebiotic activity, and to exploit the commercial possibilities of these extracts. This was to be achieved through the following specific objectives:

(a) the development of novel LMWP derivatives of agar and alginates;
(b) the screening of novel LMWP products for potential beneficial effects on gut microflora;
(c) the composition (bifidogenic activity) and bacterial metabolism (SCFAs) and to provide evidence for potential to increase calcium absorption in the gut;
(d) provision of evidence of efficacy of selected LMWP in human volunteers in terms of bifidogenic activity, gut health, blood glucose and plasma lipids;
(e) the generation of additional evidence for production of a beneficial SCFA profile within the colon using a novel gut model system;
(f) the LMWP technology transfer and scale-up.

Two new methods were developed, optimised in the laboratory and then validated on the pilot scale for the production of alginate and agar LMWP fractions. Both in vivo and in vitro data on agar and alginate LMWPs indicated changes in bacterial populations. However, they do not seem to potentially increase numbers of beneficial bacteria. Furthermore, almost negligible fermentation levels occurred in the gut models, and significant but low levels similar to the control from the human study indicate a lack of fermentation of these substrates by gut bacteria. Since valuable prebiotic activity has not been demonstrated, the exploitable results relate solely to the processing technology.

The developed processing technology is versatile, and can be used to manufacture:

(a) LMW alginates and agars of various molecular weights;
(b) seaweed extracts containing LMWPs; and
(c) general seaweed extracts.

Exploitation of the developed processing technology will target three sectors, namely:

(a) horticultural market;
(b) animal feed market; and
(c) human food market.

Roko are using technology developed by HYFFI to produce a range of low MW agars that have been successfully validated at pilot scale by customers and are now proceeding to commercial scale up for incorporation into their own food products ranges. The previous source of such LMW agar from Japan was expensive, and since the problems of the tsunami and the nuclear accident in Japan, this is no longer available.

1. Contribution at the European level of the HYFFI project work programme impacts

1.1 Economic impact for SMEs

The pre-competitive HYFFI research applies to the production of a range of different molecular weight seaweed extracts on a
pilot scale so further demonstration is needed to prove techno-economics and to further broaden acceptance for such extracts by horticultural, animal feed and human food customers. The SMEs will continue to drive exploitation of the processing technology foreground which they own. It is envisaged that products based on intellectual property (IP) generated within the HYFFI project will be introduced progressively, starting by July 2012. The degree and rate of expansion will depend on the economies of scale in LMW seaweed extract production, pricing policies and customer / consumer acceptance. Whilst regulatory problems in these markets are unlikely, it is recognised that further scientific evidence will be needed to support marketing of LMW alginate products for horticultural and animal feed applications, and LMW agar products for human food use.

According to the Centre d'Etude et de Valorisation des Algues (CEVA), world production of seaweeds stood at 16 million tonnes (live weight equivalent) in 2008, with 93 % cultivated and 7 % harvested in the wild. China towers over other seaweed producers at 64 % of supply in a world market valued at USD 7.4 billion in 2008, where the human food segment occupied 65 % of that value and the colloids segment another 30 %. European seaweed production, at around 1.3 % of world supply, is focused around Norway and France, with a significant contribution from Ireland. Core markets for European Union (EU) seaweed are agriculture, nutrition and health, and cosmetics, whilst emerging markets lie in biorefining, green materials and bioenergy. The SMEs’ plan to realise commercial value within the core markets of agriculture (including horticulture) and nutrition and health (human food). More specifically the SMEs will use the HYFFI processing IP to:

(a) manufacture a range of ascophyllum nodosum seaweed extracts for sale into the horticultural market (Hebridean Seaweed Company LTD, Outer Hebrides of Scotland);
(b) develop a new base Aquafibre that will be tailored to the three largest global animal industries - dairy, swine and poultry (Marigot LTD, Ireland); and
(c) manufacture a range of different molecular weight and solubility agars for sale into the human food market (Industrias Roko S.A., Spain).

1.1.1 Horticultural market

Hebridean Seaweed Company LTD is the largest industrial seaweed processor in Great Britain. The company manufactures seaweed products for use in the animal feed supplement, soil enhancement, alginate and nutraceutical sectors.

According to the Global Horticulture Assessment Team (2005), horticulture is one of the most dynamic of agricultural trade areas, due in part to recognised health benefits in the developed world and the need for dietary improvement in the developing world. According to Ecoland International Inc., the global gardening and outdoor living market in 2008 had a value of USD 167.5 billion (bn) and this is forecast to have a value of USD 183.1 bn in 2013, an increase of 9.3 % since 2008. The Global market consists of the Americas at USD 65.4 billion (39 %), Europe at USD 65.8 billion (39.3 %) and Asia-Pacific at USD 36.3 billion (21.7 %). The plants, shrubs and growing media sales proved the most lucrative for the global gardening and outdoor living market in 2008, generating 57.7 % of the market's overall revenues or USD 96.7 billion and assuming a constant ratio this would be USD 105.7 billion by 2013. The growing media (composts, fertilisers and soil conditioners) sub group of the plants, shrub and growing media amount to 30 %.

Seaweed horticultural extracts are used by organic farmers and gardeners wishing to avoid synthetic fertilisers or fertilisers made from animal products. Nowadays seaweed extracts are becoming more and more popular, and there are a number of dried and processed seaweed extracts available on the market. Powdered extracts are used as soil conditioners and liquid extracts are commonly applied as foliar feeds, where the nutrients are sprayed onto the foliage and taken up through the leaves.

Our research supports opportunities for bulk and retail Hebridean liquid seaweed fertiliser and soil conditioner products within the growing European growing media segment of the horticultural market, which was reported in 2004 to have an estimated
value of USD 30 million by the Martin Ryan Institute, National University of Ireland, Galway. Whilst it is a competitive market, with successful European seaweed based suppliers of growing media such as AlgaeGreen Horticulture, Arramara, Celtic Sea Minerals, green-tech Horticulture, Hebridean Seaweed Company and Sanoway, the Hebridean Seaweed Company already has in place channels of distribution for soil enhancement products and a collaborative R&D support network, including the Aberystwyth University and Cybercolloids LTD, to realise such new horticultural market opportunities in the United Kingdom (UK) and Ireland.

HYFFI project process technology will be used by the Hebridean Seaweed Company to produce the Hebridean soil conditioner product in powder form which contains LMW alginate. LWP alginates will readily decompose adding bulk, and will aid water retention via carbohydrate gels and flocculate the clay as a result of the organic matter. These products will improve fruit and vegetable growth as result of increased root mass, root hair production, nutrient uptake, bud initiation and elongation, and chlorophyll, carbohydrate and protein production. A general purpose Hebridean liquid seaweed extract containing LMW alginates, which enhances root growth and helps plants overcome periods of stress, will be developed using the HYFFI project process technology. This product, upon dilution, will be suitable for foliar spray applications to plants.

The Hebridean Seaweed Company is acknowledged as being important to the Highlands and Islands region of Scotland and the company has built a strong positive relationship with Highlands and Islands Enterprise (HIE) in its achievement of high growth over the last 5 years. The HIE will be an important part of the support network in enabling the Hebridean Seaweed Company to establish factory scale production of LMW alginate products for use in horticultural and animal feed markets. It is anticipated that:
(i) a feasibility study on factory scale LMW alginate production will be completed by the of end 2011;
(ii) plant trials on the two horticultural products will be carried out by July 2012; and
(iii) the production of the new soil conditioner and liquid seaweed fertiliser will be established by end of 2012.

The Hebridean Seaweed Company plans to market the retail Hebridean products in both local and national garden centres and on the company’s website. The bulk Hebridean products will be marketed to companies who supply farmers in bulk. The products will be promoted using promotional literature, trade shows, and on the Internet.

The Hebridean Seaweed Company has produced confidential growth plan financials for the two retail and bulk products, and a 14 % profit before tax is estimated as the return on these new sales over a period of 5 years.

1.1.2 Animal feed market

Marigot Ltd., specialises in the development, manufacture and marketing of natural animal feed products based on calcareous marine algae. Calcareous marine algae is the collective term for several species of calcified red seaweed where a white calcareous skeleton develops over time. This skeleton is rich in bioavailable calcium, magnesium and other minerals necessary for optimal animal health.

According to a recent report by Global Industry Analysts Inc. on the Animal Feed Additives market, the USA, Europe, and Asia-Pacific markets have been the traditional contributors to the overall market, accounting for a combined share of 73.5 % of the total revenue generated in 2009. Despite the damper cast by the recession, the medium to long-term outlook for the animal feed industry is encouraging and is expected to reach US$18 billion by 2015. Growth fundamentals such as population, per capita meat consumption, and consumption in developing nations is expected to drive growth in the post-recession period. Increasingly health-conscious consumers, continued breakthroughs, especially in research and clinical applications areas, and expanding commercial applications will ensure sustained growth in the global animal feed additives market over the next few years.

It is known that fibre is crucial to the digestive health of many animal industries including dairy, swine and poultry. Significant
scientific studies are still required to determine the type and quantity of fibre that should be incorporated into animal diets. These include the digestibility of different fibres, the rate of fermentation, the end-products of the digestion, animal growth and health, the consequences for milk output and composition and meat and egg quality.

Calcium, magnesium and other minerals are of the utmost importance in bone development in animals. These minerals are provided by Marigot’s portfolio of existing products. Fibre has been proven to enhance calcium and other mineral uptake and absorption. This IP protected process will allow development of novel fibres ideally suited for maximal mineral uptake and bone development in animals.

Marigot LTD plan on developing a new base product called AquaFibre that will be tailored specifically for the three largest global animal industries - dairy, swine and poultry. AquaFibre for cows will focus on enhancing digestive health, optimum buffering of the rumen and maximising uptake of calcium and other minerals for higher quality milk and meat. AquaFibre for pigs will optimise digestive health and calcium and mineral uptake for bones. AquaFibre for poultry will also focus on digestive health along with increased mineral uptake for increased bone and egg shell strength.

Significant animal feeding trials need to be carried out to determine the exact length and composition of the seaweed extracts in combination with the calcareous seaweed to maximise digestive health and bone strength for the markets outlined above. AquaFibre for the dairy, swine and poultry feed markets would not require European Food Standards Agency approval under Article 8 of Regulation 1831/2003 which controls the use of additives in animal nutrition within the EU.

Marigot Ltd., currently has existing sales channels in 47 different countries globally. These channels will be exploited when launching AquaFibre on the market. Marigot LTD also plan to build upon existing websites, promotional literature and trade show attendance to promote AquaFibre.

Financial projections are not feasible at this stage as further R&D is required to determine the specific benefits of AquaFibre in each of the individual animal target markets.

1.1.3 Human food market

Industrias Roko SA is recognised as an international reference in the Agar industry. The company is the largest agar manufacturer in Europe, exporting its microbiology, food industry and technical applications products to every continent.

Agar is a polysaccharide which is extracted with hot water from a red seaweed such as Gelidium or Gracilaria species. Agar is an important gelling agent used in the food industry as a texture modifier. According to CyberColloids agar production, of which 10% lies within Europe, has an estimated global market value of USD 200 million, occupying 0.87% of the USD 23 billion food ingredients market. Important goals in the development of the food grade agar market have been to produce cold soluble agars for ease of solution and low gelling agars as suspending agents. Roko already buys a low gelling agar from Japan at approximately EUR 25/kg so plans to produce low gelling agars in-house which will lead to an extra contribution to the company’s bottom line.

HYFFI process technology is currently being use by Roko to produce cold soluble, LMW agar products (RS 30, RS 60, RS 100 and RS 200) with gel strengths ranging from 30 to 200 g/cm². These products are targeted at the confectionary and dairy markets. Both are dynamic food sectors looking for new products, textures and applications. These products will enable the development of spreadable coatings for confectionary applications as well as glazes and icings, and drinkable yogurts and desserts for dairy applications. The major Japanese manufacturer of similar products has withdrawn from the market thus creating a major marketing opportunity for Roko.

Roko intends to market the low gelling agar products in the first instance with existing customers and distributors who are
performing tests for validation of recipes. The products will be promoted through dedicated seminars and meeting with customers. In addition, specific technical datasheets and dedicated space on the company's existing website will be developed for these products. Roko has produced confidential growth plan financials for the low gelling agar products (RS 30, RS 60, RS 100 and RS 200), and a 14.4 % profit before tax is estimated as the return on these new sales over a period of 5 years.

1.2 Effect on competitiveness of SMEs

The recessionary pressures over the last three years have resulted in falling profit margins for many European SME suppliers of agrifood products. This is a concern shared by the Hebridean Seaweed Company, Marigot and Roko, where agrifood applications are dominant within each business. Whilst all three SMEs have given serious consideration to the cost-effective use of resources within their operations, strategically all three SMEs have committed to innovation as the basis of maintaining their competitiveness. During the HYFFI project all three SMEs have made further investments in research and innovation to underpin future new product offerings. The Hebridean Seaweed Company and Marigot are partners within the ‘Seaweed derived Anti-inflammatory agents and antioxidants’ (SWAFAX) project which received funding under the Research for SMEs Theme of the EU’s Seventh Framework Programme (FP7). Roko is developing low gelling agar products.

Whilst the SMEs recognised the opportunities that successful introduction of LMW alginate and agar process technology would give them, they would not have had the resources or know-how to do this directly without participation in the HYFFI project. The role of CyberColloids should be particularly highlighted in validating the LMW alginate and agar process technologies on a pilot scale, and thus providing the Hebridean Seaweed Company and Roko with strong technology platforms upon which to add value to their respective raw materials of Ascophyllum nodosum and Gelidium seaweeds. When the HYFFI project did not produce significant scientific evidence to substantiate the use of the LMW alginate and agar products within the high value, gut health, functional food ingredients market, the SMEs were guided by CyberColloids in the planning of value creation from the LMW alginate and agar processing IP for other applications. These other horticultural and food applications, as outlined in 1.1.1 and 1.1.3, are forecasted to command profit margins before tax of 14 %, which will make a highly significant contribution to the competitiveness of the Hebridean Seaweed Company and Roko. Whilst it is not possible to make financial projections at present on the use of LMW alginate processing IP in the animal feed market, the combined scientific and marketing capabilities within Marigot supports the belief that it also will gain future competitive advantage from the HYFFI project.

Human health is an important driver for innovation within all three SMEs. The HYFFI project has significantly increased the functional food ingredient capabilities within all three SMEs through knowledge gained from the leading European nutritional scientists, the Gut Health and Prebiotics dissemination event (June 2009), the Seaweed, Texture and Health dissemination event (June 2010) and the http://seaforhealth.org website.

1.3 Economic justification of the HYFFI project

It was anticipated that the total investment of EUR 936 575 in the HYFFI project would have been recovered in three years after project completion through commercial exploitation of LMW alginate and agar processing technology by the SMEs in the gut heath, functional food ingredients market. For product entry to this market, the science is critical and when the science from in vivo and in vitro testing for prebiotic activity of LMW alginate and agar products was evaluated it was not deemed to be of sufficient weight to pursue this market. As forecasts on profit before tax for new animal feed products are not possible at this stage, the number of years required to recover the total investment through commercial exploitation of HYFFI processing IP in the horticultural, animal feed and human food markets cannot be stated. However, HYFFI enabled the Hebridean Seaweed Company to network with people from the seaweed industry, who they would otherwise have been unlikely to meet, and to obtain detailed analysis about their product composition and other scientific data that they were then able to supply to new potential customers. As a result of this the Hebridean Seaweed Company has gained new customers in both the human food grade sector and animal feed/horticulture sector. HYFFI allowed Marigot direct access to scientific expertise and networking opportunities within the Universities of Ulster and Reading. Such access to excellence in science is invaluable to
Successful introduction of the LMW alginate and agar processing technology by the SMEs is anticipated to lead to longer term adoption of the technology by others SMEs in the European and international seaweed industry.

1.4 Contribution towards Community societal objectives

Any change that has a positive impact on a sustainable food system is of relevance to all European government agencies and companies involved in the agrifood industry. The Hebridean Seaweed Company is a true model of sustainability, harvesting a renewable resource in an environmentally responsible way creating much needed year round jobs on the Isle of Lewis. This made the company a clear winner of The Crown Estate, Marine Business Award in 2010. In addition, the development of LMW alginate product technology within the HYFFI project for horticultural and animal feed applications will encourage local food, urban horticulture and sustainable gardening, and make a contribution to animal health. Furthermore, the development of LWM agar product technology for human food use will have a positive impact on food quality and will bring production to Europe of a gelling agar product which is currently sourced in Japan. Whilst valuable prebiotic activity of LMW alginate and agar products was not demonstrated within the HYFFI project, there still is a healthy eating message around fibre which food products for human use can carry. In conclusion, the HYFFI project has had positive effects on a range of Community societal objectives including a more sustainable food system, increased employment and improved food quality.

1.5 Effect of transnational technological cooperation

The HYFFI project brought together leading European nutrition and hydrocolloids RTD performers, and innovative, non-competing SMEs in the business of supplying seaweed derived products to European and international markets. The complementary expertise of the three RTD performers, and their past experience of working together, helped to maximise the value of the HYFFI project work undertaken.

While some innovations can be developed and introduced at a single SME level, this opportunity for adding value to seaweed was best implemented by a group of European SMEs. Under these circumstances, the SMEs looked towards Cyber Colloids to take the lead in developing the LMW alginate and agar processing technologies, and towards the two universities in how best to conduct the scientific studies to support gut health market opportunities. Operation of all three SMEs and CyberColloids in international markets, and both universities in international collaborations, helped to steer the direction of the research and to ensure SMEs had maximum opportunities to service both domestic and international markets. Transnational technological cooperation was further enhanced by two ‘Health and texture’ club events organised by CyberColloids which enabled the transfer of knowledge to the SMEs from 9 food sector related companies across 7 countries, and from research scientists at other UK and Danish universities. It would not have been possible to achieve all the benefits from the work undertaken in a single EU state.

2. Dissemination and exploitation of project results and management of IP

2.1 Project results and intellectual and property rights (IPR)

The participants in the HYFFI project agreed to adopt the default position regarding IP, namely that the SMEs will retain full ownership of the project results (foreground). This principle, and others on the ownership of IPR and user rights, were written into the consortium agreement and duly signed by all participants. In particular, the SMEs gained full rights to exploit and disseminate the Project results, and the RTD performers granted the SMEs free access to all relevant background information so that exploitation is not impeded. In return the RTD performers were fully reimbursed for their costs incurred during the course of the research, and they retain ownership of their own background information and will be granted the rights to pursue further R&D on LMW polysaccharide processing technology (excluding alginates and agars) and on in vivo and in vitro
testing for prebiotic activity of any food grade substance.

The SMEs as joint owners of the project results agreed to vest it as follows:

(a) Marigot shall own all foreground resulting from the processing and manufacture of wholly seaweed derived prebiotic and mineral formula products, and the in vitro calcium uptake studies on LMWP produced from agar and alginate sources;
(b) Roko shall own all foreground resulting from the processing and manufacture of prebiotics from agar sources, the in vitro batch culture and gut model fermentations on LMWPs produced from agar sources, and the human intervention study on the most efficacious LMWP produced from an agar source.
(c) Hebridean Seaweed Company shall own all foreground resulting from the processing and manufacture of prebiotics from alginate sources, the in vitro batch culture and gut fermentations on LMWPs produced from alginate sources, and the human intervention study on the most efficacious LMWP produced from an alginate source.

If the owner of the foreground, as detailed above decides not to proceed with the exploitation of the foreground, the other SMEs shall have first refusal to exploit the foreground at no further cost. In the event that all SMEs decide not to proceed with exploitation of the foreground it shall be reassigned to the European Commission (EC). If any of the SMEs wish to transfer ownership of some or all of its foreground, it must notify all the other partners in writing. Should the proposed transfer of ownership be outside the European Community notice must be given to the EC of no less than 45 days. The EC reserves the right to refuse permission.

The participants in the HYFFI project each undertake to use reasonable endeavours to keep confidential and not to disclose to any third party (other than an affiliate) or to use themselves other than for the purposes of the project any confidential or secret information in any form directly or indirectly belonging or relating to the other, its affiliates, its or their business or affairs, disclosed by one and received by another pursuant to or in the course of the project, including without limitation any Background of the other (confidential information). The obligations contained in the above clause shall remain for 10 years after project completion but shall not apply to any confidential information which:

(a) is publicly known at the time of disclosure to the receiving party;
(b) after disclosure becomes publicly known otherwise than through a breach of the project;
(c) agreement by the receiving party, its officers, employees, agents or contractors;
(d) can be shown by reasonable proof by the receiving Party to have reached its hands otherwise than by being communicated by the disclosing Party including being:
   (i) known to it prior to disclosure;
   or (ii) having been developed by or for it wholly independently of the disclosing party; or
   (iii) having been obtained from a third party without any restriction on disclosure on such third party of which the recipient is aware, having made due enquiry;
(e) is required by law, regulation or order of a competent authority (including any regulatory or governmental body or securities exchange) to be disclosed by the receiving Party, provided that, where practicable, the disclosing party is given reasonable advance notice of the intended disclosure and provided that the relaxation of the obligations of confidentiality shall only last for as long as necessary to comply with the relevant law, regulation or order and shall apply solely for the purposes of such compliance; or
(f) is approved for release, in writing, by an authorised representative of the disclosing party.

The SMEs agreed to manage exploitation of the project results. For the production of LWM alginate and agar fractions, it was decided not to apply for patent protection but to keep associated technology transfer document and supporting raw materials, process and product knowledge as secret information. When scientific evidence for prebiotic effects in batch culture studies, gut model systems and human intervention studies was weak, it was decided that both universities should pursue publication of the project results in peer-reviewed scientific journals. All three SMEs have identified trademarks to use in the exploitation
2.2 Dissemination and use

2.2.1 Web-based management and dissemination system

The University of Reading developed and maintained a web-based knowledge management and dissemination system at http://seaweedforhealth.org to support the HYFFI project partners and their activities, and to publicise the activities of the consortium. The web-based system includes a public section and a confidential domain. The public web pages provide:

(i) information on the partners and their expertise;
(ii) a seaweed for health forum;
(iii) publications;
(iv) news and events;
(v) a gallery of relevant photos;
(vi) a contact communication channel; and
(vii) non-confidential project findings.

The restricted area of the website is accessible only by the partners via user names and passwords. This restricted area enabled geographically dispersed project team members to efficiently share and exchange information, and to discuss and jointly modify project resources, in real time. This played a major role in speeding up the decision-making process. It also enhanced the integration of project partners, and offered facilities to support the coordination and management of the project. The HYFFI website will be maintained beyond the end of the Project for at least 18 months, as the SWAFAX website has also how been established at http://seaweedforhealth.org.

2.2.2 Training to enhance innovation capability

Bespoke training in LWM alginate and agar processing technology was provided by CyberColloids at each SME factory site. In addition, CyberColloids ran a half day training workshop in Oviedo on 'Route to market opportunities for participating SMEs', which covered:

(i) competitive market forces and how they shape our strategic thinking;
(ii) opportunities from the perspective of Marigot; and
(iii) potential opportunities for Hebridean Seaweed Company and Roko.

2.2.3 Market feasibility and business plans

Early in the project there was significant intelligence collected on the global prebiotics market which was presented at the Cork, ‘Health and Texture’ Club event by CyberColloids. At the Stornoway, Health and Texture’ Club event Steve Galloway from Exigo Marketing gave a comprehensive overview of the Japanese soft drinks industry, highlighting the significant consumer and lifestyle drivers currently influencing the market, recent ingredient trends, and a wide range of examples of direct relevance to the audience. When insufficient weight of scientific evidence for prebiotic activity was identified for LMW alginate and agar products, CyberColloids directed the SMEs towards horticultural, animal feed and human food opportunities. Hebridean Seaweed Company, Marigot and Roko then carried out market analysis and business planning exercises for the introduction of new products based on HYFFI processing IP to the respective horticultural, animal feed and human food markets. Summaries from their work can be seen in sections 1.1.1 to 1.1.3.

2.2.4 External dissemination of the results to the scientific community

After approval by the SMEs results from the batch culture studies were presented by the University of Reading at the 2010
International Scientific Conference on Probiotics and Prebiotics in Kosice, Slovakia. The title of the poster was 'Fermentation in vitro and prebiotic potential of novel LMWPs derived from agar and alginate seaweeds' by Priya Ramnani, Roberto Chitarrari, Kieran Tuohy, John Grant, Sarah Hotchkiss, Ross Campbell, Glenn Gibson and Ian Rowland. Work is in progress by both universities to produce two joint publications in peer reviewed journals based on in vitro and in vivo Project results. Lack of demonstration of significant prebiotic activity is likely to limit the impact factor of the journals which will accept the papers for publication. For exploitation reasons, there is also a limit to what can be said in the publications about the processing technology used to prepare the study samples. Publications will be sent to the SMEs for their approval 45 days before submission, and the consent of the SMEs will be obtained for scientific publication. The first publication entitled 'In vitro fermentation and prebiotic potential of novel LMWPs derived from agar and alginate seaweeds', by Priya Ramnani, Roberto Chitarrari, Kieran Tuohy, John Grant, Sarah Hotchkiss, Kevin Philp, Ross Campbell, Chris Gill, Phillip Allsopp, Peter Mitchell and Ian Rowland has been accepted for publication in the journal 'Anaerobe'. The second manuscript entitled 'Impact of low molecular weight algal polysaccharides on gut microbiota' is in preparation.

2.2.5 ‘Third-party’ SME workshops and networking events

The formation of a ‘Health and Texture’ club, a concept developed by CyberColloids, is an example of a best practice in the dissemination of results from the EU ‘Research for SMEs’ programme to third parties. In addition to the HYFFI partners, the ‘Health and Texture’ club which met twice during the project, included representatives from the following organisations:

- Andi Johnson Konjac Company LTD, China (see http://andi-johnsongroup.com/ online),
- Borregard Industries LTD, Norway (see http://www.borregaard.com online),
- Brenntag, Germany (see http://www.brenntag.com/en/ online),
- Diana Drummond LTD, Scotland (see http://www.dianadrummond.co.uk/ online),
- Hindustan Gum & Chemicals Ltd, India (see http://www.hindustangum.com/ online),
- Johnsonville, USA (see http://www.johnsonville.com/home.html online),
- National Research Council (NRC), Canada (see http://www.nrc-cnrc.gc.ca/eng/index.html online),
- KMC, Denmark (see http://www.kmc.dk/ online),
- Newcastle University, Institute for Cell and Molecular Biosciences, England (see http://www.ncl.ac.uk/camb/ online),
- Socius Ingredients LLC, USA (see http://www.sociusingredients.com/ online),
- Seagreens LTD, UK (see http://www.seagreens.co.uk online),
- The James Houghton Institute, Scotland (see http://www.scri.ac.uk/ online), and
- The Scottish Association for Marine science (see http://www.sams.ac.uk/ online).

The first ‘Health and Texture’ club meeting, linked to the 2nd Governing Council meeting at Cork, comprised two dissemination events on ‘Gut Health And Prebiotics’ and ‘Innovation in Texture’ which took place on consecutive days. The second ‘Health and Texture’ club meeting, linked to the 4th Governing Council meeting at Stornoway, comprised a single dissemination event on ‘Seaweed, Texture and Health’ which took place over two days. The first club meeting was reported within the consortium by the University of Ulster, whilst the second club meeting was reported within the consortium and publically by CyberColloids at http://seaweedforhealth.org.

Two further dissemination events took place in Northern Ireland associated with the Institute of Food Science and Technology (IFST) and the University of Ulster’s Knowledge Club. The former event on the ‘Accessing support through EU Research for SMEs programme’ Theme was reported in the IFST Keynote newsletter (May 2010), whilst the later event on the ‘Healthy everyday culinary applications of seaweeds’ Theme was reported in the University of Ulster, Inside magazine (April 2010).

List of websites: http://www.seaweedforhealth.org
Coordinator: Professor Ian Rowland
Email i.rowland@reading.ac.uk
Related information

Result In Brief
Searching for new prebiotics from seaweed

Documents and Publications
Final Report - HYFFI (Hydrocolloids as functional food ingredients for gut health)
Final Report - HYFFI (Hydrocolloids as functional food ingredients for gut health)

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